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Preface

This thesis was conducted from January 3rd to May 15th, 2023, at the Department of Mechanical and Structural Engineering and Material Science, at the Faculty of Science and Technology at the University of Stavanger. It forms part of a collaborative project involving three other engineering disciplines through the student organization UiS Subsea, which has been actively engaged in similar projects since its establishment in 2013. This project aimed to design, develop, manufacture, and test a fully functional remote-operated vehicle, commonly known as an ROV, and a scientific float for participation in the Marine Advanced Technology Education (MATE) ROV competition and TAC challenge scheduled for June 2023.

We extend our profound appreciation to the Faculty of Science and Technology at UiS, as well as the UiS Subsea organization, for allowing us to participate in this project and the accompanying challenges. The project has proven to be an exceptionally educational and challenging experience, characterized by a steep learning curve. It offered an excellent platform to develop mechanical, collaborative, creative, and practical skills that will be highly relevant to our future professional endeavors.

We want to express our sincere gratitude to all our sponsors, consultants, and fellow students who contributed with their valuable ideas and inspiration, enabling us to complete the project and deliver fully operational products successfully. A special thanks go to our supervisor Professor Yihan Xing, and co-supervisor, Chief Lab Engineer Jon Erik Karlsen from the University of Stavanger for their guidance and support during the project. We are also grateful to the university's lab engineers in the machine shop for their ideas, advice, assistance, and involvement in procuring and manufacturing vital components.

Stavanger, May 15th 2023
Joar Rodrigues Miranda
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Nomeclature:

PDP:	Product Development Process: A method to systematically create new products
ROV:	Remotely operated vehicle. Unoccupied subsea vehicles operated from ship or land
Autonomous:	Independent, separate
AUV:	Autonomous underwater vehicle. An unoccupied autonomous subsea vehicle, with no need for continuous input from operator
Float:	Scientific floatation device: Autonomous robot used for collecting data at low depths
FEM:	Finite Element Method: Method for numerically solving complicated systems
FEA:	Finite Element Analysis: Computer simulation of a complex system using FEM
Thruster:	Propulsive device used to create thrust force
CAD:	Computed-aided design: Used to create 3D models and mechanical drawings
G-code:	Programming language that uses set instructions to guide the manufacturing tool in desired paths
Tether:	Umbilical cord for routing power and communication to the ROV
Turning:	Machining process: Object is cut by a using a lathe
CNC:	Computer Numerical Control: used to remote-machine mechanical parts
Ballast:	Heavy substance used to increase an object's mass.
DFE:	Design for environment
Trenching:	Excavating a trench in the seabed to facilitate installation, inspection or maintenance of pipelines and cables
Deadging:	Excavating material from water environments

Summary

This thesis aspires to design, manufacture and construct a ROV frame, an electronic enclosure, and a scientific float by using the product development process. The thesis is part of a larger project collaboration with eight other bachelor theses from three disciplines connected through the student organization UiS Subsea. The final products of the overall project will compete in TAC and MATE challenge in June 2023. UiS Subsea is an organization with set moral guidelines and a limited budget. Therefore the thesis revolves around minimizing the cost, environmental impact, and timetable of every decision involved in the product and product development process while accommodating the other theses sub-products.

Product development is a method constructed for designing and developing new products in a timely and cost-efficient way. This thesis includes its main phases: planning, concept development, system level design, detail level design, and testing and refinement, with all phases containing smaller sub-phases and steps relevant to the product. As UiS Subsea already had completed parts of the planning phase before the start of the project, this phase revolved around investigating and researching the different targets and limitations the different stakeholders had for the project, including UiS Subsea themselves and the MATE ROV competition. This research made the concept development phase easier and time efficient since the needs and expectations were explored and established. Concepts could therefore be effectively created, discarded, and selected based on the target specification, calculations, and simulations. The system level design could thereby focus on connecting and assembling all the parts needed together into a functioning final product. After developing a functioning assembly in system level design, the detail design focused on final improvements, setting final dimensions through analysis and simulations, material choice for each component, and calculations surrounding buoyancy and stability. All material choices and final dimensions were verified to be strong enough to withstand all expected forces and loads while fulfilling the product's strength, buoyancy, environmental and cost requirements. When verified, the final parts were manufactured, assembled, and underwent non-destructive testing. Based on the results of the tests, improvements, and altercations were made to the final products.

Overall, the product development process helped with planning, coordination, creativity, and overall structure of the project, which were beneficial during an interdisciplinary project. The standard product development process had many steps that were not necessary for every project, so each company and project should select the steps best suited to their project for the best utilization of the method. For this thesis, that included deriving each phase's own targets and goals based on the standard process's contents and striving to fulfill these goals.

The final products were satisfactory overall, did well during testing, and completed the necessary tasks to qualify for the MATE competition. However, improvements and altercations could always be made to enhance the products further. The products are designed and well-suited for next year's graduates to upgrade and improve the products to AUVs.

The links to the demonstration and qualification videos for MATE are as follows:

- **ROV:** https://www.youtube.com/watch?v=yg9I5MSf8y8
- **Float:** https://www.youtube.com/watch?v=8TjbKXvulRo

1 Introduction

This thesis is part of a larger project of designing and developing a functioning ROV and scientific float for the student organization UiS Subsea and competing in the TAC and MATE challenge in June 2023. This chapter presents the premise of the UiS Subsea organization and the different tasks of every team involved in the project. This is a collaborative introduction for all UiS Subsea theses. It also aims to provide sufficient information about the thesis objective, scope, and limitations. Next, the MATE competition and its specific tasks, challenges, and scoring system. It is also an introduction to the background information about the ROV and floats, as well as information about the report's structure.

1.1 About UiS SubSea

UiS Subsea is a student organization at the University of Stavanger, engaging students in underwater technology since 2013. The primary goal of this organization is to provide students with the experience of working in a team consisting of different engineering disciplines.

This year, at UiS Subsea, nine bachelor groups are working together to design and build a complete underwater ROV (remotely operated underwater vehicle). This year's ambitions are to build upon and improve from last year's ROV project. The goal is to create a new ROV that is easier to maintain, has more efficient cooling, and can upgrade the software to an AUV (autonomous underwater vehicle). Though it will not be completely autonomous, it should be able to compete in the autonomous challenges from MATE.

There are two groups of mechanical engineering bachelor students on the team. Their responsibility is to design, craft, and construct the chassis, manipulator, and electronic enclosure for the ROV (Remotely Operated Vehicle).

Additionally, five groups of electrical engineering students are responsible for various tasks. Their responsibilities include working on sensors, regulation systems, communication, power, and circuits. They are also in charge of establishing communication between the ROV and the topside system.

On the topside, there are two groups of computer engineering students. Their primary responsibilities include sending and receiving commands and data. They also work on displaying the ROV in a graphical user interface (GUI), handling controls, and performing image processing tasks.

Through several years, Subsea has built ROVs and partaken in international competitions, this year: the MATE ROV competition. This provides a basis for more advanced problem-solving and teamwork to create a positive and healthy environment for learning and developing technical skills. UiS Subsea opens up the opportunity for students to collaborate with industrial companies. Several companies are interested in these projects, providing components and other resources through sponsorship deals. To further improve the relations between the organization and the industry, Subsea annually holds an event called 'Subsea dagen,' where companies from the sector can participate with their stand and promote themselves. UiS Subsea and the companies generate a lot of exposure from such an event.

In previous years the organization has suffered from a lack of continuity due to the participants writing their bachelor's, and a handover between current and new bachelor students has been non-existent. This year, the previous leader and second leader of Subsea decided to stay one more year to help guide the students and the overall course of the project. This reduces the learning curve for the new students while also implementing a stream of previous knowledge and experiences to the future project.

This year's board consists of the following roles and leaders:

- **Project manager:** Joar Rodrigues de Miranda
- **Second Project manager:** Thomas Matre
- **Technical leader Electro:** Jesper A. Flatheim
- **Technical leader Computer:** Filip Sølvberg Herrera
- **Technical leader Mechanical:** Haakon Aleksander Schei

Figure 1.1: UiS Subsea logo

1.2 Mechanical

Design of ROV frame, electronic enclosure, and Float

Following the product development process, this thesis aims to design and build the frame of the ROV, the electronic housing, and the shell of the float. The primary focus of the design is to mesh together all the individual parts into one functioning ROV while also ensuring the ROV can perform the tasks in the MATE- and TAC ROV competitions.

In light of the present environmental challenges, a secondary focus will be sustainability, and recyclable materials, to minimize the environmental impact of this process. Effective use of DFE can also help reduce cost and production time while increasing product quality. Material choice, structural, flow, FEM, and buoyancy analysis are tasks to be solved in this thesis.

Manipulator

The main task is to develop and design a functional manipulator for tasks the ROV completes. The goal is for the mechanical arm to be useful for MATE requirements while being uncomplicated enough for production and maintenance. Creativity and problem-oriented solutions are necessary to complete this task. Deciding degrees of freedom, which mechanical principles to implement, and material choice are some problems that need to be solved.

In addition, cooperation with electrical engineers is essential regarding manipulator compatibility with the rest of the electrical system. Stress, bending, and shear analysis are fundamental for the success of this task.

1.3 Electronics

Power module

The power module's primary function is to regulate and distribute the input voltage provided by the topside system. Its role also includes protecting the components from overload and preventing short circuits. Given that the input voltage is 48V, the system must lower the voltage to ensure that each element receives the appropriate amount of power.

Communication ROV

The communication group's main task is to create a standard system so that electrical circuit boards are connected and can communicate with the rest of the system. By utilizing CAN-bus in addition to C-code, the system can efficiently convey signals and commands between each other. In addition, communication between ROV and the topside system has to be solved. Here control signals from topside to ROV, process data, and video feed from ROV to topside need to be processed efficiently with minimal delay.

In addition, the internal design of the electronic enclosure is this group's responsibility.

Regulation system

The primary objective is to design a navigation and regulation system for the ROV. The system's core components include selecting the appropriate thruster configuration and manipulator motor and developing a circuit board in collaboration with the mechanical groups. These components ensure the ROV's physical limitations and characteristics align with its interactions within the environment.

The circuit board will serve as an interface between the motor controller and other circuit boards. The choice of thrusters and motors must comply with competition standards. Additionally, a significant responsibility of this group is to develop a control system. This system will interpret commands and sensor measurements from the topside and other circuit boards, enabling the ROV to operate and maneuver effectively. Ensuring stability, maintaining orientation, and achieving a desired depth position are vital tasks that need to be addressed by the regulation aspect of the system.

Mathematical models and functions will be required to digitally replicate its behavior to accurately simulate the various degrees of freedom of the ROV.

Sensor system:

The main task of the sensor system is to maintain and disperse information from the different sensors and act upon the vital data. These are orientation(IMU), leak, and pressure sensor. IMU retrieves angle data and axis relation and generates data the regulation system uses to control and drive the thrusters. The Leak sensors consist of 3-4 leak probes placed along the inside of the electronics enclosure to detect eventual leaks and aptly react to the information to minimize damage to critical electrical components. The temperature sensor is divided into three identical sensors along the enclosure at critical points. This is to monitor internal temperature and the dispersion of it. The pressure sensor is the only one externally mounted, retrieving changes in water pressure due to depth changes.

FLOAT:

The float is the only component not attached to the main ROV. It is essentially its own AUV, with a pre-programmed flight path and power supply. It gathers vital information about ocean health and the underwater environment.

The competition requires that the float completes two vertical profiles: Sink to the bottom and return to the surface. Afterward, it has to relay the completion time with a ping to the topside system, temperature, and pressure.

1.4 Computer Science

Image Processing:

The main task of the Image processing group is to complete a subtask for the MATE ROV competition, which is based on processing image data to solve several tasks. These require camera vision with depth perception and autonomous programming. The tasks are the following:

- **Autonomous Docking**
- **3D Modelling of sick coral**
- **Count frogs along a transect line**
- **Monitor/analyze of seaweed growth**

GUI:

The primary objective is to develop a monitoring and control system for the ROV (Remotely Operated Vehicle). To achieve this, we need to implement a system that enables the transmission of commands and control data from the topside to the ROV. This task requires close collaboration with the communication group.

Furthermore, we aim to present all relevant information and video feeds to the user in real time through a custom graphical user interface (GUI). It is crucial to create a user-friendly GUI that includes control commands and controller settings, as these aspects significantly contribute to the overall quality and usability of the product.

1.5 Objectives and limitations

This thesis objective is to design, develop manufacture and test the ROV frame, electronic enclosure and float though following a product development process. For the frame that includes facilitating for all other parts that the other teams or this team develops, while for the float and enclosure the objective revolves around constructing the outer shells protecting the electronics the other groups make. The common goal for all products is that they are well suited for participation in TAC and most importantly MATE competitions. To achieve that goal the UiS organization developed organizational objectives and limitations for this years project that includes:

- The development process should focus on minimizing the environmental impact of the ROV
- The ROV should weight under 25kg and operate at 100m depth
- The ROV should be as compact as possible
- The ROV is highly modular and is easy to assemble, disassemble and maintain
- To make products stable both in water and on land
- The float should be lightweight and operate at 10m depth
- The project should be designed and produced in a cost efficient way to keep within the organizational budget
- The products should be able to perform the MATE tasks

The product development process is chosen as the method for designing and producing the products as it has been proven to help with planning, coordination, creativity and quality assurance during the process and in the final products. The method has also proven to help with the structure of projects, making it easy to locate, modify and compile the different parts across products as the process progresses. As the product development process is a time consuming process that often takes years of revisiting and redesigning if done properly, products that have limited time like this one often has to pick and chose which phases that are most vital for success in their specifics project. As this project aims towards constructing a one-off prototype ROV, the production ramp up phase is not relevant to the project and is excluded. The system level design and detail design is also simplified in order to meet time restrictions. Lastly the testing and refinement phase is reduced to mostly non-destructive testing to battle cost and time of replacement issues. The other steps will also include only the parts relevant to the thesis. Many hand calculations will also be excluded as FEA analysis will be performed instead to test and verify if a component can withstand calculated forces and pressures.

1.6 Structure of report

This thesis follows the product development process and will be structured accordingly. That includes one chapter for every phase that was involved in designing, manufacturing and testing the products. In a standard product development process, it is normal to evaluate each phase after its completion, in this thesis, all the evaluations done during the process and of the product is merged in a collective chapter at the end of the thesis. The structure of the report is therefore introduction, planning, product development, system level design, detail design, testing and refinement, evaluation of product and process and lastly conclusion.

1.7 MATE - Marine Advanced Technology Education

The primary goal of UiS Subsea for this project is to develop competitive products that can participate in and succeed during the MATE competition in June 2023. To achieve this objective, it is crucial to understand the nature and requirements of the MATE challenge thoroughly. This involves identifying the various challenges involved and comprehending the scoring system so that we can optimize our products to score as many points as possible. We will gather the necessary information from the competition's website and manual to ensure the design of satisfactory products. The following information has been obtained from the organizations' websites. [16] [17]

The ROV created by UiS subsea this year follows the specification determined by the international competition, *MATE ROV COMPETITION*. This competition is hosted by organization *MATE.The Marine Advanced Technology Education (MATE) Center* is a partnership av a multitude of American organizations, established in 1997. These partners mainly comprise schools, research institutes, governments, and Marine institutes. This cooperation's primary goal is to improve marine technical education, strengthening the future American workforce for maritime operations. In 2021, *MATE* transferred the responsibility for student activity over to *Marine Advanced Technology Education for Inspiration and Innovation's*, otherwise known as *MATE II*. Their main objective is to motivate students' interest in maritime knowledge, mainly by hosting *MATE* competition every year. They challenge students to implement engineering principles and expertise to solve subsea tasks. UiS Subsea is competing in the EXPLORER class, reserved for students with Higher technical educational backgrounds.

Figure 1.2: MATE logo

1.7.1 MATE ROV Competition

The information about the competition is retrieved from the competition manual [18].

This year's competition themes are no different from the previous two, highlighting the importance of the United Nations Decade of Ocean Science for Sustainable Development (2021-2030). Their innovation is to increase ocean knowledge and ensure that society implements this knowledge, thus contributing to the UN's Sustainability goals. This year's task is to create an ROV and a scientific float. This year's themes are the facilitation and production of clean energy, surveillance, and tracking of the ocean's biological diversity.

Figure 1.4: MATE Competition logo

Points

Table 1.1 demonstrates the available points' segmentation. Product demonstration is the first part, where UiS Subsea will solve three practical tasks within 15 minutes. If this is achieved, additional points are given, 1 per minute and 0.01 per second. Extra points are given for ROVs below 25 kg and good teamwork under the competition. These practical tasks are meant to test the operational characteristics of the ROV. The secondary segment points are designated for the technical documentation and how the organization portrays itself. The final points are given based on the safety of the ROV and how the relevant dangers have been adequately analyzed and addressed. .

Table 1.1: Points structure

Product demonstrations	
Tasks	300 points
Time bonus	10 points
Weight restrictions	10 points
Organization efficiency	10 points
Engineering and communication	
Technical documentation	100 points
Product presentation	100 points
Marketing	50 points
Company specification sheet	20 points
Company responsibility	20 points
Safety	
Review of safety documentation	20 points
Safety inspection	30 points
Safety job analysis	10 points
Total	**680 points**

1.7.2 Task 1: (Maritime, renewable energy)

UNs Sustainability goals:

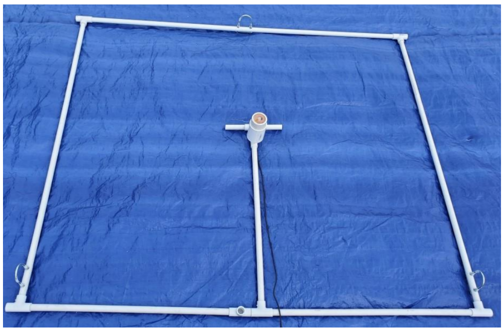
7 Clean energy for all

12 Responsible consumption and production

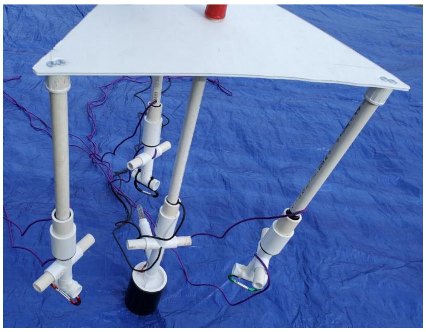
The first task is designed to simulate an offshore installation of floating solar panels in an established floating wind farm, removal of biofouling, and piloting the ROV either Autonomously or manually into an underwater docking station

1.1: Installation of a collection of floating solar panels

- Maneuver the solar panels between 3 existing wind turbines: 10 points.
- Moor 3 moorings to the solar panels: 15 points.
- Remove the lid from power port entry: 5 points
- Connect plug from solar panels: 10 points.



(a) Seabed anchor for installation



(b) Floating solar panel

(c) Hook for mooring

1.2: Remove biofouling from the floating wind turbines

biofouling is simulated either with red PVC pipes connected with Velcro or chenille pipe cleaners twisted together.

- Remove 1-2 units av biofouling: 5 points
- Remove 3-5 units av biofouling: 10 points
- Remove 6 units av biofouling: 15 points

(a) Biological material on structure

(b) Biological material on rope

1.3: Maneuver the ROV into docking station

To be allowed to compete in the competition, the ROV has to fit inside the docking station, with extra points given for the automation of the docking.

- Maneuver autonomously into docking station: 15 points
- Maneuver manually into docking station: 10 points

Figure 1.7: ROV Docking station

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1.7.3 Task 2A: Coral reef and blue carbon

UNs Sustainability goals:

13 Stop climate change

14 Ocean life

The second task is divided into two parts: 2A and 2B. Part A represents scientific tasks: scanning a coral reef, identifying organisms by utilizing eDNA, exposure to UV light on sick coral reefs, inspection, and installing an environmental mooring system to protect seaweed on the seabed.

2A.1: Measure, model, and identification of disease on coral reef

- Measure diameter on a coral reef: 5 points
- Measure height on a coral reef: 5 points
- Measure area of infection: 5 points
- Make a 3D autonomously: 15 points
- Make a 3D model in CAD manually: 5 points

All measurements must be done within 2cm and can be completed autonomously or manually with reference objects.

Figure 1.8: Main coral with white spots

.

2A.2: Identify coral reef organisms with eDNA

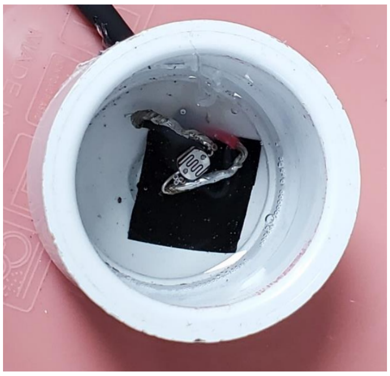
- Extract water sample from the bottle: 10 points
- Identify fish species based upon three samples provided by hosts: 5 points

(a) Water bag connection

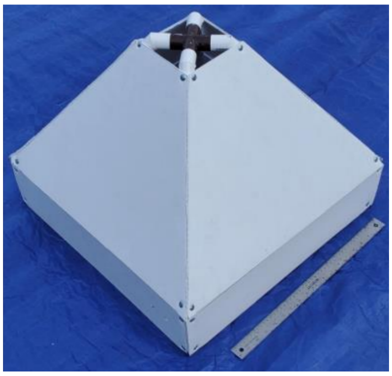
(b) Connection for sample extraction

2A.3: Administrate Rx medium to infected coral

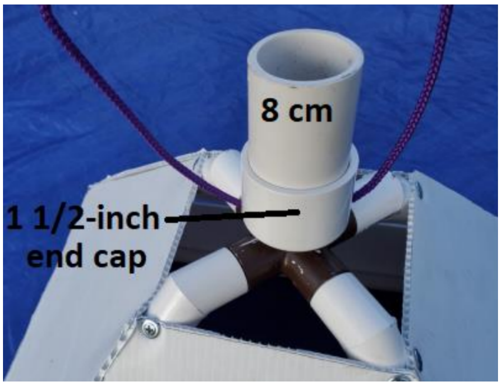
- Position UV-light above infected area: 5 points
- Activate light and cure: 5 points
- Place tent above coral reef: 10 points
- Place syringe in tent opening: 5 points
- Remove syringe contents inside the tent: 5 points



(a) Photo resistor



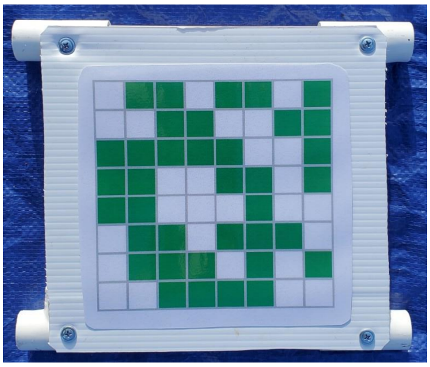
(b) Tent



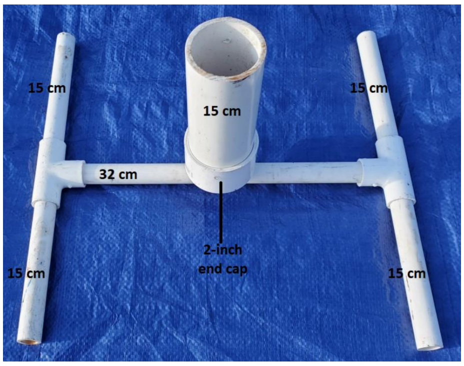
(c) Syringe connection

2A.4: Seaweed habitat protection and surveillance

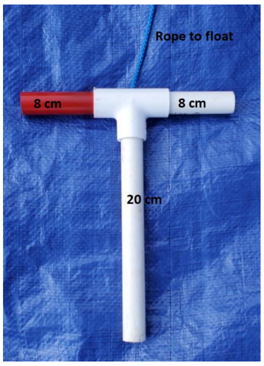
- Identify if seaweed habitat has been rehabilitated, remained unchanged, or worsened, based upon images: 5 points
- Install Eco-Mooring system on the seabed, inside a base, and rotate mooring 720°in the base: 10 points



(a) Seaweed



(b) Eco-Mooring base



(c) Mooring

1.7.4 Task 2B: Lakes and rivers

UNs Sustainability goals:

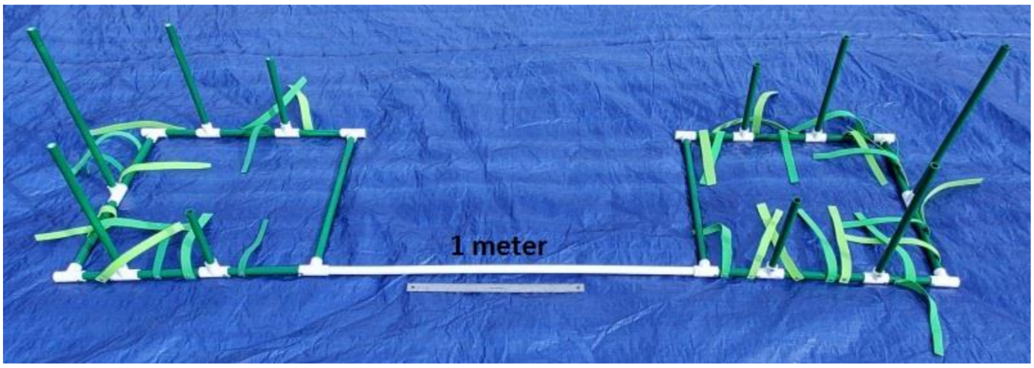
13 Stop climate change

14 Ocean life

Task 2B primarily focuses on working with freshwater bodies. The objectives of this task are to locate fish, assess whether they are invasive species, and release fry in safe areas. Additionally, there is a requirement to inspect ropes, remove larger objects, follow a designated transect line, count frogs, and install an underwater camera.

2B.1: Re-introduce endangered species of Northern Redbelly Dace fry

- Survey 2 areas, and identify which is safe to place to release the fry: 10 points
- Acclimatize fry to a safe area: 5 points
- Release fry in the safe area: 10 points



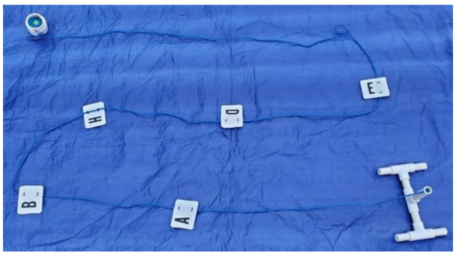
(a) Habitat area

(b) Fry

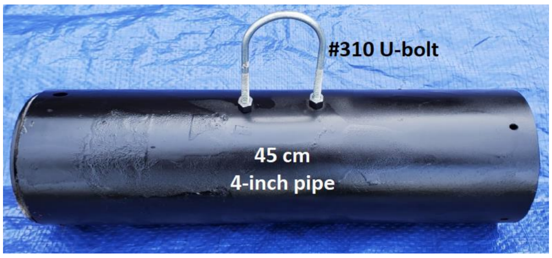
(c) Current fish species

2B.2: Ensure the health and safety of the Dillion reserve

- Inspect rope for a buoy and display the ten letters attached: 10 points
- Display the documentation of the ROVs lifting capacity: 5 points
- Lift object a maximum of 120 Newton above water: 10 points
- Return object to land: 5 points



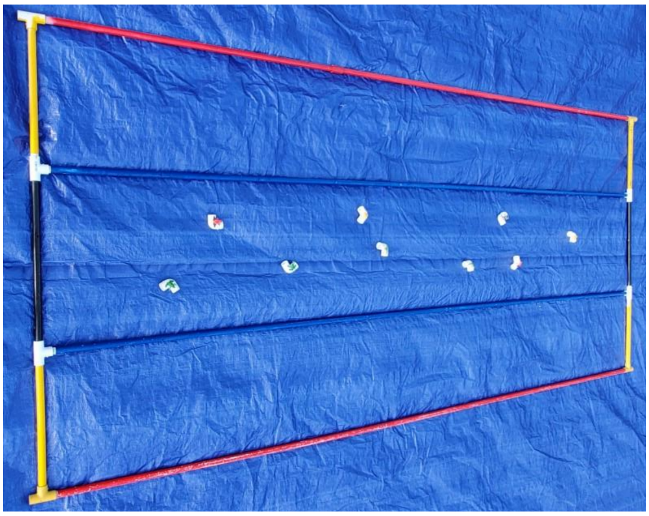
(a) Rope with letters



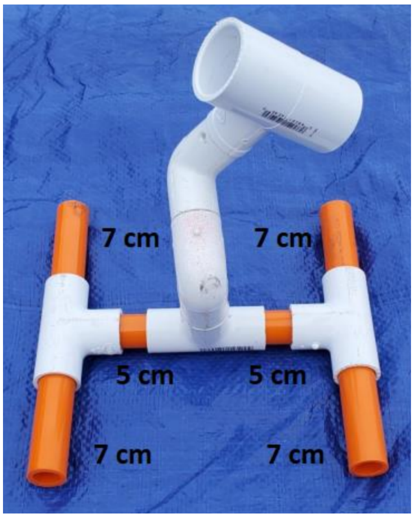
(b) Heavy object which is to be removed

2B.3: Surveillance of endangered Lake Titicaca frogs

- Fly a transect line and maintain the image within the area: 10 points
- Count the number of frogs within an area: 5 points
- Install a camera on a designated area: 5 points



(a) The transect line area that the ROV will fly over



(b) The camera which is to be installed

1.7.5 Task 3: (MATE Floats!)

UNs Sustainability goals:

13 Stop climate change

This task represents the construction of a functioning scientific float, which will transmit data when it reaches the ocean surface.[19]

3.1: MATE Floats! 2023

- Design and construct a functioning vertical profile float: 5 points
- Float communicates with land before submersion: 10 points
- Float transmits to land the time of completion after first vertical profile: 10 points
- Vertical profile 2, the float sinks and rises after impact with seabed: 10 points
- Float transmits to land the time of completion after second vertical profile: 10 points
- Vertical profile 1, the float sinks and rises after impact with seabed: 10 points

1.7.6 Restrictions and demands

The competition has certain physical restrictions with size, weight, the operational environment, and electrical limitations. The only vehicle to be utilized is an ROV.

Environment:
The ROV shall be able to operate in fresh, salt, or chloride water in a temperature span of 15 to 30 °Celsius.

Materials:
The ROV shall be able to operate at a minimum four meters depth while being under a maximum of 35 kg.

Tether length:
The tether has to be long enough to operate within an area 10 meters from the edge and 4 meters deep. The topside control system can be up to 3 meters from the pool's edge.

Thrusters:
The thrusters shall be adequately protected and meet IP-20 standards. The thrusters shall be designed to operate underwater.

Electrical:
The organizer provides a power supply of 30A and 48 VDC for ROV. Conversion to lower voltages has to happen inside the ROV. Overload protection on 150% of nominal power usage on the ROV shall also be implemented.

Float:
Batteries utilized shall be of type: AAA, AA, A, A23, C, D, or 9V alkaline batteries. The float shall be protected with a 7.5A fuse. There must be a pressure relief valve with a minimum diameter of 2.5cm.

1.8 About ROV Project

1.8.1 ROV history

The creation of the first ROV can be credited to Dimitry Rebikoff, with his invention shown below. [1] The aptly named Poodle was made in 1953, complete with a tethered connection and operated with a topside control panel.

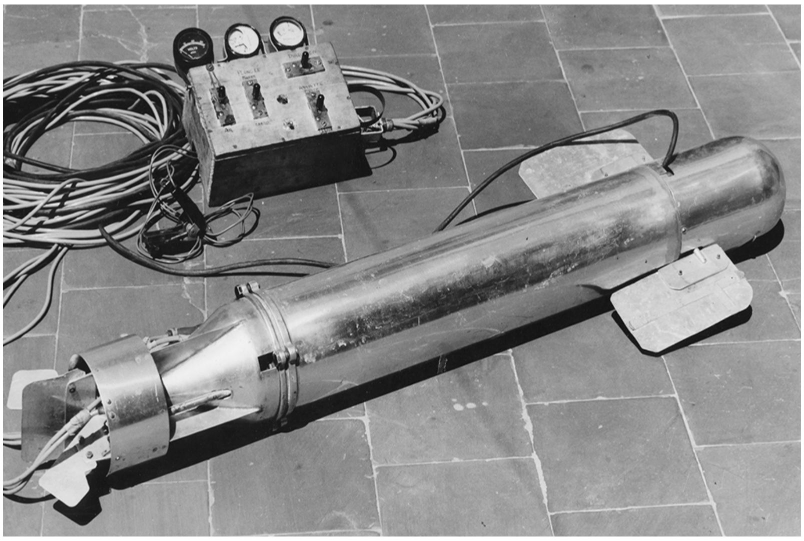


Figure 1.15: The world's first ROV

The subsea sector has come a long way since then, and modern ROVs are quite different. In the 1960s, the U.S. NAVY utilized ROVs as recovery drones for underwater equipment. Within 20 years, there were over 500 ROVs worldwide, mostly in the commercial market, each designed with a specific task and purpose. There are some common components of standard ROVs, being: [1]

1. Thrusters
2. Tether
3. Camera
4. Lights
5. Frame
6. Pilot controls
7. Buoyancy element

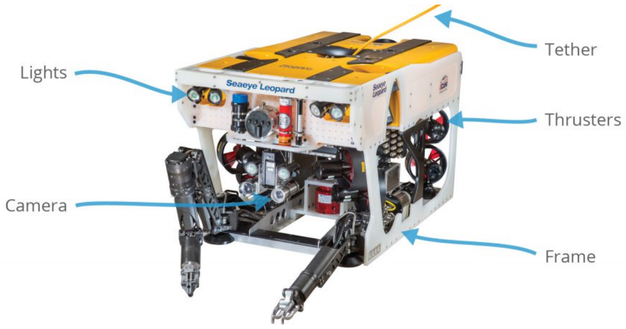


Figure 1.16: Diagram of common components [1]

Newer ROVs are designed based on the given task; some can be: observation, high-speed survey, inspection, trenching, burial, intervention, and construction. Some ROVs can be used for many tasks, while others are limited in design. There are seven main classes of ROVs, from I to VII [20]:

I -Pure observation [21]

II -Observation with payload option [22]

III -Work class vehicles [23]

IV -Seabed-Working vehicles [24]

V -Prototype or development vehicles

VI -Autonomous underwater vehicles (AUV) [25]

VII -High-Speed survey vehicles[26]

Figure 1.17: The different ROV classes

There are several benefits and limitations to each class. Class I: Pure observation vehicles are physically limited to video observation however highly maneuverable. Generally, they are small vehicles fitted with video cameras, lights, and thrusters. They cannot undertake any other task without considerable modification.

Class II – Observation with payload option has the same capabilities as a pure observation ROV, but usually with additional functionality, such as manipulator, color cameras, other cameras, sonar, and cathodic protection measurement system.

Class III: Work class vehicles are large enough to carry additional sensors and manipulators. They have semi-autonomous capabilities, also known as multiplexing capability, which allows heavier equipment to run without being *hardwired* through an umbilical system. Furthermore, they have enough stability and buoyancy to carry additional detachable equipment without losing functionality. This class is larger than the previously mentioned, with three sub-classes based on power rating:

1. Class III A – Work class vehicles $<$ 100 Hp
2. Class III B – Work class vehicles 100 Hp to 150 Hp
3. Class III C – Work class vehicles $>$150 Hp

Class IV: Seabed working vehicles are utilized, as the name suggests. They maneuver on the seabed by a wheel or belt traction system, thruster propellers, water jet power, or a combination. These vehicles are usually even larger than Class III, with their main purpose being subsea work: dredging, mining, cable and pipeline trenching, excavation, and other subsea construction work.

Class V: Prototype or development vehicles are classified as under development or have not been sufficiently tested. Most special-purpose vehicles or one-off prototypes end up here since any of the previous classes cannot categorize them. Class VI and VII are in this class according to the Norwegian standard of ROVs since they are still under development and only a select few companies produce these vehicles.

1.8.2 YME

This year, the ROV developed and produced a class II vehicle with 6 degrees of freedom and a compact design. The goal is to create a vehicle based upon well thought existing solutions while following UN Sustainability goals.

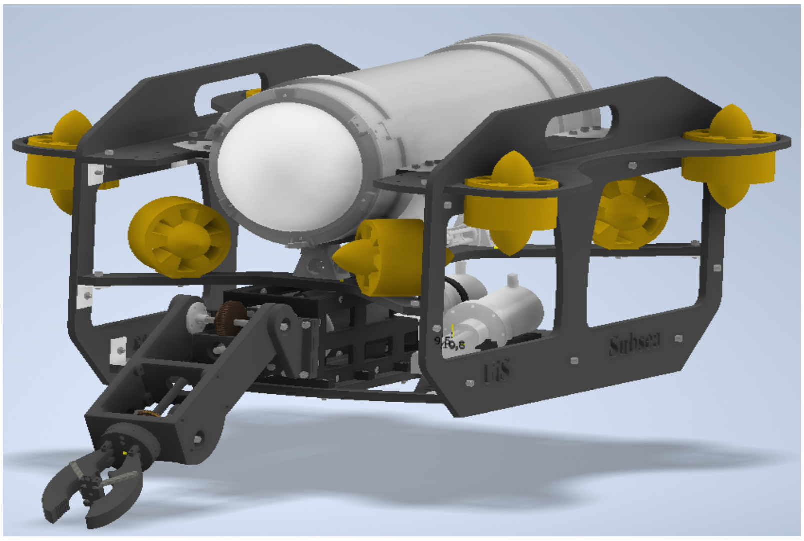


Figure 1.18: 3D model of ROV

YME is controlled by a customized GUI, which communicates via an umbilical cord to the ROV. The project's primary goal is to compete at the MATE ROV competition; thus, the vehicle is designed for this purpose. Additionally, the project participants have set a personal goal to be able to operate at 100m depth. The design is modular, something that makes parts easily replaceable and further developed, both as an ROV and AUV (Autonomous Underwater Vehicle)

1.8.3 Float-Balder

Scientific floats have been utilized for a long time, ever since Henry Melson Stommel came up with the idea back in 1955.[27] The main goal of a float was to track and monitor deep drift currents, and the first was manufactured of aluminum with a depth rating of 4500m. Using a buoyancy engine, it changes its depth to pre-programmed heights. A biochemical float uses an array of optical and chemical sensors to gather valuable data at otherwise difficult locations.[28]

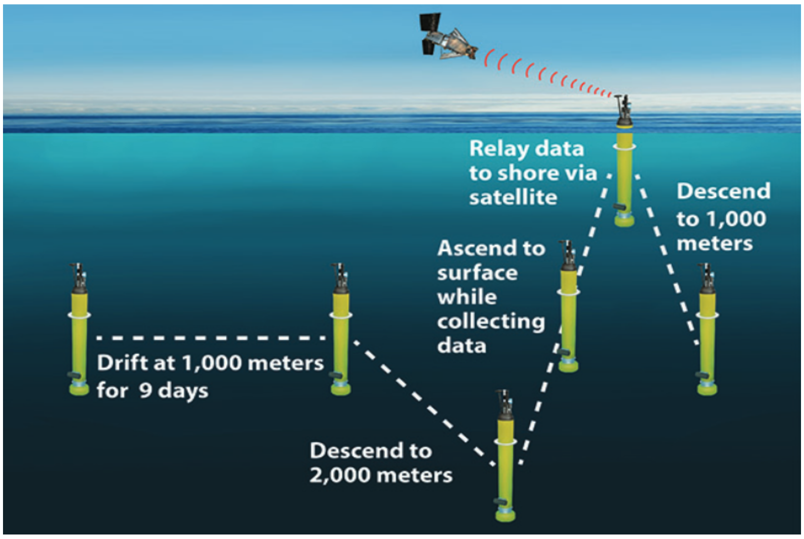


Figure 1.19: Diagram of a float cycle [2]

Figure 1.19 Shows a normal float cycle. Firstly, they descend to a depth of 1000m, drifting for 5-10 days while acquiring valuable data. This is repeated at 2000m and finally ascends to the surface for data transmission. An average float will have a life cycle of about five years once the battery is depleted.

2 Theory

2.1 Forces

The forces acting upon a subsea vehicle can be split into five groups: Thrust, drag, lift, weight, and buoyancy. The thrust force (F_T) is generated by propulsion machinery, propelling or pulling the vehicle within its local x-y plane. The drag force (F_D) acts opposite to the vehicle's direction of motion and is determined by the object's shape, speed, size, the fluids' density, and the drag coefficient. According to Newton's 2^{nd} law, the weight force (F_G) acts downwards due to the vehicle's mass and is expressed as: [29]

$$(m) : F_G = mg = \rho g V \tag{1}$$

Where g is the earth's gravitational acceleration, ρ is the object's density and V is the object's volume. The lift force is a hydrodynamic force perpendicular to the oncoming fluid flow/ the object's motion and is influenced by the vehicle's speed and shape [30]. The buoyancy force (F_B) acts upwards, opposite to the weight force, and is caused by fluid displacement. The buoyancy force varies based on the volume of fluid displaced, the fluid density, and the earth's gravitational acceleration.

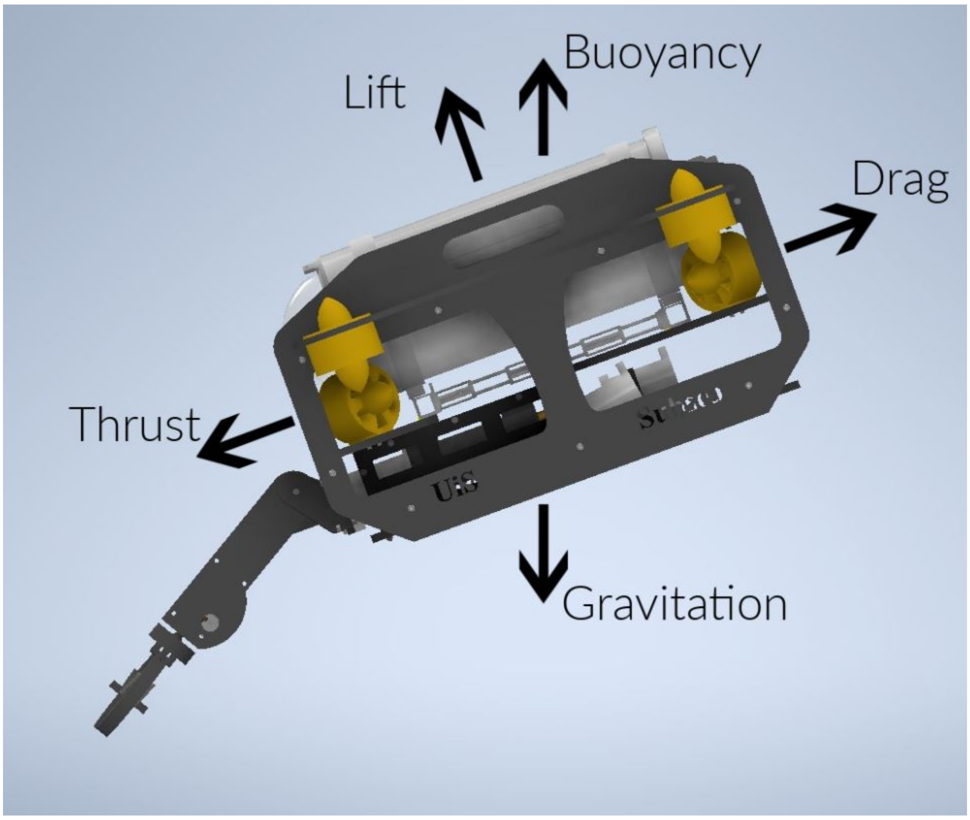


Figure 2.1: Forces on a subsea vehicle

2.1.1 Buoyancy

According to Archimedes' principle, any object fully submerged in a fluid is pushed upwards by a force equal to the weight of the fluid displaced [31]. This force is called the buoyancy force.

The buoyancy force occurs due to the pressure disparity between the top and bottom of an object. When an object is submerged in a fluid the fluid exerts pressure on all sides of the object, which increases proportionally with the depth. This pressure can be calculated using the Hydrostatic Gauge Pressure Equation [32].

$$P_{gauge} = \rho g h \tag{2}$$

where h is the distance from the fluid surface, ρ is the fluids density and g is the earth's gravitational acceleration

As the dept increases, the fluid pressure increase. Consequently, the pressure exerted on the top surface is lower than the pressure exerted on the top. This results in the total pressure being positive, facing upwards. The total fluid pressure is calculated with

$$F_B = \rho g A(h_{bottom} - h_{top}) \tag{3}$$

where $(h_{bottom} - h_{top})$ = the height of the object and A is the objects cross-sectional area. Since the height of the object stays constant, the buoyancy force stays constant when the pressure alternates. Archimedes' principle rewrites Equation 3 to calculate the buoyancy force based on the volume of water displaced [31].

$$A \times h = V_{object} \quad | \quad V_{object} = V_{fluid\,displaced} \tag{4}$$

$$F_B = V_{fluid} \times \rho_{fluid} \times g. \tag{5}$$

There are two forces acting on a non-moving subsea vehicle, the buoyancy force (F_B) and the weight force (F_G). These forces act in opposite directions in the vertical direction, and the relationship between these two forces dictates if the vehicle ascends or descends when submerged. This net vertical force is referred to as the vehicle's buoyancy. Subsea vehicles use flotation systems to increase the buoyancy force, to achieve near-neutral buoyancy. Neutral buoyancy allows a subsea vehicle to maintain a constant depth without significant power consumption. This is especially important when moving close to the ocean floor since sediment disruption would greatly decrease camera vision. The standard is to use flotation elements attached to the frame or to have large tanks filled with gas. A flotation element can be constructed of any material less dense than water, but it is important that the material is somewhat in-compressible. As a safety measure, the buoyancy is desired to be slightly positive so that the vehicle is able to float to the surface in case the propulsion system fails, usually $1 - 2\%$ of the vehicles' total weight [5]. Buoyancy is calculated by subtracting the objects buoyancy force from the vehicles weight force:

$$Buoyancy = F_B - F_G \tag{6}$$

2.2 The drag force

When a subsea vehicle moves through the water, its propulsion system must overcome the oncoming resistance asserted by the water. This force is called drag force and is the result of an object moving through a fluid, consequently pushing the fluid away. The drag asserts force in the opposite direction of the relative motion between the fluid and the object. Overcoming drag can consume a lot of power, and as a result, it is important to design the vehicles as hydrodynamic as possible.

While the drag force is categorized into many distinct groups, the most relevant for this project is Parasitic drag. Parasitic drag is primarily a result of the object's shape, material, and construction, which is caused by the object displacing water molecules as it moves. Parasitic drag includes form- and skin drag. Form drag relates to the object's shape, where some are more hydrodynamic than others. The form drag coefficient C_D can be seen in Figure 2.2 and determines the magnitude of form drag. For instance, a streamlined half-body has a lower drag coefficient compared to a cube, thereby making it more hydrodynamic. Skin drag arises due to the materials' surface roughness, meaning that an increase in surface roughness corresponds to greater drag. Having a smooth surface with gradual form changes is important to reduce drag on a hydrodynamic body. The skin drag is often negligible in calculations because the form drag is significantly larger.

$$F_D = \rho A v^2 C_D \tag{7}$$

Where F_D is the drag force, ρ is the fluid density, A is the object cross sectional area, v is the relative speed and C_D is the form drag coefficient [33]

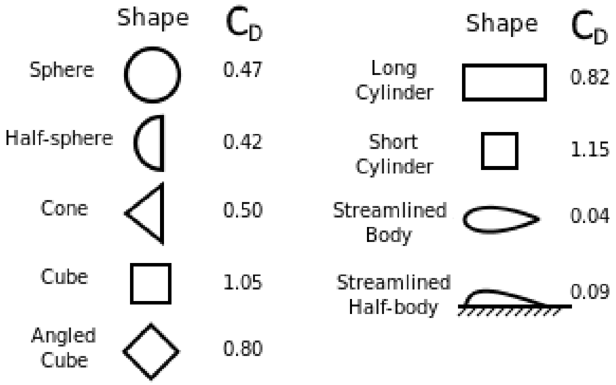


Figure 2.2: Form drag coefficients [3]

2.3 Stability

Stability is essential for ROV control and camera platform stability [5]. Stability is a critical function in a functioning ROV. Depending on the classification of ROV, the solution to this problem differs. However, since the aim is to create a light work vehicle, the necessity for stability increases.

2.3.1 Stability - geometry, and weight

Two concepts are central when distributing the ROV's different parts and weights, the center of gravity and the center of buoyancy. The center of gravity CG is the average point of weight, which is the point where F_G is located. The center of buoyancy is the average point of buoyancy and is where F_B is located. To calculate the center of gravity and the center of buoyancy, the following equations can be used:

$$CG_x = \frac{\Sigma xm}{m} \; CG_y = \frac{\Sigma ym}{m} \; CG_z = \frac{\Sigma zm}{m} \tag{8}$$

$$CB_x = \frac{\Sigma xm}{m} \; CB_x = \frac{\Sigma xm}{m} \; CB_x = \frac{\Sigma xm}{m} \tag{9}$$

Where x,y,z is the distance from the ROVs center to the respective directions and m is the mass of each point/part. To calculate the mass of buoyancy, the mass of water displaced is calculated:

$$m \; (mass \; of \; buoyancy) = \rho_{water} \times V_{part} \tag{10}$$

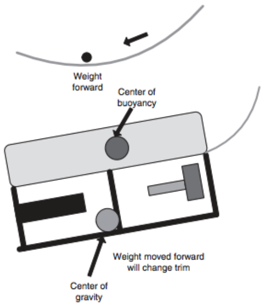


Figure 2.3: CB and CG [4]

"The equilibrium attitude of the buoyancy body floating is determined by the interaction between the mass acting through CG and the buoyancy acting through CB. CG and CB must pass through the same axis to be in static equilibrium; if not, the ROV will align when submerged to achieve static equilibrium", [5]. Consequently, CB and CG must be centered on the same vertical axis to prevent ROV rotation when submerged. Positive Stability is an essential characteristic of ROVs, as it is the ability of an upset object to right itself to a steady state. The greater the distance between CB_z and CG_z, the greater the stabilizing force generated. These principles are essential when considering the weight and buoyancy placement on an ROV. To achieve higher stability, the ROVs center of mass should be positioned low, and the center of buoyancy should be placed high. This produces a stable ROV on the pitch and roll axis, increasing the stabilizing moment, called the Righting moment. Geometry also plays a significant part in the ROV's Stability. The ratio between the length and width of an object is called the aspect ratio. A long and narrow body reduces form drag, creating better hull stability. Hull stability is defined as Stability when moving in a straight line. A short and wide body experiences more drag when moving and is not well suited for observational tasks, as depicted in Figure 5.23. Short and wide bodies perform better than long and narrow ones for stationary tasks at lower speeds. This is why working-class ROVs usually have a square-shaped body, while observational ROVs usually are long and narrow. Additionally, positioning the thrusters further away from the center point makes the ROV easier to control and stabilize [4].

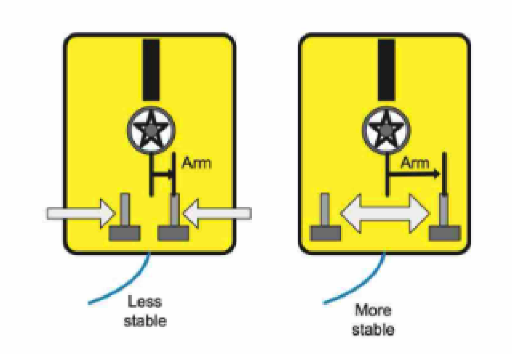


Figure 2.4: Optimal arm length [5]

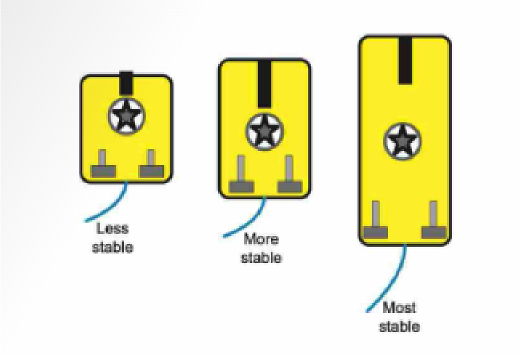


Figure 2.5: Increasing stability further away from center [5]

Float

Scientific floatation devices are usually deployed by vessels undertaking ocean health surveys. The device ascends when submerged due to its slightly negative buoyancy. Once the float has collected data at the desired depth, it positively adjusts its net buoyancy and ascends to the surface. This adjustment can be achieved by increasing volume or decreasing mass, depicted in 1.19.

Increasing the float's volume is accomplished by inflating a bladder. Subsequently, when it is time to descend, the float deflates the bladder to reduce the net buoyancy. Alternatively, the float can adjust its weight by drawing water into a container, decreasing the net buoyancy, and then expelling it to ascend. It is vital to keep the CB and CG centered on the vertical axis to keep its vertical profile at all times. Both flotations methods move the position of either CB or CG. Consequently, calculations to ensure that the CG remains lower than the CB are of significant importance when designing a float.

2.3.2 Thruster configuration

The ROV must have a propulsion system to create the thrust force previously explained. ROV propulsion systems come in three formats: Electrical, hydraulic, ducted jet propulsion. [34] The location and environment in which the propulsion system must perform often decide which system is desirable. For example, the need for heavy tooling aboard the ROV favors hydraulics, while the vicinity of free-floating consolidated debris, which could be pulled into the thrusters, favors ducted jet systems. [4] At a minimum, every functional ROV must have three thrusters, two diagonally and one vertically. However, it is desired for modern-day ROVs to have enough thrusters to accomplish 6 degrees of freedom, which includes: the standard Cartesian coordinate axes x, y, and z directions while also including yaw, pitch, and roll. The x,y, and z movements are controlled by linear translation. This is done by defining a datum reference frame in which each axis is perpendicular to each other. Furthermore, yaw, pitch, and roll are controlled through axial rotation, with a parts datum reference frame being the pivot point. Each of the rotational degrees describes rotation around a translation axis. Yaw is rotation around the Z-axis, roll around Y, and pitch around X. [6]

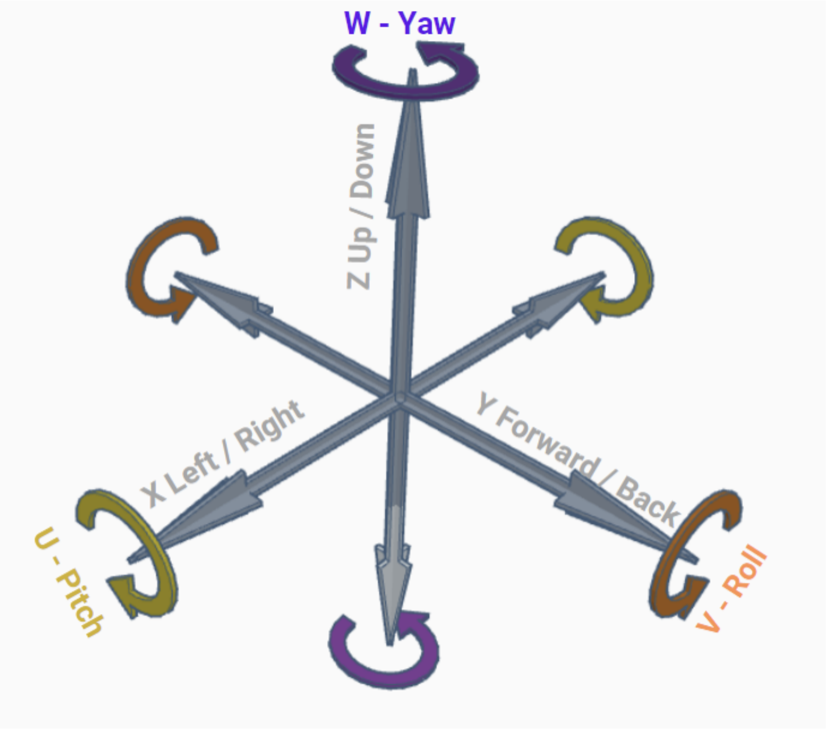


Figure 2.6: Degrees of freedom [6]

Horizontal thrusters

The horizontal thrusters should be placed so that the moment arm of the thrusters, relative to the center of mass, allows for good maneuverability and stability. For horizontally mounted thrusters, the main focus is maneuverability, while vertical thrusters are more related to the stability and regulation system. The goal of thruster configuration theory is to reach the optimal amount and placement of thrusters. In other words, the lowest amount that allows all six degrees of freedom. As illustrated in Figure 2.7, two horizontal thrusters result in longitudinal translation and yaw. In comparison, three thrusters include lateral motion, and four thruster configurations allow all four thrusters to thrust in any horizontal direction simultaneously and are thereby, the more efficient approach. [7]

Furthermore, the 4 thruster configuration allows for the placement of thruster force off the longitudinal axis, which will enhance the turning momentum and the longitudinal stability of the ROV

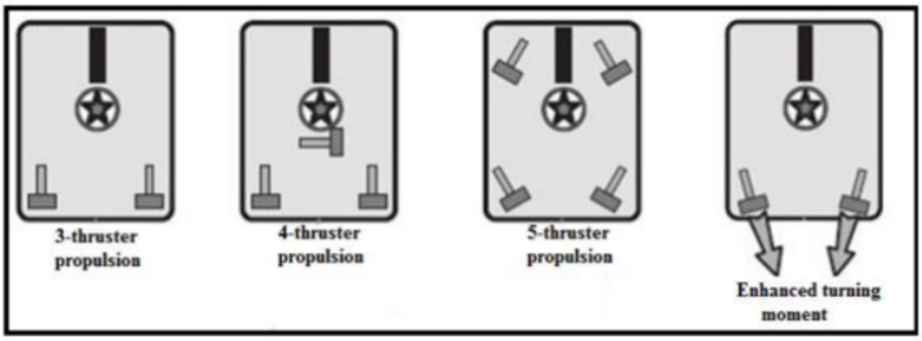


Figure 2.7: Different thruster configurations [5]

To further illustrate the point behind the four horizontal thrusters at the configuration, Figure 2.8 shows how different inputs from the driver to the thruster result in different horizontal motions in the ROV. In this configuration, each thruster acts as a part of a system resulting in vectorial thrust forces, combining different motions from each thruster to get the desired movement as in the other configurations. The vector thrust system facilitates better maneuverability and control but requires more advanced computer software and navigational equipment than the other configurations. [35]

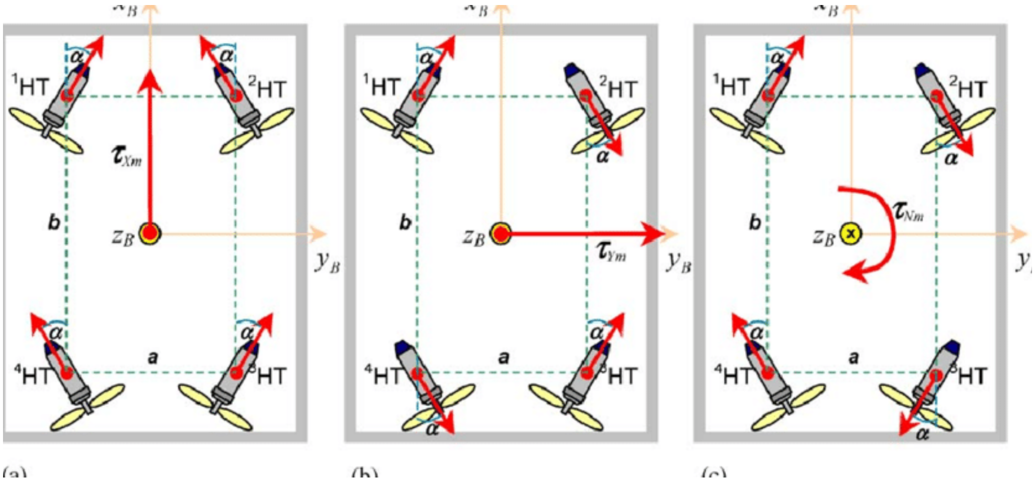


Figure 2.8: Thruster inputs [7]

The thrust force is created by pushing fluid in the opposite direction. The thruster does this by pulling the water through it, thus creating a low-pressure space in front and a high-pressure space behind. This creates a net force against the flow of water. For the thruster to do this with maximum efficiency, the thrusters need a free flow of water. While the frame must be designed to allow free flow, the thrusters must not be placed so that they interfere with each other's flow. If one thruster's outgoing high-pressure space interferes with another's low-pressure space, the total efficiency will drop significantly. In addition, when designing the frame, letting the high-pressure space behind the thrusters be open and not blocking the water flow is essential. If not, the frame would cause the high-pressure space to tail off sideways and offset the forward force exerted from the low-pressure space. [8]

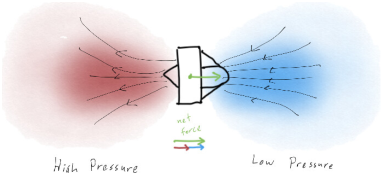


Figure 2.9: Pressure dynamics thrusters [8]

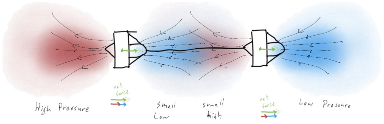


Figure 2.10: Pressure interference [8]

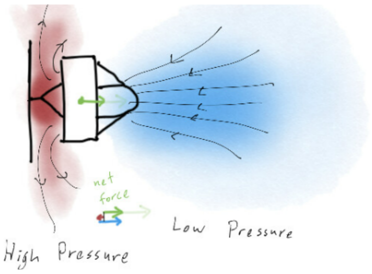


Figure 2.11: Blocked water flow [8]

2.4 Subsea sealing

2.4.1 Sealing rings

Subsea sealing has always been crucial when submerging humans and electronics underwater. Most electronics risk permanent damage if they come into contact with water. Historically, the O-ring and the gasket have been used to water-seal most subsea installations.

The O-ring is mainly used to connect two cylinders with an inner and outer gland. Usually, the O-ring sealing consists of an O-ring with two backup rings as a security measure in case of failure or incorrect installation. The backup O-rings also prevent the outer O-ring from extruding into the installation, damaging potential hardware. Extrusion of an O-ring can lead to leakage, harming electronics, the environment, and humans. The O-ring was switched out for the T-seal as subsea installations went deeper than before. The T-seal is composed of a T-shaped cross-section with two built-in backup rings. The T-seal prevents extrusion in both static and dynamic situations. The t-seal is favored over the O-ring for ROVs because it is more secure and space-saving in high-pressure environments.[36]. The gasket is a ring or sheet made from a supple material that seals static applications. The gasket gets compressed between two flat surfaces, sealing their connection. The gasket requires the correct amount of surface area and compression force to grant sufficient sealing [37]. Subsea sealing requires highly precise tolerances and manufacturing; The required information and requirements regarding the sealing object are in their respective datasheets.

The o-ring

The O-ring is a simple seal, creating a low-cost and secure sealing solution. During the assembly process, the O-ring is inserted within the gland between two components. Subsequently, the O-ring undergoes compression as the inner and outer walls of the gland exert pressure, establishing a force that ensures sealing. When the system is submerged and subjected to water pressure, the O-ring responds by conforming to the lowest pressure wall, generating an even greater sealing force. After surfacing, the O-ring returns to its original shape and is ready to be used again. These properties establish the O-ring as a good, available, and cheap method of sealing. As mentioned, the O-ring has limitations and constraints that are important to consider when designing and choosing the connection. For instance, it is important to choose the correct O-ring material depending on the glad material and subjected pressure. [38].

2.4.2 Press- and shrink fitting

Press and shrink fitting is an easy and low-cost method of assembling 2 components to act as a singular part. This method is mainly used for components where transfer of torsion is a problem, for example, axles, shafts, hubs, bearings, or gear transfers. The end result is a more cost-effective result with regard to the production of parts and material waste management. Other methods that generate the same result would be advanced bolt mechanics or welding [39]. Depending on the requirement, several different tolerances are available through the ISO 286 standard for shafts, holes, and fits [40] [41].

Additionally, the required formulas for determining the safety factor for leaks are calculated by the following equations:

$$n_k = \frac{F_0}{F_0 - F_k} = \frac{F_0}{F_m} \tag{11}$$

where F_0 is derived from torsion equation:

$$\begin{aligned} M_T &= kF_0 d_s \\ F_0 &= \frac{M_T}{kd_s} \end{aligned} \tag{12}$$

where M_T = tightening torque, k = experimental predetermined factor and $d_s = \sqrt{\frac{4 \times A_s}{\pi}}$

F_m is calculated from the following equations:

$$F_m = (1 - \phi)F \tag{13}$$

where F is the applied force per bolt due to internal pressure and ϕ is:

$$\phi = \frac{k_s}{k_s + k_m} \tag{14}$$

where k_s is the bolt stiffness and k_m is the surface stiffness. k_s is explained with the following equations:

$$k_s = \frac{k_{s1}k_{s2}}{k_{s1} + k_{s2}} \tag{15}$$

where $k_{s1} = \frac{A_s E}{L_k - Lst}$ is the stiffness of thread and $k_{s2} = \frac{AE}{L_{st}}$ is the stiffness of non-threaded part of the bolt

and k_m is expressed with:

$$k_m = \frac{\pi(D^2 - d_h^2)}{4} \frac{E}{L_k} \tag{16}$$

where $D \approx 2d$

2.5 Additive Layer Manufacturing

Additive layer manufacturing is a manufacturing process where the desired part is built up layer by layer by computational control. The process is the opposite of subtractive manufacturing, where the material is removed to achieve the desired shape. Additive manufacturing results in less machining, less scrap, and a low buy-to-fly ratio. Moreover, ALM allows for greater complexity, lower lead time, and cost-efficiency compared to subtractive manufacturing. However, it has a smaller material selection, size range, and lower detail capability. [42]

Additive layer manufacturing is a term that encompasses processes such as rapid prototyping, rapid tooling (TR), direct digital manufacturing (DDM), and layer manufacturing. This product development process is only considered using rapid prototyping and direct digital manufacturing. Thus, the theory of these two methods will be expanded on. [43]

Rapid prototyping generates non-structural and non-functional demo pieces or one-off components for proof of concept and visualization, usually with the help of materials such as resins, paper, or plaster. Rapid prototyping allows developers to get an accurate idea of the finished product's appearance before investing time and resources into manufacturing. [44]

Direct digital manufacturing is the manufacture of fully functional and scalable end-use products directly from a computer file, like CAD, with no intervening tooling. This allows for the production of parts with complex geometries or internal features that otherwise could not be made without extensive assembly operations. With no required tooling, the manufacturing process is often economical and time efficient for one-off components, provided the result has acceptable mechanical properties. The material selection for the process is wide and includes various thermoplastics, metals, and nylon. [44]

Both rapid prototyping and direct digital manufacturing work by converting a CAD file into a g-code. The manufacturing tool interprets the code and acts out. This is done in the following steps. [42]

- Import the CAD- file and convert it to STL format
- Section the part into a succession of layers from bottom to top
- Bases and supports are added if needed
- Reduce each layer to a set of tool paths and operations

After the process, the bases, supports, and excess resin is removed before sintering the component to increase its strength. Lastly, the stair-stepping artifacts are removed by mechanical finishing. [44]

In principle, there is three different main ALM process that is used:

- Liquid-based processes such as Stereolithography (SLA)
- Powder-based processes such as Selective Laser Sintering/Melting (SLS/SLM)
- Deposition-based processes such as Laminated Object manufacturing (LOM)

In this product development process, only Liquid-based and Powder-based processes were discussed, which will therefore be explained further.

2.5.1 Liquid-based process

Stereolithography (SLA) involves a structured support base, a tank of photosensitive liquid, and a UV laser. The support base is positioned on an elevator structure and immersed into a tank of liquid photosensitive monomer, with only a thin liquid film remaining above the base. A UV laser then cross-links the monomer on the liquid film before the support base is lowered to reveal a new fresh layer of liquid monomers, and the process is repeated. The polymer must be very transparent to UV light in liquid form and very absorbent in solid form to avoid bleeding solid features into the layers underneath. The advantages of SLA involve fast lead time, good resolution, and no need for support materials, while photosensitive polymers have acceptable mechanical properties. Disadvantages include costly equipment and materials, as photosensitive resins are a costly and limited material selection. [44]

There are two fundamental variations of SLA. Scanning stereolithography is when the laser beam is rastered onto the surface and constructed point-by-point and line-by-line. In contrast, projection stereolithography is a parallel fabrication process in which all the voxels in a layer are exposed simultaneously. Therefore, the topology to be printed at each layer is defined by 2D shapes.

2.5.2 Power-based process

Selecting Laser Sintering involves a fabrication piston, powder delivery piston, powder, a scanner system, and a laser beam. Firstly, a continuous layer of powder is deposited on the fabrication platform. Then the laser beam sinters the powder particles within the layer. The scanner system then scans the laser beam to define a 2D slice of the object within the layer. Afterward, the fabrication piston is lowered, the powder delivery piston is raised, and a new layer is deposited. When the process is finished, the unsintered dry powder is brushed off. The advantages to this process are no need for support structures as the excess powder acts as a natural support and a wide material selection, including nylon, metals, and fiber-reinforced PMCs. Further, SLS is one of the cheapest ways to produce structural components and is one of the few technologies allowing complex metal parts. However, the quality of the metal is not as high compared to higher-cost processes such as EBM. [44]

2.6 Product Development Process

The product development process is a set of activities that leads from identifying an opportunity to producing, selling, and delivering a product. This involves a series of activities companies use to create, design, manufacture, and market a concept and later create a product. The process allows companies to identify customer needs and quickly create products and services that meet those needs at the lowest economic costs by improving cross-functional teams' abilities to plan and work together to develop products. The product development process usually consists of six steps, where each step includes several sub-steps to ensure everything necessary is considered and covered. These six steps are planning, concept development, system-level design, detail design, testing and refinement, and production and marketing. Between each step, a reflection step is added to make the participants reflect on the process and choices made to catch mistakes and optimize the process next time. Additionally, each move from one step to another reflects a gate of no return. Once the team has reflected and concluded a step, that part of the process is closed and may not be revisited and changed to ensure stability throughout the process. [9]

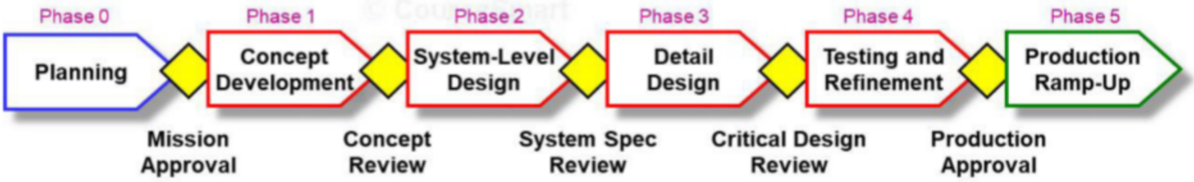


Figure 2.12: Six steps of product development process [9]

2.6.1 Phase 0: Planning

Planning, often referred to as phase 0, precedes the project approval and possible launch. Firstly, a process to identify the opportunities of the company is done. After this process, the planning team is left with a few outstanding opportunities. The target is to decide which opportunities to continue developing, which product platform to venture into, make a portfolio of the projects, and allocate time and resources to each project. The output of this phase is a mission statement that includes a description of the product, target market, business goals, key assumptions and constraints, benefits propositions for the product and any stakeholders in the firm, and the process. [9]

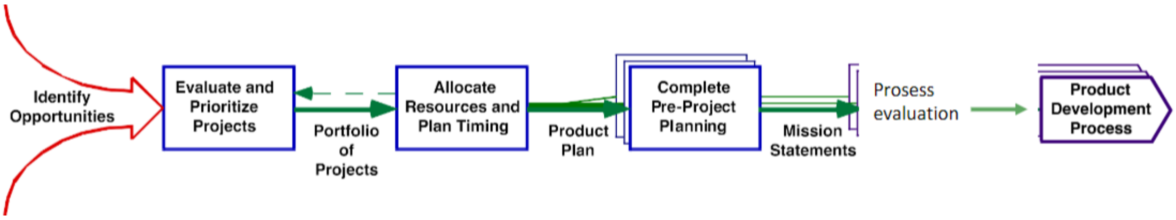


Figure 2.13: Product planning process [9]

2.6.2 Phase 1: Concept Development

In concept development, the customer needs are explored and identified before these needs are interpreted and converted into necessary metrics for the product. Based on these metrics, several alternative concepts are generated, tested, and evaluated, usually done with a screening matrix. Lastly, one or a few promising concepts are chosen for further development, and final specifications are set. The output of this phase is a development plan consisting of a description of the product's form, function, and features, usually accompanied by the final specifications and the bench-marking of competitive and similar products already on the market and the economic view of the process. [9]

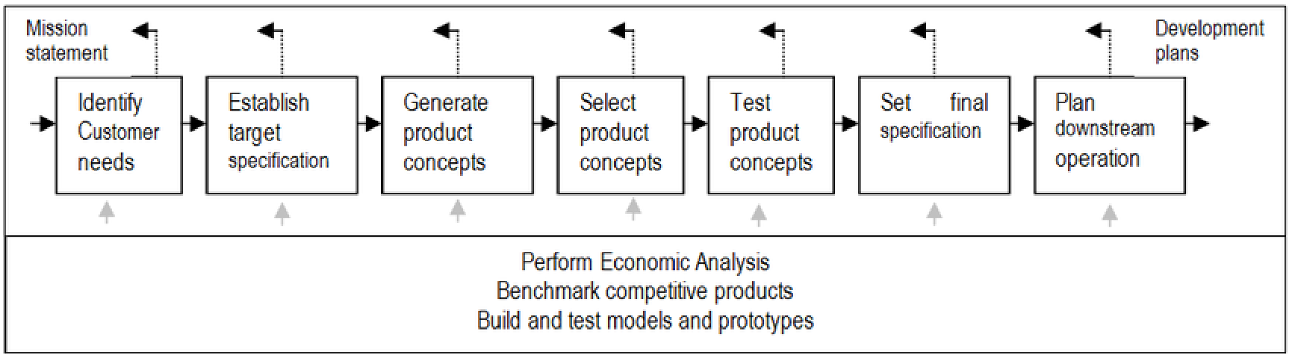


Figure 2.14: Concept development process [10]

2.6.3 Phase 2: System level design

Phase 2 of the product development process involves defining the product architecture, decomposing each product into subsystems and components, and further creating the preliminary design of these components. This phase aims to define a geometric layout of the product, a functional specification of each subsystem, and a preliminary flow chart for the final assembly process. Initial plans for the production system and final assembly are also defined during this phase. [9]

2.6.4 Phase 3: Detail design

This phase includes finishing all designs and setting all parts' final geometry, materials, and tolerance specifications. Furthermore, all the standard parts bought from suppliers must be identified. Issues in focus in the detail design phase should be on material selection, performance, and calculating production cost. The output of this phase should be a control document containing blueprints, either drawn by hand or made in CAD, describing each part's geometry and production tooling, as well as the specification for the purchased parts. A process plan for manufacturing and assembling the product should also be created to understand and control the supply chain. [9]

2.6.5 Testing and refinement

Multiple product prototypes are created, tested, refined, and evaluated in this phase. Firstly, early "alpha" prototypes are often made to test if the product works as expected and satisfies key customer needs. Later, more advanced Beta prototypes are made to test and evaluate the product's performance, reliability, and scalability to identify the necessary changes needed before the final product goes into production. [9]

2.6.6 Production Ramp-Up

In this phase, production is gradually transitioning from production ramp-up to ongoing production using the intended production system with the intention of training the workforce to work out any remaining problems. Initially, only a few products are produced and often shipped to key customers for a final evaluation. Later, full-time production starts, and the product is launched on the market for common distribution. After the launch, a process to evaluate the development process is carried out to find improvements and points of value from the project to ensure the optimization of the process. [9]

3 Product Development Process – Planning

The UiS Subsea ROV project student organization was comprised of 24 students, divided into nine bachelor's theses, cooperating to create one product. This meant that using PDP was essential to the success of the tasks assigned to this thesis, helping with the planning, coordination, management, quality assessment, and improvement of the product. The product development process is a generic plan that can be implemented on any product. Therefore some steps were deemed surplus to the requirements of this thesis due to time and resource restrictions. Most notably, production ramp-up was cut from the process because the product was a one-off prototype, and the testing and refinement phase only consisted of non-destructive testing. Lastly, the system-level design primarily focused on connecting all the parts. Furthermore, the UiS Subsea organization had partially completed the planning phase before the project started.

As stated previously, the planning phase consisted of five steps. Firstly, the organization starts by identifying the market opportunities, deciding which market and technology to pursue further, and then evaluating and prioritizing the possibilities into a product idea. These steps had already been achieved during the foundation of UiS Subsea and were not implemented as a part of this project.

As a result, the planning phase of this phase involved allocating time and resources by making a product and development plan and completing the pre-project planning by identifying the product's targets and limitations through a mission statement. This mission statement was then used as the foundation for the rest of the project.

3.1 Allocation of Resources and Plan timing

The allocation of resources and plan timing were crucial steps in the product development process. To maintain a consistent pace of development and achieve mission success, it was necessary to allocate resources appropriately and avoid excessive resource and time usage.

A comprehensive list was created for the entire project to ensure effective allocation, including limits, goals, and demands from MATE. Each item on the list was assigned a level of difficulty and importance, along with the reasons behind it and the responsible group for its completion. This clarified how the engineering teams should allocate the ROV parts and tasks. The primary components assigned to the mechanical engineering team were the float, electronic enclosure, manipulator, and ROV frame. Since this team had one more engineer than the other mechanical team, they were assigned three parts: the electronic enclosure, the ROV frame, and the float.

Once the tasks were allocated, a Gantt chart was used to determine the timing of each phase. The project team carefully planned the expected start date and the time required to complete each phase. This allowed for easy monitoring and progress evaluation. Each phase had a scheduled starting date and time, which was used to track how well the team adhered to the schedule. The Gantt chart was revised monthly to compare the actual time spent with the expected time.

All tables, lists, minutes of meetings, mechanical work drawings, and matrices from the project can be found in the Appendix of this report.

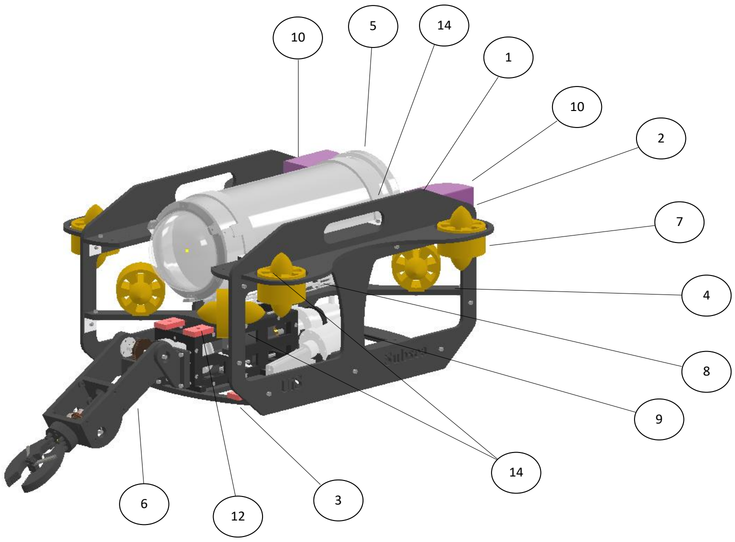
Due to the annual replacement of the organization UiS Subsea, including the finance department, the budget could not be finalized before the completion of the planning process. The budget relied heavily on sponsorship deals and support acquired by UiS Subsea and planned component purchase costs. This team set an estimated budget of 10,000-12,000 NOK, with 12,000 NOK later confirmed as the final budget. A comparison with the parts costs from previous years determined that contacting firms for component sponsorship and streamlining expertise as early as possible were crucial for the team's production.

3.1.1 ROV

During the first UiS Subsea meetings, it was established the ROV frame would consist of these main parts:

- The frame (Including top plate, bottom plate, and side plates)
- Mounting for thruster
- Mounting point for electronic enclosure
- Mounting points and space for manipulator
- Buoyancy element

Additionally, based upon project success at MATE [16] and TAC, the ROV was desired to contain the following applications and mechanisms.



1.	Sideplate
2.	Top plate
3.	Bottom plate
4.	Stiffener
5.	Electronic enclosure
6.	Manipulator
7.	Thrusters
8.	Cable transporter
9.	Rear end camera
10.	Bouyancy element
11.	Ballast
12.	Light mounting
13.	Electronic enclosure brackets
14.	Thruster mounts

Figure 3.1: Rov component list

Based on discussions with the previous year's group regarding their challenges and areas for improvement, it was determined that this year's primary focus for the ROV frame would be compactness, improved stability, and power efficiency to minimize drag. Another important aspect was to design a frame that adequately protects vital external electrical cables on the ROV. The third key objective was to enhance the ROV's stability to perform MATE tasks efficiently [18]. However, it was recognized that prioritizing stability would result in a trade-off with maneuverability. Consequently, the ROV would be slightly heavier and slower but capable of withstanding currents and external forces acting on the vehicle. The goal was maintaining a steady position with minor adjustments while the manipulator performed tasks.

3.1.2 Electronics enclosure

The electronic enclosure design included five teams: four electrical and one mechanical engineering group. The electronic enclosure was designed and produced solely by electrical engineers the prior year. However, based on feedback from the previous year's UiS Subsea team, it was revealed that the electronic enclosure on Fenris was not well-optimized. As a result, it was decided to assign this task to the mechanical engineering team while maintaining close collaboration with the electrical engineers to ensure all parties were involved.

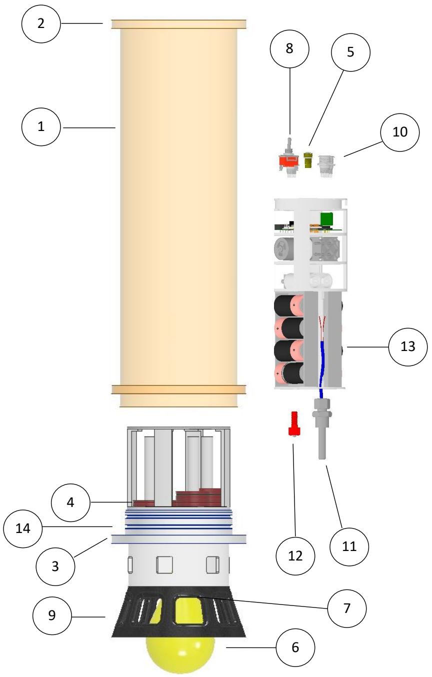
The responsibilities of the electrical engineers encompassed programming, circuit boards, system sensors, connectors, and other electronic components. The enclosure's interior would be constructed in close cooperation with the mechanical engineers, although the electronics design would determine the internal dimensions.

On the other hand, the mechanical engineers were tasked with creating the external structure of the enclosure, with a specific focus on factors such as drag, weight, buoyancy, material selection, sealing, and overall design considerations.

3.1.3 Float

Two teams were involved in this year's float: one electronic and one mechanical engineering team. The electronic engineering team took charge of the float's system sensors, circuit boards, and programming. On the other hand, the mechanical engineering team was responsible for designing and manufacturing the exterior of the float, with a specific emphasis on sealing and hydrodynamics. Additionally, the mechanical engineers assisted in the manufacturing of the internal structure that housed the electronic components and ballast.

The collaboration between the two teams focused on designing and integrating the buoyancy engine and bladder systems. In the initial meetings with the electronic engineering group, certain mechanisms were identified as essential components of the float.



1.	Body
2.	Top end-cap
3.	Bottom end-cap
4.	Ballast
5.	Pressure relief valve
6.	Bladder
7.	Bladder connector
8.	Power switch
9.	Impact module
10.	RBG lights
11.	Temperature sensor
12.	Pressure sensor
13.	Power supply
14.	Maintenance lid

Figure 3.2: Rov component list

3.2 Completing pre-project planning

To finalize the planning phase creating a mission statement encompassing various aspects was necessary. This included defining product descriptions, articulating the benefit proposition, establishing key business goals, identifying the primary market, and recognizing the stakeholders and constraints involved. Additionally, developing moral and economic guidelines to guide the project was essential.

Correctly identifying and assessing each of these positions was very important in effectively addressing the project's foundational elements. This meant that the project team ensured that all necessary considerations were considered and a clear direction was established for execution.

3.2.1 Internal demand

The first item on the agenda to complete the mission statement was identifying the internal demands within the UiS Subsea organization. This year, a key focus was on addressing the environmental impact, aligning with the heavy emphasis on the United Nations' sustainability goals associated with participating in MATE. Additionally, producing an eco-friendly product would maintain the organization's public image, which is to produce sustainable products with low environmental impact.

Furthermore, there was a need to reduce production costs, considering UiS Subsea's limited budget and resources. To facilitate the acquisition of sponsorship deals and maintain good relationships with external experts, team members were expected to behave and contribute in a manner that supported these objectives. Designing and manufacturing the product cost-efficiently would involve minimizing material waste, thus satisfying both environmental and financial demands. The moral guidelines presented in Table 3.1 outlined the expected behavior and mindset for the team, with the primary objective of safeguarding the organization's image and interests.

Table 3.1: Guide lines to satisfy internal demands

Public image	• Design and manufacture with the environment in mind • Limit long distance shipping
Cost reduction	• Limit unnecessary parts and manufacturing attempts • Design and manufacture locally
Cooperation partners	• Same progressive values as UiS Subsea • Preferably local to promote UiS Subsea's standing in the working environment in Stavanger
Safety	• Limit toxic materials and sharp edges that potentially could harm wildlife

3.2.2 External demand

As previously stated, the MATE and TAC challenges prioritize minimizing the environmental impact on the participating products. The competition rules and settings impose additional constraints on the final ROV and float. Firstly, the MATE competition takes place in a chlorine pool, while the TAC challenge takes place in salt seawater. Secondly, these competitions are not held at the ROV's assembly point, with the MATE competition in the USA. This necessitates that the ROV be easy to assemble and disassemble for transportation. Lastly, the ROV and the float are subject to constraints outlined in the MATE challenge manual. The ROV must weigh under 35kg, fit in a docking bay measuring 0.85m^3, and have slight positive buoyancy to be eligible for competition. The float must possess either a pressure relief valve or a non-bolt sealing technique, be under 1m tall, and have a width of 18cm [18].

Furthermore, the electronic enclosure also has its own set of constraints. It needs to accommodate the circuit boards created by the electronic engineers, necessitating careful consideration of size. Additionally, material selection for the enclosure is crucial as it must effectively dissipate the heat generated by the electronics. When formulating the mission statement, these external and internal constraints and demands must be considered.

3.3 Mission Statement

Once the internal and external constraints for the project development process were identified and the mapping of integral parts was completed, the mission statement could be formulated. This involved defining product descriptions, benefit propositions, key business goals, assumptions and constraints, primary market, and stakeholders. It also incorporated areas of improvement based on lessons learned from last year's ROV.

The mission statement was a comprehensive document outlining the team's visions and targets for the remainder of the project. It provided a clear direction and served as a helpful baseline for ensuring the team focused on tasks aligned with the mission statement. This way, the team could effectively address their main objectives and avoid spending unnecessary time and energy on tasks that did not align with the mission statement's goals.

Table 3.2: Mission statement

Mission Statement	
Product description Frame	The ROV frame consists of modular parts that protect and carry vital components and instruments for the ROV's functionality
Product description electronics enclosure	The electrical enclosure protects critical electrical components from impact and water damage
Product Description Float	The Float protect critical electrical components from water and impact damage while maintaining two vertical profiles
Benefit proposition	• Lightweight • Environmentally friendly • Stable in both land and on water • Able to perform MATE tasks • Chlorine and salt resistant • Compact and manoevreable • Easy to assemble and disassemble • Maintenance friendly
Key Business Goals	• Ready for first underwater test April 11th • Ready for promotional video MATE May 15th • Manufacture within budget • Perform at a high level at MATE competition
Primary market	• Subsea organizations • MATE and TAC
Assumptions and constraints project	• Perform at 4 m depth • 12 000 NOK (Total budget) • Under 35 kg excluding tether • 10 N neutral buoyancy force • Perform in salt and chlorine environment
Assumptions and constraints Frame	• Less than 0.85m^3 • Lightweight
Assumptions and constraints electronic enclosure	• Minimum thermal coefficient of $200\,\mathrm{W/m \times K}$ • Perform with internal temperature of 100 °
Assumptions and constraints Float	• Buoyancy engine • Battery driven • Less than 1m tall and 18 cm wide (MATE) • Pressure relief valve
Stakeholders	• University of Stavanger • UiS Subsea • Sponsors of UiS Subsea

4 Product Development Process – Concept Development

After reflecting on the mission statement and completing the planning phase, the concept development phase commenced. This phase aimed to create a preliminary concept of the product's appearance and determine its desired features and characteristics. This involved identifying customer needs, establishing target specifications, generating and selecting product concepts, and conducting testing. Throughout each sub-phase, the team continuously reviewed and questioned their decisions to ensure the overall quality of the process. Since the team was part of a larger organization with evolving requirements, these reviews and revisions were essential to keep all design aspects current and aligned with the changing demands.

4.1 Identify Customer needs

The first step in the concept generation phase was to identify the customer needs. The team primarily focused on mapping the requirements stated in the competition manuals of MATE and TAC, as these were the targeted competitions for the ROV. It was essential to transform these requirements into specific and tangible needs. Additionally, the team considered the needs of the Uis Subsea organization and other groups involved in the project. Close collaboration with the electronics engineering groups working on the float and electronic enclosure was crucial to ensure optimal design concepts. Furthermore, the team translated the moral and ethical guidelines established in the planning phase into concrete needs. Following the standard formulation of customer needs, the needs were presented as follows:

- Expressed in terms of what the product has to do, not how to do it
- Expressed in a positive phrasing
- Expressed as specifically as the raw data
- Expressed as an attribute of the product
- The word "must" and "should" was avoided

4.1.1 ROV-frame

Several demands from the MATE and TAC competitions concerned the ROV frame. It was crucial for MATE competition compliance that the ROV fit within a 0.85 m^3 docking bay, weigh under 35 kg, and remain positively buoyant. Additionally, the ROV needed to withstand submergence in chlorine conditions for at least 15 minutes, as that was the set time to complete the tasks. The minimum depth rating required was 4 meters, matching the depth of the competition pool. Easy assembly and disassembly were also essential for transportation, as the competition was held overseas. On the other hand, the TAC challenge required the ROV to endure extended submergence in saltwater and incorporate lights for actual underwater conditions.

The Uis Subsea organization and other project groups also had specific needs for the ROV frame. The frame needed mounting points and protection for the parts of other groups. Transportability and safety were also important considerations, as the groups were responsible for transporting the ROV. UiS Subsea set target needs for a depth rating of 100 meters and a weight below 25 kg.

Furthermore, the development team established internal goals for the ROV. The aim was to build a stable and compact ROV that was easy to maneuver while prioritizing environmental friendliness and cost-efficient production.

After mapping all the external and internal needs, they were rated according to importance and organized in a hierarchy. The need matrix, as shown in Table 4.1, includes primary needs from MATE and TAC competitions, secondary needs from UiS Subsea and other groups, and tertiary needs from the development team itself.

Table 4.1: Needs matrix ROV-frame

Needs matrix ROV-frame		
Nr	**Need**	**Priority**
1	The ROV-frame allows for good manoeuvrability	4
2	The vertical thrusters are placed on the corners	3
3	The ROV-frame is hydrodynamic	4
4	The ROV-frame fit in docking bay	5
5	The ROV-frame can operate at 4m (MATE)	5
6	The ROV-frame can operate at 100m (UiS Subsea)	3
7	The ROV-frame is designed for assembly	4
8	The ROV-frame has a balanced weight distribution	5
9	The ROV is marginally positive net buoyancy force	5
10	The ROV-frame can operate in chlorine pool (MATE)	5
11	The ROV-frame can operate in salt water (TAC)	4
12	The ROV-frame causes minimum amount of drag	3
13	The ROV-frame is produced cost-effectively	3
14	It is easy to add and remove ballast to the ROV-frame	2
15	The ROV-frame is produced in an environmentally friendly way	3
16	The ROV weight below 35 kg (MATE)	5
17	The ROV weight below 25 kg	3
18	The ROV is stable on land and in water	4
19	The ROV-frame has mounting points for manipulator	4
20	The ROV is easy to transport	2
21	The ROV is easy to lift	4
22	The ROV does not contain parts do not with the ability to injure people	5
23	The ROV-frame protects critical parts	5
24	The ROV-frame contains mounting points for thrusters	4
25	The ROV-frame contains mounting for electronic enclosure	4
26	The ROV-frame contain mounting points for lights	3
27	The ROV-frame contain mounting points for downwards camera	3

4.1.2 Electronic enclosure

Regarding the electronic enclosure, the MATE and TAC challenges did not impose any additional requirements beyond those previously discussed, such as the depth rating and submergence in salt and chlorine conditions. However, there were some essential needs to address. These included ensuring the enclosure was watertight and capable of releasing pressure in the event of overpressure situations.

On the other hand, the other groups, particularly the electronic engineers, had specific needs for the enclosure. Since the circuit cards were housed inside, close collaboration and discussions were necessary to ensure an optimal fit. Additionally, the circuit cards generated a significant amount of heat that needed to be effectively cooled within the enclosure. It was also determined that the camera would be placed inside the enclosure, requiring sufficient space and a transparent end-cap. Furthermore, the enclosure needed seven connectors to establish connections between the circuit cards.

As for our group's internal targets, our focus was on making the enclosure as hydrodynamic as possible to enhance the ROV's maneuverability.

To prioritize the needs of the ROV, they were assessed based on importance and organized in a hierarchical structure. The primary needs corresponded to MATE, TAC, and external requirements, while the secondary needs represented the needs of other groups involved. Lastly, the internal needs of our group were classified as tertiary needs.

Table 4.2: Needs matrix electronic enclosure

Needs matrix electronic enclosure		
Nr	**Need**	**Priority**
1	The enclosure cool the electronics	5
2	The enclosure house all electronics	5
3	The enclosure has space for a dome and a camera	4
4	The enclosure is watertight	5
5	The enclosure can operate at 4m (MATE)	5
6	The enclosure can operate at 100m (UiS Subsea)	3
7	The enclosure is hydrodynamic	3
8	The enclosure has space for 7 connectors	5
9	The enclosure has space for a pressure relief valve	5
10	The enclosure can operate in chlorine pool (MATE)	5
11	The enclosure can operate in salt water (TAC)	4

4.1.3 Float

Regarding the float, the MATE competition manual outlined specific requirements. It stated that the float should have a maximum height of 1 meter and a width of 18 cm. Additionally, it needed to be battery-driven and equipped with a buoyancy engine. MATE also specified either a pressure relief valve that would sufficiently address overpressure or a non-bolt sealing technique. To meet MATE's standards, the float had to withstand exposure to chlorine conditions for a minimum of 10 minutes and perform two vertical profiles within that timeframe. Since the float was solely intended for MATE, no requirements related to the TAC challenge existed.

Due to close collaboration with the electronic group regarding the float, the remaining needs were determined through discussions and were considered desirable rather than mandatory. Both groups agreed the float material should be non-magnetic to enable hands-free operation. It was also crucial for the float to withstand the shock impact from hitting the bottom. The inclusion of a secondary buoyancy engine in case of failure, as well as a handle for external operators to handle the float, were deemed advantageous. Additionally, the electronic group expressed the need for mounting points on the top of the float to accommodate lights.

As with the frame and enclosure, the needs were prioritized based on importance and organized hierarchically. The primary needs represented the MATE requirements, while the secondary needs encompassed the needs of the electronic group and our group's internal requirements for the float.

Table 4.3: Needs matrix Float

Needs matrix float		
Nr	**Need**	**Priority**
1	The float has a height less than 1m (MATE)	5
2	The float has a width less than 18cm (MATE)	5
3	The float is hydrodynamic	3
4	The float completes two vertical profiles	5
5	The float is watertight	5
6	The float uses a buoyancy engine	5
7	The float is wireless	5
8	The float is fit for dept operation	3
9	The float descends with deflation of bladder and ascends with inflation of bladder	5
10	The float can operate in chlorine pool (MATE)	5
11	The float has a pressure release valve	4
12	The float is produced cost effectively	3
13	It is easy to add and remove ballast to the float	3
14	The float is lightweight	3
15	The float is produced in a environmentally friendly way	4
16	The float contains space for LED lights on top	2
17	The float has a shock resistant bladder shield	4
18	The float contains a handle for manipulator	4
19	The float has space for secondary buoyancy system	3
20	The float is battery driven	4

4.2 Establishing target values

The subsequent stage in the concept development phase involved establishing target values for the products. This entailed setting specific goals and objectives for the product that would align with the customers' needs. Defining these target values entailed determining the ideal value, which would provide maximum customer satisfaction, as well as the marginal value, representing the minimum requirement for acceptability. This process ensured that the product development process remained customer-centric and focused on meeting their needs and expectations.

Establishing target values was crucial in guiding the entire product development process. It provided a clear reference point for the development team to work from. With specific targets, the team could direct their efforts towards achieving these goals and ensuring that the final product adequately fulfilled the customers' requirements. This approach mitigated the risk of developing a product that would not resonate well with stakeholders and enhanced the prospects of competition success. Furthermore, establishing good target values facilitated adherence to budgetary and timeline constraints, which were vital for overall project success. In essence, establishing target values represented a pivotal step in the product development process, enabling the development team to focus on meeting customer needs and expectations.

4.2.1 ROV-frame

The target values for the ROV frame are shown in Table 4.4. These values were established based on both marginal and ideal criteria. The marginal values were derived from the competition manuals, particularly the MATE manual, which outlined the minimum requirements. On the other hand, the ideal values were determined based on stakeholders' preferences, the needs expressed by other teams involved in the project, and the overall vision of UiS Subsea for the final ROV.

When target values were derived from the requirements and needs of other teams, the marginal value was set according to their specific demands. In contrast, the ideal value represented the aspirations of the development team. The units were designated as subjective for targets that did not have discrete numerical values. This meant the development team would conduct inspections and analyses to ensure the targets were satisfactorily achieved. These evaluations would involve decisions such as material choices and planning of attachment points for various components and functionalities.

Furthermore, the stress values assigned to the ROV frame were based on the team's assumptions and expectations regarding the forces the frame would encounter on land and water. These values were subject to change as the development progressed and more accurate information became available.

Table 4.4: Target specifications ROV-frame

Target specifications ROV-frame						
Metric (No)	**Need (Nos)**	**Metric**	**Imp**	**Units**	**Marginal Value**	**Ideal value**
1	1,2,24	Thruster attachment	3	Nr	>5	8
2	3,11	Minimum Drag	3	Subj	OK	OK
3	4	Maximum size	5	m^3	$0,85$	$< 0,85$
4	5,6	Operational dept	5	m	4	100
5	7,13	Design for assembly	4	Subj	OK	OK
6	8,18,21	Center of mass to center x-y plane	4	cm	+- 5	0
7	9	Marginal positive buoyancy	5	N	5-15	10
8	10	Operate in chlorine environment	5	Subj	OK	OK
9	11	Operate in salt water	4	Subj	OK	OK
10	13	Total cost production	3	NOK	12 000	< 12 000
11	15	Environmental friendly	4	Subj	OK	OK
12	16,17,21	Max weight	5	Kg	35	25
13	18,20	Stability on land	3	Subj	OK	OK
14	19	Mounting points on bottom plate	3	Nr	6	8
15	20,21	Easy to transport	2	Subj	OK	OK
16	22	No sharp edges	5	Subj	OK	OK
17	25	Mounting electronic enclosure	4	Subj	OK	OK
18	26	Mounting for lights	3	Nr	2	4
19	27	Mounting for downward camera	3	Subj	OK	OK
20	1,8,18	Distance between CM and CB (x-y plane)	5	mm	5	0
21	1, 18	Distance between CM and CB (z-direction)	4	mm	>25	25-50

4.2.2 Electronic Enclosure

The target values for the electronic enclosure are presented in Table 4.5. Since there were limited requirements from MATE and TAC regarding specific metrics for the enclosure, the target values were primarily derived from the needs expressed by other groups and the overall vision of UiS Subsea for the final product. However, it is worth noting that the enclosure was required to withstand submersion in salt and chlorine conditions for extended periods, influencing the target values.

Similar to the ROV frame, the marginal values for the enclosure were determined based on the needs and demands of other teams and UiS Subsea. On the other hand, the ideal values were established according to the development team's goals for the enclosure. It is important to mention that certain metrics were not quantifiable and were labeled as subjective. This indicates that the team would design, control, and inspect solutions that would fulfill these subjective metrics during the development process.

Table 4.5: Target specifications electronic enclosure

Target specifications electronic enclosure						
Metric (No)	**Need (Nos)**	**Metric**	**Imp**	**Units**	**Marginal Value**	**Ideal value**
1	1	Thermal conductivity rating	5	$\mathrm{W/m \times K}$	200	>200
2	1	Inside surface area	5	m^2	$0,065$	$> 0,065$
3	2, 8	Internal width	5	mm	180	180
4	2	Internal length	5	mm	435	435
5	3	Mounting points for dome endcap	4	Nr	4	6-8
6	3	Transparent endcap	4	Subj	OK	OK
7	4	Watertight seal	5	Subj	OK	OK
8	7	Hydrodynamic shape	3	Subj	OK	OK
9	11	Operate in salt water	3	Subj	OK	OK
10	10	Operate in chlorine pool	5	Subj	OK	OK
11	-	Environmental friendly	4	Subj	OK	OK
12	5,6	Pressure resilience	5	bar	1,4	10
14	9	Pressure relieve valve	4	Subj	OK	OK

4.2.3 Float

The target specifications for the float can be found in Table 4.6. These specifications were mainly derived from the MATE competition manual [19] since the primary purpose of the float was related to the MATE competition. The minimum values specified in the MATE manual were considered the marginal values for the metrics associated with MATE requirements. On the other hand, the ideal values were determined based on the development team's goals and the eventual goals set by other teams involved in the project. Since the team collaborated closely with an electronics group, some metrics were derived from their specific needs and goals for the float.

In addition to the competition requirements and other teams' goals, UiS Subsea had aspirations regarding the desired functionalities of the final product. These aspirations were considered and labeled as subjective metrics in the table. This means they would be evaluated and considered during the later design, testing, and manufacturing stages.

Table 4.6: Target specifications float

Target specifications float						
Metric (No)	**Need (Nos)**	**Metric**	**Imp**	**Units**	**Marginal Value**	**Ideal value**
1	1	Total length	5	m	1	0,5
2	2	Total width	5	m	0.18	0.14
3	4	Vertical profiles	5	Nr	2	>2
4	4,8	Operational dept	5	m	4	10
5	5	Watertight	5	Subj	OK	OK
6	6	Buoyancy engine	5	Subj	OK	OK
7	20	Battery	4	V	12	<12
8	10	Operate in chlorine environment	5	Subj	OK	OK
9	11	Pressure release valve rating	5	psi	12	<12
10	12	Total cost production	3	NOK	12 000	< 12 000
11	15	Environmental friendly	4	Subj	OK	OK
12	3	Hydrodynamic shape	3	Subj	OK	OK
13	9	Net buoyancy before inflation	4	N	<0	-1,5
14	9	Net buoyancy after inflation	4	N	>0	>1
15	14	Lightweight	3	Kg	12	10
16	16	Holes for led lights	2	Nr	1	3
17	17	Impact resistance bladder	4	Subj	OK	OK
18	18	Working handle for manipulator	4	Subj	OK	OK
19	19	Space for secondary buoyancy system	3	Subj	OK	OK
20	13	Easy to add/remove ballast for weight distribution	4	Subj	OK	OK
21	7	Wireless	5	Subj	OK	OK

4.3 Generate Product concepts

The concept development phase proceeded to the next step, which involved concept generation. The group gathered input regarding the target specifications and product limitations in this step. The objective was to generate as many concepts as possible. These concepts could be drawings, simplified written descriptions, or CAD files. The key to success in this step lies in utilizing creativity and imagination.

To foster an environment conducive to creativity and problem-solving, it was crucial to thoroughly explore every aspect of the market and gather extensive information about the problem. To ensure comprehensive exploration, the group employed a five-step process. These steps encompassed clarifying and breaking down the problem, searching internally and externally for potential solutions, exploring the range of solutions discovered, and finally, reflecting on the entire process.

4.3.1 Clarifying and decomposing the problem

Decomposing a problem aims to break down intricate problems into smaller and simpler ones. This approach facilitates the group's understanding of the core problem and lets them contemplate potential solutions.

In the case of the ROV frame, there were multiple complex target specifications to consider. To ensure stability on land and in water, the group identified a solid and stable foundation, symmetrical design, and strategic placement of buoyancy elements at a higher position and weight elements at a lower position as critical factors for success.

In terms of meeting weight limitations, hydrodynamics, and environmental impact goals, the group concentrated on minimizing material usage and designing the frame to be as compact as possible. By adopting these strategies, they aimed to optimize the ROV's weight, improve hydrodynamic performance, and reduce the overall environmental footprint.

The outcome of the decomposition process was the fundamental concept of a symmetric and compact skeleton frame. This frame design incorporated buoyancy elements integrated into the top plate and weight elements placed in the bottom.

Regarding the float and electronic enclosure, the primary objective was clear: they both needed to be watertight. Furthermore, it was crucial to address factors such as internal overpressure, external water pressure, and impact strength to prevent any issues resulting from design flaws. Additionally, precise calculations of the CG and CB were required for the float to accomplish its mission tasks, which involved performing two vertical profiles.

4.3.2 Search externally

Searchin externally aims to investigate other companies' experiences in tackling similar problems. This can be accomplished through various means, such as consulting with experts and lead users, exploring relevant patents and literature, and conducting benchmarking analyses of competitive products and previous offerings in the market.

In this particular case, the group opted to concentrate on two main aspects: consulting expertise provided by the sponsors of UiS Subsea and benchmarking previous UiS Subsea products, as well as examining existing ROVs available in the current market. By leveraging these resources, the group aimed to gather valuable insights and knowledge from industry experts and learn from the successes and shortcomings of both internal and external products.

Consulting expertise

The group sought the expertise of Seal engineering to assist with designing and selecting appropriate sealing options for both the electronic enclosure and the float. Before the meeting, the group had explored various sealing options, including O-rings, S-rings, and T-rings, each with advantages and disadvantages. Gaining insight into an expert opinion on these products' optimal use, versatility, and effective sealing techniques for the enclosures would prove invaluable. The group acknowledged their inexperience in this field and sought insights into different sealing alternatives. During the consultation, various sealing and fastening techniques were discussed, including tension rods, pressure sealing, bolt sealing, and press and shrink fitting.

Additionally, the previous year's group was consulted to gain insights into their challenges and the solutions they implemented in designing the ROV frame and float. Topics of discussion included strategies to enhance the compactness and maneuverability of the previous ROV, efficient design of cable canals, areas where material usage could be minimized, and specific design considerations for Fenris 2022. The previous group emphasized their issues with fragile thruster protection, poor space optimization, and difficulty maneuvering the ROV in pitch and roll movements. On the positive side, they highlighted stability, hydrodynamics, and ease of assembly as strengths in their design.

Benchmarking products

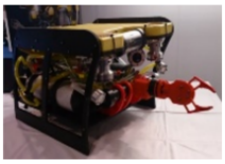
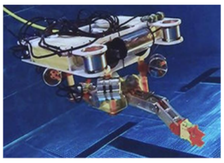
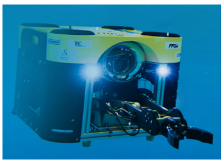
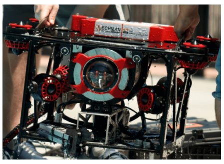
Benchmarking involves studying previous or existing products with similar functionality to better understand their strengths, weaknesses, and opportunities for improvement.

In the case of the ROV project, the group began by exploring UiS Subsea's previous ROVs. These vehicles were chosen due to the availability of files and physical access. Among the numerous ROVs, the group focused on Fenris 2022 and Hymir 2021, the most modern and relevant ROVs to the current project. Additionally, Njord 2014 and Tor 2015 were examined, since these vehicles performed relatively well in the MATE competition.

This benchmarking process provided valuable insights into factors such as weight class, material selection, size, and each ROV's specific strengths and weaknesses. A common observation among most vehicles was inadequate cable management and thruster protection. Recognizing these as crucial requirements for the ROV, the group identified material waste and excessive weight as general shortcomings across the previous designs. The knowledge gained from this benchmarking exercise proved essential during the concept generation phase, guiding the group toward effective solutions.

ROV-frame

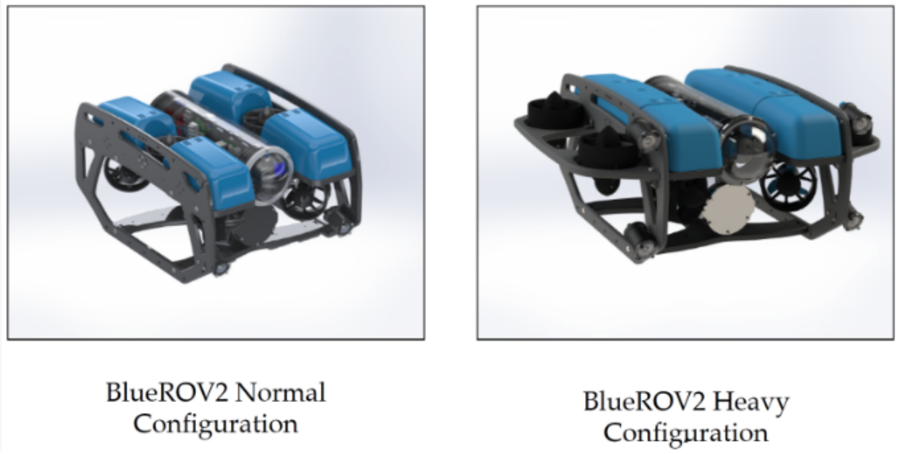
Table 4.7: Benchmarking ROV

Benchmarking ROV				
Products	Njord 2014 	Tor 2015 	Hymir 2021 	Fenris 2022 
Placement in MATE	14th	19th	NA	16th
Weight	35	40,7	30	26
Size mm (LxWxH)	658x524x450 §	810x635x450 §	450x250x250	674x698x408 mm
Frame material	PEHD1000	PEHD1000	Aluminium 6063, ABS, PE	PLA, aluminium (brackets)
Electronic enclosure	-	-	Aluminium	Aluminium
Buoyancy material	Divinycell H80	Divinycell H80	HCP30	PUR
Total cost	-	-	-	-
Pros	• Open • Compact • Easy to assemble/ disassemble • CG and CB placement	• Free flow • Compact	• Stable (land) • Compact • Impact resistant	• Free flow • CG and CB placement • Stable (Water and land) • Easy to carry • Easy to assemble/ disassemble • Good risk factor
Cons	• Heavy • Loose cables inside the frame • Limited water flow • Unstable (land)	• Heavy • No protections for vertical thrusters • Unstable (land)	• Heavy • Unstable (water) • Net buoyancy force too high • Unnecessary high safety factor	• Enlarged (non-compact) • Hard to maintain tilt • float seal did not hold • Poor heat dispertion (EL.H) • Vacuum sealing (EL.H)

It was crucial to correctly identify competitive products in the market to classify the ROV appropriately. After researching the MATE manual [18] and the standard ROV manual [20], this year's ROV was classified as a Class II B vehicle. This classification denotes it as an observation ROV with additional functionalities, including a manipulator, color cameras, additional cameras, sonar, and a cathodic protection measurement system.

The market for Class II B ROVs is relatively limited. Manufacturers often prioritize Class III ROVs, which are capable of more complex tasks in real-life scenarios and can operate at greater depths. However, some similar products are available, mainly from websites catering to private hobby enthusiasts.

One such product is the "BlueROV2" by Blue Robotics, depicted in Figure 4.1. It is an affordable, modular, and lightweight ROV designed for commercial sales to individuals. The ROV has comprehensive assembly instructions and can be easily modified with optional extensions. Two variants are available: the first features six thrusters and is primarily intended for observation, accommodating smaller configurations such as lights and a small gripper. The second variant, with eight thrusters, allows for heavier designs, including manipulators, sonars, and additional cameras. The second variant was examined more closely as it incorporated the functionalities required for our ROV. Furthermore, this design offers enhanced stability and maneuverability compared to the standard variant. Both variants are classified as Class II B, with dimensions of 457x338x254 mm, a weight of 11-12 kg, and a depth rating of 100m, which aligns with our targets. The frames are manufactured using a combination of thermoplastic PEHD (Polyethylene High Density) and aluminum, while the buoyancy elements are made of urethane foam R-3318.[21] [45]


BlueROV2 Normal Configuration

BlueROV2 Heavy Configuration

Figure 4.1: The two different specs of Blue Robotics ROV [11]

Float

The scientific float falls under the Class VI classification, as defined by the previously established standard. It is a simplified AUV that follows a pre-programmed path. The float has an onboard power supply and a buoyancy engine, enabling it to maintain vertical profiles while collecting data. The MATE competition's official website references GO-BGC (Global Ocean Biogeochemistry Array) floats to illustrate the structure and application of a standard float [28]. These floats are battery-powered and utilize oil as the fluid for their buoyancy engines. They are equipped with various sensors that gather and store data such as pH, temperature, conductivity, depth, nitrate, and CO2 levels. This data is transmitted once the float resurfaces. Although the example floats in the MATE competition had a much greater depth rating than our target values, they provided valuable insights into size, weight, and shape. For instance, all the example floats were cylindrical, which served as a basis for this year's float design. Additionally, the concept design of the float drew inspiration from the SOCCOM profiling float, as depicted in Figure 4.2.

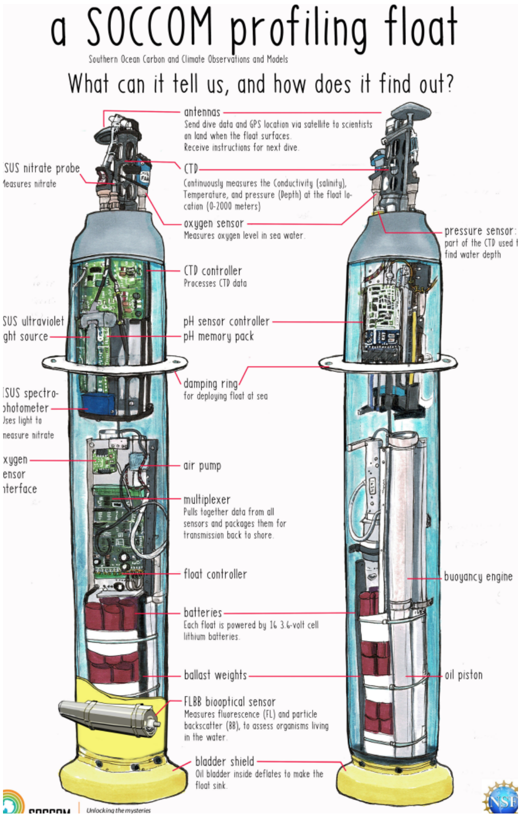


Figure 4.2: SOCCOM example float [12]

Table 4.8: Bench marking float

Benchmarking float			
Product	Navis (BGC) Sea-bird [46] 	Alto MRV [47] 	FRØYA UiS Subsea 
Weight [Kg]	< 20	19,2	4,23
Length [cm]	167	133/110	50,5
Diameter [cm]	14 // 24	16,5	12,5 (cylinder) //15 (cone)
Dept rating	2000 [dbar]	2000 [m]	100 [m]
Material	Aluminium	-	PE and PLA
Lifetime [cycles]	250	-	-
Volume change %	1,7	4,2	-

4.3.3 Search internally

The next phase of the concept generation process involved conducting an internal search within the group. This step was crucial for exploring and developing a wide range of solutions for the product. After completing an external search for patents, expertise, literature, and similar products, the development team shifted its focus internally to gather inspiration and ideas from within the group.

During this phase, the team aimed to generate and realize each member's ideas, thoughts, and solutions related to the conceptual challenges. The starting point for the internal search was the information gathered in the previous phase, including the target values. Using this information as a foundation, the team sought to generate as many concepts as possible. Creativity and thinking outside the box were encouraged, even considering unconventional and outlandish ideas. The objective was to create diverse concepts that could be evaluated and refined to ensure alignment with the project's goals.

Team members initially worked independently to avoid prematurely fixating on any single concept, generating their ideas and concepts. Subsequently, they reconvened to discuss and evaluate each other's contributions. All ideas were carefully examined and assessed during this collaborative process based on their alignment with the project's target values.

Throughout this step, the team focused on creating ideas that fulfilled as many of the target values as possible. This approach ensured that the concepts generated were in line with the project's objectives and had the potential to be developed into a final product that met the needs of the target market.

ROV frame

In the concept generation phase of the ROV frame, the development team considered several important factors when exploring different design options. The team prioritized vital metrics such as size restrictions, stability on land, and ease of transportation. Special attention was given to avoiding sharp edges that could potentially cause harm to team members during competitions, as this would not meet the safety requirements set by the MATE competition [18].

Functionality was also a crucial consideration in the design process. The ROV frame needed suitable mounting points for various functions, such as for a manipulator, and should be easy to assemble and disassemble when necessary.

Furthermore, the team incorporated their vision of a compact and hydrodynamic ROV during the design process. By allowing team members to focus on their individual goals and visions for the product, innovation, and differentiation from existing market offerings could be achieved. The outcomes of each team member's brainstorming session were consolidated and presented in Figure 4.3 demonstrating the diverse range of design concepts and ideas generated by the team. The concepts are listed directionally from A to J

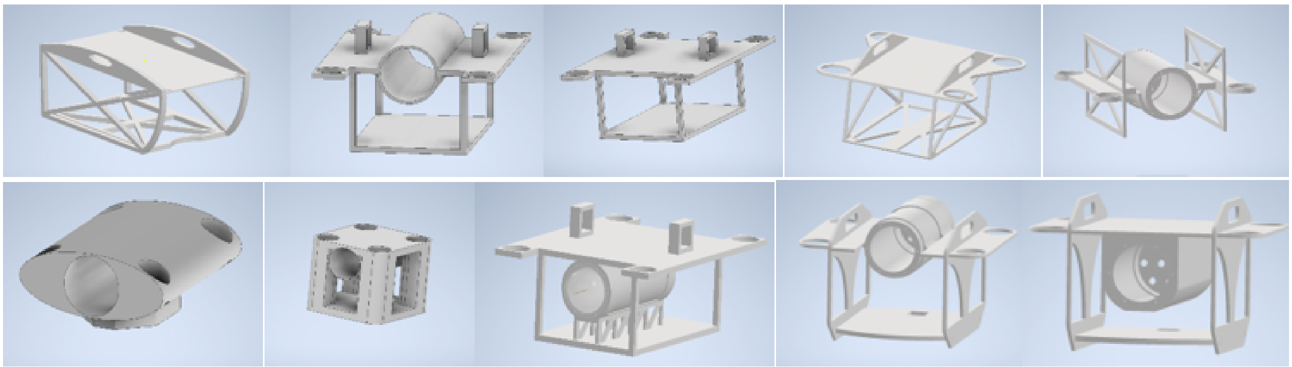


Figure 4.3: Different concepts after brainstorming

During the discussions, it became apparent that several concepts proposed by team members independently shared similar functionalities. As a result, the team decided to concentrate their attention on three distinct ideas, namely E, F, and G. Additionally, they focused on the more advanced "skeleton" designs, H, I, and J. Concepts A, B, C, and D were set aside during this phase to maintain flexibility and explore the most promising "skeleton" design more thoroughly. The six concepts, represented in Figure 4.4, were subjected to further evaluation and testing as part of the concept selection phase.

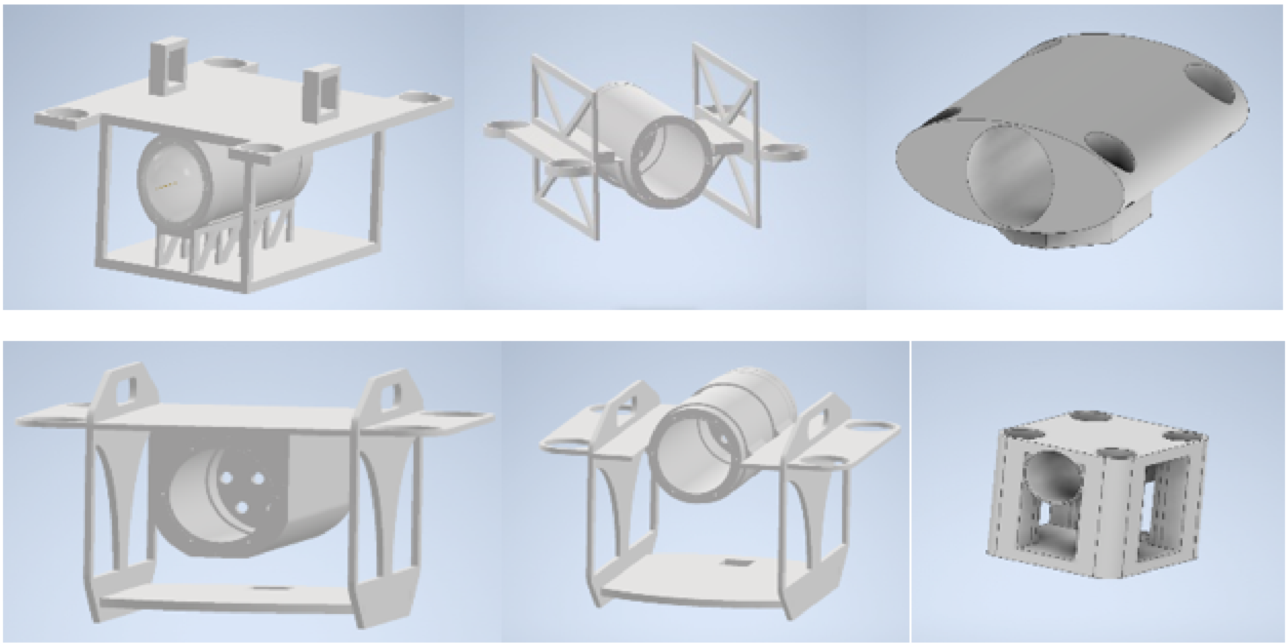


Figure 4.4: Remaining concepts after initial screening

Electronic enclosure

When designing the electronic enclosure for the ROV, the development team identified several primary metrics to guide the design process. The group considered UiS Subsea's plan to upgrade this year's ROV to an AUV in the following year, emphasizing the need for space optimization and sufficient internal surface area to facilitate electronics cooling. Additionally, the ease of sealing and attaching the enclosure to the frame were essential to address.

Secondary metrics included accommodating a transparent dome to house the primary camera. Here, ample space was required to provide a sufficient field of view. The bottom end-cap needed adequate space for all connectors and cables and ease of access for future modifications and maintenance. In addition, the team aimed to incorporate their aspirations for the product. These include hydrodynamic shape optimization and enhanced pressure resilience to improve the ROV's power efficiency in water and at greater depths.

Figure 4.5 presents the outcomes of each team member's independent concept generation process. Each team member contributed three distinct concepts, but there were noticeable similarities among the variations of their ideas. As a result, the team decided to include all three concepts for further evaluation and testing, considering the selection and exclusion process employed for the frame design unnecessary in this case.

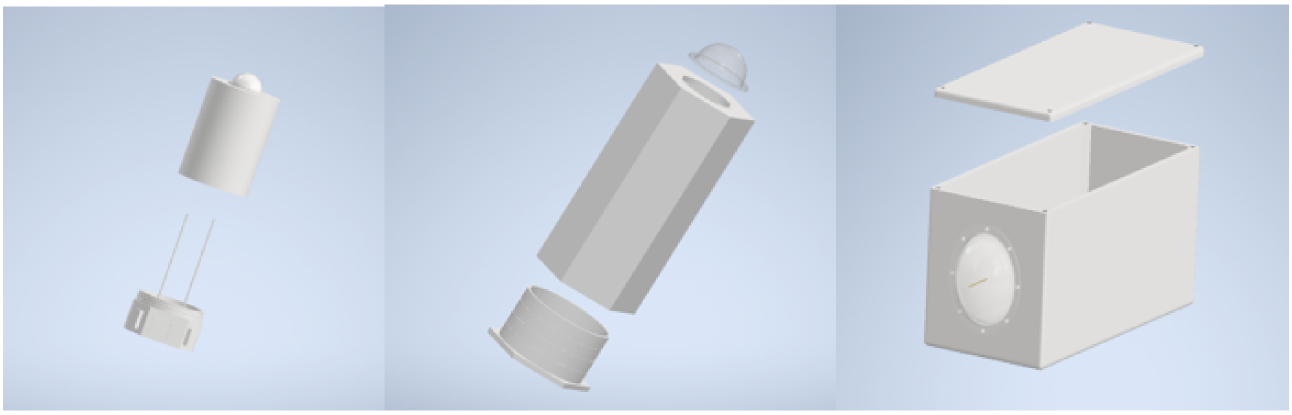


Figure 4.5: Remaining concepts after initial screening electronic enclosure

Float

After conducting external searches for benchmarking and consulting expertise, the team recognized that the design options for the float were limited, as existing products in the market were quite similar. Discussions with the previous year's group revealed that the float used by UiS Subsea in 2022 faced significant challenges related to sealing methods and fastening the end-caps to the body. Consequently, the team prioritized addressing these challenges initially, focusing primarily on different sealing and maintenance options during the concept generation phase.

During the design phase, the team's primary focus was to adhere to the guidelines outlined in the MATE manuals and ensure the float could complete the MATE tasks, as the MATE competition was the primary purpose for creating the float. Accommodating the electronic team's requirements became crucial in achieving the MATE qualification.

Additionally, the team took into account their aspirations for the product. In this case, their aspirations revolved around creating a streamlined design incorporating all the necessary features to make the product user-friendly and easy to manage.

Figure 4.6 illustrates the various concepts for different lid sealing options. Since the team had limited experience with sealing options, all the different alternatives were created, designed, and explored collectively, contrasting the approach taken for generating other product concepts.

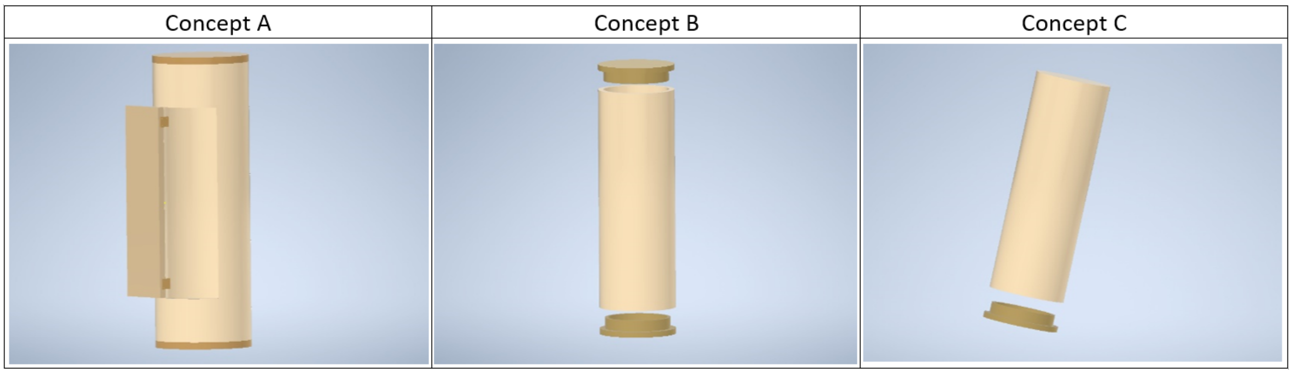


Figure 4.6: float concepts: maintenance lid

4.4 Concept selection

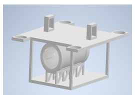
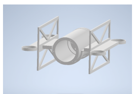
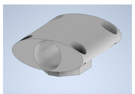
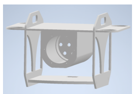
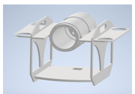
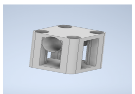
After generating a range of concepts and ideas, the next phase involved selecting the most relevant concepts for further testing and development. To effectively analyze and evaluate the strengths and weaknesses of each concept, a screening matrix was created based on the metrics established in Chapter 4.2, "Establishing target values." Each concept was assessed and assigned a grade for each metric in the matrix. The metrics used for evaluation included factors such as size optimization, stability, sealing capability, ease of assembly, hydrodynamic shape, and pressure resilience. For each metric, the concept was given a rating of "+" for an advantage, "-" for a disadvantage, or "0" for neutral performance compared to other designs.

Using the grading system, the scores for each concept were calculated. Based on these scores, concepts were either discarded from further development or chosen to proceed with additional testing and refinement. This approach allowed the team to objectively evaluate the concepts and make informed decisions on which designs to prioritize for further exploration, ensuring that the chosen concepts aligned with the project's target values and objectives.

4.4.1 ROV-Frame

The concept generation phase resulted in the generation of six different concepts for the design of the ROV frame. After completing the screening process, concepts D and E were selected for further development. These concepts demonstrated favorable attributes such as maneuverability, free flow, and stability, which are crucial for the practical function of the ROV. The remaining concepts were discarded; however, the team retained the ideas generated during this phase for potential incorporation into the design of subsystems during subsequent stages of the product development process.

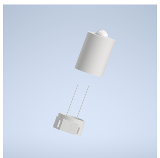
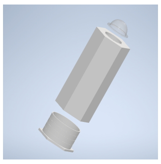
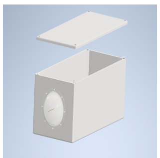
Table 4.9: Screening matrix ROV-frame

	Screening matrix ROV-Frame					
Selection Criteria	Concepts					
	A	B	C	D	E	F
						
Fit in docking bay	+	+	+	+	+	+
Hydrodynamic	+	0	+	+	+	-
Operate at 100m	0	0	0	0	0	0
Operates in salt conditions	0	0	0	0	0	0
Operates in chlorine conditions	0	0	0	0	0	0
Easy to assemble/Disassemble	0	-	-	0	0	-
Weight under 35kg	0	0	0	0	0	-
Environmentally friendly	0	0	0	0	0	-
No parts to with ability to injure	0	0	+	+	0	+
Stable on land	+	-	0	+	+	+
Stable in water	+	0	-	+	+	0
Protects critical parts	-	0	+	0	0	+
Mounting for manipulator	+	-	-	+	+	+
Mounting electronic enclosure	0	0	0	0	0	0
Marginally positive buoyancy	0	0	0	0	0	0
Good manoeuvrability	+	+	-	+	+	-
Free flow (frame + thruster)	+	+	-	+	+	-
Compact	0	+	0	0	+	0
Sum +'s	7	4	4	8	8	5
Sum 0's	10	11	9	10	10	7
Sum -'s	1	3	6	0	0	6
Net score :	6	1	- 2	8	8	- 1
Rank:	2	3	5	1	1	4
Continue? :	No	No	No	Yes	Yes	No

4.4.2 Electronic enclosure

During the concept generation phase for the electronic enclosure, three distinct concepts were developed, each with a different shape. Concept C featured a square shape, initially designed to optimize the internal space based on previous years' rectangular circuit boards. However, after consulting with the electronic engineers, it was determined that circular circuit boards could be used instead. Concept B was created to accommodate the specific placement requirements of individual electronic connectors along the enclosure, requiring a flat surface. On the other hand, Concept A was primarily inspired by benchmarking existing products on the market. Following the scoring and ranking process, concept A was chosen for further development, as it showed the most potential for meeting the project's objectives.

Table 4.10: Screening matrix electronic enclosure

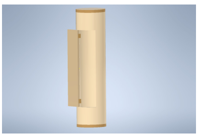
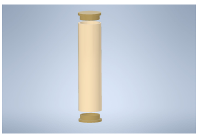
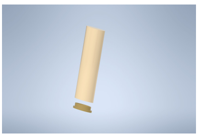
	Screening matrix electronic enclosure		
Selection Criteria	Concepts		
	A	B	C
			
Efficient heat dissipation	+	0	+
Hydrodynamic	+	0	-
Operate at 100m	0	0	0
Operates in salt conditions	0	0	0
Operates in chlorine conditions	0	0	0
Dome end-cap	0	0	0
Space for 7 connectors	0	+	+
Space for pressure relief valve	+	+	+
No parts to with ability to injure	0	0	0
Easy to disassemble	+	+	-
Easy to maintain electronics	0	0	+
House all electronics	0	0	0
Easy to seal	+	+	-
Easy to mount	+	0	-
Efficient space utilization	+	0	-
Sum +'s	7	4	4
Sum 0's	8	11	6
Sum -'s	0	0	5
Net score :	7	4	- 1
Rank:	1	2	3
Continue? :	Yes	No	No

4.4.3 Float

During the concept generation phase for the float, three main concepts were developed: Concept A, Concept B, and Concept C. Concept A featured a maintenance lid on the side of the cylinder, providing easy access to the electronics and ballast inside the float. This would allow the electrical engineers to do maintenance, without needing to remove the electronics from the rest of the structure. However, removing the electronics to do advanced maintenance would be complicated. Concept B had two lids, allowing for maintenance from both sides. This design enabled electronic engineers to perform specific maintenance tasks without removing the electronics from the float. Concept C was similar to Concept B, but only the bottom cap was removable. This concept offered manufacturing efficiency, cost, and time advantages. Having only one removable part made it easier to seal and reduced the risk of sealing failure.

After scoring and evaluating the concepts, Concept A was discarded due to its more challenging sealing requirements compared to Concepts B and C. Both Concept B and Concept C were chosen for further development, with the final decision depending on the future needs of the electronic engineers and considerations related to production time and cost.

Table 4.11: Screening matrix float

	Screening matrix float		
Selection Criteria	Concepts		
	A	B	C
			
Easy to maintain	-	+	0
Easy to seal	-	0	+
Fit for dept operations	0	0	0
Placements for lights,sensors and valves	0	0	0
Easy to produce	-	0	0
Require extra parts	-	0	+
Easy to design	0	0	+
Requires no welding	+	+	-
Sum +'s	1	2	3
Sum 0's	3	6	4
Sum -'s	4	0	1
Net score :	-3	2	2
Rank:	3	1	1
Continue? :	No	Yes	Yes

4.5 Test product concepts

Concept testing encompasses various activities to evaluate a concept's potential success in the target market. This phase involves testing the mechanical properties of each selected concept and gathering feedback through surveys and interviews with stakeholders and organizational leaders. The goal is to gather insights and perspectives to help identify the most promising concept and ensure that the final product aligns with market demands, stakeholder expectations, and organizational requirements.

By involving stakeholders and organizational leaders in the concept testing process, there is an opportunity to foster their engagement and familiarity with the product. This involvement helps gather valuable feedback and increases their understanding and support for the product, leading to a more favorable reception within the organization. Ultimately, concept testing is crucial in refining and validating concepts, ensuring that the chosen concept has the best chance of success in the targeted market. It helps mitigate risks, make informed decisions, and shape the final product to meet the market's and organization's needs and expectations.

4.5.1 Testing of mechanical properties

In order to assess the feasibility of the concepts and identify areas that required optimization, FEA was utilized. This method effectively evaluated the viability of different features within the concepts. The selected concepts for further development were subjected to rigorous testing and analysis.

Autodesk Inventor was utilized for the 3D modeling the various concepts during the concept generation phase. This software proved instrumental in creating accurate representations of components for 3D printing and generating mechanical drawings. Subsequently, the concepts were transferred to ANSYS Workbench for the FEA. The forces, pressures, and supports acting on the models within ANSYS were established to the best of this team's abilities. It is important to note that while ANSYS is a powerful tool, its results are contingent upon the team's understanding and proper utilization of the input parameters. Additionally, it is acknowledged that ANSYS may not always provide a completely accurate model. As a result, the team complemented the FEA with manual control calculations. The team sought guidance from experts to ensure that the forces, pressures, bearing loads, and supports were accurately defined, aiming for the most precise results achievable. By employing this combination of software tools, manual calculations, and expert consultation, the team aimed to evaluate the concepts thoroughly, identify potential design flaws, and refine the selected concepts for further development.

ROV-frame

During the evaluation of the ROV frame, various forces were examined, with particular emphasis on the bearing load from the electronic enclosure and the weight applied by the manipulator. To simulate the impact of these forces on the frame when it was lifted, fixed supports were positioned inside the handles while the bearing load and force were directed downward.

At this stage of the development process, the specific material for the frame had not yet been determined. Therefore, the material used in the previous year's frame, PEHD (Polyethylene High-Density), was selected for both models to ensure an equal and realistic simulation. Although the material selection was not critical for comparing the concepts at this stage, the team believed it was valuable to understand the concepts' safety factors, with further consideration of material choice during the detailed design phase. As the exact magnitude of the forces acting on the structure was unknown, an overestimated approximation of the maximum weight of the enclosure and manipulator was utilized for the simulation. The concepts' resultant deformation and Von Mises equivalent stress were evaluated with these forces applied to the structures. The results of the FEA are presented in Figure 4.7, providing insights into the performance of the different concepts in terms of structural integrity and stress distribution.

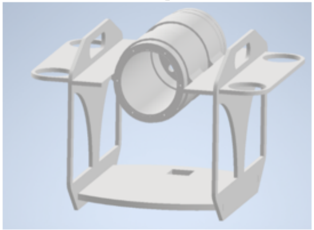
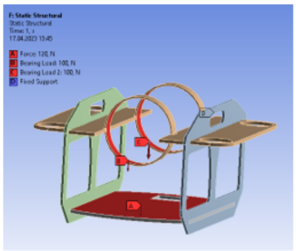
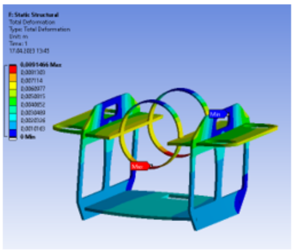
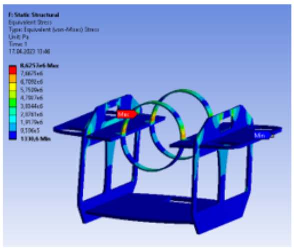
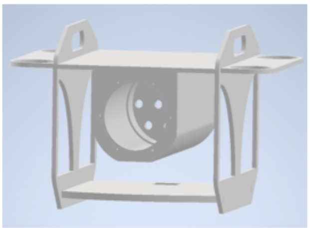
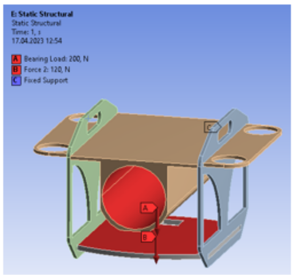
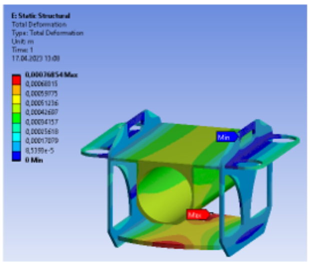
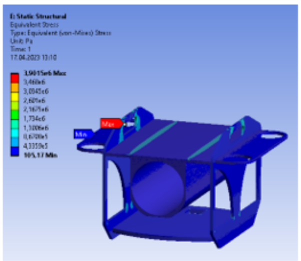
Concept	**Forces And supports**	**Deformation**	**Equivalent stress**
Concept A 			
Concept B 			

Figure 4.7: FEA results of testing ROV-frame

The FEA results indicated no significant differences between the two concepts for the ROV frame, and both concepts were found to be structurally sound without any signs of failure. However, Concept A exhibited higher stress concentrations and deformation than Concept B. The stress concentrations were primarily observed in the bands of Concept A. Still, since the bands were smaller separate parts, they could be manufactured using a more robust material without impacting the product's overall performance. This flexibility in material selection for the bands provided an opportunity to enhance their strength. Furthermore, the analysis results highlighted the potential for material saving by reducing the thickness of various components during the detailed design phase. By downsizing the thickness of the components, it would be possible to optimize the use of materials without compromising the product's structural integrity. This result suggested room for further refinement and optimization regarding material usage in the subsequent stages of the design process.

Electronic enclosure and float

The objective of the electronic enclosure and float was to simulate the external hydrostatic pressure experienced when the ROV dives to a targeted depth of 100m, and the float dives to a targeted depth of 10m. The analysis focused primarily on the wall thickness of the bodies of the concepts.

To begin with, the team manually calculated the slimness of the body and determined that it was lower than the critical slimness. This meant the body was outside the Euler area and would yield before buckling in the axial direction. To identify the critical stress that must be considered for dimensioning, an FEA was performed, and the wall thicknesses were set to 8 and 12mm, respectively, for the enclosure and float. The simulations analyzed the deformation, and Von Mises equivalent stress resulting from the axial, radial, and hoop stress caused by the external pressure on the constructions and provided the results as well as a safety factor for the failure of the bodies.

The detailed results of the test can be found in Figure 4.8.

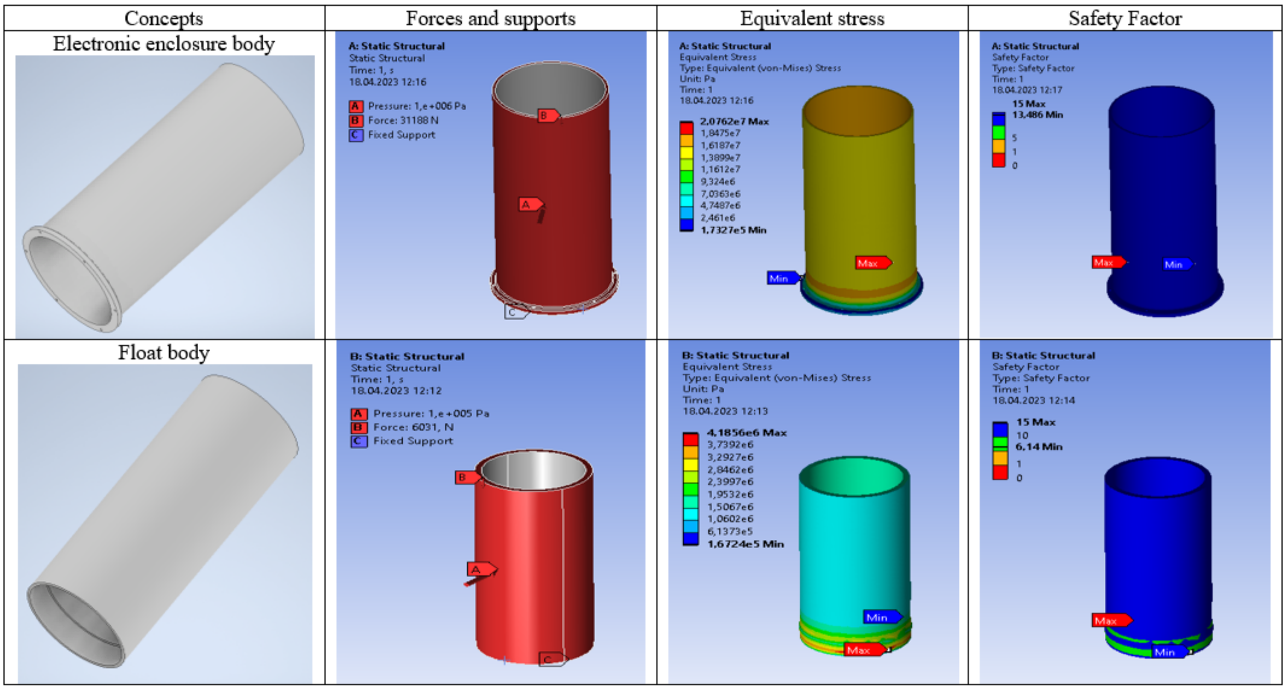


Figure 4.8: FEA electronic enclosure and float

The FEA and manual calculations confirmed that both enclosures, with the specified wall thickness, could withstand the targeted environment in terms of equivalent stress. This implies that the selected concepts are structurally robust and suitable for their intended use. Additionally, the analysis revealed that implementing a thinner wall thickness for the enclosures is feasible. This finding suggests there is potential for further optimization during the detail design phase, allowing for fine-tuning of the enclosures' dimensions and materials to achieve the desired balance between structural integrity, weight reduction, and accommodating internal components.

4.5.2 Consulting stakeholders and leaders of organization

Various techniques were employed to consult stakeholders and leaders of the organization, including interviews, prototyping of different designs, and individual surveys. These methods were used to gather feedback on the preferences of each party and their suggestions for design modifications. The aim was to ensure that all stakeholders were included, satisfied, and well-informed about the ongoing design process. This approach also allowed the team to receive fresh ideas and perspectives for the development process. This step was primarily focused on the concepts of the ROV frame, as the design choice significantly impacted the organization's and its groups' overall appearance. Similar surveys were conducted on a smaller scale for the enclosure and float, involving the teams responsible for these components.

ROV-frame

Based on the surveys and interviews, it was found that most stakeholders and organizational leaders preferred concept E. This concept stood out by offering more differentiation from the previous year's ROV, being more compact, providing improved stability, and demonstrating better material optimization. It was perceived as a significant step forward compared to the previous year's design, while Concept D was seen as a more upgraded version of the previous ROV. However, the surveys also raised some concerns regarding the lateral stability of concept E. The design featuring a split top plate with bands between them was considered less stable than a single rigid top plate. There were concerns about the bands' ability to support the weight of the electronic enclosure, particularly during moments of high inertia caused by sudden changes in direction. Another general concern highlighted by the leaders of UiS Subsea with prior experience with the project, was the safe routing of cables from the electronic enclosure to the various thruster and light connections. They emphasized the importance of addressing this issue in further development.

The prototypes used in the surveys and interviews are depicted in Figure 4.9 and 4.10.

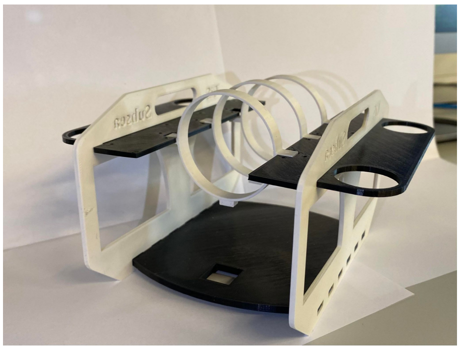


Figure 4.9: Prototype: Concept E

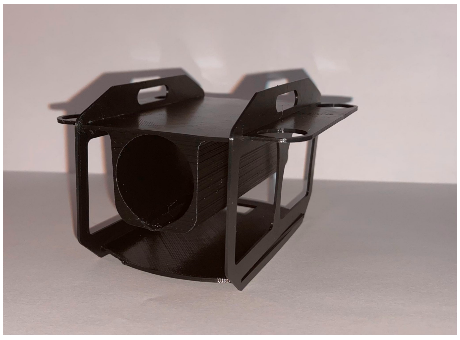


Figure 4.10: Prototype: Concept D

Electronic enclosure and float

For the electronic enclosure and float, the teams involved were presented with the preliminary design using the Autodesk Inventor model and were asked to provide feedback. The electronic enclosure and float designs are depicted in Figure 4.11 and 4.12, respectively.

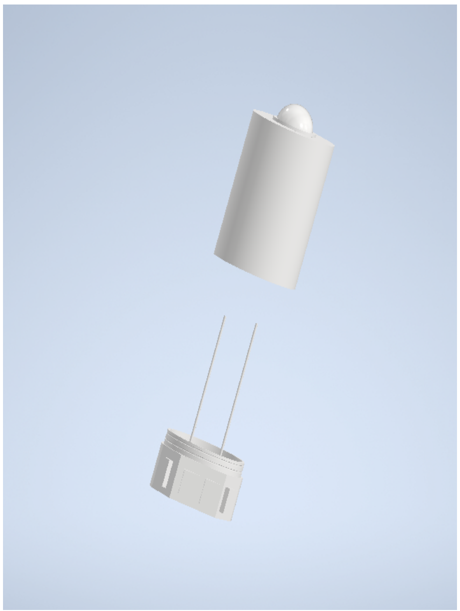


Figure 4.11: Preliminary design: Electronic enclosure

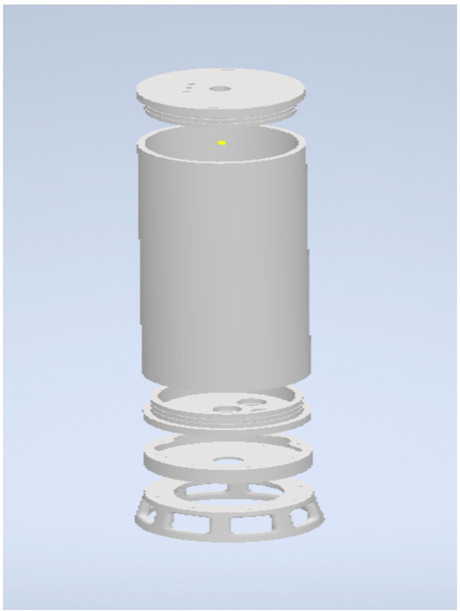


Figure 4.12: Preliminary design: Float

During the feedback sessions for the electronic enclosure, it was determined that the rod stiffeners inside the enclosure were unnecessary, as the electronic teams had already incorporated stiffness features into their internal design. However, mounting points were needed for the internal electrical components, preferably in the end-cap, to facilitate their removal. Additionally, it was discovered that the circular concepts did not require flat sides for connectors and sensors. Instead, the bottom of the end-cap could be redesigned with appropriate holes for all the required components, allowing for a reduction in material use and weight. The feedback also highlighted the need for a larger dome in this year's enclosure to address issues encountered with the camera tilting.

4.6 Set final Specifications

The last step in concept development involves setting the final specifications for concepts that will undergo further development. Setting final specifications entails defining the specific features, requirements, and standards that a product must meet to fulfill the target market's needs. This process includes evaluating the feasibility of the product concept, determining the technical and material requirements, and ensuring that the product can be manufactured cost-effectively. The conclusions and solutions in this phase are reached based on feedback gathered from stakeholders and organizational leaders during the concept testing phase.

To ensure that all the targets of the final specification step are met, a list of materials to explore and a cost model were developed. This involved investigating the available material options and estimating each component's cost before considering any sponsorships or discounts.

4.6.1 Revising designs after feedback

The preliminary designs underwent a review process involving stakeholders, organizational leaders from the previous year's project, and other teams participating in the ongoing project. During this review, specific concerns and potential problems were raised. The team conducted a mini-concept development phase to ensure a flawless design before proceeding to the system-level design phase for each identified problem. During this mini concept development phase, the team had brainstorming sessions to generate possible solutions for the raised concerns. Furthermore, they utilized Autodesk Inventor and ANSYS to model and test the feasibility of these solutions. Evaluating the compatibility with mounting, possible placements, and mechanical properties enabled the team to select the most optimal solution, which was then incorporated into the comprehensive model.

It is important to note that this report will focus solely on the chosen solution and will not provide further details regarding the discarded options for each problem.

ROV-frame

The ROV frame presented several primary concerns, including improved lateral stability, support for the electronic enclosure bands, and cable protection for the thrusters and lights. After evaluating different concepts, the team arrived at a solution involving the installation of a cross stiffener on each of the outer side plates. The purpose of this design was twofold. Firstly, the cross stiffener would enhance the lateral stability by serving as a rigid beam positioned between the two side plates. Secondly, it would provide support to the bands. The cross stiffener would be placed on top of the manipulator's rigid cage and then connected to the bands, either directly or using brackets. By doing so, the bearing load would be distributed across various components instead of being solely borne by the bands holding the enclosure. Additionally, the team considered the potential use of the cross stiffener as mounting points for horizontal thrusters and gateways for cable routing. However, the specific design for thruster mounting had not yet been finalized at this stage of the project. Nonetheless, the modeling process accounted for the possibility of incorporating mounting points on the cross stiffener, which was considered during the concept selection phase for this particular component.

Figure 4.13 illustrates the preliminary design of the cross stiffener, which evolved through iterative revisions.

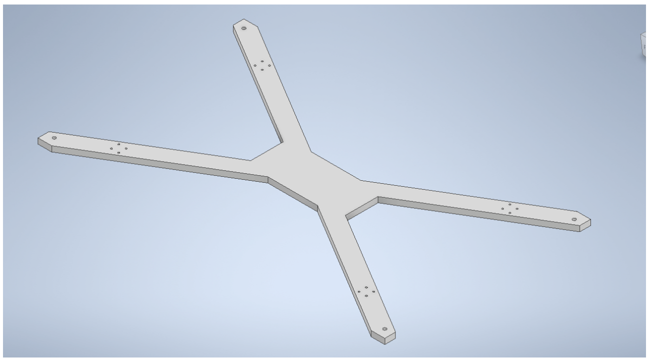


Figure 4.13: CAD-model of preliminary cross stiffener

Electronic enclosure

Regarding the electronic enclosure, the electronic engineers from another team raised design changes that had already been considered but ultimately discarded due to perceived unattainability. However, it was discovered that connectors, sensors, and valves could all be positioned on the back of the end-cap. This realization prompted a complete redesign of the end-cap, eliminating the need for the extra space allocated for sensors between the body and the bottom of the cap. Consequently, the entire enclosure became shorter and more compact. Furthermore, this redesign allowed for a bolting connection between the body and the end-cap. Additionally, the rod stiffeners, originally intended to reinforce the internal electrical components on the circuit cards, were deemed unnecessary by the electronic engineers. They found that the internal electrical components were already adequately rigid. The rod stiffeners had previously been viewed as a potential weak point in the enclosure design and were intended to be external components threaded into holes in the end-cap. With their redundancy established, the solution involved repurposing the holes initially created for mounting the rod stiffeners to instead serve as mounting points for the internal electrical components. As a result, the rod stiffener design was discarded.

Lastly, the diameter of the hole in the flange and top-cap, intended for the dome, was expanded to match the desired dome size specified by the electronic engineers. After revising the design, the concept ready for the system-level design phase is depicted in Figure 4.14.

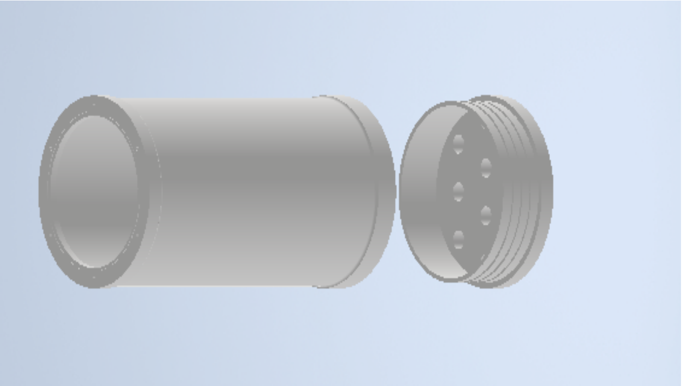


Figure 4.14: CAD-model revised electronic enclosure

Float

Upon receiving the final specifications for the sensors, the design of the end-caps could commence, considering the requirements for sealing and appropriate placement of the sensors. The temperature sensor and power switch were observed to lack available sealing options. Consequently, it was decided that all sensor holes would be threaded, and gasket sealing would be implemented between the cap and the end of the sensor thread. In collaboration with the electronic engineers, the initial height and width of the electronics-skeletal design were determined. Recognizing the potential for revisions during testing and considering the likelihood of 3D printing the structure, it was concluded that it should be divided into multiple parts that could be easily assembled and replaced. These adjustments and refinements are addressed in detail during the subsequent design phase.

4.6.2 Material exploration

The team investigated various materials to gain an initial understanding of the material options for each component and the appropriate manufacturing methods. This investigation involved assessing the different material properties and considering the advantages and disadvantages of each relevant material. Through this process, the team deepened their understanding of each material, providing a solid basis for establishing the original dimensions before conducting any FEA. This approach ensured that the dimensions chosen were realistic and viable for the intended purposes.

ROV Frame

The selection of an appropriate material for the ROV frame involved considering several key factors, including strength, compatibility with chlorine and saltwater environments, lightweight properties, and cost-efficiency. In addition, in alignment with the UN's sustainability goals, the environmental impact and sustainability of the materials played a crucial role in the decision-making process.

Previous UiS Subsea ROVs have utilized aluminum and various polymers for their frames, commonly employed in the subsea industry. Aluminum, specifically Aluminum 6061-T6 and 6061-T651 [48], along with high-density polyethylene (HDPE) [49] and polyvinyl chloride (PVC) [50] [51], were considered as potential materials for the ROV frame. The latter two are common polymers used in the industry with similar material properties. Given that the ROV would operate at low speeds in shallow waters for short durations, all three materials were deemed satisfactory for the intended purpose. A pros-and-cons matrix was created to assess and determine the most suitable material for the ROV frame to facilitate the decision-making process.

Table 4.12: Material Exploration ROV-frame

Material exploration ROV-frame			
Material	Aluminium	HDPE	PVC
Density $[g/m^3]$	2,7	0,94	1,44
Cost [NOK/kg]	24,15	1,216	1,182
Water absorbent [Prosent]	0	0,01	0,04-0,4
Yield strength [MPa]	276	23	55
Impact strength $[kJ/m^2]$	90	8,5	8
Environmental impact	• Recyclable	• Easy to recycle • Maintains material properties	• Non-recyclable • Additives • Microplastic
Pros	• Durable • Ductile • No water absorption • Easy to machine • Corrosion resistant (Depends on alloy choice)	• High density to strength ratio • Impact and scratch resistant • Low water absorption • Cost efficient • Environmental friendly • Lightweight • Corrosion resistant • Neutrally buoyant • Easy to machine	• Durable • Cost efficient • Corrosion resistant • Easy to machine
Cons	• Expensive manufacturing • Sinks in water		• Pollutant • Sinks in water

Among the three material options, aluminum is the most robust choice, offering a tremendous strength-to-weight ratio with high impact and yield strength. PVC and HDPE both have their advantages and disadvantages. PVC is durable, cost-efficient, and corrosion-resistant, making it highly desirable for the intended application. It possesses a high yield strength and exhibits excellent durability. However, it should be noted that PVC is a non-recyclable and toxic plastic.

On the other hand, HDPE is a softer plastic compared to PVC, featuring a lower yield strength. However, HDPE demonstrates nearly neutral buoyancy in water, making it particularly well-suited for water applications. HDPE is renowned for its corrosion resistance, favorable density-to-strength ratio, and low environmental impact. An advantageous characteristic of HDPE is its ease and affordability in welding, allowing for watertight and robust welds. Both plastics exhibit similar impact strength, which is crucial for an ROV frame.

Electronic enclosure

When exploring materials for the electronic enclosure, it was crucial to consider various metals to understand the available options. Thermal conductivity and lightweight properties were the two main requirements for the material selection. After careful evaluation, aluminum was determined to be the most viable material that met both criteria.

Different options were explored to identify the most suitable alloy for the application. The alloys considered were 6061-T6 aluminum, 5052 aluminum, and 6063 aluminum. Each alloy was assessed based on its pros and cons, outlined in Table 4.13 [52]. This analysis aimed to identify the alloy that would best fulfill the requirements of the electronic enclosure.

Table 4.13: Material Exploration electronic enclosure

Material exploration electronic enclosure			
Material	6061-T6 Aluminium	5052 Aluminum	6063 Aluminum
Pros	• High strength to weight ratio • Excellent corrosion resistance • Machinable • Capable of being joined	• Machinable and workable • Excellent corrosion resistance • Weldable • High fatigue strength	• Smooth appearance • Paintable • High corrosion resistance • Good for complex geometries
Cons	• Strength reduction when exposed to high temperature • Susceptible to cracking when bent	• Lower tensile and shear strength • Can only be hardened by cold working	• Lower strength • Is not easily machined

3D printing material

The design complexity of the cross-stiffener and electronic enclosure bands posed challenges in terms of production, making a trial-and-error approach likely. To address this, 3D printing was considered to produce both components. 3D printing offers advantages such as reduced production time and minimized material waste compared to traditional manufacturing methods. In the case of enclosure supports, using other conventional techniques would involve multiple machines and cutting tools. However, when selecting a 3D printing material, it was essential to ensure its suitability in chlorinated and saltwater environments. One concern with plastic materials is the potential for water pollution when exposed to chemicals and UV light. Given that the ROV will operate in seawater, the environmental impact of the chosen material during its use was an important consideration.

Considering the anticipated impact and weight forces on both components, the selected material needed to exhibit strength and durability. Three materials were evaluated for 3D printing: Polyethylene terephthalate glycol (PET-G) [53], Acrylonitrile-butadiene-styrene (ABS) [54], and Polylactic acid (PLA) [55]. These materials are widely used and readily available for 3D printing. A comprehensive assessment of the pros and cons of each material, as well as their properties and environmental impact, can be found in Table 4.14.

Table 4.14: Material Exploration 3D-printing

Material selection 3D-printing			
Material	PET-G	ABS	PLA
Density [g/m^3]	1,23	1,04	1,24
Cost [NOK/kg]	20-60	10-40	10-40
Environmental impact	• Recyclable • Non-toxic • Non-biodegradable • Micro-plastics	• Non-biodegradable • Petroleum-based • Recyclable • Toxic fumes • Micro-plastics	• Biodegradable • Non-toxic • Recyclable • Low carbon • Footprint
Impact strength [J/m]	101	200	26
Pros	• Water resistant • Chemical resistant • Impact resistant	• Impact resistant • Durable High temperature resistant	• Environmental friendly • Low printing temperature • Available
Cons	• Low print speed • Expensive	• High printing temperature • Not environmental friendly	• Brittle • Water absorbent • Deform when exposed to UV-light • Not well suited for chlorine conditions

PLA, the most commonly used 3D printing material, is known for its low environmental impact. It is a bio-plastic derived from renewable resources like cornstarch or sugar cane. Being biodegradable and non-toxic, PLA is suitable for aquatic environments. However, PLA's material properties degrade quickly under UV light and chlorine/salt conditions, resulting in brittleness, especially considering its already limited impact strength. Additionally, PLA is water absorbent, causing changes in buoyancy over time. While it takes about three months to decompose under ideal conditions, the decomposition rate may vary.

Among the listed materials, ABS stands out for its strength. It offers excellent impact resistance, light weight, durability, and high-temperature resistance, all crucial for the intended parts. However, ABS has an environmental impact due to its petroleum-based nature. Although it is recyclable, the production of ABS contributes to adverse environmental effects. Over time, ABS can release plastic particles into the water as it is not biodegradable. PET-G, another strong material, is generally suitable for chlorinated and saltwater applications. It is non-toxic and easily recyclable. However, PET-G is not biodegradable, and prolonged exposure to UV light and high temperatures can lead to the generation of microplastics.

Considering these factors, selecting a 3D printing material for the ROV components should carefully balance strength, environmental impact, and suitability for the intended application.

4.6.3 Cost model

To ensure the project's financial viability, a cost model was developed to estimate the expenses associated with the development and production of the product. This model considered all the costs involved in the production process, including raw materials, labor, manufacturing overheads, and other indirect expenses. By understanding the cost structure, the team could make informed decisions regarding pricing, selecting producers, and allocating resources effectively.

At this stage of the process, many prices were uncertain, and it was essential to assess whether the project would stay within the budget cap of 12,000 NOK set by the UiS Subsea organization. This estimate was crucial in initiating production methods, finalizing material choices, and conducting sponsor negotiations. Given the significant costs associated with building an ROV, some sponsor negotiations had already taken place individually or through preexisting partnerships with UiS Subsea. However, the level of sponsorship and discounts offered by these sponsors was still uncertain at this point. Therefore, the cost model assumed the original price of each component without considering any sponsorship. The prices were based on website information or original quotations obtained during the research phase, providing rough estimates of the anticipated costs if the components were produced or purchased externally.

Table 4.15: Cost model

Preliminary cost model	
Parts	Cost (NOK)
ROV-frame	
Manufacturing of plates	6 000
3D-printed components	20 000
Buoyancy element	10 000
All brackets and screws	Unknown
Total estimated cost frame	36 000
Electronic Enclosure	
CNC machining of top-cap and end-cap	6000
Turning of body	4500
Dome	635
Pressure relief valve	557
3D-printed Flange	500
O rings	510
Vacuum plug	700
Total estimated cost electronic enclosure	12 767
Float	
CNC machining of end-cap	3 000
Purchase of body	600
Pressure relief valve	557
Manufacturing Top-cap	1 000
O rings	510
3d- printed components	6000
Total estimated cost float	11 667
Total estimated cost of project	60 434

The preliminary cost model revealed that the actual cost of producing an ROV and float exceeded the budget provided by UiS Subsea. This highlighted the need to explore various sponsor deals, manufacturing methods, and the possibility of local manufacturing at the University of Stavanger. Special attention was given to reducing the costs of high-priced components such as the plates, top and end-caps, and 3D printed parts. The objective was to bring the overall project cost within the allocated budget. By seeking cost-saving opportunities in these areas, the team aimed to ensure the project could be successfully executed while staying under budget.

5 Product Development Process - System level design

The system-level design phase encompassed several crucial steps in the development process. These steps included defining the geometry and design of the concept, dividing it into subsystems, and designing, testing, and evaluating various alternatives for each subsystem. The objective of this phase was to establish a geometric layout for the product, create functional specifications for each subsystem, and generate a preliminary flow chart for the final assembly of the product. Additionally, exploring different manufacturing methods was an integral part of this phase, considering various options and selecting the most suitable approach.

5.1 Defining architecture of concept and dividing into subsystem

The process of developing a high-level architecture involved defining the overall structure and components of the system. This entailed breaking down the system into its major components and establishing their interfaces, relationships, and interactions. During the design of each subsystem, it was crucial to consider factors such as assembly, maintainability, reliability, and other targets set during earlier phases. By keeping these considerations, the design could be developed to fulfill all the necessary requirements and meet all the identified needs.

5.1.1 Major components and subsystems ROV-frame

The major components of the ROV frame were identified as the plates and other prominent features of the ROV. Each major component required mounting points, additional components, or brackets to ensure smooth interaction and integration, ultimately creating a cohesive system rather than just an assembly of parts. The team thoroughly evaluated the relationships between these major components and compiled a list of subsystems that required design options and further development. The table displaying the major components and subsystems of the ROV frame can be found in Table 5.1.

Table 5.1: Major components and subsystems ROV

Major components and subsystems ROV	
Major components	**Identified subsystems**
• Left top plate • Right top plate • Left side plate • Right side plate • Bottom plate • Support bands for electronic enclosure • Cross stiffener • Thrusters • Manipulator • Electronic enclosure • External camera • Lights	• Connections bottom plate - side plates • Connections side plates - top plates • Connections top plate - bands electronic enclosure • Connections side plate- cross stiffener • Connections cross stiffener - bands electronic enclosure • Connection cross stiffener - manipulator • Mounting points bottom plate for manipulator • Mounting points and hole for the external camera on bottom plate • Mounting points for thruster brackets • Mounting points for lights in top plate • Mounting points for the electronic enclosure to ROV frame

5.1.2 Major components and subsystems electronic enclosure

In the case of the electronic enclosure, the major components were carefully assessed and identified as the enclosure itself, the internal electrical components, and the various connections associated with the enclosure. Once these major components were determined, an evaluation was conducted to identify the subsystems that required design options and further development.

Table 5.2: Major components and subsystems electronic enclosure

Major components and subsystems electronic enclosure	
Major components	**Identified subsystems**
• Enclosure body • end-cap • Topcap • Flange • Bottom plate • Dome • Internal electrical components with electronics • Connectors, sensors, and valves	• Connection enclosure body - end-cap • Connection dome-flange-top-cap • Connection enclosure body - top-cap • Mounting points internal electrical components - end-cap • Hole placements in end-cap for connectors, sensors and valves

5.1.3 Major components and subsystems float

The major components and subsystems in need of design options and development on the float were determined to be:

Table 5.3: Major components and subsystems float

Major components and subsystems float	
Major components	**Identified subsystems**
• Float body • Top end-cap • Bottom end-cap • Structure for the electronics • Air bladder system • Sensor and valves • Ballast system • Impact module • Sensor spacer	• Connection: body - top end-cap • Connection: body - bottom end-cap • Connection: skeletal structure - end-cap • Hole placements in end-caps for valves and sensors • Connection: Air bladder - bottom end-cap

5.2 Designing, testing and evaluating subsystem ROV frame

Once the different subsystems required for assembly were clarified, the development and solutions for each subsystem could begin. Revising each concept followed the same approach as in concept testing. A mini concept development process was undertaken for each subsystem, involving group brainstorming sessions to generate various solutions. These ideas were then tested for feasibility, production method, and durability, ultimately selecting the best option for each subsystem. The team decided against developing these ideas separately and instead focused on discussing the different options collectively. This approach was chosen to optimize time management, considering that time was a scarce resource for the project. While some subsystems necessitated selection matrices for a comprehensive evaluation, others did not require extensive analysis due to the clear superiority of certain options.

5.2.1 Thruster mounting

To enhance the maneuverability and user-friendliness of the ROV, a decision was made to equip it with eight thrusters. Among these, four vertical thrusters facilitated linear movement in the z-direction and rotational roll and pitch movements. Additionally, four horizontal thrusters were incorporated to enable linear movement in the x and y directions and yaw movement. As discussed in the theory chapter, the thrusters operated by propelling water from the front to the back, creating a pressure difference that propelled the ROV forward. It was crucial to mount the thrusters in a manner that eliminated any degree of freedom. This was necessary to ensure that the momentum exerted on the thrusters was effectively transferred to the ROV, optimizing its performance.

Vertical thruster mounting

The mounting points for the vertical thrusters were positioned perpendicular to the side plates, allowing for direct placement of the thrusters without the need for brackets. The vertical thrusters were desired to be aligned with the top plate to ensure stability. However, since the top plate was intended to slide into the slit in the side plate, the mounting points and thrusters had to be placed slightly above or below the level of the top plate. After consulting with the organizational leaders, who had received a warning from the 2021 team about potential issues with submerging the ROV when the vertical thrusters were placed above the buoyancy elements, a decision was made to position the mounting points slightly below the slit in the side plate. The specific placement of the mounting points for the vertical thrusters is illustrated in Figure 5.1.

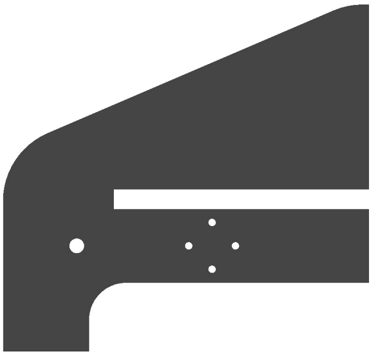


Figure 5.1: Vertical thruster mounting points

Horizontal thruster mounting

Unlike the vertical thrusters, the mounting points for the horizontal thrusters were parallel to the side plate. This meant they could be placed in the bottom or top plate, or a secondary part could be mounted to the side plate. However, positioning the thrusters far away from the center of mass of the ROV would negatively impact maneuverability, particularly in terms of yaw rotation. To address this, it was decided to develop thruster brackets that would allow the thrusters to be mounted closer to the center of mass on the side plate.

Several potential solutions for horizontal brackets were developed to ensure that the ROV's needs were adequately met. After testing the feasibility of each concept, three concepts were selected for further evaluation. Concept A involved mounting points directly in the cross stiffener, allowing the thrusters to be mounted close to the center without additional parts. Concept B was derived from benchmarking the previous year's ROV and involved mounting the thrusters to a rod, which was then mounted at each end of the side plates. This concept offered the benefit of placing the thrusters further away from the horizontal center, making yaw movement easier to implement. It also provided greater freedom of placement along the longitudinal axis. Concept C entailed using smaller brackets directly mounted into the pillars of the side plate, enabling the thrusters to be positioned as far out as possible while offering flexibility in the vertical direction. However, it was less flexible regarding placement along the longitudinal axis.

After conducting a screening process, concept A was chosen. This decision was based on the concept's minimized production cost, weight optimization, and effectiveness in solving cable transportation issues. By selecting concept A, multiple problems could be addressed with a single part. The complete screening matrix can be found in Table 5.4.

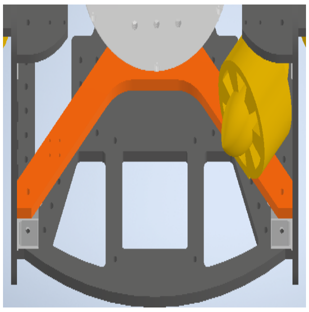


Figure 5.2: Cross stiffener thruster mounting points

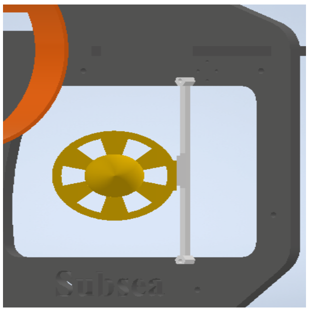


Figure 5.3: Rod mounting points

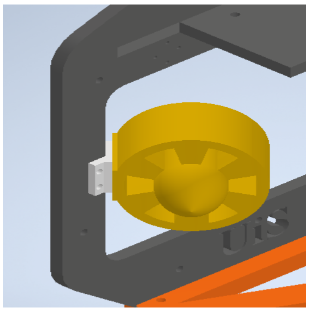
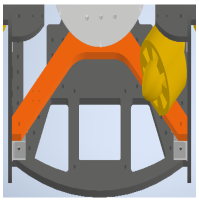
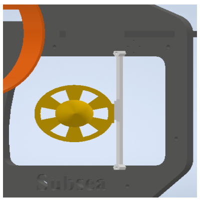
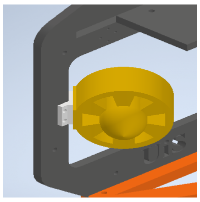


Figure 5.4: Mounting points on small bracket

Table 5.4: Screening matrix thruster brackets

	Screening matrix Thruster brackets		
	Concepts		
Selection Criteria	A 	B 	C 
Fits within ROV boundaries	0	0	0
Easy to assemble and disassemble	+	0	-
Free flow through frame	0	0	0
Easy cable access	+	-	0
Requires no extra parts	+	-	-
Structurally stable	+	-	+
Does not interfere with horizontal thruster flow	+	+	-
Do not contain part that could injure	0	0	0
Sum +'s	5	1	1
Sum 0's	3	4	4
Sum -'s	0	3	3
Net score :	5	-2	- 2
Rank:	1	2	2
Continue? :	Yes	No	No

5.2.2 Connections between the plates and cross stiffener

To improve production efficiency and manage time effectively, a decision was taken to standardize the connection method for all plates and the cross stiffener. This standardization aimed to streamline the production process, particularly regarding time management. Since all the connections involved perpendicular components, it was logical to standardize this specific type of connection. This standardization effort focused on developing three different methods that emphasized ease of manufacturing. Considering the team's personal manufacturing of these parts was important since this would minimize production costs.

After carefully evaluating ideas generated through brainstorming and competitive benchmarking products, two viable options remained for further investigation. Concept A involved creating threaded holes and using screws to connect the parts. This concept was advantageous as it required no additional brackets and facilitated easy assembly and disassembly. However, it was determined that this design would only work for the side plate-cross stiffener connection due to limitations in plate thickness. Moreover, the shear force exerted on the screws in the bottom plate to the side plate connection would be significant. To overcome this shear force problem, a solution was proposed involving modifications to the bottom plate design and creating slits in the side plate. Unfortunately, no viable solutions were found to incorporate threaded holes and screws in the top plate-side plate connection. Consequently, an alternative connection method using brackets became necessary for this specific connection. Since the brackets would likely need to be manufactured regardless, this concept was discarded, considering the sub-optimal nature of the side plate-bottom plate screw connection.

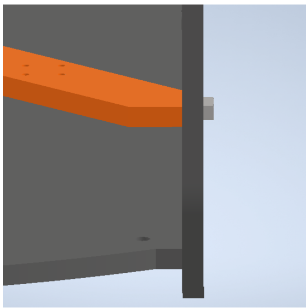


Figure 5.5: Cross stiffener - side plate screw connections

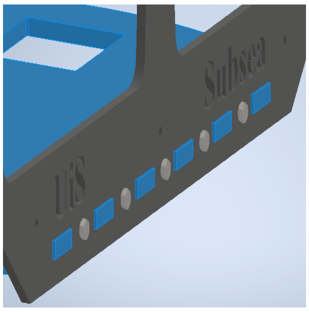


Figure 5.6: Bottom plate - side plate screw connections


Figure 5.7: No possibility to for screw connections top plate- side plate

Concept B involved creating 90-degree corner brackets using residual material from the machining lab at UiS. These brackets would be connected and tightened using bolts and nuts. Although this option required extra material and manufacturing time, it offered several advantages. The significant parts could be easily assembled and disassembled, and the brackets were easily replaceable. This solution eliminated the need for design changes to the plates and the cross stiffener. Additionally, incorporating metal brackets into the plastic frame at critical points helped strengthen the overall structure and reduce the risk of failure.

Although the possibility of rotation of the brackets was sub-optimal with this concept, it was not a significant concern. This was because the cross stiffener would be connected to the manipulator cage and electronic bands, restricting rotation in that area. Moreover, the brackets provided superior support and a higher safety factor than the screw option. Considering all these factors, the bracket concept was also the optimal choice for this connection.

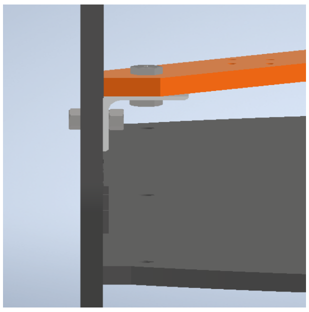


Figure 5.8: Bracket connection cross stiffener - side plate

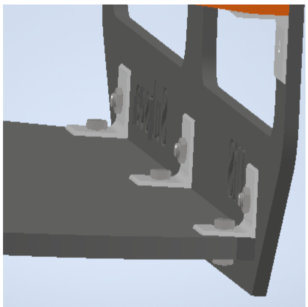


Figure 5.9: Bottom plate - side plate bracket connections

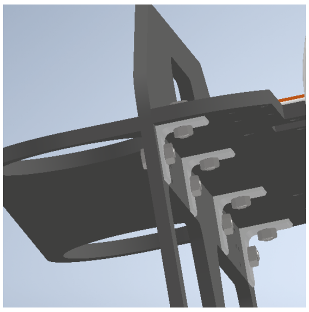


Figure 5.10: Top plate- side plate bracket connections

5.2.3 Connections bands - top plate

Another area that required a solution was the connection point between the top plates and the bands holding the enclosure. This connection needed high tolerance for movements due to the significant stress exerted by the electronic enclosure. Considering that the bands were expected to be produced through 3D printing, there was ample room for creative solutions. It was also important for the chosen solution to allow sufficient space for buoyancy elements, as the size and dimensions of these elements were unknown before water testing.

Two main concepts were considered. Concept A involved using a fork-like structure that would be bolted to the top plate. This design had the advantage of not requiring any additional parts or modifications to the top plates. It was also easy to assemble and disassemble, requiring only two bolts for each fork connection. The connection provided additional support to the bands. However, there were concerns that this solution might compromise the overall rigidity of the top plate. Upon further evaluation, it was discovered that the shear stress at the transition point of the fork could potentially lead to failure. Therefore, this concept was discarded as a viable option.

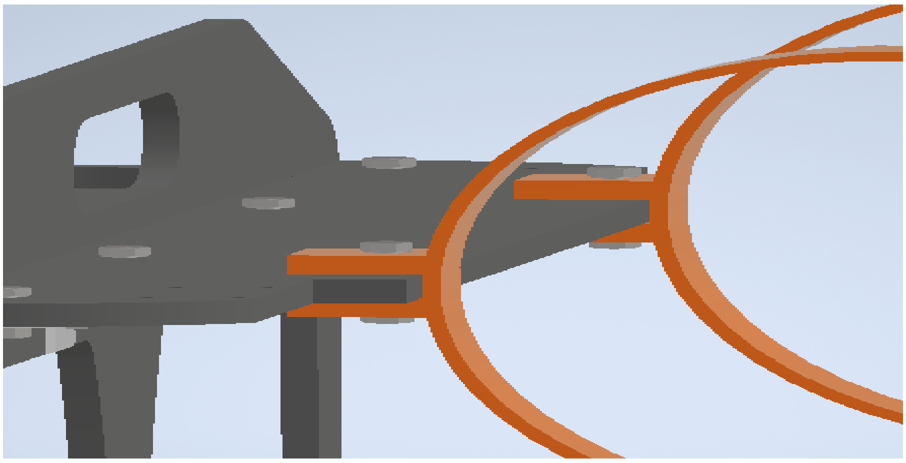


Figure 5.11: Fork connection bands - top plate

Concept B involved modifying the top plates by adding rectangular extrusions to the bands. This modification required adjusting the design of the top plates to accommodate the change. Thin hexagonal metal brackets would be manufactured to secure these extrusions to the top plate. Each connection point would utilize two brackets, resulting in eight parts that needed to be produced. While this solution made disassembly slightly less convenient, it significantly increased the overall strength of the connection. After considering the trade-offs, the team decided that the advantages of concept B, including enhanced strength and stability, outweighed the additional time required for manufacturing and assembly. As a result, concept B was selected as the preferred option.

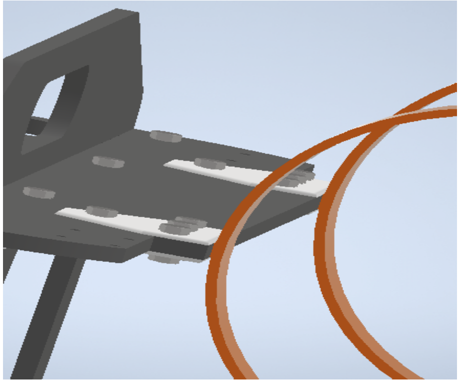


Figure 5.12: Bracket connection bands - top plate

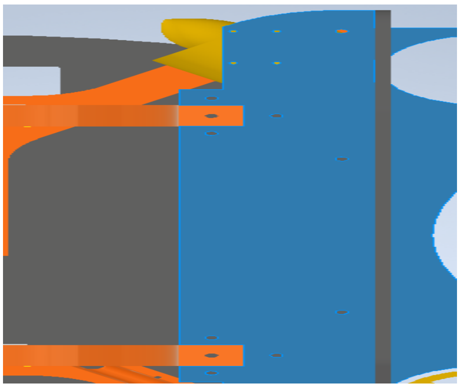


Figure 5.13: Bird view of fitting the squares into indents

5.2.4 Connections cross stiffener -bands enclosure

To provide support for the bands, an additional component was needed between them and the cross stiffener. 3D printing this part offered advantages such as reduced production time, ease of replacement, and the ability to retain elastic properties. The cross stiffener, being rigid, would contribute to the overall stability of the structure in both vertical and horizontal directions. However, since the exact dimensions of the manipulator cage, bandwidth, and thickness were unknown, it was crucial to have a component that could easily accommodate potential revisions.

One important consideration was strength, which both concepts addressed effectively. Concept A involved modifying the bands by adding a T-shaped extension at the bottom with holes on both sides. This design required no extra parts and was simple to assemble and disassemble. It provided direct support between the band and the cross stiffener without the complexities of additional components. Furthermore, modifying the T-beam's height would be a straightforward adjustment if needed. However, there were concerns about the T-beam. To 3D print the part without excessive supports and material usage, the width of the beam had to be no wider than the bands themselves. This slender design could lead to failure under unforeseen stress, such as a drop or impact. Additionally, the concept posed challenges for mounting devices to support table transportation around the ROV.

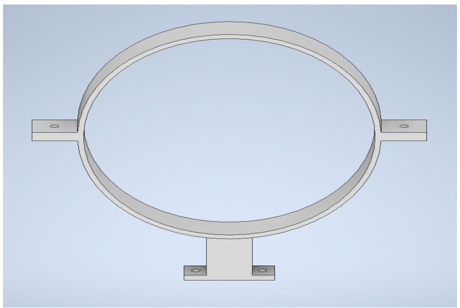


Figure 5.14: T-connection CAD-model

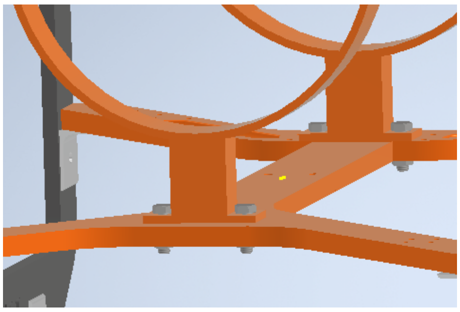


Figure 5.15: T-connection in assembly

Concept B involved adding a small extension to the underside of the bands and creating a 3D-printed bracket to connect the bands to the cross stiffener. This design allowed the bracket to have the necessary thickness to withstand unforeseen external forces. It offered the advantage that only the small bracket would need to be redesigned and re-manufactured in the event of failure, rather than the entire bands as in the previous concept. The hollow design of the bracket also allowed for the later mounting of cable connector parts. It was easily adjustable both vertically and horizontally to accommodate different requirements.

Although this concept required slightly more effort to assemble and disassemble the part into the product and involved more complex modeling in distributing vertical stresses evenly across the bolt connection from bands to bracket, it was considered more robust and better aligned with the overall vision for solving the remaining challenges in the process. As a result, Concept B was selected for incorporation into the final product, while Concept A was discarded.

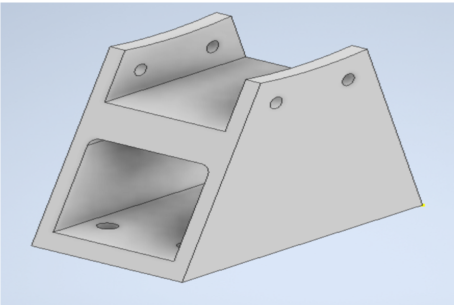


Figure 5.16: Bracket connection bands - cross stiffener CAD model

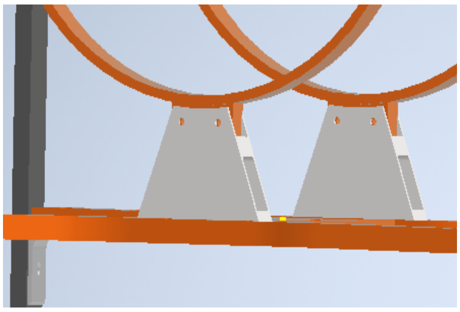


Figure 5.17: Bracket in assembly

5.2.5 Mounting points and hole for manipulator and camera in bottom plate

At this stage of the process, the manipulator cage was nearing completion by the manipulator group. This allowed for modifications to be made to the bottom plate to accommodate the cage's mounting points. Similarly, mounting points were needed for the camera house around the view hole for the downward-facing camera. Creating a pattern that would optimize material usage while strengthening the overall structure was also necessary. Since these modifications were relatively minor and aimed at facilitating the attachment of other structures to the ROV, there was no need for alternative concepts or ideas. The appropriate approach involved removing material where the cage and the external camera would be placed, creating a pattern based on standard truss geometry.

During this redesign of the bottom plate, various mounting points for ballast were also added. This was due to uncertainties regarding the specific placement and quantity of ballast required. As a result, many universally distributed mounting points were incorporated across the bottom plate, with a particular emphasis on the sides. It was recognized that placing weight further from the center of mass would significantly impact the ROV's stability and performance.

Finally, certain areas of the bottom plate were identified as redundant and subsequently removed to reduce material usage and overall weight. However, pillars were strategically retained to maintain structural integrity and ensure the stability of the plates. Additionally, some areas were left out to accommodate the uncertainties surrounding the placement of the manipulator motors by the manipulator group.

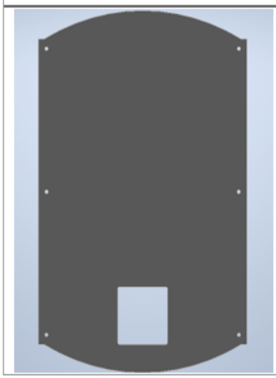
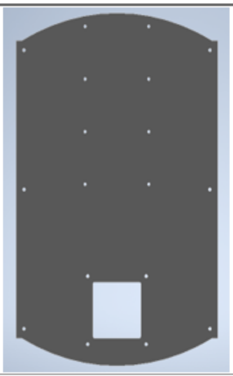
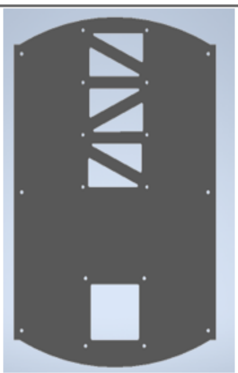
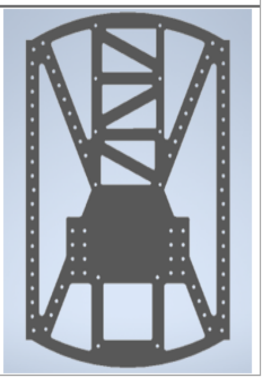
Original design	Added mounting points manipulator and camera house	Strength optimized pattern	Material and weight saving	Added mounting points ballast
				

Figure 5.18: Bottom plate modification process

5.2.6 Mounting points electronic enclosure - ROV-frame

The bands held the enclosure vertically and laterally, but additional mounting points were required to ensure longitudinal stability. It was essential to design these mounting points in a way that did not impede the sliding motion of the enclosure. The lip on the electronic enclosure and the width of the top plate was intentionally designed to prevent forward movement of the enclosure once it was in place. Therefore, the mounting concepts needed to address backward motion and rotational movement, which could disrupt the functioning of the gyro.

Concept A involved a device mounted on the underside of both top plates, positioned where the back of the enclosure would be when fully inserted. This device consisted of a bracket and a sliding rod. The concept relied on contracting the rod when removing the enclosure, allowing it to slide into position, and then extending the rods behind it to secure it. This concept facilitated maintenance operations, which was considered important by the organization and electrical teams involved in the project. However, Concept A required several additional parts and mounting points on the top plates. It also needed careful placement to avoid interfering with the connectors at the back of the enclosure. Furthermore, as the bands were dimensioned with a slightly larger inner diameter than the enclosure's outer diameter to facilitate insertion, this mounting mechanism was expected to compensate for any small movements that might occur. Unfortunately, concept A did not effectively address this issue in a satisfactory manner.

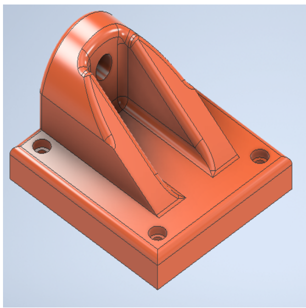


Figure 5.19: Bands- flange connection in assembly

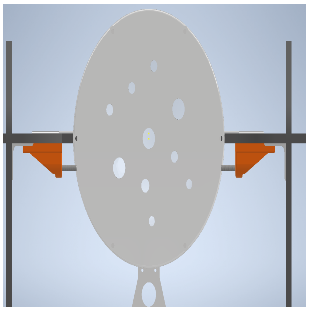


Figure 5.20: Band after modifications

To address the issues above more effectively, concept B was developed. This concept leveraged the design freedom offered by additive manufacturing, explicitly modifying the bands and flange to tackle the problem. The main idea behind concept B involved creating an extrusion that extended from the front band to the plane of the flange. Mounting points around the flange and the band extension would be added, allowing for a secure bolted connection. This concept could eliminate rotational and longitudinal movements resulting from the clearance between the bands and the electronic enclosure. Importantly, no additional parts were required, with only this small modification necessary.

One drawback of concept B was the intricate assembly process each time the enclosure was removed or added from the bands. There were also concerns about the durability of the extensions on the electronic bands if subjected to unexpected external stress. However, simulations conducted in ANSYS indicated that these concerns were unfounded, and such modifications were deemed unnecessary for this project.

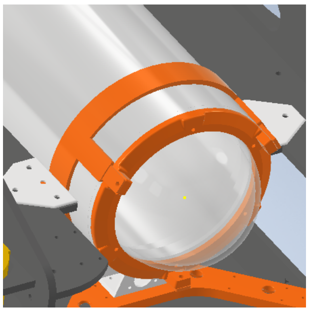


Figure 5.21: Bands- flange connection in assembly

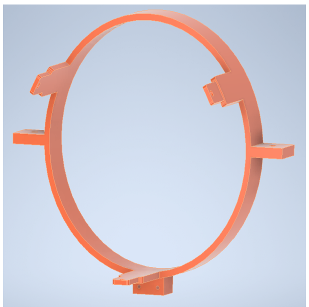


Figure 5.22: Band after modifications

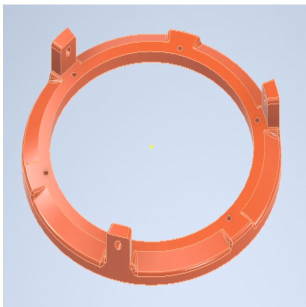


Figure 5.23: Flange after modification

5.3 Designing, testing and evaluating electronic subsystem enclosure

The electronic enclosure subsystems were developed using the same concept development method as the ROV frame subsystems. Instead of splitting up, the team brainstormed ideas during the concept generation phase. Each concept was subsequently tested and selected for further development. Since the enclosure needed to be watertight, the main focus during concept generation was on creating designs that would make it easy to achieve this attribute in the detailed design phase. Additionally, the team valued the ease of disassembly and extraction of internal electrical components during the brainstorming phase. Seal Engineering was consulted to assess the ease of water sealing different concept connections to ensure these requirements were met.

5.3.1 Connection: top-cap to enclosure body

Two distinct connection types were primarily considered for connecting the top-cap and enclosure body. The first type involved bolting connections. In this concept, the enclosure body would have a flange at its end, and the top-cap would also implement a flange extrusion, with the bolting connection around the body's exterior. Tension rods could extend from the top cap down to the end-cap. Both concepts offered relative ease regarding water sealing and machining, requiring only minor modifications to the top-cap and body for the flange concept and the top-cap and end-cap for the tension rods concept. Both concepts also facilitated easy assembly and disassembly of the enclosure when necessary.

However, these concepts presented challenges when fitting the enclosure into the ROV. Since the enclosure was going to be inserted into the ROV from behind through the bands, the bands would need to have an inner diameter that accommodated the lip or the placement of the tension rods. Alternatively, the enclosure would need to be placed inside the ROV before the top-cap was mounted onto the rest of the enclosure. The team felt that these concepts either occupied unnecessary space within the ROV. It would create difficulties in securely fastening the previously discussed flange-bands concept, or they would prove unnecessarily complicated to assemble and disassemble, particularly in an urgent situation during competitions. Consequently, both bolting-type concepts were eliminated from further evaluation.

The other type of connection considered was a press fit or shrink fit. In this concept, the top-cap would be either press fitted or shrink-fitted into the body, creating a permanent and tightly fitting connection between the two parts. Since the electronic components only required a single opening for removal, and all the connectors were connected through the end-cap, it was determined that the ability to remove the top-cap was not necessary, and securing it to the body was a feasible solution. This connection required no additional space outside the body, allowing the enclosure to be inserted from behind through the bands. The previously discussed flange-bands connection required no further modification. Combining two components into one also simplified the assembly and disassembly process of the enclosure, in addition to mounting. Press fitting and shrink fitting methods provide watertight seals when using gaskets, sealants, or O-rings, satisfying the requirement for ease of water sealing.

However, unlike the bolting connection, this type of connection resulted in parts of the top-cap being situated inside the body. Consequently, it limited the height at which the internal electrical components could be placed within the enclosure. The top-cap occupied the same space as the electronics, thus resulting in unutilized space at the top. This required the enclosure to be slightly longer than a bolting connection would require and posed challenges in positioning the camera on top of the internal electrical components towards the dome. Nonetheless, the team believed that the advantages of this connection type outweighed the disadvantages, and thus, it was selected for further consideration.

To determine the optimal fit for the connection, the team conducted a literature search and consulted with the employees in the machining shop at the University of Stavanger. Based on their findings, a press fit was deemed the optimal choice due to its lower risk of component damage and lower sensitivity to temperature changes than a shrink fit. Press fits were also easier and quicker to achieve at the machine shop. Although shrink fit had advantages in torque and high-stress situations, it was felt that the advantages and disadvantages of press fit better suited the purpose of this connection, as the enclosure did not require torque transmission capabilities and hopefully would not be subjected to high-stress situations.[56]

5.3.2 Connection end-cap- enclosure body

Since the top-cap would be permanently assembled, a solution where the end-cap could easily be disassembled would be required. This was to adequately satisfy customer needs for the electrical engineers, facilitating the maintenance of electrical components. This meant that the fitting connections used for the top cap were unsuitable. The first connection type considered was the bolt connection mentioned earlier in the discussion of the top cap-body connection. However, like with that connection, tension rods would create difficulties in assembling and disassembling the enclosure within the ROV. On the other hand, the flange concept did not require a wider band diameter since the lip would not pass through any of the bands. This concept offered easy sealing, assembly, and a seamless fit with the rest of the ROV.

However, the downside of the lip concept was the machining process. Designing such a structure would require welding on the lip or ordering an oversized thick tube and then turning it, which would be time-consuming and generate a significant amount of waste material, which is not ideal from an environmental standpoint. At this stage, the material for the enclosure had not been finalized, but the idea was to use an aluminum alloy. Since aluminum is difficult to weld, neither of these methods for creating a lip in the enclosure body was ideal. Hence, alternative options for connecting the body and end-cap were explored.

Another concept considered was vacuum sealing, which would involve incorporating space for an additional vacuum plug on the back of the end-cap. Vacuum sealing would eliminate the need for a lip and make the manufacturing process of the enclosure easier and less time-consuming. It would also prevent water from entering the enclosure due to pressure differences. However, vacuum sealing was not optimal for enclosures requiring frequent maintenance due to the time-consuming process of adding and removing air using a vacuum pump. Moreover, removing all the air from the enclosure would eliminate any airflow responsible for cooling inside, which was a concern given that the electronics generated heat. Considering these drawbacks, vacuum sealing was deemed unsuitable, and the concept was discarded. The bolting connection through a flange was ultimately chosen to connect the end-cap and enclosure body, with o-rings as the preferred sealing option.

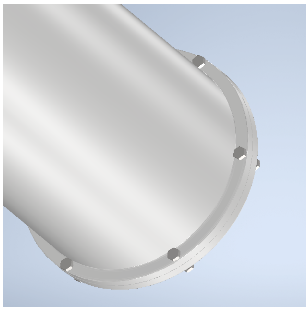


Figure 5.24: Bolt connection body - end-cap

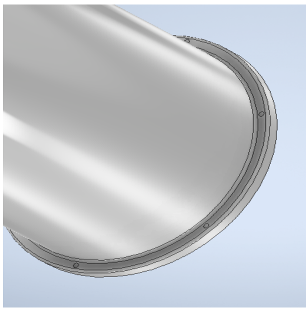


Figure 5.25: Flange on enclosure body

5.3.3 Connection dome to flange- topcap

Due to the dome being supplied with pre-drilled holes, the available connection methods for fastening the dome, flange, and top cap together were limited. The options were narrowed down to either bolting through the top cap, creating threaded holes, or using screws. Bolting through the top cap would provide a higher tension force but require additional sealing techniques to ensure water-tightness. On the other hand, threaded holes would inherently be watertight, eliminating the need for additional sealing methods. Therefore, the option of threaded holes was chosen over through holes to address the concern of water tightness. To ensure a watertight seal between the underside of the flange-dome and the top cap, a gasket was incorporated into the product, effectively sealing the two components.

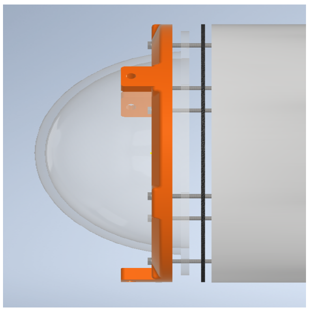


Figure 5.26: Bolt connection flange - dome - gasket - top cap

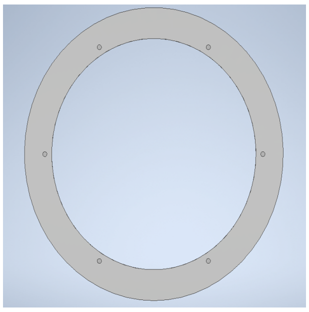


Figure 5.27: Threaded holes in top cap

5.3.4 Mounting points electronic internal electrical components- end-cap

As mentioned earlier, the mounting requirements for the internal electrical components and the end-cap were reassessed during the concept testing phase. The electronic engineers determined that stiffeners were unnecessary, simplifying the mounting concept. Instead of dimensioning space and mounting points for rod stiffeners, the focus shifted to identifying suitable mounting points for the internal electrical components.

Figure 5.30 illustrates the end piece of the internal electrical components created by the electronic group. The end-cap was expected to accommodate the three holes in this piece. Similar to the design process for the manipulator and camera house mounting points, the design considerations aimed to accommodate other parts. There was no perceived need for different design options.

Small extrusions were added to the end-cap to support the internal electrical components. It was important to consider that the connectors inside the internal electrical components required some space before being connected to the rest of the electronics. Therefore, the mounting points were designed accordingly.elevated.

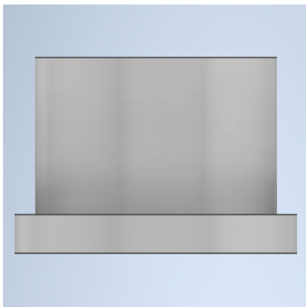


Figure 5.28: Side view of end-cap

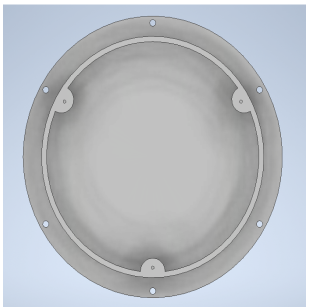


Figure 5.29: Top view of end-cap

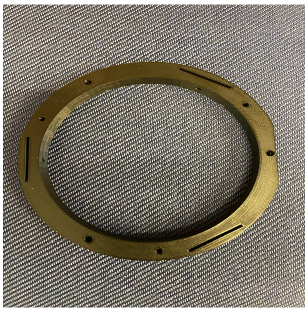


Figure 5.30: End piece of internal electrical components

5.3.5 Hole placements end-cap for connectors, sensors, and valves

The production of the end-cap had to be delayed until all external components were determined. This included connectors, sensors, and valves, which were specified based on size, weight, and intended purpose. Seven connectors, one sensor, and one valve needed placement within the end-cap.

These components' CAD models and maximum dimensions were obtained to determine the optimal placement. Placing the largest connectors on the same plane and considering their external diameter ensured centralized weight distribution and minimized displaced volume. The three connectors provided power, communication, and power to the thrusters from the electronic enclosure. Three of the remaining four connectors were rectangular and used for communication with external cameras. It was important to consider the largest rotational diameter of these connectors to avoid assembly issues. They were positioned downward to reduce cable weight and length.

The final connector provided a power supply and communication to the manipulator. The placement of this connector was influenced due to the requirement of being near the thruster power connection, which in turn allowed for optimized internal cable management. As for the pressure relief valve and pressure sensor's placement was arbitrary since no specific considerations regarding weight, logistics, or volume were required.

The resulting configuration of the connectors, sensor, and valve can be seen in Figures 5.31 and 5.32.

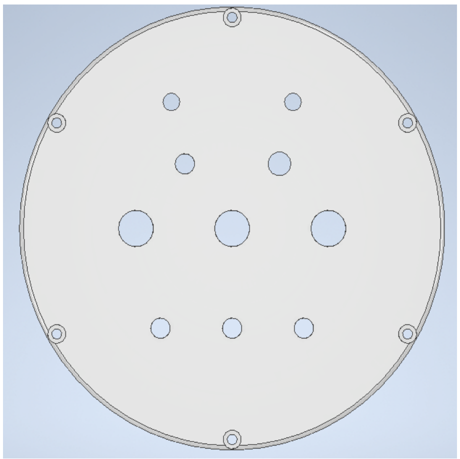


Figure 5.31: Hole placements

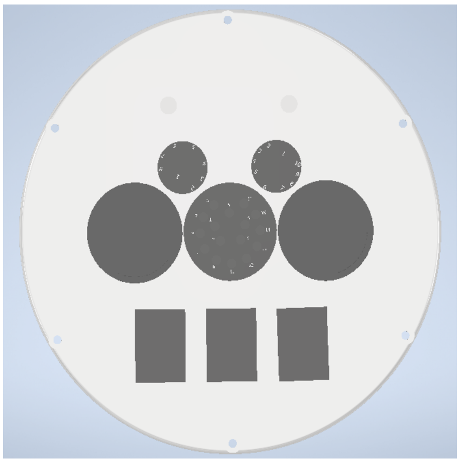


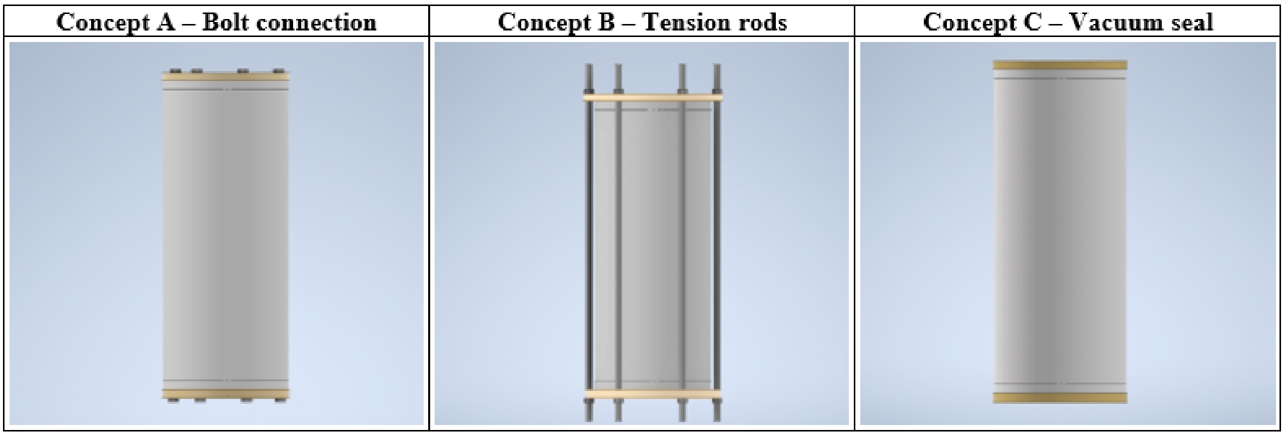
Figure 5.32: Endcap with connectors

5.4 Designing, testing and evaluating subsystem float

The same approach was taken for the float, following the ROV frame and electronic enclosure methodology. The primary objectives for the float were to ensure it was watertight, impact resistant, and easily maintainable for the electronic engineers. This team and the Seal-Engineering team brainstormed various ideas for the subsystems and major components, and these were subsequently addressed in the detailed design phase.

5.4.1 Fastening and sealing the end-caps

Various fastening methods were evaluated for the top and bottom caps of the float. Specifically, securing the bottom cap to the body posed a more significant challenge due to the need to support the weight of the internal construction, facilitate easy removal, and ensure effective sealing. Three concepts were considered for fastening the bottom end-cap to the body: screws, tension rods, vacuum seal, and welding. These concepts are illustrated in Figure 5.33.



Concept A – Bolt connection

Concept B – Tension rods

Concept C – Vacuum seal

Figure 5.33: Float fastening concepts

Concept A involved connecting the end-caps to the body using nuts screwed into the float's body. However, this concept required thicker material to accommodate the screw holes, which increased buoyancy without leaving space for potential ballast. Additionally, creating durable threads in plastic would be challenging. Despite these drawbacks, Concept A offered effortless assembly and disassembly from the body.

Concept B utilized tension rods to secure the end-caps. This design eliminated the need for threading plastic since the rods were fastened with nuts on both sides. The tension rods would provide sufficient force to keep the end-caps in place, eliminating the concerns about them coming off. However, Concept B had no streamlined appearance, and both caps would have to be loosened for electronic maintenance. Moreover, this concept required excessive use of material for the tension rods, which contradicted the project's goal of environmental friendliness.

Concept C, inspired by Frøya, involved pumping out the air inside the float after inserting the end-caps. The pressure difference would hold the end-caps in place, offering an easy sealing method without requiring a pressure relief valve. However, this concept was unsuitable for this project due to the electronic engineers' design of the air bladder system, which would transfer air from inside the float to the bladder. Vacuum sealing would not serve as an appropriate fastening method as it could lead to the destruction of the internal electronics in case of overpressure during testing or competition due to material expansion caused by electronic heating.

For the top end-cap, welding was chosen based on discussions with the electrical engineers. It was determined that the top cap did not need to be removed from the body. Welding the top end-cap would reduce costs and save time by eliminating the need for machining. Moreover, welding provides sufficient sealing and a solid connection to the body. For the bottom end-cap, Concept B using tension rods was selected. Instead of using tension rods along the entire body, a flange was designed near the bottom cap to hold the other end of the tension rods. This design ensures easy access for electrical engineers while maintaining a secure and streamlined structure. The final fastening method for the top and bottom end-cap can be seen in Figure 5.35.

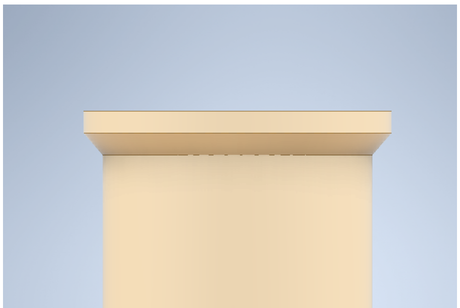


Figure 5.34: Weld design

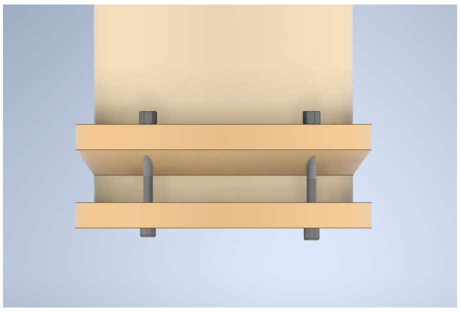


Figure 5.35: New tension-rod design

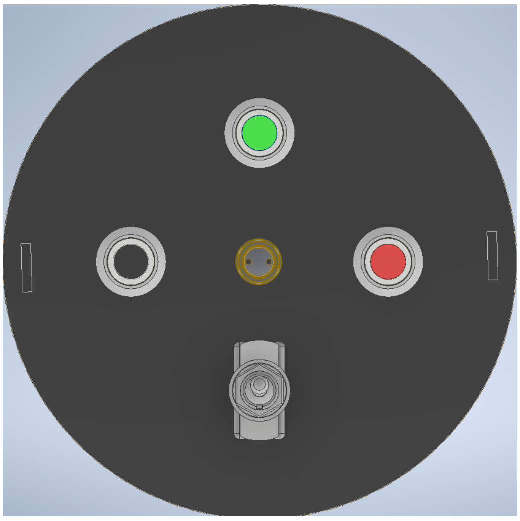
5.4.2 Hole placements in end-caps for valves and sensors

Top end-cap

On the top end-cap, the electronic engineers required the placement of 3 RGB lights [57], one power switch [58], and one pressure relief valve [59]. The specific location of these components was not crucial for the electronic engineers as the cables connecting them to the electronic system needed to be longer than the entire body of the float. This team decided to position the pressure relief valve and the electrical components near the center of the end-cap. The RGB lights and pressure relief valve were designed for subsea installations and came with O-rings and nuts. To ensure proper fitting, the team chose to thread the top-cap according to the respective thread type of each component. This allowed enough space to insert and secure the component with a nut inside the float. However, the power switch product did not include sealing mechanisms, requiring the team to design a custom gasket. Furthermore, the delicate thread of the power switch was not ideal for installation or sealing purposes. To address this issue, the team decided to re-thread the component to attach a counter nut, resolving the sealing problem.

The specific placements of these components on the top end-cap can be observed in Figure 5.36.

Figure 5.36: Top end-cap float | Placements



Bottom end-cap

The bottom end-cap of the float had specific requirements for watertight holes to accommodate a thermopocket [60], a potted cable penetrator [61], and the bladder connector. The placement of these components was strategically determined to ensure optimal functionality. The balloon connector, which needed to be positioned at the float's center to maintain vertical stability, was given priority. This placement ensured the buoyancy force would be evenly distributed, keeping the float upright. The potted cable penetrator and thermopocket were placed on either side of the bladder connector, maintaining a safe distance between them to avoid any contact or interference. The potted cable penetrator was designed with all the necessary sealing components, such as a nut and O-ring, and required a 10.2mm through-hole in the bottom end-cap for installation. In the case of the thermopocket, it did not come with O-rings or a counter nut. To achieve a watertight seal, the team purchased an O-ring separately and threaded the bottom end-cap. By utilizing a threaded hole combined with an O-ring/gasket, the desired sealing performance could be achieved for the thermopocket. The connector between the balloon and the cable was designed to be threaded and screwed into the bottom plate. It was designed to be further sealed with a nut and two O-rings to ensure a secure seal, providing additional protection against water ingress.

6 Product Development Process – Detail Design

The detail design phase was a crucial stage in the product development process, where the initial product concept was transformed into a comprehensive and detailed design. During this phase, a thorough plan was created, encompassing all aspects of the product's functionality, specifications, material selection, cost analysis, and manufacturing processes. The design also considered aesthetic factors, material and weight optimization, and enhancing the overall user experience. The primary objective of the detail design phase was to ensure that the product design met all the specified requirements, was efficient to manufacture, and provided a user-friendly experience. A meticulous detail design minimized potential issues during manufacturing, thereby increasing the likelihood of developing a successful and well-rounded product.

6.1 Final product design ROV-frame

Once the various connections were developed and integrated into the final product, the overall design of the ROV was considered complete. Subsequent phases involved determining the manufacturing methods and selecting suitable materials for each component. The project emphasized excelling in both the MATE competition and environmental aspects. Thus the design was optimized to achieve material and weight savings. Furthermore, any parts on the ROV that could pose a potential hazard were identified and removed, aligning with MATE requirements [18] to ensure safety. Manual calculations were insufficient to determine the appropriate thickness of each part; therefore, FEA was employed for material optimization. Additionally, the team conducted thorough manual inspections to detect and eliminate any potentially harmful elements from the design.

6.1.1 Detail changes to the design

During the design refinement phase, every component of the ROV frame underwent a comprehensive evaluation. Some parts required no further adjustments or only minor modifications resulting from changes in other components. However, certain parts underwent more substantial modifications, such as alterations in shape and hole placements, to enhance their functionality and integration within the overall design. The goal was to ensure that each part was optimized for its intended purpose and properly aligned with the evolving design requirements.

Top plate

During this phase, the team identified that the top plate of the ROV was unnecessarily large, particularly the extrusions meant for thruster protection. Concerns arose regarding the potential for unnecessary forces on the rest of the ROV if someone attempted to lift it by these parts of the ROV. Nevertheless, the top plate needed to maintain its structural integrity and adequately protect the thrusters, avoiding the inadequate thruster protection from the previous year's ROV design.

To address these concerns, removing as much material as possible from the top plate without compromising the thruster's protection was undertaken. Additionally, some material in front of the enclosure was carefully removed to ensure an unobstructed camera vision. Similar modifications were made to the back of the top plate to maintain symmetry in the design. Furthermore, strategically placed holes were incorporated in the front and back of the top plate to serve as mounting points for lights and the tether.

Figure 6.1 shows the resulting modifications and the updated top plate.

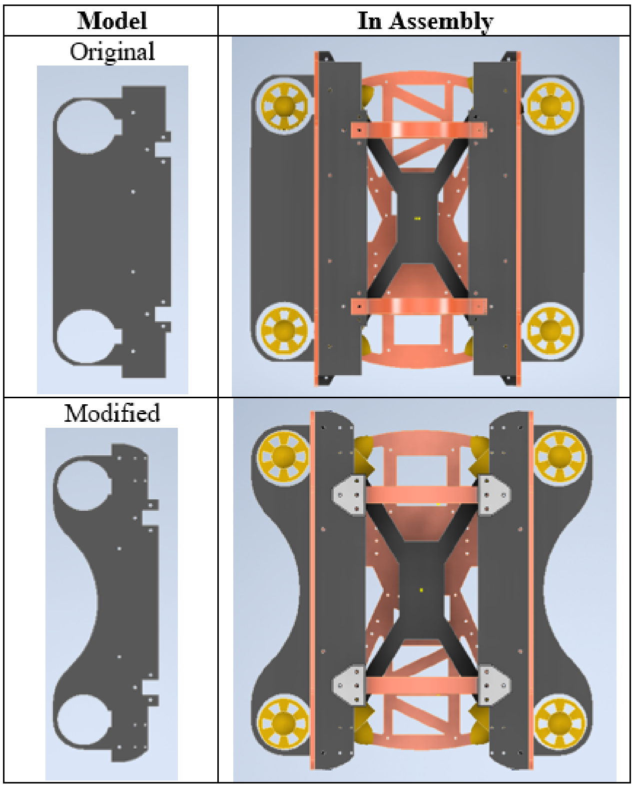


Figure 6.1: Modifications to top plate

Cross stiffener

To optimize the manufacturing process, reduce costs, save time, and minimize environmental impact, it was decided to produce the cross stiffener separately at the University of Stavanger instead of manufacturing it along with the plates. However, this decision presented a challenge since the original cross stiffener design was too large for the 3D printer available in the lab. To overcome this limitation, the cross stiffener was divided into two smaller parts: the front stiffener and the back stiffener, both taking on a boomerang shape. The front stiffener was designed to be attached to the manipulator cage, providing vertical support. On the other hand, the back stiffener required an extension from the boomerang body to the back of the cage. Holes were incorporated into both stiffeners to facilitate cable management.

Due to this modification, the middle section of the cross stiffener that was initially planned for cable transportation had to be removed. An additional part was designed to be mounted on the electronic band brackets to address this issue. Minor adjustments were made to the brackets to accommodate this modification, effectively resolving the cable transportation concern. For a visual representation of the modifications made to the cross stiffener, brackets, and cable transporter, please refer to Figure 6.2.

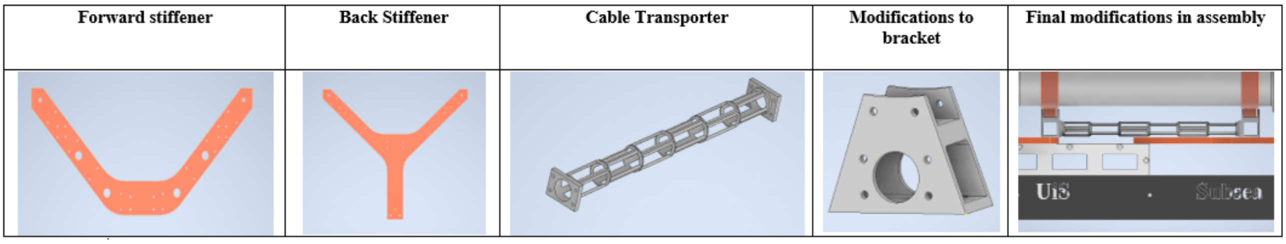


Figure 6.2: Modifications to cross stiffener, brackets, and cable transporter

6.1.2 Material Choice And Manufacturing method

Once the design of each part was completed, the next step involved exploring, evaluating, and selecting the appropriate materials and manufacturing methods for their production. Given the project's limited budget and the cost model developed during the concept development phase, which indicated expenses exceeding the budget, it was necessary to seek sponsorships and alternative production methods to ensure cost-effectiveness. Additionally, the environmental impact of each manufacturing method was taken into consideration, with a focus on minimizing waste material. Whenever feasible, additive manufacturing processes were preferred over subtractive manufacturing, and it is more environmentally friendly.

The goal was to find the most cost-efficient manufacturing solutions while minimizing the project's ecological footprint. The project aimed to reduce costs, limit waste generation, and achieve a sustainable production process by securing sponsorships and utilizing additive manufacturing wherever possible.

Plates

In the early stages of the project, the team thought about 3D-printing the plates in the machine shop at the University of Stavanger as it would save time and environmental impact. However, the 3D printer accessible was not big enough to fit the entire plates, leading to either splitting the plates into printable parts requiring additional assembly methods,s or selecting another manufacturing method. As the only material available in the printer was ABS plastic, which, as shown in concept development, is not biodegradable and releases particles into the water during tedious exposure, 3D printing of the plates was discarded as an option.

After researching the market for different solutions, water cutting at one of UiS Subsea's sponsors, IKM industrigravøren, was selected for manufacturing the plates. Water cutting allowed for the precise cutting of a wide array of materials. Water cutting also generates no heat during manufacturing, making it optimal for manufacturing plastics. This meant the plates could be manufactured in a lower density plastic like HDPE or PVC without concern of imperfections in the final product, instead of an aluminum alloy which would lead to unnecessary weight. Water cutting was also considered an environmentally friendly way of manufacturing due to not producing any hazardous fumes and particles. The negatives with water cutting, such as limited thickness in the product and rough edge finish, did not affect this product as it was neither thick nor required smooth surface finishes. Water cutting is a production method with a high initial cost, but since IKM industrigravøren was an established sponsor of UiS Subsea and the plates would be produced at a discount, this was not a concern. [62]

When discarding aluminum as a material option for the plates, the remaining candidates from the investigation completed in concept development were PVC and HDPE. PVC is a common polymer and is widely available and affordable. Since the ROV should be able to withstand impact, the brittle properties of PVC were not favored. PVC is also a toxic material and releases hazardous pollutants and chemicals during production and recycling. HDPE and PVC have similar notched impact strength, with PVC having a much larger yield strength. Regarding weight, HDPE is close to neutrally buoyant, which is highly advantageous with water applications. HDPE was chosen as the material for this ROV for its corrosion-resistant properties, environmental impact, lightweight, and relatively high impact strength.

Cross stiffener

The initial plan for the cross stiffener was to 3D-print the entire component, as developed during the concept development phase. However, it was not feasible to produce the stiffeners using this method due to limitations in the 3D-printing capabilities and budget constraints at the University of Stavanger. The 3D lab engineers informed the team that explicit permission would be required from the machine shop to produce high-cost parts for the student project, which was impossible within the given budget. Considering the environmental impact and material selection, using ABS in the 3D printer was not optimal. As an alternative, laser cutting was suggested by the lab engineers as a time-efficient and environmentally friendly manufacturing method. Laser cutting allows for easy automation, low tool wear, and does not require cooling liquid. Moreover, it provides high precision and can cut a variety of materials.

After considering the lab engineers' recommendation, acrylic was chosen as the material for the cross stiffeners due to its high yield strength and rigidity, which aligned with the purpose of the stiffeners. However, there were limitations in the thickness of the parts that could be produced through laser cutting, and the cost was relatively high. Fortunately, the lab engineers offered to use the university's laser cutting facilities and residual material, thus eliminating the cost of production. Although reverting the design of the cross stiffeners to the original plan and discarding the cable transporter was considered, the limited availability of acrylic sheets in the machine shop prevented any changes. It was decided to keep the design to avoid the need to purchase additional acrylic sheets. Consequently, the cross stiffeners were manufactured by the lab engineers locally at the University using laser cutting [63].

Bands and brackets

Due to the complex geometry of the front band and the issues associated with subtractive manufacturing, it was decided to 3D-print these parts. Subtractive manufacturing would generate excessive waste material and require cooling liquid. The availability of student printers at the university meant that 3D printing the bands would be cost-free for the project without requiring permission. Additionally, 3D printing offered the advantage of quick production of spare parts in case of unforeseen failures. It should be noted that 3D-printed bands would result in lower lateral stability in the ROV's top plane than metal bands, as plastics are more elastic. However, the metal enclosure inside the bands was expected to prevent any significant compression or stretching of the ROV. A bracket was designed to connect the bands to the stiffeners, and 3D printing was also chosen as the manufacturing method for this component. The bracket served as a buffer part that could be easily modified if assembly problems arose, making 3D printing with the student printers the optimal choice for quick production and design changes.

When selecting a suitable material for 3D printing, several options were explored during the concept development phase. Three materials stood out as potential matches for the ROV's requirements. The first material considered was PLA, which is biodegradable and non-toxic, making it environmentally friendly for aquatic environments. However, PLA has low impact strength and becomes brittle over time under UV light and exposure to chlorine or saltwater [64]. Moreover, PLA is water-absorbent, leading to changes in buoyancy over time. Due to these limitations, PLA was discarded as an option for parts in contact with water.

Another material considered was ABS, known for its strength, impact resistance, light weight, durability, and high-temperature resistance. However, ABS is petroleum-based and has a negative environmental impact during production. It is not biodegradable; it can release plastic particles into the water over time. Consequently, ABS was also ruled out for parts in contact with water. The final material considered was PET-G, which is strong, durable, and capable of withstanding the elastic strains experienced by the bands. PET-G exhibits high chemical and UV resistance, making it suitable for chlorinated and saltwater applications. It is non-toxic and easy to recycle. Although not biodegradable, proper disposal can prevent pollution. PET-G's lower temperature resistance was not a concern because the ROV was not intended for use in high-temperature environments. Considering its strength, chemical resistance, and recyclability, PET-G was chosen as the material for parts in contact with water.[53]

Remaining brackets

To ensure rigidity and overall strength at potential failure points of the ROV, it was decided early on to use metal brackets in the connections between the plates, side plate and stiffeners, and top plate and bands. Although manufacturing the brackets locally at the machine shop at the University of Stavanger would involve higher time consumption, environmental impact, and cost compared to buying standard parts, the team believed that the process would boost morale and improve efficiency, as the design phase had been time-consuming. Additionally, the additional time, cost, and environmental impact of local manufacturing were considered negligible in the project's larger context.

Aluminum was chosen as the material for the brackets. It is a lightweight material with high corrosion resistance and a favorable strength-to-weight ratio, making it well-suited for ROV applications. Aluminum is also relatively easy to work with, which was advantageous for the inexperienced team. The team briefly considered the possibility of needing a metal with higher strength and melting point, as those properties are weaker aspects of aluminum. However, after evaluating the requirements, it was determined that aluminum could provide sufficient strength for the brackets and that the ROV would not be exposed to high-temperature environments that could compromise the material's performance.

6.1.3 Material saving ROV-frame

After completing the design of the components and determining the material selection for each part, the next step was to establish the final thickness of the components. The objective was to minimize the thickness while maintaining an adequate safety margin for each component. To achieve this, FEA was conducted using the ANSYS software. The analysis was carried out under the supervision of experienced employees from the University of Stavanger who were familiar with the program. Their expertise ensured that the forces and supports were accurately defined in the analysis, allowing for an optimized determination of the component thicknesses.

Plates

During the evaluation of plate thickness, various options were considered and tested. Thicknesses of 5mm, 8mm, and 10mm were explicitly evaluated for suitability. The forces applied by each bolt and the manipulator when lifting the ROV were estimated and used as a basis for the analysis. Due to the uncertainties surrounding the exact forces and weights involved, a conservative approach was taken. The dimensions were intentionally over-dimensioned with a safety factor well above the required standard.

For the side plate, it was observed that a thickness of 5mm resulted in high-stress concentrations on each side of the slit for the top plate, and it provided a relatively low safety factor of 4.3. On the other hand, a thickness of 10mm showed significantly reduced stress concentrations and a higher safety factor of 8.8. Comparatively, the 8mm thickness exhibited stress concentrations similar to those of the 10mm thickness, with a safety factor of 7.4. Considering the relatively low safety factor of the 5mm thickness, it was determined that an 8mm wall thickness would be a suitable compromise in terms of material savings and maintaining a satisfactory safety factor for the side plates.

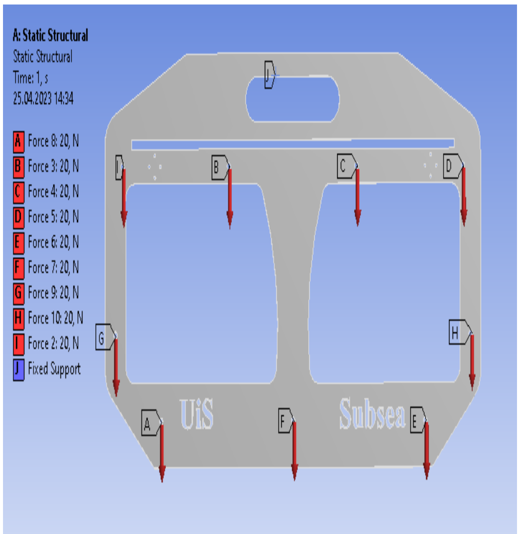


Figure 6.3: Forces and supports set on side plate in ANSYS

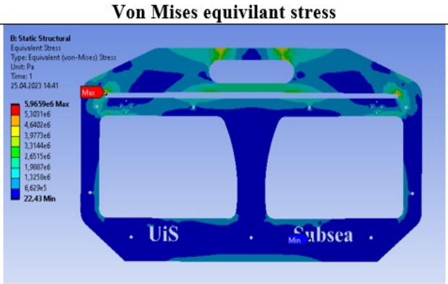
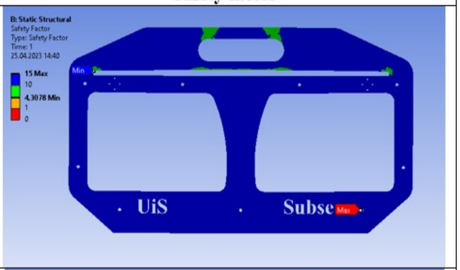
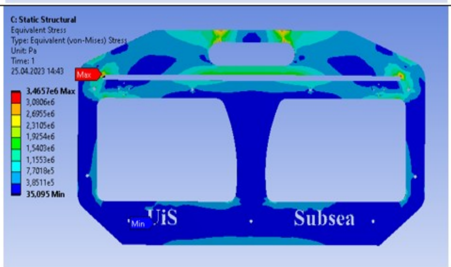
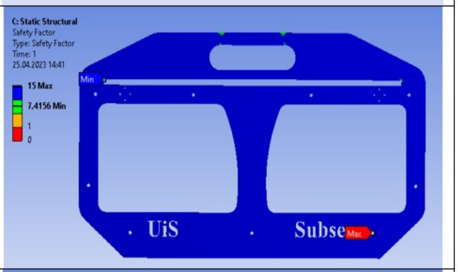
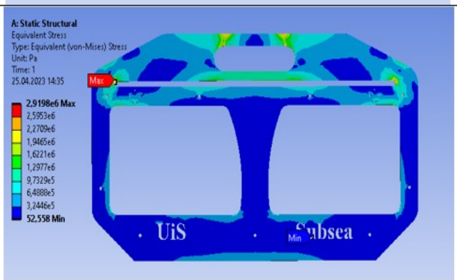
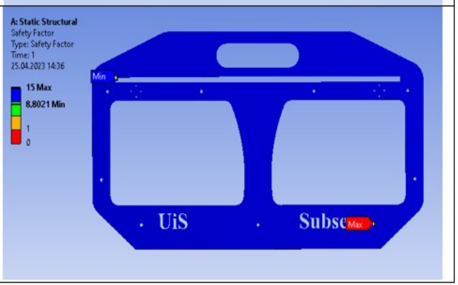
Thickness	Von Mises equivilant stress	Safety factor
5mm		
8mm		
10mm		

Figure 6.4: Thickness, equivalent stress and safety factor side plates

Similar to the side plates, the evaluation of thicknesses for the top plate also took place. The same 5mm, 8mm, and 10mm options were tested and analyzed. The stress concentrations and safety factors were crucial factors in the decision-making process. A thickness of 5mm for the top plate resulted in high-stress concentrations and a relatively low safety factor of 1.9. On the other hand, a thickness of 10mm exhibited small stress concentrations and a higher safety factor of 5.2. The 8mm thickness, with a safety factor of 3.7, was chosen as a compromise between the two extremes, aiming to balance material savings and retaining sufficient strength in the top plate.

By selecting the 8mm thickness, it was possible to reduce stress concentrations compared to the 5mm thickness while maintaining an acceptable safety factor.

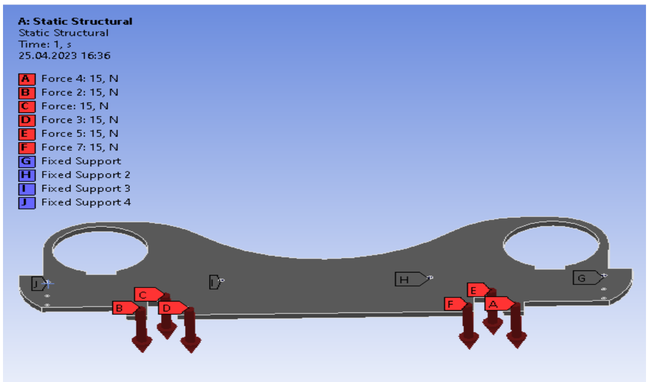


Figure 6.5: Forces and supports set on the top plate in ANSYS

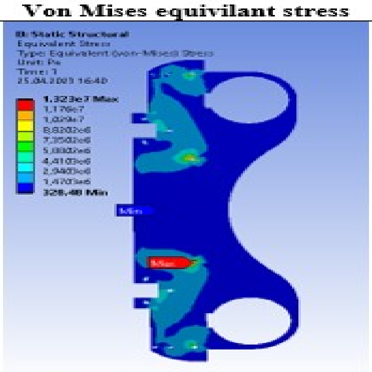
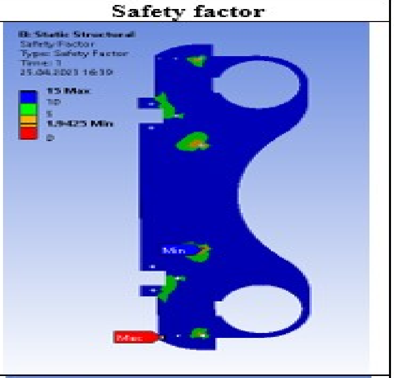
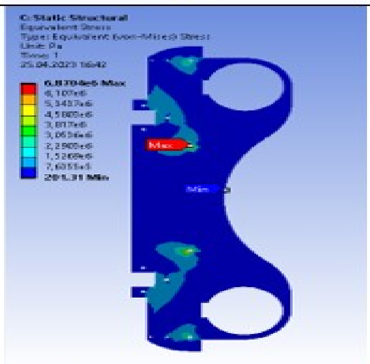
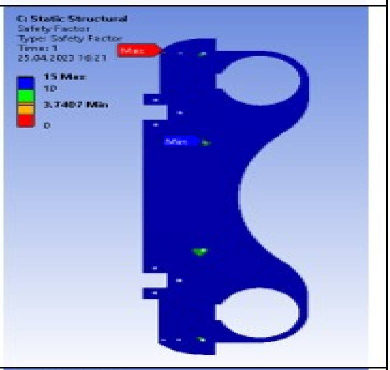
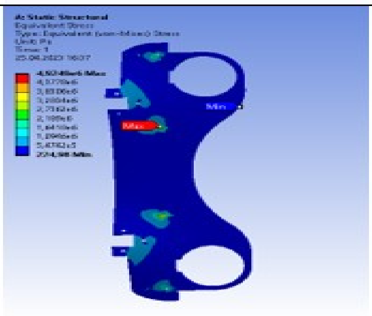
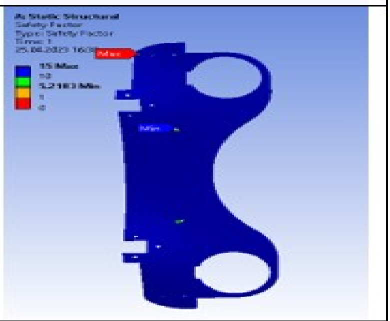
Thickness	Von Mises equivilant stress	Safety factor
5mm		
8mm		
10mm		

Figure 6.6: Thickness, equivalent stress and safety factor top plates

During the evaluation of thicknesses for the bottom plate, the stress concentrations and safety factors were carefully considered. Both 5mm and 8mm thicknesses showed high-stress concentrations, with safety factors of 0.75 and 3.26, respectively. It was crucial to account for the weight absorbed by the bottom plate from the manipulator and electronic enclosure through the stiffeners and manipulator cage. Therefore, a significant safety factor was required as a precautionary measure.

Considering these factors, a thickness of 10mm was chosen for the bottom plate. This thickness provided a safety factor of 6.1, ensuring an adequate margin of safety. In this case, material savings were neglected to prioritize the strength and stability of the bottom plate, given its essential role in supporting the weight and load distribution of the manipulator and electronic enclosure.

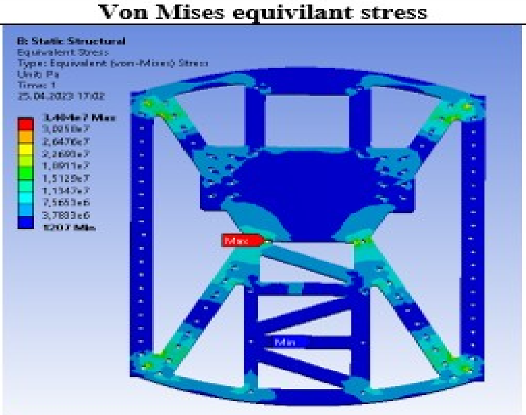
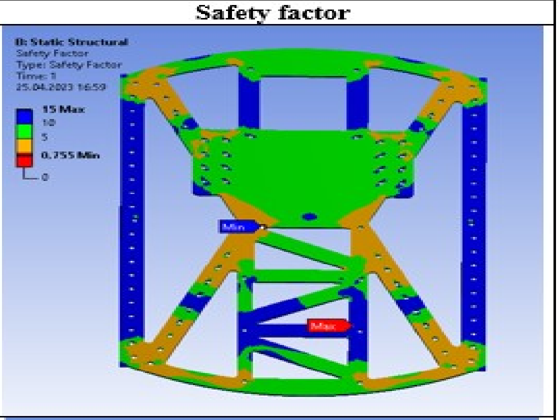
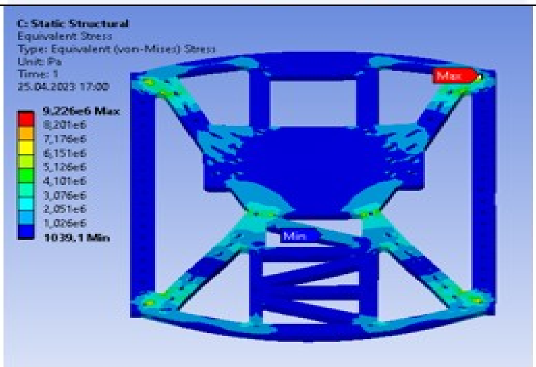
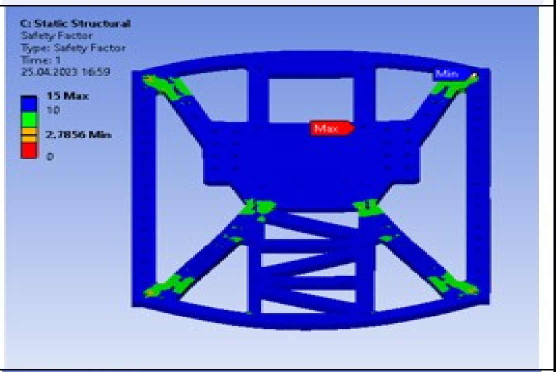
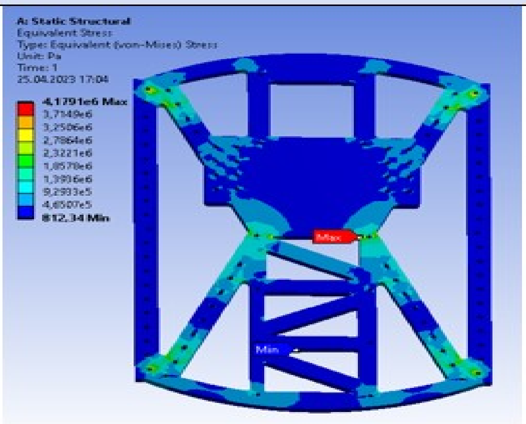
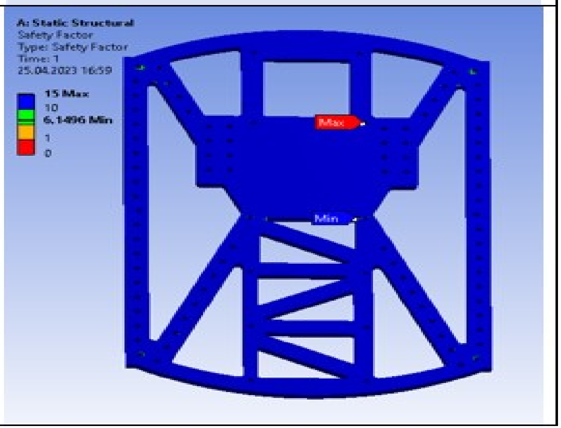
Thickness	**Von Mises equivilant stress**	**Safety factor**
5mm		
8mm		
10mm		

Figure 6.7: Thickness, equivalent stress and safety factor bottom plate

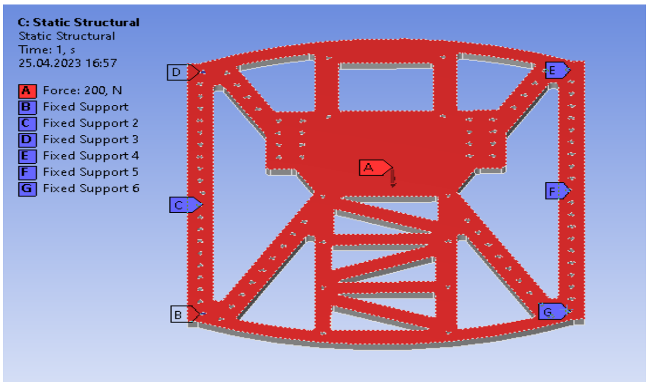


Figure 6.8: Forces and supports set on bottom plate in ANSYS

6.2 Final product design Electronic Enclosure

Good communication with the electrical engineers was vital in ensuring that the customer's needs were met and that all components fit perfectly within the electronic enclosure. The design choices ensured proper product functionality, maintenance ease, and durability.

The material selection for the enclosure was based on the available options that could meet the required dimensions. Aluminum 6061 was chosen for the end-caps, while aluminum 6082 was selected for the body, as it was the only material available in the required dimensions. The material choice was heavily influenced by the customer's needs from the electronic groups, who specified a material with a thermal coefficient of at least $200\,\mathrm{W/m} \times \mathrm{K}$. The selected material had to be aligned with this requirement. In addition to material selection, clarifying the number and type of connectors was an important task during the design phase. This ensured that the enclosure could accommodate the necessary connectors for seamless integration with the electronic components.

6.2.1 Detail changes to electronic enclosure

Sealing and design

When deciding between male or female o-ring glands, careful consideration was given to each choice's implications on the manufacturing process. A male o-ring gland indicates that the o-ring groove is on the piston, while a female groove signifies that the o-ring groove is within the bore. In this case, factors such as the wall thickness of the electronic enclosure with regard to effective heat dispersion and the freedom to choose the thickness of the end-cap were taken into account.

In addition, it was highly likely that the team would manufacture the body of the electronic enclosure. At the same time, with its more complex design, the end-cap would be better suited for professional machining. Consequently, the decision was made to position the o-ring grooves on the bottom end-cap. This choice allowed for easier creation of the grooves on the end-cap, resulting in material savings. Moreover, by relying on professional machining services externally or locally by lab engineers, higher accuracy and smaller tolerances could be achieved for the end-cap.

Therefore, the male gland o-ring grooves were chosen, as they would be positioned on the bottom end-cap. A visual comparison between the male and female glands can be seen in Figure 6.9.

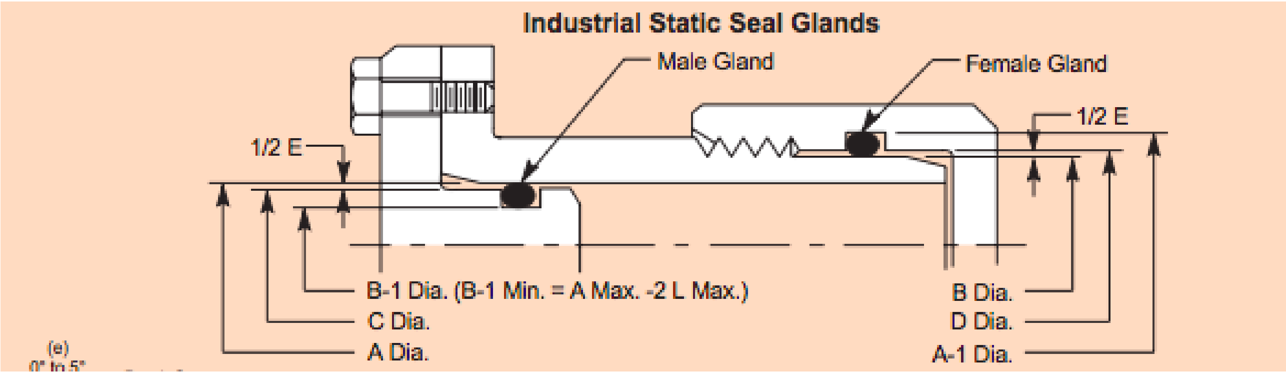
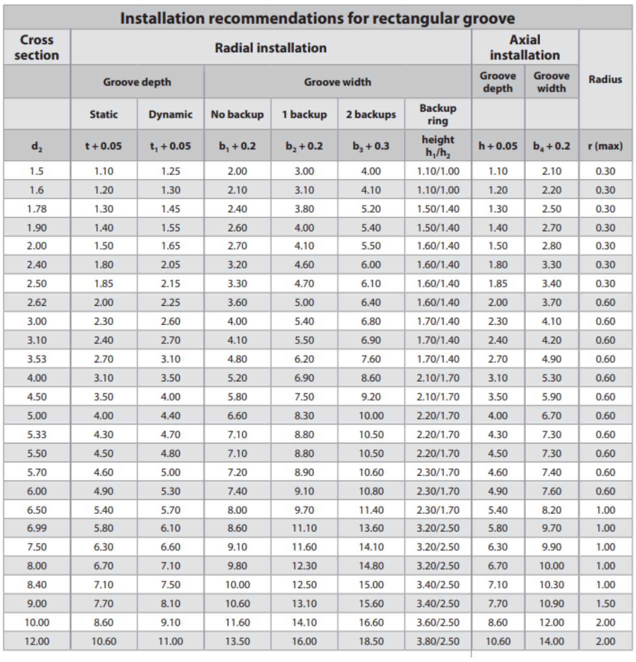


Figure 6.9: Parkers O-Ring Handbook [13]

The O-ring seal for both the float and electronic enclosure was designed to be static, meaning that the gland parts would not move relative to each other. To ensure proper design dimensions for the O-ring grooves, guidance was sought from Seal Engineering's technical data sheet [65]. After discussing several available o-ring materials with Seal Engineering, Nitrile was chosen as the best alternative. Nitrile is a cost-effective and readily available material compatible with aluminum and HDPE, allowing for the use of the identical O-rings in both the float and electronic enclosure.

Seal Engineering suggested using 3mm O-rings, which are widely available in various diameters and provide sufficient sealing performance at the targeted depths. This decision meant that the O-ring dimension did not need to be a significant consideration when designing the main dimensions of the bottom end-caps. The specific measurements for the O-ring grooves were obtained from Seal Engineering's handbook, and they can be found in Figure 6.10.



Installation recommendations for rectangular groove

Cross section	Radial installation						Axial installation		Radius
	Groove depth		Groove width				Groove depth	Groove width	
	Static	Dynamic	No backup	1 backup	2 backups	Backup ring			
d_2	$t + 0.05$	$t_1 + 0.05$	$b_1 + 0.2$	$b_2 + 0.2$	$b_3 + 0.3$	height h_1/h_2	$h + 0.05$	$b_4 + 0.2$	r (max)
1.5	1.10	1.25	2.00	3.00	4.00	1.10/1.00	1.10	2.10	0.30
1.6	1.20	1.30	2.10	3.10	4.10	1.10/1.00	1.20	2.20	0.30
1.78	1.30	1.45	2.40	3.80	5.20	1.50/1.40	1.30	2.50	0.30
1.90	1.40	1.55	2.60	4.00	5.40	1.50/1.40	1.40	2.70	0.30
2.00	1.50	1.65	2.70	4.10	5.50	1.60/1.40	1.50	2.80	0.30
2.40	1.80	2.05	3.20	4.60	6.00	1.60/1.40	1.80	3.30	0.30
2.50	1.85	2.15	3.30	4.70	6.10	1.60/1.40	1.85	3.40	0.30
2.62	2.00	2.25	3.60	5.00	6.40	1.60/1.40	2.00	3.70	0.60
3.00	2.30	2.60	4.00	5.40	6.80	1.70/1.40	2.30	4.10	0.60
3.10	2.40	2.70	4.10	5.50	6.90	1.70/1.40	2.40	4.20	0.60
3.53	2.70	3.10	4.80	6.20	7.60	1.70/1.40	2.70	4.90	0.60
4.00	3.10	3.50	5.20	6.90	8.60	2.10/1.70	3.10	5.30	0.60
4.50	3.50	4.00	5.80	7.50	9.20	2.10/1.70	3.50	5.90	0.60
5.00	4.00	4.40	6.60	8.30	10.00	2.20/1.70	4.00	6.70	0.60
5.33	4.30	4.70	7.10	8.80	10.50	2.20/1.70	4.30	7.30	0.60
5.50	4.50	4.80	7.10	8.80	10.50	2.20/1.70	4.50	7.30	0.60
5.70	4.60	5.00	7.20	8.90	10.60	2.30/1.70	4.60	7.40	0.60
6.00	4.90	5.30	7.40	9.10	10.80	2.30/1.70	4.90	7.60	0.60
6.50	5.40	5.70	8.00	9.70	11.40	2.30/1.70	5.40	8.20	1.00
6.99	5.80	6.10	8.60	11.10	13.60	3.20/2.50	5.80	9.70	1.00
7.50	6.30	6.60	9.10	11.60	14.10	3.20/2.50	6.30	9.90	1.00
8.00	6.70	7.10	9.80	12.30	14.80	3.20/2.50	6.70	10.00	1.00
8.40	7.10	7.50	10.00	12.50	15.00	3.40/2.50	7.10	10.30	1.00
9.00	7.70	8.10	10.60	13.10	15.60	3.40/2.50	7.70	10.90	1.50
10.00	8.60	9.10	11.60	14.10	16.60	3.60/2.50	8.60	12.00	2.00
12.00	10.60	11.00	13.50	16.00	18.50	3.80/2.50	10.60	14.00	2.00

Figure 6.10: Seal Engineering - O-ring dimensions

The ideal cross-sectional compression rate for the O-Rings was $10\% - 20\%$ [65]. To calculate this, the following formulas were used:

$$\text{Ø}_{Body\ groove} = \text{Ø}_{Bottom\ end-cap} + x\% \times d_2 - (d_2 - t_1) \tag{17}$$

End-caps

After finalizing the sealing method as a male o-ring gland, the next step was to specify a refined solution for the seal. The decision to use a male o-ring gland was based on its ease of manufacturing and maintenance. The dimensions of the end-cap were determined considering an external pressure of 11 bar and an o-ring compression range of $10\% - 20\%$.

To ensure a reliable seal, the design incorporated one o-ring groove, with an additional two grooves included as backups in case one groove proved insufficient. With an outer diameter of 181 mm, the end-cap would fit seamlessly into the main body without any issues. Furthermore, careful attention was given to the geometry and space allocation for connectors and sensors to meet the customer needs of the electrical groups.

To validate the feasibility of the design, a brief conversation with the lab engineers was conducted to ensure that the part could be effectively sent for production. Their input and insights helped to confirm the manufacturability of the design.

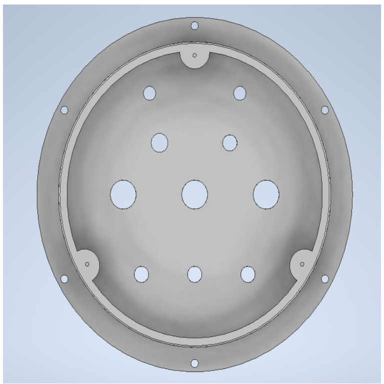


Figure 6.11: Electronic enclosure endcap top-view

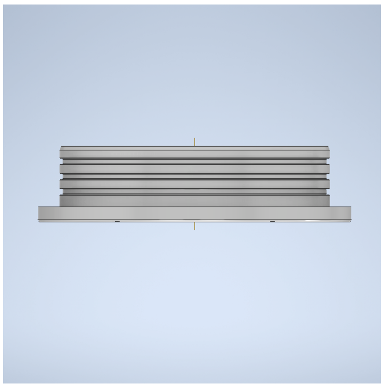


Figure 6.12: Electronic enclosure endcap side-view

Top-cap

A press-fit solution was selected to connect the body and the top cap. This method required specific dimensions and tolerances to be defined prior to manufacturing. An H8/r7 tolerance was chosen for the press fit, following the guidelines provided by ISO 286 for shaft, hole, and fit [40]. This tolerance selection ensured an interference fit, which the team could assemble through cold pressing. The top cap would securely and tightly fit onto the body by adhering to these tolerances, providing a reliable and robust connection.

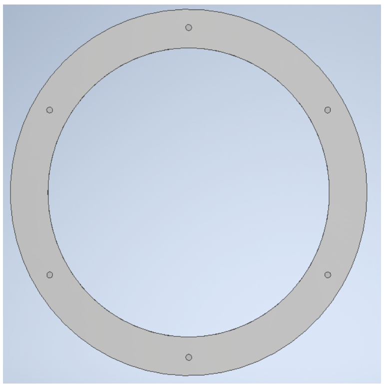


Figure 6.13: Electronic enclosure top-cap top-view

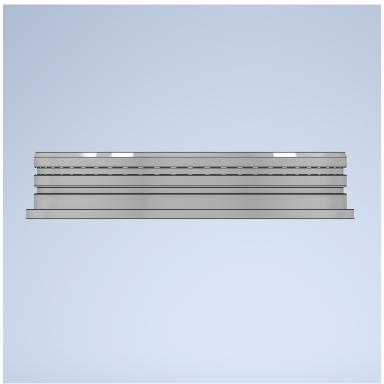


Figure 6.14: Electronic enclosure top-cap side-view

Additionally, a gasket would be placed between the dome and the flange with the top-cap. To ensure that this critical part would not leak, the following calculations were performed to determine the safety factor for a leak using formulas [66] and [67]

Bolt dimension	E (GPa)	R_m ($\frac{N}{mm^2}$)	R_m ($\frac{N}{mm^2}$)	L_{st} (mm)	L_k (mm)	τ (Nm)
M4	190	700	450	5	15	2.2

Table 6.1: Material Properties M4 bolt

With the values presented in Table 6.1, the following calculations could be done to determine bolt stiffness and surface stiffness using Equations: 15 and 16

$$k_m = 483830.4\frac{N}{mm},\ k_{s1} = 166820\frac{N}{mm} \text{ and } k_{s2} = 333640$$

thus giving

$$k_s = 111213.333Nmm$$

Given the calculated values, the stiffness ratio of the bolts could now be determined with Equation 14:

$$\phi = 0.187$$

Before the surface force could be determined, the applied force per bolt needed to be calculated. This was determined based on maximum internal pressure, which could not exceed 15 psi due to the pressure relief valve. This would be acting on the internal surface of the dome, calculated with:

$$A_{dome} = 2\pi hr = 33943mm^2 \tag{18}$$

The internal pressure force would then be established

$$F_{internalpressure} = 103421 \times 33943 = 3510.4N \tag{19}$$

This force would be divided upon the 6 bolts on the flange resulting in the final value being

$$F_{bolt} = \frac{F_{internalpressure}}{6} = 585.1N$$

The surface force was determined using Equation 13

$$F_m = 475.7N$$

Second to last the force exerted by bolt torsion was calculated with Equation 12

$$F_0 = 4038N$$

Finally, with this value, the safety factor for the leak could be established with Equation11

$$n_k = 8.49$$

This is relatively high and within the standardized values of 1-1.3, depending on whether it is a soft or hard gasket. These calculations meant that the design was within the requirements defined by the project.

Enclosure body

To determine the wall thickness of the remaining part of the enclosure body, choosing a male o-ring gland necessitated a calculation considering safety factors. This calculation was initially performed manually, followed by ANSYS software verification to optimize material usage. Discussions with the electronic engineers indicated a minimum internal diameter requirement of 180mm for accommodating the electronics. Considering o-ring compression, the established internal diameter requirement was 181.2mm. Consequently, the wall thickness variations would impact the external diameter of the enclosure. The critical wall thickness for a tube with infinite length was then calculated. At a depth of 100m in seawater, the external pressure reaches 11 bar. The necessary E-modulus and ν values were obtained from [48]. The Von Mises Buckling equation was utilized to calculate the critical pressure of a tube with infinite length [68]. This calculation ensured the enclosure's structural integrity by considering the external pressure and selecting an appropriate wall thickness to prevent buckling and maintain its functionality.

$$t_{Critical} = \sqrt[3]{\frac{P_{crit} \times (1 - \nu^2)}{2E}} \times D \tag{20}$$

$$t_{critical} = 3,32mm$$

The Von Mises Buckling calculation, in addition to the ANSYS simulations done in the material savings chapter, determined the final wall thickness of the electronic enclosure.

6.2.2 Material choice and manufacturing methods electronic enclosure

The manufacturing aspect of this thesis played a crucial role in ensuring the product's success during competitions. To achieve this, the team sought guidance from the lab engineers at the machine shop located at the University of Stavanger. Their expertise and knowledge helped determine the appropriate production methods for the project. Additionally, the team received valuable training on operating the necessary machines, enabling them to carry out the manufacturing processes required for the project effectively. This collaboration with the lab engineers and their support in determining production methods and providing training was essential in ensuring a smooth and successful manufacturing phase.

Enclosure body

In considering the manufacturing options for the electronic enclosure body, the team identified two main alternatives. CNC machining was initially considered but deemed excessive due to the pipe's large size and bore depth limitations. Turning the body and drilling the holes was another option. Still, it would have been time-consuming and resulted in significant waste due to the excess material left after turning. Another approach was to order the tube and lip as separate parts and weld them together, which would reduce waste material by allowing the use of a tube with a smaller wall thickness. However, none of the team members had the welding experience or authorization, requiring the manufacturing process to be outsourced. Considering the team's expertise and authorization, turning was chosen as the preferred manufacturing method for the body.

The selection of aluminum as the material for the body was based on meeting customer needs for thermal conductivity and lightweight design. Aluminum, with a density of 2710 kg/m^3 and a thermal conductivity rating of 247 $W/m*K$, exceeded the minimum requirements of 200 $W/m*K$ [48] [69]. While aluminum was chosen, the specific alloy needed to be determined. Both 6061-T6 and 5052 aluminum exhibited excellent corrosion resistance and machinability. However, 6063 aluminum offered higher corrosion resistance at the expense of ease of machining. Considering the superior strength-to-weight ratio of 6061-T6 aluminum and its overall suitability for the project, it was selected as the preferred aluminum alloy for the electronic enclosure body.

End- and top-cap

High precision and accuracy were required in the manufacturing process to ensure the proper fit and seal of both end-caps, which featured small geometry, o-ring grooves, and crucial connector placements. The dimensions for the press fit had to be exact to achieve the desired outcome. Two manufacturing options were considered: turning the top-cap or ordering CNC machining from the machine shop at the University of Stavanger.

Turning the top-cap did not require additional training, saving time. On the other hand, CNC machining offered higher accuracy, although there was some uncertainty regarding the production time. Since this component's accuracy was more critical than production time, CNC machining was chosen as the preferred manufacturing method. Consistent with the material choice for the body, aluminum 6061-T6 was selected for the end-caps. This decision was made due to its desirable properties and suitability for the project. The Final design of the electronic enclosure is presented in Figure 6.15

Figure 6.15: CAD model of final design

Flange

The flange plays a crucial role in the electronic enclosure as it applies even pressure on the gasket and dome rim, ensuring a watertight seal. Two primary production methods were considered for this component: 3D printing and CNC machining. 3D printing was attractive because it created complex geometries without generating excessive waste material. On the other hand, CNC machining offered higher precision and accuracy in the final part. Considering that the complexity of the structure was deemed more important than the precision required for the fastening methods to the bands, 3D printing was chosen as the preferred manufacturing method for the flange. Regarding material selection, PET-G was chosen based on the material exploration conducted during the concept development phase. This exploration indicated that PET-G was the most suitable plastic for parts in contact with water, making it an appropriate choice for the flange.

6.2.3 Material saving electronic enclosure

In order to determine the final wall thickness of the enclosure body, a critical step was taken to optimize material usage and provide certainty during the manufacturing phase. Three different wall thicknesses, namely 3mm, 5mm, and 8mm, were analyzed using ANSYS software. The objective was to assess their safety factors and stress concentrations.

All three alternatives demonstrated acceptable safety factors and stress concentrations, indicating their feasibility for the application. However, considering the goal of material conservation, the option with an 8mm wall thickness was eliminated. Additionally, since the team intended to undertake the turning operation, a desired safety margin to account for potential imperfections during manufacturing was implemented. Choosing a 3mm wall thickness would leave little room for errors during the manufacturing process. Therefore, it was deemed less favorable. On the other hand, the 5mm wall thickness achieved a balance between material savings and allowing for minor discrepancies during turning. Consequently, the 5mm wall thickness was selected as the optimal choice for the body of the enclosure.

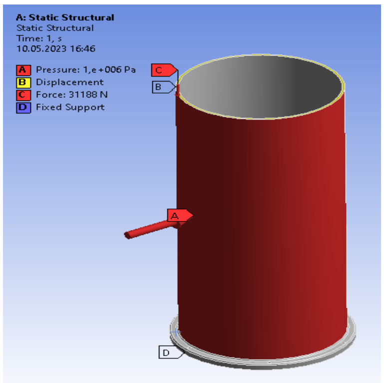


Figure 6.16: Forces and supports on electronic enclosure

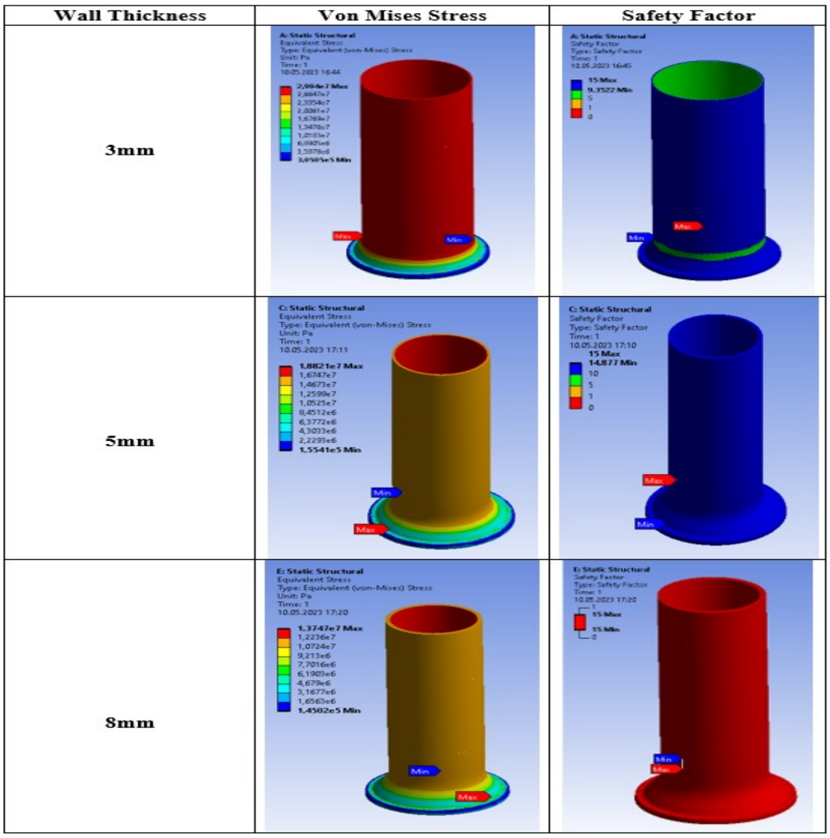


Figure 6.17: FEA analysis of electronic enclosure

6.3 Final product design Float

The detail design phase of the float encompassed various aspects, such as calculating the appropriate thicknesses, exploring sealing options, selecting suitable materials, and performing buoyancy calculations. The chosen concept C for the float's end-caps and internal structure underwent further refinement and development. Additionally, detailed design work was carried out for the outer structure, including the cylinder body, end-caps, impact module, and sensor spacer.

6.3.1 Detail changes for float

Sealing and design

The same sealing methods employed for the bottom end-cap of the float were also utilized for the electronic enclosure, as described in Equation 17. Considering that the float's body would likely be made of plastic to avoid Bluetooth interference with the electronic components, the team could manufacture the body, which could introduce higher inaccuracies. However, the bottom end-cap would need to be machined by professionals, making it more convenient to design the O-ring grooves on the bottom end-cap.

End-caps

The design of the bottom end-cap followed a similar approach to the electronic enclosures' bottom end-cap. Considering that the float's maximum depth requirement was 10m, it was determined that two O-rings would suffice, aligning with the electronic engineers' preference for compactness. The end-cap would be positioned within an extruded part of the cylinder, ensuring that the end-cap inner diameter is aligned with the body's inner diameter. This internal end-cap would provide additional support to the thinner section of the body, eliminating the need to factor it into calculating the critical wall thickness.

To connect tension rods on the outer side of the float's body, the bottom of end-cap required a diameter larger than $\text{Ø}_{end-cap} > 140mm$. To achieve this, a flange needed to be incorporated into the body above the end-cap. Welding a plastic flange onto the body was the most effective method. After consulting with Joar Landa, a certified plastic welder responsible from the communications group in UiS Subsea, a secure weld for the flange necessitated a 10mm width, thus an outer diameter of $\text{Ø}_{end-cap} = 160$ was established to ensure the weld's strength. This outer diameter was also adopted for the top-cap, flange, and end-cap. The required outer diameter of the piston was verified using FEA, explicitly considering the O-ring grooves.

As for the top-cap, its design aimed for a permanent connection to the body, with only necessary modifications for accommodating holes and threads for sensors and the relief valve. Similar to the earlier approach, the end-caps diameter was set at Ø160mm, and excess material not essential for the weld would be removed.

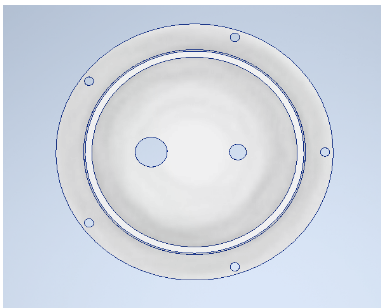


Figure 6.18: Float end-cap top-view

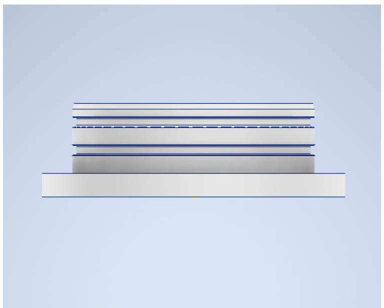


Figure 6.19: Float end-cap side-view

Body

During discussions with plastic tube manufacturers at Halling Plast, the team learned that plastic pipes are available in pre-set sizes. Consequently, a pipe was ordered with the appropriate outer diameter and planned to machine the inner diameter to achieve the required dimensions. The E-modulus and ν (Poisson's ratio) values for the plastic material were obtained from [49] and utilized for subsequent calculations.

To determine the final outer diameter and wall thickness, ANSYS was employed, in addition to hand calculations were used as a safety measure. The inner diameter needed a minimum of 120mm, so the outer diameter was set to 140mm for further calculations, resulting in a wall thickness of $t = 10mm$. The critical pressure for a tube with infinite length was calculated using the Von Mises buckling Equation 20.

$$P_{critical} = \frac{2E}{1-\nu} \times (\frac{t}{D})^3$$

Since the targeted depth of the float was set to be 10 meters, the $P_{critical} = P_{10m} = 2atm$. To calculate the critical wall thickness, Equation 20 Von Mises Buckling equation was used:

$$t_{Critical} = \sqrt[3]{\frac{P_{crit} \times (1-\nu^2)}{2E}} \times D$$

$$t_{critical} = 6mm$$

Finally, the preliminary safety factor n_f was calculated to estimate the required wall thickness for the body.

$$t = \frac{D_{outer} - D_{inner}}{2} = 10mm$$

$$n_f = \frac{t}{t_{critical}} \approx 1,67$$

The recommended safety factor for the float's body was ideally between 2-2.5 [41]. The calculated safety factor for the cylindrical shape did not meet this requirement. However, it's important to note that this calculation assumes infinite length, whereas the actual float would have a finite length. Consequently, the actual safety factor for the wall thickness would be higher. To ensure the structural integrity of the float's body, a wall thickness of 6mm was utilized as a guideline during FEA testing in ANSYS.

Impact module

Once the overall design of the float was finalized, the impact module could be created. The purpose of the impact module was to ensure the float's stability and provide protection to the sensors located on the bottom end-cap. The design of the impact module drew inspiration from competitive market floats and took into account the previous year's impact module.

During the design process, it was essential to address the customer needs raised in Table 4.3 in Chapter 4. The primary focus of the impact module was to effectively absorb or deflect the energy transfer upon the float's contact with the ocean floor. Additionally, the design had to accommodate the various components underneath the float.

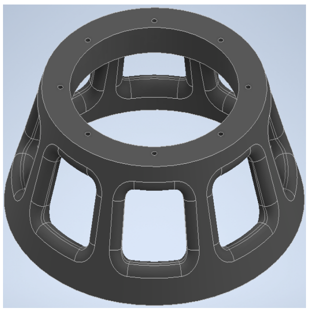


Figure 6.20: Impact Module

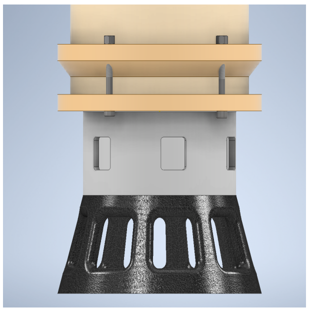


Figure 6.21: Impact Module and spacer in assembly

Furthermore, it was crucial to adhere to the specified dimensions provided by MATE [19] for the float. According to the guidelines, the float could not exceed a diameter of 180 mm. Considering the customer requirements and the overall structure of the float, the impact module had two shape options: cone and cylindrical. Given that the bladder within the float would be semi-spherical and required sufficient volume to expand into, the impact module had to either take on a cone-shaped design or maintain a cylindrical shape with a diameter of 160 mm. Opting for a cone shape offered several advantages, as it facilitated attachment to the remaining components of the structure and minimize the number of potential failure points for the float. Therefore, the cone shape was selected as the optimal design for the impact module.

Spacer module

The spacer module was specifically designed to fulfill the requirements of the electronic engineers, addressing two main aspects: increasing the distance between the thermopocket and the sea floor and allowing controlled water flow to the sensors. Additionally, the spacer module needed to withstand the impact experienced by the float, as it was positioned between the bottom end-cap and the impact module.

To meet these requirements, the diameter of the spacer module was set to match the top of the impact module, ensuring a seamless connection. The height of the spacer module was determined based on the preferences of the electronic engineers and set at 40mm. The design of the spacer module, when assembled with the other components, can be observed in Figure 6.21. This visual representation showcases how the spacer module integrates into the overall structure of the float, highlighting its positioning and relationship with the adjacent modules.

Internal structure

One of the primary requirements for the internal structure was its ease of insertion and removal from the float. As discussed during the system-level design phase, maintenance would involve removing the bottom end-cap and the internal structure. Therefore, the structure had to be designed to allow it to slide in and out smoothly and support its own weight without side supports. A specific customer need expressed by the electronic engineers was modularity. They wanted the ability to replace parts of the structure without requiring a complete redesign or reproduction. The requirements for the internal structure could change over time due to future upgrades in electronics or the possibility of certain components breaking. Hence, it was essential to facilitate easy part replacement without needing a complete reconstruction of the internal structure.

Consequently, the internal structure was divided into two primary components: the electronic structure and the ballast structure. The ballast structure was designed to securely hold the ballast while allowing for convenient weight distribution within the float. This was crucial because the float needed sufficient ballast to achieve the desired sinking effect and required careful weight balancing of the electronics. Additionally, the ballast structure needed to provide ample space for cables to extend from the bottom end-cap to the top-cap.Two designs were considered for the ballast system, as depicted in Figure 6.22 and Figure 6.23. These designs explored different approaches to achieve the desired functionality of the ballast system.

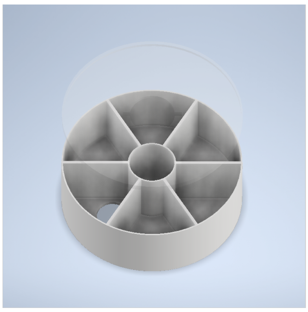


Figure 6.22: Ballast module - Concept A

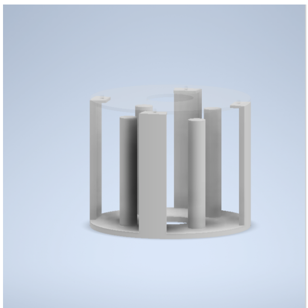


Figure 6.23: Ballast module - Concept B

Concept A was developed to accommodate six points where the ballast could be positioned, allowing for fine-tuning of the weight distribution. This design prioritized sturdiness, ensuring stability and strength for the overall structure. However, it had a drawback - a large hole in the middle, necessary for accommodating various sensors and cables at the bottom end-cap. Another drawback was that this design required the ballast to be either produced by the team or obtained through a special order from a company. Additionally, the structure would require a significant amount of material, as it was compact and highly robust, which was considered excessive for the internal structure of the float. Moreover, using this design would necessitate removing the ballast structure from the electronic structure whenever redistributing the ballast.

Figure 6.24: Leftover ballast

Concept B, focused on facilitating the easy redistribution of ballast and reusing ballast previously used by UiS Subsea in past years, shown in Figure 6.24. This structure consisted of four support rods with overhangs, fastened to the electronic structure using M3 screws. It also included four rods for ballast distribution, strategically positioned with enough space from the top to slide the ballast in and out of the assembled internal structure. Although this design did not provide the same strength to the internal structure as Concept A, it was deemed sufficient to support the electronic structure. Considering these factors, Concept A was chosen for the internal ballast structure. The finalized internal ballast structure can be seen in Figure 6.25 and the electronic structure in Figure 6.26.

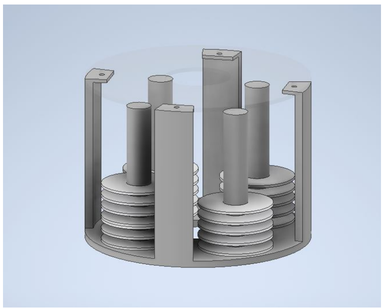


Figure 6.25: Ballast structure

Figure 6.26: Electronic structure

6.3.2 Material and manufacturing choice Float

Body and top-cap

The need for non-metallic material influenced the choice of material for the float's body due to the utilization of data-transmitting components using Bluetooth. It was crucial to select a plastic material that was both environmentally friendly and suitable for applications in chlorinated water. Two options considered for the float body material were PVC and HDPE, as they are commonly used for subsea pipes.

As discussed earlier, HDPE and PVC have similar attributes [70], but notable differences exist. HDPE is an environmentally friendly material, while PVC is known to emit hazardous pollutants and chemicals, making it unsuitable for this project. HDPE is well-suited for welding, which opened up the possibility of using welding as a manufacturing method. Considering these factors, HDPE was chosen as the float's body and top cap material. Additionally, there were opportunities to obtain affordable and environmentally friendly HDPE plate and pipe scrap cutoffs from companies, further supporting the decision. The float body could be constructed using an HDPE pipe, which would be machined to achieve the desired dimensions. Turning the inside and outside of the pipe would help achieve the correct inner and outer diameter. The length of the tube could be easily cut with a jigsaw. Since the top-cap and body were designed to be made from HDPE, they could be welded together using HDPE welding techniques. Any excess material from the top-cap not required for the weld could be removed using a lathe.

Bottom end-cap

When considering the material choice for the bottom end-cap, the options were aluminum and High-Density Polyethylene (HDPE). The advantages and disadvantages discussed in Chapter 4 - Final Specifications were considered during the selection process. Both aluminum and HDPE could be machined to achieve the desired shape. However, there were specific considerations to be made.

HDPE is known to be sensitive to heat and tends to expand. This poses a challenge regarding O-ring sealing, as a tight fit between the glands is required for effective sealing. Furthermore, the ordering time for machined HDPE was estimated to be 4-6 weeks, which was deemed too long for this project's deadline. On the other hand, aluminum offers some distinct advantages. It is a heavier material but provides the added benefit of bonding to epoxy or other sealants. Additionally, aluminum exhibits high heat resistance and better heat dispersion than polyethylene. These attributes are beneficial in situations with a risk of overheating electronics.

Taking all these factors into consideration, aluminum was selected as the material for the bottom end-cap. CNC machining allowed the creation of the bottom end-cap from a block of aluminum with high precision and efficiency. This manufacturing method was superior to other standard methods in terms of accuracy and time. Furthermore, the University of Stavanger possessed its own CNC machine and CNC operator, enabling the production to be carried out at a low cost and with reduced ordering time.

The spacer module and the 3D printed internal structure

Due to the complex designs involved in the internal structure, spacer, and impact modules, 3D printing was the ideal manufacturing method. Other production methods would have resulted in excessive material waste, increased costs, and longer production times. By utilizing 3D printing, this team was able to produce the components quickly, cost-effectively, and with the ability to make revisions as needed. Furthermore, the internal structure would need to be reproduced periodically due to potential revisions in the electronics throughout the float's lifetime.

When considering the materials for 3D printing, PLA and PET-G emerged as the most promising options for this project. PET-G is particularly well-suited for environments with exposure to chlorinated and saltwater, and boasting superior impact resistance. On the other hand, PLA is a more affordable and environmentally friendly choice. Given the absence of a specific requirement for a load-bearing material tailored for water usage, PLA was selected for the internal structure. The team prioritized PLA for its environmentally friendly attributes and sought to use it wherever possible.

In the case of the spacer, located outside the float and positioned between the bottom end-cap and impact module, PET-G was deemed the better choice. Its exceptional impact, chemical, and water resistance made PET-G the ideal material for this specific application.

Impact Module

Furthermore, when considering materials for the impact module of the float, the key attributes of impact resistance and elasticity were taken into account. The previous year's impact module had utilized cheap 3D-printed materials that proved brittle and unsuitable for their intended purpose. To address this issue, guidance was sought from the lab engineers at the University of Stavanger and the team's counselor.

After careful evaluation, Ninjaflex, a new rubber filament available on the market, was selected. Ninjaflex is known for its flexibility and durability, with the ability to stretch up to 660 percent of its initial length before failure. It exhibits higher abrasion resistance than commonly used filaments like PLA and ABS. Ninjaflex demonstrates excellent shock absorption properties, making it an ideal choice for the impact module. It is important to note that Ninjaflex has some drawbacks, such as limited precision during printing, compatibility issues with certain printers, and a higher cost than standard rigid filaments. However, after consulting with the lab engineers, the University of Stavanger agreed to sponsor the production of the part and had 3D printers that were compatible with Ninjaflex. Consequently, Ninjaflex was chosen as the material for the impact module of the float. [71]

Air bladder - balloon, and valve

After discussions with the previous year's groups, it became evident early on in the project that a different approach would be necessary for the balloon. Extensive meetings with the electrical engineers helped identify the need for a stronger and more durable balloon to meet stakeholders' requirements.

Several alternatives were considered, including a small scooter tire, a punching bag bladder, and a heavy-duty helium balloon. The heavy-duty helium balloon was quickly dismissed due to the previous float issue of balloon breakage caused by excessive inflation and deflation, which degraded the bladder quality over time. Therefore, this year's focus was on a balloon with a predetermined shape and made of durable rubber, such as latex. Various scooter tires were available on the market that could meet the requirements. One advantage of this solution was that it had a valve suitable for our buoyancy engine, making assembly straightforward. However, the main challenge was that no available scooter tires had dimensions small enough for our needs. As a result, the option of using a punching bag balloon, as depicted in Figure 6.27, was chosen as a suitable alternative.

Figure 6.27: Punching bag inner balloon [14]

Figure 6.28: Bicycle valve [15]

Moreover, a recurring issue in the prior year was attaching the balloon to the float without causing any damage to the material. The inflation device featured a one-way valve designed for a ball pump but lacked a lip for attaching a hose clip. This presented a challenge that required further consideration and brainstorming. To address this issue, the team explored retrofitting a bicycle valve to the balloon and sealing it with rubber. This solution would enable the balloon to be securely screwed into the float, meeting the requirements of a waterproof and easily maintainable product. In addition, a connection between the valve and a 5mm tube was necessary. It was decided that a custom adapter for the valve would be manufactured and screwed onto the valve end. This adapter, illustrated in Figure 6.29, ensured that the threading process would not damage the tube of the buoyancy engine, providing a reliable and effective connection.

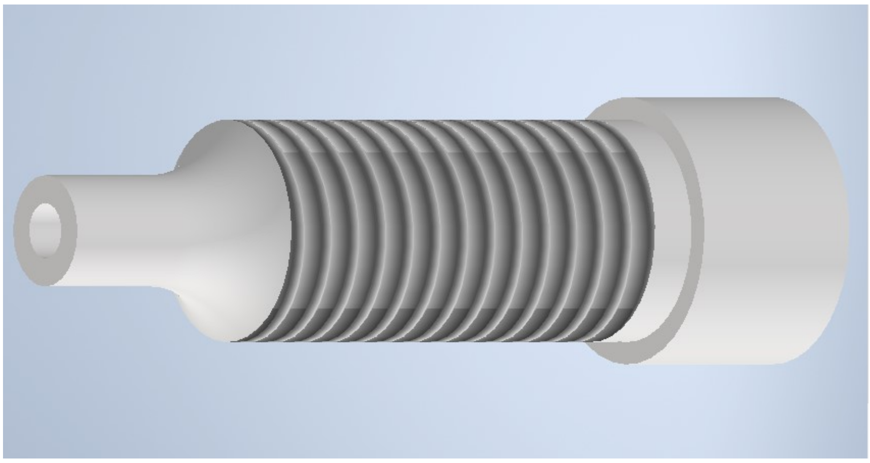


Figure 6.29: Custom valve adapter

6.3.3 Material savings for float

The float underwent an FEA to evaluate the structural integrity of its body and determine the appropriate wall thickness. Various wall thicknesses, specifically 10 mm, 8 mm, and 6 mm were tested during the analysis to identify the optimal balance between structural safety and material efficiency. The FEA results indicated that a wall thickness of 6 mm resulted in a lower safety factor than desired, suggesting potential structural issues. On the other hand, a 10 mm wall thickness provided sufficient safety margins and allowed for material savings. However, considering manufacturing tolerances and potential inaccuracies, an 8 mm wall thickness was ultimately chosen for the float's body. By selecting an 8 mm wall thickness, the team ensured the float would maintain a good safety factor while optimizing material usage. Additionally, this thickness provided some leeway for potential manufacturing variations, further enhancing the overall quality and reliability of the float's construction.

Figure 6.30: Forces and supports on float

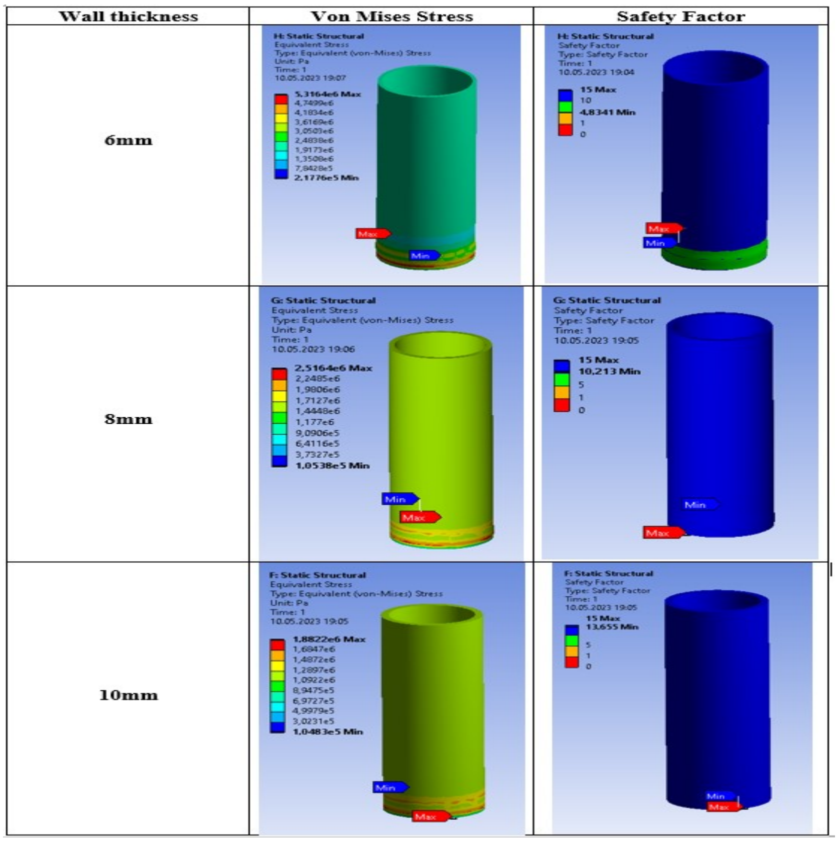


Figure 6.31: FEA analysis of float

6.4 Buoyancy and stability - ROV

Once the designs for the ROV frame and electronic enclosure were finalized, the next step was to calculate the weight and buoyancy of the ROV. This information was crucial for determining the required ballast and flotation elements. It was important to estimate the ROV's net buoyancy, center of buoyancy (CB), and center of gravity (CG) early in the design process since the production of ballast and flotation elements would take time.

During the target specification phase, it was specified that the ROV needed to have a marginally positive buoyancy. This requirement was set by MATE, ensuring that the ROV would float to the surface on its own in the event of an electrical failure. This meant that the thrusters would not be necessary to maintain the ROV's static position when submerged, reducing power consumption and minimizing electronics heating. To calculate the weight and buoyancy, the total mass of each part and their respective centers of mass were obtained from Autodesk Inventor. The buoyancy and center of buoyancy were determined in Inventor by filling the hollow sections of the structures while assuming a uniform material throughout. This approach allowed the center of volume and, consequently, the center of buoyancy to align with the center of mass displayed in Inventor.

The total mass, buoyancy, CB, and CG were computed and recorded in Table 6.2. This information served as a reference for further design considerations. [72]

Mass and buoyancy calculations: ROV					
Part	**Quantity**	**Weight of part [N]**	**Displaced water [cm^3]**	**Bouyant force [N]**	**Net buoyancy force [N]**
Electronic enclosure	1	78,912	14790,66	144,661	65,749
Brackets (flat)	18	1,419	56,192	0,550	-0,942
Brackets (angeled)	16	1,589	62,5743	0,612	-0,942
Bolts, washers & nuts	32	0,177	1,95	0,019	-0,158
Plate (side)	2	17,383	1863,4	18,225	0,842
Plate (top)	1	11,988	1276,825	12,488	0,500
Plate (bottom)	2	10,399	1113,612	10,892	0,493
Cross stiffener (front)	1	0,961	82,15826	0,804	-0,158
Cross stiffeners (rear)	1	1,413	121,4488	1,188	-0,225
Manipulator	1	61,499	3230,935	31,600	-29,899
Support bracket	2	0,314	28,2307	0,276	-0,038
Thruster	8	36,108	2550,678	3,188	-11,154
Enclosure fasteners	2	2,354	227,6909	2,227	-0,127
Cables	-	-	-	-	-
Lights	4	-	-	-	-
Rear camera	1	6,739	418,379	4,092	-2,647
Cable organizer	1	0,265	≈ 0	≈ 0	-0,265
Total		234,233	23592,894	252,866	18,633

Table 6.2: Mass and buoyancy calculations ROV

To verify the accuracy of Autodesk values, the weight and buoyancy were manually calculated using Equation 1. This analysis revealed that the ROV would possess a net buoyancy of $18,633N$, indicating that it would float when submerged in water. This was primarily due to the electronic enclosures' large volume and low mass. Furthermore, the ROV frame exhibited a slight positive buoyancy, with only the manipulator, screws, and brackets having a negative net buoyancy.

Given these circumstances, the ROV required ballast to reduce its buoyancy. As per the theory discussed earlier, the net buoyancy should amount to approximately $1-2\%$ of the ROV's total weight to ensure that it would gradually rise to the surface in the event of a propulsion system failure. The necessary amount of ballast was thus determined by subtracting the desired buoyancy from the calculated buoyancy:

$$Buoyancy_{target} = 0,015 * m_{ROV} = 0,358kg \approx 3,5Newton$$

$$Ballast_{required} = Buoyancy_{Calculated} - Buoayncy_{target} = 1,54kg$$

Ensuring stability in water was a critical requirement for this ROV. The ROV needed to complete tasks in the MATE ROV Competition and TAC challenge, necessitating maneuverability and stability. Achieving stability and maneuverability relied on the precise positioning of the center of mass (CG) and center of buoyancy (CB) of the ROV. Ideally, the CG and CB should align along the same vertical axis. Misalignment between the CB and CG would result in the ROV becoming tilted when submerged.

Calculating the vertical distance between the CB and CG was also crucial. A greater distance between the CB and CG would produce a more substantial righting moment, enhancing stability in the water. However, this would also make it more challenging to tilt, roll, and pitch the ROV. The optimal distance between the CG and CB had to be determined through testing by the ROV pilot, striking the right balance between stability and maneuverability.

Positioning the CG beneath the CB was necessary, as the righting moment would naturally place the CB above the CG. In this assembly, the CB was located 35.08 mm above the CG, providing a satisfactory distance that generated an adequate righting moment while allowing for easy tilting. If a more substantial righting moment was desired, additional ballast could be added to the bottom plate and equal flotation elements on the top plate to increase the vertical distance between CB_z and CM_z. Conversely, adding ballast to the top plate would raise CM_z, resulting in greater maneuverability.

The ROV would exhibit a slight tilt in the X and Y directions, which could be addressed by adjusting the ballast. The coordinates of the CB and CG for the ROV can be observed in Table 6.3, with the global origin positioned at the assembly center in the Z and Y directions and the rear end of the ROV in the X direction. Figure 6.32 provides a visualization of the CB and CG.

Table 6.3: CG and CB table ROV

CB and CG calculations [mm]			
Coordinate	**CB**	**CG**	**Δ**
X	-2,756	4,638	7,394
Y	363,065	360,495	3,861
Z	62,916	27,836	35,08
Total			36,058

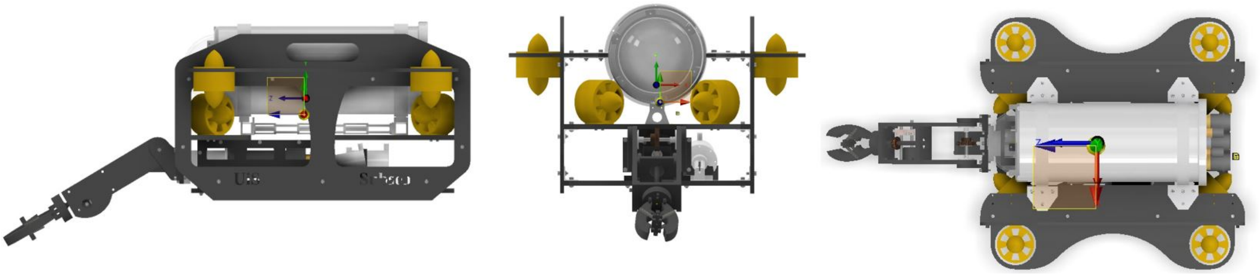


Figure 6.32: ROV CB and CG

Note: Autodesk Inventor uses Y as the vertical axis and Z and X as the horizontal, while this team uses Z as the vertical axis.

6.4.1 Buoyancy and stability - Float

Weigh and buoyancy

The float would descend without any air in the balloon, requiring the float to have slightly negative buoyancy. The float's air-bladder system would apply enough added volume to give the float a positive buoyancy, making it ascent back to the surface. The air-bladder system required the float to have a net buoyancy of a maximum of $-1.5N$. This would increase the air bladder's net volume enough to make the float ascend. The float's weight and volume were found to ensure the right amount of ballast was added. The total mass was calculated using Equation and from values retrieved from Inventor. The buoyancy was calculated manually for the body, end-caps, and flange with Equation 6, to ensure the values from Autodesk Inventor were correct. The buoyancy for the Spacer- and Impact module was retrieved from Autodesk Inventor. When calculating the buoyancy, the sensors were neglected as they would add marginal buoyancy, making calculations easier. The weight and buoyancy for the float can be seen in Table 6.4.

Table 6.4: Buoyancy table Float

Mass and buoyancy calculations: Float					
Part	**Quantity [pair]**	**Weight of part [g]**	**Displaced water [cm^3]**	**Bouyant force [N]**	**Net buoyancy force [N]**
Spacer module	1	17,129	13,8141	0,135	-0,033
Impact module	1	245,543	198,82	1,945	-0,464
body	1	1282,030	6927,211	67,752	54,038
top end-cap	1	184,317	193,61	1,894	0,089
Flange	1	43,731	45,936	0,449	0,018
bottom end-cap	1	658,16	193,61	1,894	-4,561
Bolts & nuts	5	12,5	≈ 0	0	-0,098
Electronic structure	1	2350	0	0	-22,563
Ballast structure	1	104,946	0	0	-1,030
Valves, nodes etc.	-	336,644	6,22	0,061	-2,621
Total	-	5235	7610,32	74,068	22,773

The float's net buoyancy was determined to be $22,773N$, requiring a total ballast of 2.47 kg to achieve a net buoyancy of $-1.5N$. The air bladder played a crucial role in adjusting the float's total volume and lowering the center of buoyancy during ascension. Maintaining a lower center of mass than the center of buoyancy was essential to prevent the float from turning upside down during ascent due to the righting moment.

To determine the center of mass (CG) and center of buoyancy (CB), data from Inventor software was used, and calculations were performed using Equations 8 and 9. It should be noted that the precise CG and CB values would be confirmed through testing later, considering the electronics' ongoing development. However, the electrical engineers advised the team to position the heavy electrical components around the z-axis. Given the overall symmetry of the float, the CG and CB on the X-Y plane were assumed to be at the origin. Table 6.5 presents the preliminary calculations for the center of mass and center of buoyancy, and a visual representation can be observed in Figure 6.33.

CB and CG calculations (mm)			
Coordinate	**CB**	**CG**	**∆**
X	0	0	0
Y	0	0	0
Z	254,288	27,836	29,527
Total			29,527

Table 6.5: CG and CB table Float

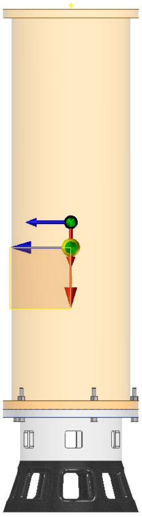


Figure 6.33: ROV CB and CG

The center of mass was located 29,5mm under the deflated center of buoyancy. This would lead to a righting moment about the vertical z-axis, but ballast had to be added to increase the distance. Since the distance between CB_z and CG_z would decrease when inflated, more ballast would secure a constant vertical axis. Since this team did not know the location of CB_{X-Y} concerning the electrical components, the required mass adjustment was unknown. As a result, this team would have to explore the correct ballast placements during testing.

Velocity

The MATE ROV Competition requires the float to complete two vertical profiles in under 10 minutes in a pool with a depth of 4 meters. The descending and ascending velocities had to be calculated to ensure the float would finish its tasks within the time limit. To mate computations easier, the float was assumed to start descending with the top of the float at the water's surface and begin ascending standing on the bottom of the pool. In reality, the float would accelerate until it reached its terminal velocity, then keep a constant velocity until reaching either the surface or bottom. It was assumed for these calculations that the float would have maximum velocity the entire distance from start to finish. This would grant a good time approximation but would require some leeway.

The weight force would act on the float downwards and would pull the float towards the bottom of the pool. The buoyancy force would act upwards, in the opposite direction of the weight force. When moving, the water would also apply a drag force in the opposite direction of the float's velocity. The float's deflated velocity was calculated by rearranging Equation 7:

$$v_descend = \sqrt{\frac{2F_D}{\rho C_D A}} = 0.49m/s \text{ [33]}$$

Where the drag coefficient for a long cylinder = 0.82 2.2, the diameter = 140mm which gives $A = \frac{\pi}{4} * D^2$, $\rho_{water} = 997\frac{kg}{m^3}$ and $F_D = F_G = 1.5N$ during terminal velocity.

The float's inflated velocity was calculated the same way, but adding the inflated air bladder volume of 4 dL with the calculated buoyancy of the float:

$$F_D = Buoyancy_{balloon} + Buoyancy_{deflated} = 2.4N$$

$$v_{ascend} = \sqrt{\frac{2F_D}{\rho C_D A}} = 0.62m/s$$

To calculate the time the float takes to complete its descent, the velocity equation can be rearranged as $t = \frac{d}{v}$, where d is the distance traveled. In this case, the distance traveled is the total height of the float, taking into account its initial position with the top of the float at the water's surface.

Assuming a 4-meter pool in the MATE Competition, the total distance traveled by the float would be 4 meters plus the height of the float. By dividing this distance by the velocity of the float, the time taken for the descent can be determined.

$$m_{distance} = 4m - 0.45m = 3.65m$$

$$t_{descend} = \frac{3.65m}{0.488m/s} \approx 7.45s$$

$$t_{ascend} = \frac{3.65m}{0.62m/s} \approx 5.9s$$

The total time required for the float to complete both vertical profiles was estimated to be 24.7 seconds, assuming a continuous descent and ascent without additional time for data gathering, inflation, or balloon deflation. However, in reality, the float would likely pause during data gathering and transmission and the inflation and deflation of the bladder. Additionally, the float would experience acceleration before reaching its maximum velocity, increasing the total time needed for the profiles.

Considering these factors, the estimated time of 24.7 seconds provides a safety factor of $n_f = \frac{10m}{24.7s} = 24.3$, which is satisfactory when accounting for the extra time required for various operations during the profiles.

7 Product Development Process - Testing and Refinement

After finalizing the detailed designs, the project began manufacturing, testing, and refinement. During this phase, every physical part of the assembly was manufactured, tested, evaluated, and potentially refined to meet the stakeholders' requirements. The testing involved subjecting the product to real-world scenarios, simulations, and trials to identify flaws, weak points, or performance issues in its design or functionality. To minimize material waste and cost, each solution that failed to meet the required standards underwent a thorough review to identify the cause of failure. Subsequently, appropriate enhancements were made to ensure the product's next iteration addressed these issues, eliminating the need for further modifications. The final cost model of the project was also derived during this phase.

7.1 Construction and manufacturing

Since the team produced many components to optimize time and cost, acquiring the requisite training and authorization for efficient and accurate manufacturing was vital to the project. This entailed participating in introductory courses held at both the machine shop and the 3D lab within the university. These courses provided the necessary training on operating the relevant machines.

7.1.1 ROV Frame

The majority of the components for the ROV frame, such as the plates and cross stiffeners, were outsourced for manufacturing and are not documented in this thesis. However, the 3D-printed parts, including the bands, band-stiffener brackets, flange, and impact module, were produced using the university's student printers, resulting in a cost-free and time-efficient production process. The manufacturing process followed the steps outlined in the additive manufacturing theory discussed in Chapter 2. The 3D printers utilized for production were the Ultimaker S5 and the Original Prusa i3 MK3. Maximum infill and supports were used during printing to achieve optimal results.

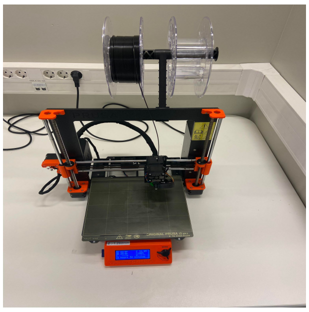


Figure 7.1: Orignial Prusa i3 MK3

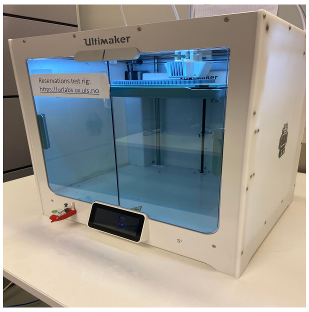


Figure 7.2: Ultimaker S5 topview

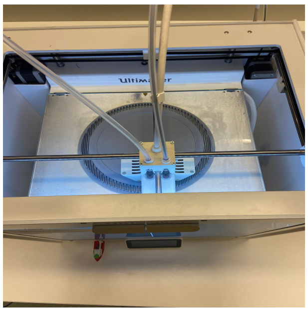


Figure 7.3: Ultimaker S5 sideview

7.1.2 Brackets

All the mounting points of the ROV used one of 2 fastening methods: Flat brackets and angled brackets. This group manufactured these by utilizing leftover materials available at the UiS Lab. They were manufactured by cutting to the correct length and drilling holes at specified locations. Eight flat brackets and 18 angled brackets were manufactured, shown in Figure 7.4.

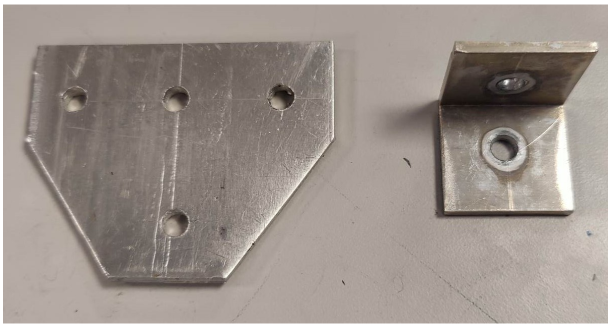


Figure 7.4: Angled Bracket and flat bracket

7.1.3 Electronic enclosure

The primary objective of the electronic enclosure was to protect critical components and provide a seal against the external environment. This necessitated employing appropriate manufacturing methods to fulfill this requirement. Achieving high accuracy, adhering to specified tolerances, and applying sufficient coolings and sharp tools were crucial for producing a high-quality product with a long lifespan.

The team undertook to manufacture the electronic enclosure body. At the same time, the lab engineers at UiS were responsible for producing the end-caps as these parts required machines the team was not authorized to use. It is important to address that the team ordered 6061-T6 aluminum but received 6082 alloy instead. This did not affect the manufacturing process or the quality of the product. This process was time-consuming, requiring significant effort to ensure the production of a high-quality product within the projected timeframe for the initial underwater test. It was essential to eliminate asymmetric turning, which could lead to production faults. The outer diameter was reduced from an initial 220 mm to 190 mm, while the internal diameter was adjusted from 160 mm to 181.2 mm.

Figure 7.5: Cutting pipe

Figure 7.6: Turning off electronic enclosure

The lab engineers utilized a CNC machine to manufacture the end-caps, which yielded the anticipated results with high precision. However, a minor issue arose: the hole placements deviated slightly from the model's intended positions. Moreover, three rectangular plugs necessitated creating custom nuts and removing threads to align with the designed hole dimensions and placements.

To ensure a watertight seal, the top-cap was press-fitted with two O-rings, using 500kg force, as depicted in Figure 7.7 and 7.8. This assembly method effectively created the desired watertight seal for the electronic enclosure.

Figure 7.7: Press fit

Figure 7.8: Final fit after press fit

After many hours and sufficient cooling, the final product was finished. To ensure the internal surface roughness of $\mu = 0.1$, the feeding speed was reduced, and red spirit was applied for a cleaner cut. The final product is shown in Figure 7.9

Figure 7.9: Final body product

7.1.4 Float

According to the plan outlined in Chapter 5, the team constructed and machined specific components. The float's body was created using an HDPE pipe sourced from Halling Plast. Fortunately, the pipe was obtained as waste material from another project, so no cost was incurred. The team initially ordered a tube with an internal diameter of Ø $<$ 120mm and an outer diameter of Ø140 mm. However, upon its arrival, the actual dimensions of the pipe were Ø124-Ø160, as Halling Plast did not have more of the initially requested size. This unexpected change necessitated a prompt adjustment in the dimensions of the main components of the float using previously employed methods and steps. The updated dimensions can be found in the Appendix.

To align with the new pipe dimensions, the outer diameter was turned to Ø140. In contrast, the bottom end-cap extrusion was turned to a diameter of Ø128.5mm, which the team deemed the thinnest without compromising the symmetry during turning. The electronic engineers faced delays and were uncertain about the height requirements of the electronics. Additionally, the availability of the HDPE welding equipment was limited, which compelled the team to proceed with the production without precise knowledge of the body dimensions. To account for this uncertainty, an additional 50mm was added to the anticipated height, and a length of 450mm was set for the body.

The top end-cap was fashioned from a waste HDPE plate, which was first welded onto the body and then cut into the desired shape to ensure a secure weld. Before progressing with the float assembly, the weld connection underwent a leakage test. The float was turned upside down and filled with water, and after half an hour, no leakage was detected, thus allowing production to continue. The top end-cap was cut and turned to align it flush with the rest of the body. The advantage of obtaining a pipe with an outer diameter of Ø160mm was that it served as a suitable base for creating the lip for fastening the end-cap to the body. A section of the remaining HDPE pipe was cut, and its internal diameter was turned to meet the target values. The holes for the bolts, RGB lights, power switch, and pressure relief valve on the top end-cap were drilled using a pillar drill and subsequently hand-threaded.

Details of the manufacturing process for the top-cap and body can be found in Figure 7.10, Figure 7.11, and 7.12.

Figure 7.10: Float welding

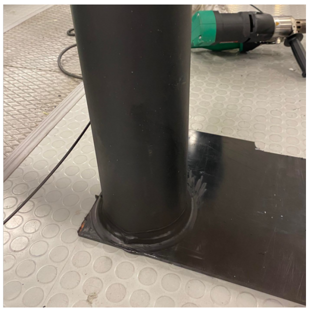


Figure 7.11: Float Top-cap weld

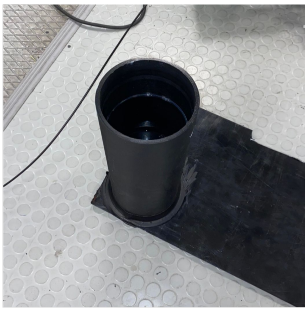


Figure 7.12: Weld water test

Hole placements end-cap for connectors, sensors, and valves

The bottom end-cap was created by the lab engineers with a CNC machine. The lab engineers cut and threaded the holes, and they fit perfectly with the O-rings and the body. The internal structure was printed with the student printer Ultimaker S5, whereas the spacer module and impact module were 3D printed with Original Prusa i3 MK3,

Bladder

When constructing the bladder, several problems arose. The thread on the valve was not specified on the package, and the lab engineers had no tools to match the thread. Due to this problem, the best option was to create new threads to M6 to remove excess material. This meant that the wall thickness of the brass valve would be dangerously thin and be in danger of breaking.

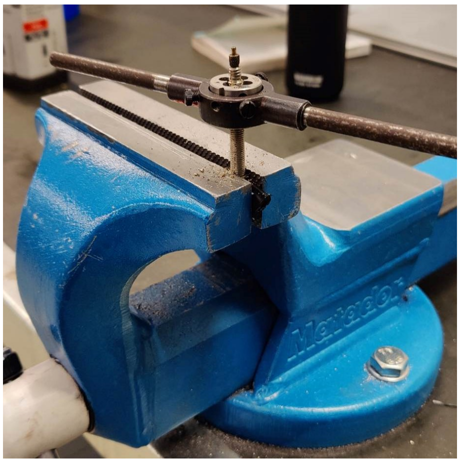


Figure 7.13: Re-threading float valve

Figure 7.14: Retrofitting of bicycle valve

The assembled float can be seen in Figure 7.15

Figure 7.15: Float assembly

7.2 Final cost model

Once the manufacturing process concluded, it became possible to calculate the final cost model for the project. The team successfully secured sponsorship deals with IKM gravøren, Halling Plast, Seal Engineering, and Mechman, which covered the expenses for most of the high-cost components. The remaining parts were either locally manufactured by the lab engineers at the University of Stavanger or produced by the team themselves. 3D-printed parts were designed to be compatible with the student 3D printers available at the university, resulting in no additional charges.

As previously discussed, alternative and more cost-effective manufacturing methods were explored for the parts initially thought to be 3D printed but that the student printers couldn't accommodate to reduce expenses. The detailed breakdown of the final cost model for the project can be found in Table 7.1

Table 7.1: Cost model

Final cost model		
Parts	Estimated Cost (NOK)	Final Cost (NOK)
ROV-frame		
Manufacturing of plates	6 000	0, Sponsored by IKM gravøren
3D-printed components	20 000	0, Student printers and laser cutting
Buoyancy element	10 000	0, Sponsored by Mechman
All brackets and screws	Unknown	0, Manufactured locally
Total cost frame	36 000	0
Electronic Enclosure		
CNC machining of top-cap and end-cap	6000	0, Manufactured locally
Turning of body	4500	0, Manufactured locally
Dome	635	1270, (A backup was needed)
Pressure relief valve	557	557
3D-printed Flange	500	0, Student printers
O rings	510	0, Sponsored by Seal Engineering
Vacuum plug	700	700
Total cost electronic enclosure	12 767	2527
float		
CNC machining of end-cap	3 000	0, Manufactured locally
Purchase of body	600	0, sponsored by Halling Plast AS
Pressure relief valve	557	557
Manufacturing Top-cap	1 000	0, Sponsored by IKM gravøren
O rings	510	0, sponsored by Seal Engineering
3d- printed components	6000	0, Sponsored by UiS
Total cost float	11 667	557
Total cost of project	60 434	3084

As indicated by the final cost model, the project managed to stay 8,916 NOK under its initial budget of 12,000 NOK, which was set by UiS Subsea. This achievement can be attributed to several factors, including the team's early investigation and assessment of initial costs, subsequent efforts to secure sponsor deals with various producers, and emphasis on designs that could be manufactured efficiently. That emphasis led to the team being able to manufacture the components locally at the machine shop, which proved to be an efficient, cost-saving measure. The UiS Subsea organization's close relationship with the lab engineers and the University of Stavanger played a crucial role, especially when specific components required using machines the team did not have the authorization to operate, but also with advice and support during the manufacturing processes, the team did alone. The cost model reflects the project's success in achieving a cost-efficient product development process. Furthermore, the savings generated provided additional resources for other groups involved in the project who may not have explored sponsor options as extensively.

7.3 Testing

Before participating in the MATE ROV Competition, it was necessary to conduct thorough testing on the ROV and float to ensure that all components met the requirements and satisfied customer needs. Preparing every component before assembling and testing was crucial to prevent any potential permanent damage caused by issues such as poor manufacturing or design flaws. Specifically, the enclosures underwent seal testing to verify their effectiveness in sealing, while the exposed parts underwent impact testing to assess their durability and resilience. These testing procedures were essential to ensure the overall reliability and performance of the ROV and float during the competition.

7.3.1 Manual inspection of ROV-frame

Once the ROV frame was assembled, the team conducted a manual inspection to identify weak connections and parts. A thorough review was also undertaken to identify any components that had the potential to cause harm to wildlife or humans. To assess the frame's structural integrity, external forces were applied to specific areas where the team anticipated such forces might occur, and the resulting reactions were measured. Furthermore, the frame underwent rigorous testing by lifting it, shaking it, and even turning it upside down to verify that no parts would come loose due to any vibrations that could occur during the competitions. These meticulous inspections and tests ensured the reliability and safety of the ROV frame.

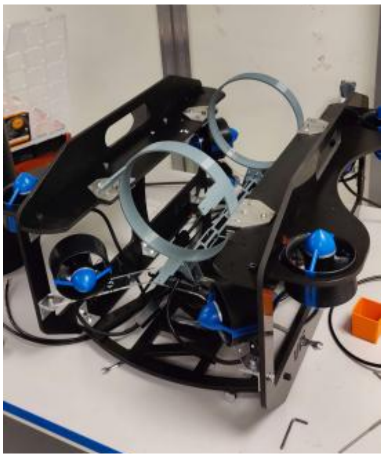


Figure 7.16: Assembly of ROV frame

7.3.2 Seal-testing

The electronic enclosure and float had the main job of protecting the electronic components when submerged. The electronic components would most likely be damaged if leakage occurred during testing or competition. It was for that reason crucial that the sealing was tested before the electronics could be installed. Four tests were completed before the electronic enclosure and float were deemed ready to water test: vacuum testing, soap testing, vacuum-water testing, and pressure testing.

Vacuum test

Before commencing vacuum testing, the various connections were submerged in a bucket of water. This step was taken to identify any significant leaks before attempting to generate negative pressure. It was essential to determine if water was entering through any connections, as sustaining pressure would only be feasible if there were no leaks. This testing encompassed the electronic enclosure's dome/flange, connectors, and the connection between the bottom end-cap and the float. The end-caps, including the relationships between the valves and sensors, were thoroughly tested for any signs of leakage. Any points where water entered had to be sealed before proceeding to subsequent tests. This ensured that each component was watertight and prepared for the following stages of testing.

After completing the initial test, the electronic enclosures could move on to vacuum testing. The vacuum test worked by pumping air out of the enclosures using a vacuum pump. The pressure relief valves installed to both the electronic enclosure and float could be used to connect the vacuum pump to apply an internal pressure of -1 bar, letting this team track the pressure inside the enclosures at all times. The pressure was pumped out until a -1 bar was reached and observed for one hour. This would be equivalent to the pressure applied by the water when submerged 10 meters underwater [73]. This pressure would yield a satisfactory result for the float since it was designed to be submerged to a depth of 10 meters. The electronic enclosure was designed to handle 10 bars of pressure. Although this vacuum test was insufficient for this goal, it would still give a good indication before testing it in a pool. During the MATE ROV Competition, the ROV would not exceed 4m making this test sufficient before competing. The pressure was monitored continuously to check for potential leakage. If not completely sealed, the negative pressure would pump air inside the enclosures, and the leakage would have to be detected. Before advancing to further testing, it was essential to know that the electronic enclosure and float were completely airtight at -1 bar to ensure it would be watertight. After 1 hour, the pressure was checked to ensure no pressure drop. A pressure drop would indicate a small leakage and could be detrimental when testing in water.

Soap test

During the vacuum testing phase, a minor pressure drop was observed, indicating the presence of a leak. Identifying the exact location of the leak proved challenging, particularly when the pressure dissipated slowly. The small size and volume of the components made it difficult to detect the cause by sound alone. To overcome this challenge, a soap test was implemented.

The soap test is a commonly used method in process engineering to identify potential leaks in pipes. It involves supplying a continuous stream of nitrogen into the pipe to create higher internal pressure. A mixture of soap and water is then applied to each connection point. In the presence of insufficient seals, the soap mixture generates bubbles, pinpointing the exact locations of leaks. Once a leak is identified, it can be promptly addressed, and the process is repeated to ensure all leaks are fixed [74].

The same soap test method was applied to locate leakage points in the float and electronic enclosure. A mixture of water and dish soap was poured over suspected areas with potential seal failures. Internal air pressure was then generated using a bicycle pump to pressurize the two enclosures. As the pressure increased, bubbles began to form at the points of leakage, allowing the team to identify the exact locations of the leaks. The pressure was subsequently reduced, and the necessary fixes were implemented to address the identified issues. After the soap test, the components were subjected to another round of vacuum testing to verify if all the leaks had been successfully resolved.

Water-vacuum test

After conducting the vacuum and soap tests, it was determined that further testing was necessary to evaluate the performance of the electronic enclosure and float in water under vacuum conditions. While achieving a successful vacuum test would indicate adequate air and water sealing, there was still a risk of potential damage to the electronics during actual water testing. Additionally, it was essential to assess if the heat would affect the sealing capabilities. To address these concerns, a submerged water test was conducted.

In this test, the air inside the enclosures was gradually pumped out until a pressure of -1 bar was reached. The electronic enclosure and float were then fully submerged in a bathtub filled with water at approximately 20 degrees Celsius. They remained submerged for 1.5 hours while maintaining internal under-pressure. Subsequently, the pressure was released, and the enclosures were carefully opened and inspected for any signs of water ingress.

This test aimed to determine if leaks were present after the submersion and under pressure conditions. If no leakage was detected, it indicated that the sealing on both the float and electronic enclosure was deemed sufficient for subsequent water testing involving electrical components. This test helped ensure the seals' reliability and integrity in real-world submersion scenarios.

Pressure testing

Furthermore, to evaluate the connections and their performance under internal pressure, this team decided to test the functionality of the pressure relief valves. It was essential to ensure that these valves operated as intended. Specifically, when the internal pressure reached a level of +15 psi, the pressure relief valves installed on the float and electronic enclosure were expected to open, releasing any excess air pressure. MATE set this requirement [18], as the end-caps of both the float and electronic enclosure were secured with bolts. It was crucial that in the event of overpressure, the end-caps would disconnect automatically, or a pressure relief valve would engage.

Testing the pressure relief valves served multiple purposes. Firstly, it allowed us to verify if the valves could withstand internal pressures of up to +15 psi without any failure. Additionally, it ensured that water would not enter the enclosures in the event of an issue. The primary focus was to assess the functionality of the pressure relief valves, as it was deemed more critical than other potential component failures. To conduct the test, the pressure sensor in the electronic enclosure was replaced with the float's pressure relief valve. This arrangement enabled us to use one pressure relief valve for inserting air while the other was assessed for pressure release.

However, due to the absence of a dedicated connection point for an additional air relief valve on the float, both relief valves had to be tested in the electronic enclosure. For the float, the team subjected it to a pressure of +15 psi and closely monitored it for any signs of breakage or failure. The pressure test for the electronic enclosure can be observed in Figure 7.21, visually representing the process.

7.4 Refinements

After completing the tests for every component, refinements were made to the failed or defective components to ensure that every component satisfied the stakeholder's needs and demands.

7.4.1 ROV-frame

During the assembly process of the enclosure into the frame, it became apparent that the extrusion on the front band, which served to fasten the enclosure to the frame, was too slim. While the initial design of the extrusion successfully fulfilled its intended purpose and endured the expected stresses of holding the enclosure, the assembly phase revealed that it did not withstand accidental momentum exerted by project members while attempting to secure the connection. Any perpendicular force applied to the extrusions at the connection points resulted in a significant enough momentum to cause them to fail at their base.

Furthermore, the electronic engineers expressed concerns regarding the elasticity of the bands, which contributed to excessive flimsiness in the frame. Although this issue was resolved by placing the solid enclosure within the frame, widening the bands was considered to address the problem. By increasing the width of the bands, the moment length of the extrusions would be reduced, resulting in a sturdier frame structure when standing alone. The updated design of the bands can be observed in Figure 7.17, showcasing the modifications made to improve their functionality.

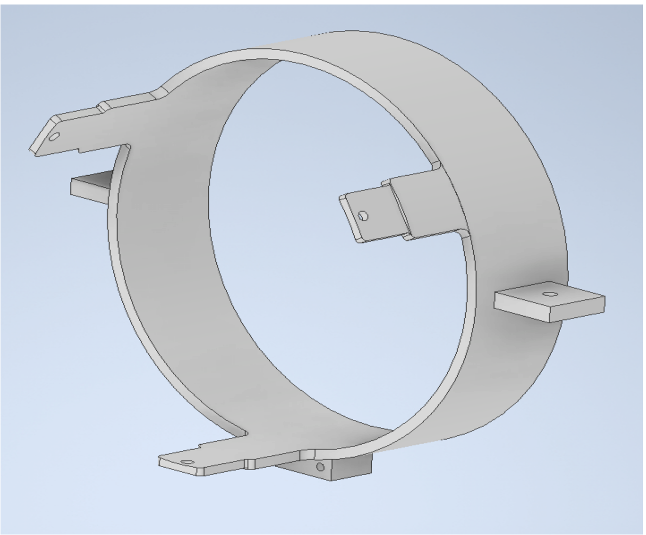


Figure 7.17: New iteration bands

7.4.2 Electronic Enclosure

Assembly

After the production of the end-caps, it became apparent that the team had overlooked specifying the thread's input start for three plugs. Consequently, these components did not fit together as intended. To achieve the desired configuration, removing the threads and manufacturing nuts that would ensure a watertight seal for the connectors was necessary. The connectors and corresponding counter nuts can be seen in Figure 7.18 and 7.19, respectively. These modifications allowed us to rectify the issue and achieve the desired sealing for the end-caps.

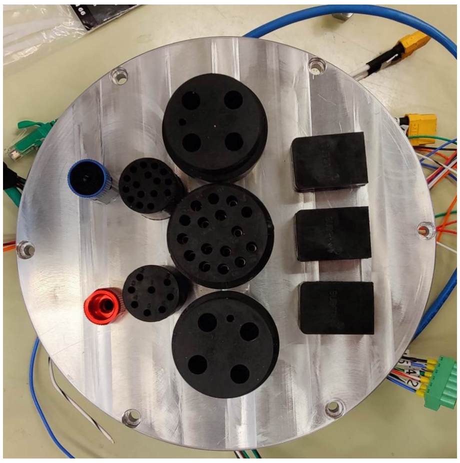


Figure 7.18: end-cap with connectors

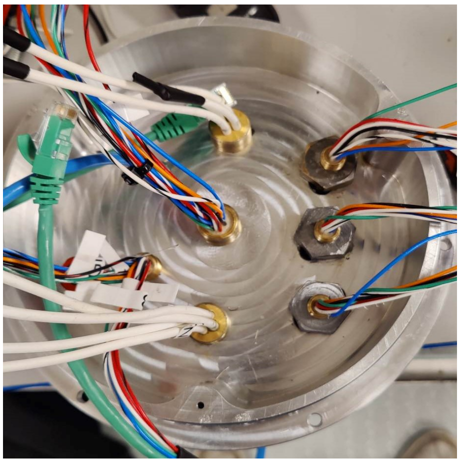


Figure 7.19: Nuts connectors

Result of Vacuum Testing

During the water and vacuum testing of the enclosure, it became evident that it was not watertight. Upon closer examination, cracks were discovered in the dome surrounding the screw holes. A thorough investigation was conducted to identify the root causes of these issues. It was determined that the problem stemmed from the elasticity and stiffness of the flange. The plastic material used in the original flange did not provide adequate transfer of clamp force onto the gasket due to the plastic bending between the different clamp forces applied by each screw. This resulted in high-pressure points around the screw holes and low-pressure points between the screws on the dome, forming cracks.

The material selection process, which involved benchmarking standard flanges from Blue Robotics, did not consider the elasticity and stiffness properties required for the flange. This oversight contributed to the leaking and crack formation on the dome. To address these issues, a new flange was manufactured using aluminum, a material known for its good elastic properties. The aluminum flange would provide the necessary universal clamp force on the dome rim and gasket, ensuring a proper seal for the enclosure.

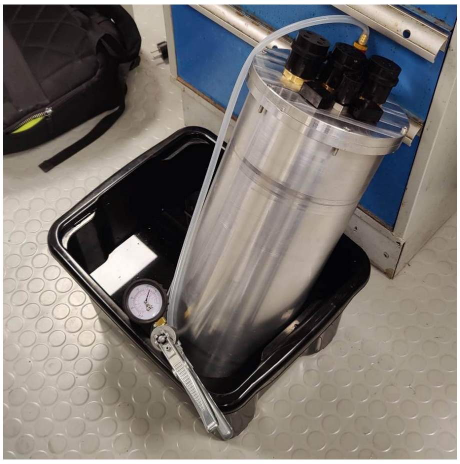


Figure 7.20: Vacuum testing of electronic enclosure

Figure 7.21: Pressure testing of electronic enclosure

The manufacturing process encountered a significant challenge due to the complex geometry of the electronic enclosure, particularly the three attachment extrusions on the front of the flange. It became apparent that a new method of attaching the electronic enclosure was needed to prevent rotational and axial movements. After exploring various alternatives, it was determined that 3D-printing modified versions of the original extrusions would be the most suitable solution. These modified extrusions would be securely attached to the new flange using bolted connections, meeting the customer's requirements.

However, a significant concern arose regarding the accuracy of hole placements during manufacturing. Since the fabrication was done manually, human error and inaccuracies were possible. Every effort was made to ensure precise hole placements to minimize potential issues.

The new flange design can be observed in Figure 7.22, while Figure 7.23 and Figure 7.24 illustrate the modified connection points and the method of fastening, respectively. These modifications successfully addressed the attachment challenges and provided a reliable solution for securing the electronic enclosure.

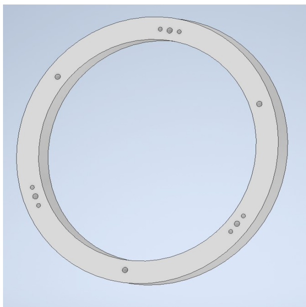


Figure 7.22: New spec flange

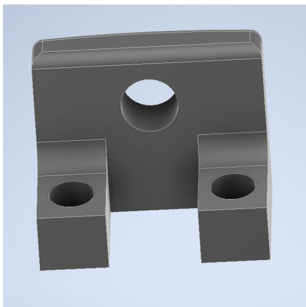


Figure 7.23: Modified connection parts

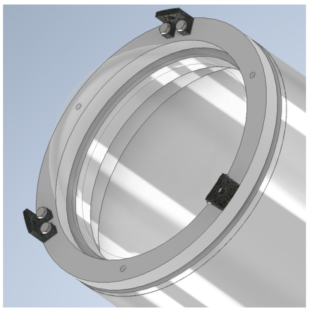


Figure 7.24: Modified connection points in assembly

7.4.3 Float

Assembly

While screwing the balloon into the end-cap, it became apparent that the strength of the thread and the rubber sealant being used were inadequate. The torsional forces exerted during the screwing process caused the seal to tear off, rendering the retrofitting ineffective. The balloon itself was made of latex, while the edge of the valve was composed of rubber. The initially chosen rubber sealant adhesive was able to maintain a watertight seal, but only if excessive movements at the base of the valve were avoided. However, this solution was not deemed satisfactory.

To address the issue, Gorilla glue was selected as an alternative. This type of glue expands and stiffens the entire retrofitting area, thereby creating a proper and secure seal. Gorilla glue provided the strength and sealing capability to ensure a reliable connection between the balloon and the end-cap.

Vacuum test

During the vacuum testing, it became apparent that the float was not adequately sealed. The hand pump failed to pressurize the float, indicating significant leakage. Despite passing the initial water testing, there were likely multiple points with marginal leakage, resulting in a substantial overall leak. To identify these leakage points, a soap test was conducted. It became evident that the RGB light mounted on the top end-cap was the source of the problem. Further examination revealed that the gaskets accompanying the RGB lights were thin and soft, causing deformation when screwed into the top end-cap.

To address this issue, new thicker and harder nitrile rubber gaskets were constructed and installed between the end-cap and lights. After inspection, the threads on the top end-cap connecting the RGB lights were also found to cause leakage potentially. This was expected, as hand-threading soft plastics often leads to inconsistencies. To mitigate this problem, PTFE thread seal tape was applied to fill open spaces between the threads and lights. With these measures in place, the vacuum test was repeated, and the team successfully built up pressure inside the float.

Although the main issue regarding the balloon and end-cap connection was resolved, another problem emerged as the pressure dissipated slowly, indicating ongoing leakage. Upon conducting a soap test, it was discovered that the custom valve adapter between the air bladder and the connector on the bottom end-cap was not completely sealed. To rectify this problem, a custom gasket was designed for internal and external applications. PTFE thread seal tape was also applied to the thread to enhance the sealing effectiveness. These measures successfully addressed the previous pressure drop issue, ensuring a satisfactory and secure seal.

7.5 Underwater testing

After conducting essential testing and making necessary refinements to critical components and connections, the float and the complete remotely operated vehicle (ROV) were deemed ready for water testing. This crucial test aimed to evaluate whether the systems and subsystems developed by all the teams at UiS Subsea met the desired specifications and if any further improvements were needed. During the water test, the team's primary focus was to assess the performance of their specific components and evaluate the water tightness of both the float and the enclosure, especially their ability to withstand the water pressure at a depth of 4 meters.

Initially, according to the project's progress plan, the aim was to fully prepare the ROV for water testing by April 11^{th}. This timeline would have allowed each team to address any necessary refinements before attempting to qualify for the MATE ROV Competition. However, as the team progressed with the preparations, it became evident that meeting this deadline would be challenging. The electronic enclosure, in particular, encountered issues that required additional attention and refinement, as discussed in the previous section. Furthermore, it was discovered that several other teams within UiS Subsea were also not yet prepared for water testing. As a result, it was decided to postpone the test until April 28^{th} to ensure all necessary preparations could be completed. Ultimately, the water test was conducted separately for the electronic enclosure and the float to facilitate a thorough evaluation of each component's performance.

Underwater testing the ROV

The first water test occurred on April 28^{th} at the University of Stavanger. During this test, the rear-end camera, manipulator, and motors were not ready and, thus, were not installed. The team tested buoyancy and stabilization by placing equivalent weights on the bottom frame. After being in the pool for 10 minutes, it became apparent that there was a minor leak in the electronic enclosure. The ROV was immediately removed from the water. Fortunately, the water leakage did not cause any significant harm to the electronics, and further testing could be carried out after addressing the issue. Upon inspection, it was discovered that one of the bolts connecting the dome to the cylinder was not tightened with enough force, resulting in inadequate clamping force on the gasket for sealing the connection. The problem was rectified, and a new water test was conducted on April 29^{th}.

Before the second water test, the electronic enclosure underwent another seal test and was determined to be ready. No leaks were detected during this test. The ROV was tested for buoyancy, stabilization, and maneuverability. The actual weight of the ROV was 25,652 kg, indicating that the ideal buoyancy should be $0,15 * 25,7kg = 37,75N$. As anticipated, the front of the ROV was heavier than the rear, necessitating ballast adjustment. The ROV's maneuverability and stabilization were evaluated by determining the correct placement of ballast and flotation elements to align the vertical axes of CB_z and CG_z. The ROV demonstrated movement in all six degrees of freedom and was easy to maneuver.

During water testing with the manipulator, it became apparent that the distance between CB_z and CG_z needed to be increased, as the stability decreased when the manipulator was in a horizontal position. This was resolved by adding equal amounts of ballast and flotation elements to the ROV. Once buoyancy calibration was completed, the "Subj." metrics could be tested. The ROV exhibited good stability in roll, pitch, yaw, heave, sway, and surge directions, with highly satisfactory maneuverability. The ROV had slightly positive buoyancy, causing it to float to the surface without thrust being utilized. The thrusters had no issues overcoming the drag, indicating unobstructed flow between the thrusters and the ROV frame. Lastly, the electronic enclosure underwent heat dispersion testing, with the internal temperature measured to a maximum of 40°C, confirming the enclosure's sufficient heat dispersion capabilities.

Figure 7.26 shows a picture from the water test.

Underwater testing the float

Figure 7.25: Float - Watertest ballast

Due to issues with the air bladder and flotation systems designed by the electronic engineers, the float test had to be rescheduled to May 9^{th}. Although this left limited time for improvements before finalizing the bachelor's thesis, the float didn't need to be fully completed for qualification on May 15th. The float was tested in a pool at the University of Stavanger and yielded positive results for this group. Only the central air bladder system was ready for testing. In contrast, the emergency air bladder and data transmission could not be evaluated due to potential Bluetooth disruption caused by the aluminum bottom end-cap. The float was wholly sealed and did not allow water to enter its body. It exhibited excellent stability with the added ballast, indicating that the calculations for CB and CG in the detailed design were accurate. The CG and CB were nearly centered, with only one ballast circle required on one side, as depicted in Figure 7.25. The total buoyancy was lower than expected, causing the float to sink quickly to the bottom of the pool with the addition of 2.8 kg of ballast. Further testing revealed that only approximately 2.4 kg of ballast was needed. Unfortunately, due to problems with electronic pressure calibrations, the motors could not pump air into the air bladder, and the distance between CB_z and CM_z could not be tested during ascent.

On May 10^{th}, the problems was corrected and the float was tested at a depth of 3.65 meters underwater. It maintained a vertical profile during ascent and descent, and no leakage was observed. The float completed one cycle in 1 minute, including data collection and transmission, indicating that it would take a little over 2 minutes in the 4-meter deep pool of the MATE ROV Competition.

The water test can be observed in Figure 7.27.

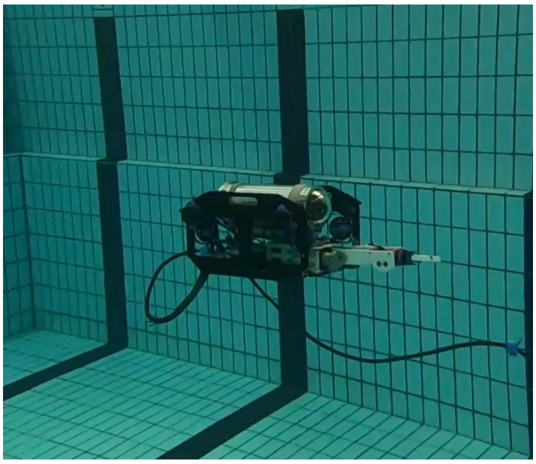


Figure 7.26: Water test ROV

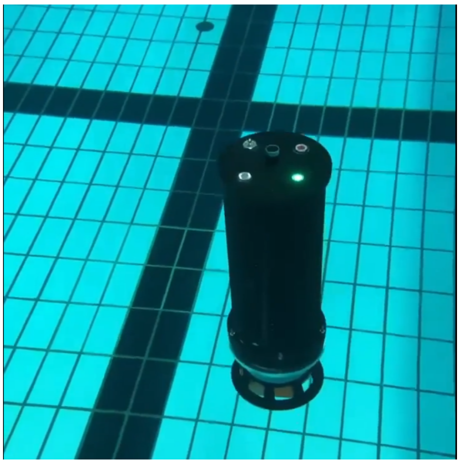


Figure 7.27: Water test float

8 Evaluation of the project and product development process

In conjunction with the Gantt chart, the product development process proved valuable in monitoring progress, planning, achieving milestones, and providing structure to the overall project. The Gantt chart was a standard tool for teams from different engineering disciplines to track their progress and milestones. It facilitated an accurate understanding of the project's status and helped identify the necessary actions to meet the deadlines set by UiS Subsea. Weekly meetings were held, where at least one team member from each team was present. All teams would summarize this week's work and what would be done the coming weeks. This was time-consuming in the early stages of the project and significantly reduced. One month before the projected water test, the primary purpose of the meetings was to inform everyone of what was completed and what remained in order to achieve a functional ROV and float.

The Gantt chart also held teams accountable for their progress and fostered a consistent work pace to stay on schedule. It enabled the project team to promptly address any issues, distribute workload effectively, and ensure progress was made on time. However, it should be noted that maintaining the Gantt chart could be time-consuming and sometimes felt intrusive for specific teams. This was particularly relevant as the thesis had two members working on the project team, and their time was partially dedicated to pushing other teams to meet their deadlines and distribute non-relevant workloads.

Furthermore, the project team had to take on additional tasks that were not initially assigned to them. This included redesigning and manufacturing the inside skeleton structure for the float group, designing the secondary buoyancy system for the float, and connecting the secondary and the primary buoyancy systems chosen by the float team to the rest of the float. Additionally, the team had to construct the camera housing for the secondary external camera for the ROV, as the electronic teams originally responsible for this task encountered challenges in creating a watertight, lightweight, and appropriately sized camera housing.

The planning phase was crucial in establishing the project's foundation by gathering all necessary information regarding objectives and limitations before proceeding to the concept development stage. However, it was observed that the planning phase ended up being longer than necessary, resulting in less time for concept development, potentially impacting the overall project timeline. One of the reasons for this was that the leaders of the organization, who were responsible for outlining the original Gantt chart, primarily had an electrical engineering background and underestimated the time required for developing and selecting different concepts to find the optimal solution.

In addition, the team faced challenges in accurately estimating the time required for each phase, mainly since they lacked previous experience utilizing the product development process. Furthermore, the Gantt chart used in this project did not include every step of the product development process, making it challenging to allocate time accurately for each phase. As a result, the concept development phase took longer than anticipated. There was a need to expedite the system-level design phase to create sufficient time for the detail-level design phase, which was expected to require more time to finalize the design for each component. Consequently, the exploration and investigation of different connection types and solutions were not extensively conducted within the scope of this thesis.

One aspect that could have been improved was the time allocated for the detail design phase. Due to the team's limited experience with this type of project, a significant amount of time was spent learning how to use ANSYS effectively and seeking feedback from expertise on setting forces and supports to obtain accurate results. The consultation with Seal Engineering also proved time-consuming, primarily due to communication issues related to file formats, minor revisions, and the need for sufficient time to receive proper responses.

As a result, the enclosure parts were technically completed but lacked timely verification. This extended the verification period, causing a delay in sending the parts for production according to the original schedule. Consequently, the testing and refinement phase had to commence later than optimal. However, it should be noted that the detail design could have been completed earlier if necessary. The team was aware that the electronics teams were significantly behind schedule, as indicated by the Gantt chart. Therefore, the team considered it acceptable to allocate the necessary time to ensure that every detail was verified correctly.

The testing and refinement phase proceeded as anticipated for the ROV, consuming the expected time. The water testing of the ROV took place on April 28th, while the product was ready on April 24th. It could have been completed earlier if reserve parts for standard components had been ordered alongside the original parts. Unfortunately, a week was lost waiting for a new dome for the enclosure, which could have been avoided with proper planning.

On the other hand, finalizing the float proved to be more challenging due to the electronic team's choice of parts that were not well-suited for use in water. The light diodes, power switch, and connections between the balloon, valve, and float required additional solutions and equipment to ensure a watertight seal. Since the team had limited experience with any sealing methods, a significant amount of time was dedicated to experimenting and determining which approaches worked and which did not.

In retrospect, a substantial reduction in time could have been achieved during the testing and refinement of the float if the team had been more involved in the procurement process for the different parts used in the float. This would have allowed for better consideration of the specific requirements and compatibility of the components, potentially avoiding the need for extensive experimentation during the testing phase.

Overall, the product development process and Gantt chart proved effective in designing and producing the products within the time and cost constraints set by the UiS Subsea organization. The products were completed on schedule, allowing for testing, optimization, and qualification for the MATE competition before the deadline. They achieved most of the ideal values and all of the marginal values that were established during the planning and concept development stages.

The final weight of the ROV, including ballast, was 26,764 kg, and the design minimized waste material that could not be recycled or repurposed. The ROV's size and maneuverability met the limitations set by MATE, making it a compact and highly agile device. While the decision to turn the enclosure body instead of welding two parts together had a slightly higher environmental impact, the waste material from the turning operation could be recycled, staying within the marginal values for environmental impact. In retrospect, welding the flange on the enclosure would save many days spent in the production phase. The enclosure design also prioritized easy access to the electronics and allowed for potential future upgrades.

Similarly, the float adhered to the size limitations of MATE, and the impact module successfully prevented external forces from deforming the rest of the structure, addressing a vital issue from the previous year's float.

However, it is worth noting that a more detailed Gantt chart, aligned closely with the product development process, could have been developed from the outset if the team had more experience. This would have reduced uncertainties regarding time allocation during the concept development, system-level design, and detail-level design phases. Customizing the Gantt chart to suit the project's specific needs, including sub-charts for each discipline involved, would allow teams to better understand their responsibilities and progress without requiring constant oversight from the project team. This approach would provide better project control while maintaining a comprehensive overview through the overarching Gantt chart.

In conclusion, the product development process and the Gantt chart provided a practical framework for the project's structure, collaboration, and production. It held each team accountable for their responsibilities and facilitated workload redistribution when necessary. The Gantt chart played a crucial role in tracking the progress of individual teams and the overall project, allowing for the adjustment of realistic deadlines as bottlenecks were encountered and resolved. Fine-tuning the Gantt chart to align with the product development process and tailoring it to the project's specific requirements would enhance its effectiveness and efficiency.

9 Conclusion

This thesis focused on designing, manufacturing, and testing the ROV frame, electronic enclosure, and the outer components of the float by following the product development method. This was completed with an additional focus on low cost, time consumption, and environmental impact. The main objective of this interdisciplinary project was to produce finished products capable of accomplishing the MATE ROV competition and TAC challenge tasks. Following the product development process, consulting expertise, and searching through existing products and literature assisted in producing successful products.

The product development process was chosen for developing our product due to its reputation for enhancing planning, coordination, cost and time efficiency, teamwork, and product quality. In the initial stages, the process helped define clear-cut objectives and limitations of the products, making it clear what was expected at the end of the project through target specifications and organizational goals. The clear vision of the path of the product helped when designing different concepts during concept development since the broad concept of what the customer and organization want was defined. The systematic approach also helped further into the project, assisting the process through investigating, evaluating, and finalizing connection methods and parts for each subsystem of the products while later designing the smaller changes in the designs, like o-ring grooves and material savings. Because the objectives of each product were known from the beginning, early FEA analysis, calculations, and manufacturing methods could be implemented during the development of the products. The structured process made the testing and refinement phase easy to implement, due to facilitating design modifications, concerning defining their impact and limitations on the rest of the system. In conclusion, the product development process was a powerful tool to make the process as structured and cooperative as possible, allowing every group member to take ownership of the process and final products. However, the product development phases did include some irrelevant to this project. This meant significant time was spent selecting which phases to include and exclude, which proved difficult as the project proceeded.

At the beginning of the project, target specifications were derived from the MATE manual, UiS Subseas aspirations, and the needs of the other teams. At the end of the process, most of the specifications were achieved within limits for ideal values. These values included maximum dimensions, time and cost budget, and ease of assembly for all products. Additionally, the ROV frame reached the ideal targets for harmful parts, buoyancy, and transport. Due to sufficient utilization of FEA, material and weight optimization were adequately addressed when selecting plate thickness. Additionally, selecting 3D printed and lightweight components meant that the total weight of the ROV was 26,764 Kg, and the frame was 15 kg, well within the specified requirements. This was just above the ideal target of 25kg set by the UiS Subsea organization. The final outer dimensions, 640x606x387mm, made the ROV one of the lightest and most compact ROVs in UiS Subsea history. The frame sufficiently addressed the environmental goals, where procuring parts from professionals meant proper waste disposal, while the University followed the same guidelines regarding 3D-printed waste. The enclosure fulfilled its individual targets for thermal conductivity, water tightness, and pressure resilience while it was designed to be big enough potential upgrade to an AUV next year. The only target not adequately satisfied by the electronic enclosure was the environmental impact of manufacturing due to the excessive material waste. It did, however, stay within the marginal values. The manufacturing for the enclosure did create approximately 25kg of waste material and excessive use of cooling fluids, which could have been reduced by using another manufacturing method, such as welding. The float accomplished its targets involving bladder impact resistance, sealing, non-magnetic material, and being battery driven and wireless. However, the solution for the handle did not reach the ideal value. The handle on the float was not possible to design big enough for the manipulator to grip through due to the dimensional constraints set by the MATE ROV Competition. That could have been solved with tighter cooperation with the electrical team earlier. Overall, the total cost of the team's efforts was 3084 NOK making the products, going 8 916 NOK under the budget of 12 000 NOK set by UiS Subsea at the start of the project.

Assessing the overall internal goals set by the team at the start of the project, the ROV reached the goals of being compact, lightweight, stable, and maneuverable. The enclosure reached the goals of it being hydrodynamic and easy to assemble into the rest of the ROV. At the same time, the float fulfilled the targets of shock absorbance, housed all the interior components well, and accomplished two vertical profiles during testing.

While the products developed were successful and able to perform tasks during the targeted competitions, some optimizations and improvements could have been made to the products and the process as a whole. The dome and flange could have been ordered as standard components from an established company, making sealing the enclosure easier and saving time for testing and refinement. When deciding to manufacture the flange individually, the elasticity and hardness should have been considered during the material choice to effectively transfer the clamping force into the gasket, thus sufficiently sealing the enclosure. A longer time budget would have allowed greater emphasis and exploration in the FEA analysis, leading to minimizing plates and other parts volume and optimizing the designs to lower safety factors with lesser material and weight use. Further exploration of the concepts in FEA would also likely reveal the problems that arose during the testing phase. These could have been prevented from the start, saving time, material use, and resources later in the project. Lastly, more time would also allow for better solutions for transporting the cables around the ROV, emphasizing shielding them from potentially harmful objects.

If given more time for the float, more emphasis would have been put on constructing a more compact design, reducing much of the unnecessary space inside the float. The team should also have been more involved in selecting and purchasing parts such as the power switch, balloon, and lights to ensure these components contained the necessary properties for the product application. When this did not happen, a better placement for the power switch would have been considered and put into greater value earlier, placing the switch on the end-cap to minimize the risk of potential leaks.

In conclusion, the project has been an incredibly educational and cooperative experience. It has been a fantastic opportunity to be a part of the UiS Subsea organization and to compete in the TAC and MATE challenges. The learning curve has been steep and new knowledge was discovered and experienced daily. The project has been hugely beneficial for developing technical, mechanical, and design skills through the product development phases, as well as collaborative and communication skills through cooperation with the other engineering applications and the organization. Overall, the products did well during testing and completed the tasks necessary for qualifying for the MATE competition in June, accomplishing the project's overall target. The maneuverable and compact ROV design and the extra space inside the enclosure for additional circuit cards leave room for upgrading the ROV into an AUV for the coming years graduates.

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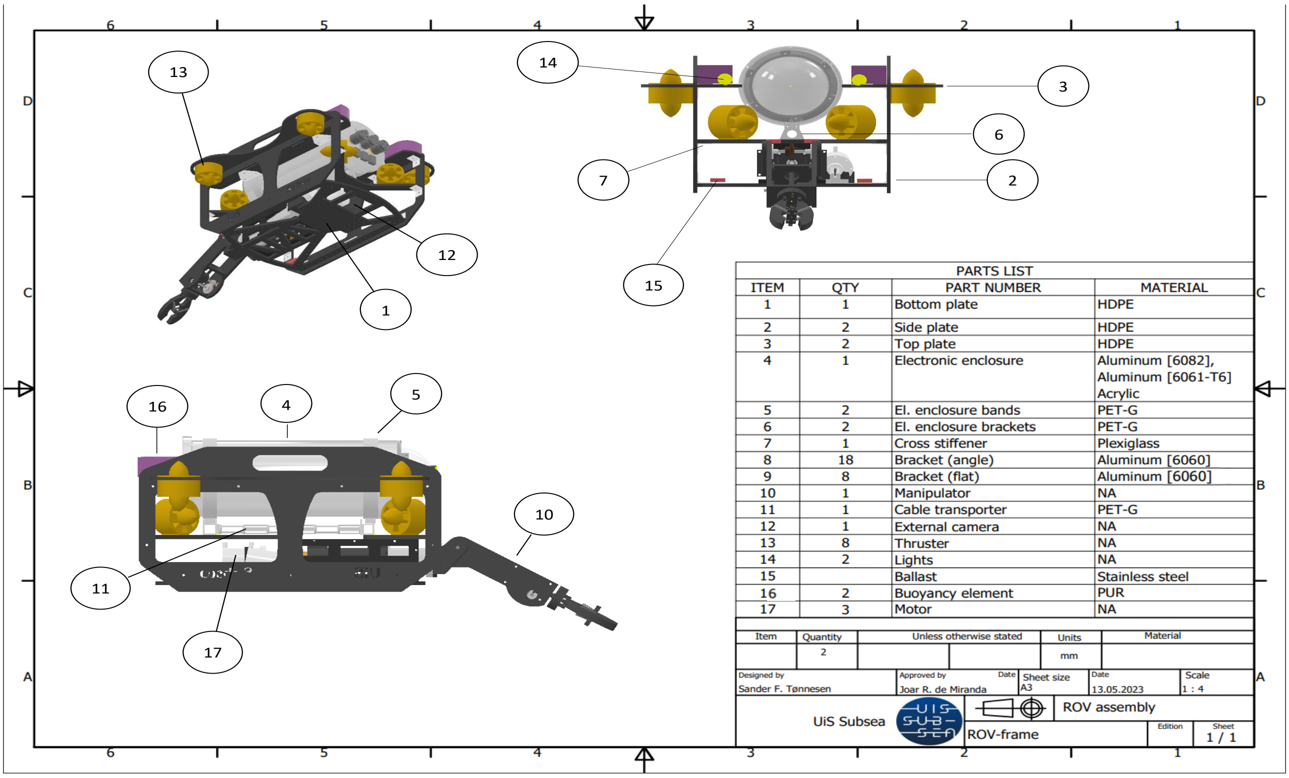
A Appendix: Technical Drawings ROV-frame

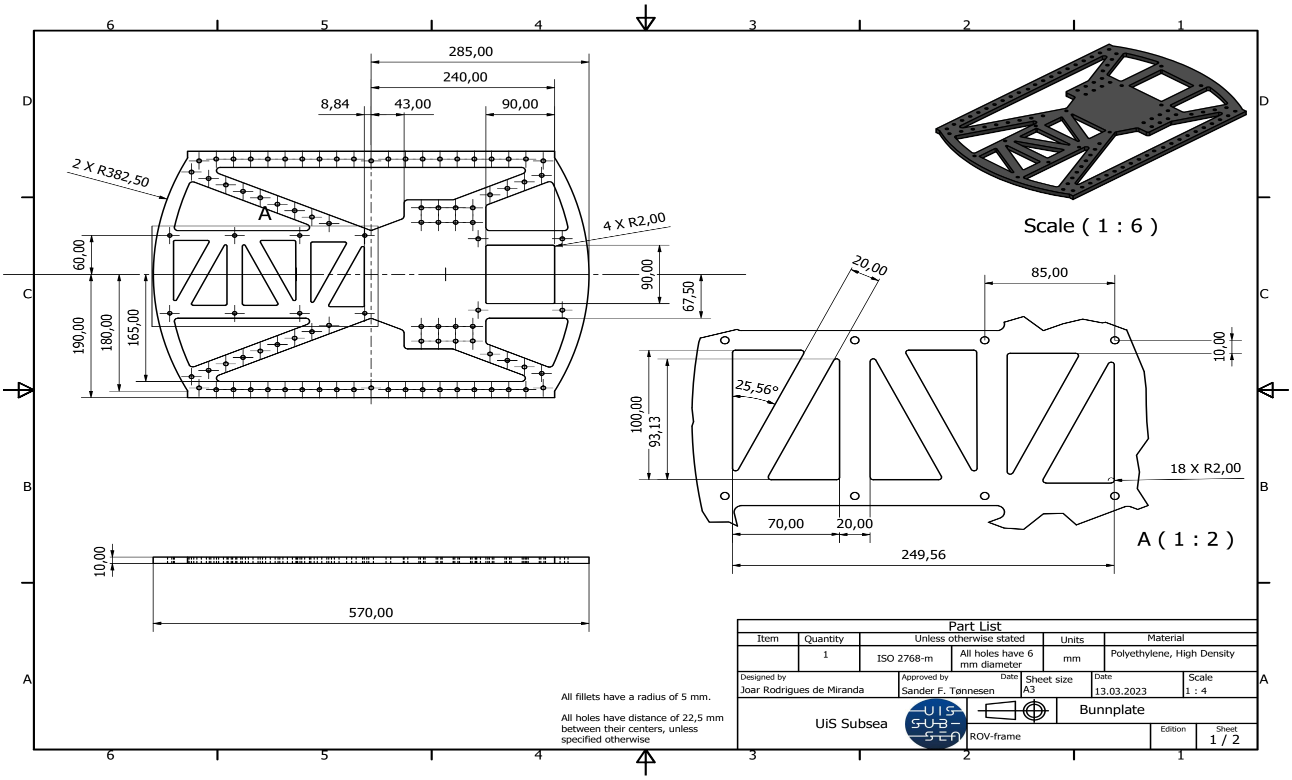


PARTS LIST			
ITEM	QTY	PART NUMBER	MATERIAL
1	1	Bottom plate	HDPE
2	2	Side plate	HDPE
3	2	Top plate	HDPE
4	1	Electronic enclosure	Aluminum [6082], Aluminum [6061-T6] Acrylic
5	2	El. enclosure bands	PET-G
6	2	El. enclosure brackets	PET-G
7	1	Cross stiffener	Plexiglass
8	18	Bracket (angle)	Aluminum [6060]
9	8	Bracket (flat)	Aluminum [6060]
10	1	Manipulator	NA
11	1	Cable transporter	PET-G
12	1	External camera	NA
13	8	Thruster	NA
14	2	Lights	NA
15		Ballast	Stainless steel
16	2	Buoyancy element	PUR
17	3	Motor	NA

Item	Quantity	Unless otherwise stated		Units	Material
	2			mm	

Designed by: Sander F. Tønnesen
Approved by: Joar R. de Miranda
Date:
Sheet size: A3
Date: 13.05.2023
Scale: 1 : 4
UiS Subsea
ROV assembly
ROV-frame
Edition:
Sheet: 1 / 1

Figure A.1: Techical drawing of the finished ROV assembly



All fillets have a radius of 5 mm.

All holes have distance of 22,5 mm between their centers, unless specified otherwise

Part List					
Item	Quantity	Unless otherwise stated		Units	Material
	1	ISO 2768-m	All holes have 6 mm diameter	mm	Polyethylene, High Density

Designed by: Joar Rodrigues de Miranda
Approved by: Sander F. Tønnesen
Date:
Sheet size: A3
Date: 13.03.2023
Scale: 1 : 4
UiS Subsea
Bunnplate
ROV-frame
Edition:
Sheet: 1 / 2

Figure A.2: Techical drawing of the bottom plate sheet 1/2

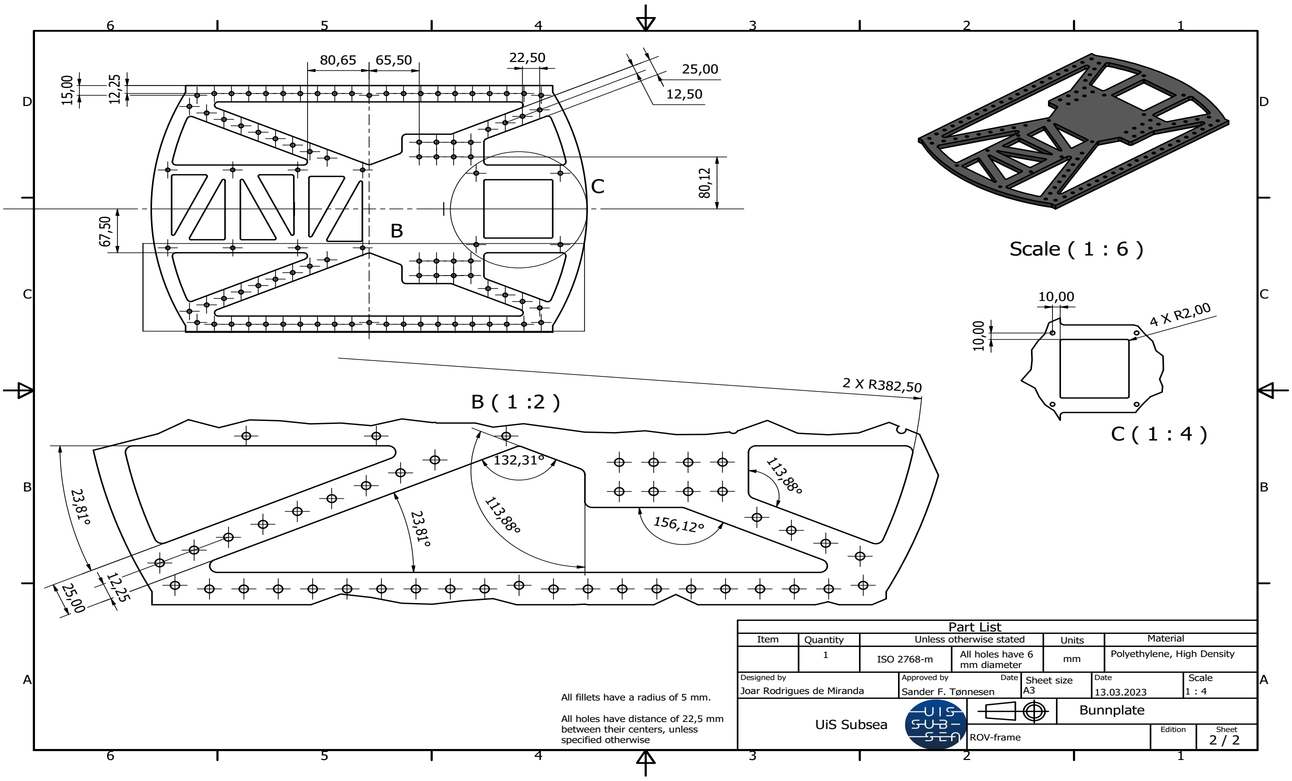


Figure A.3: Techical drawing of the bottom plate sheet 2/2

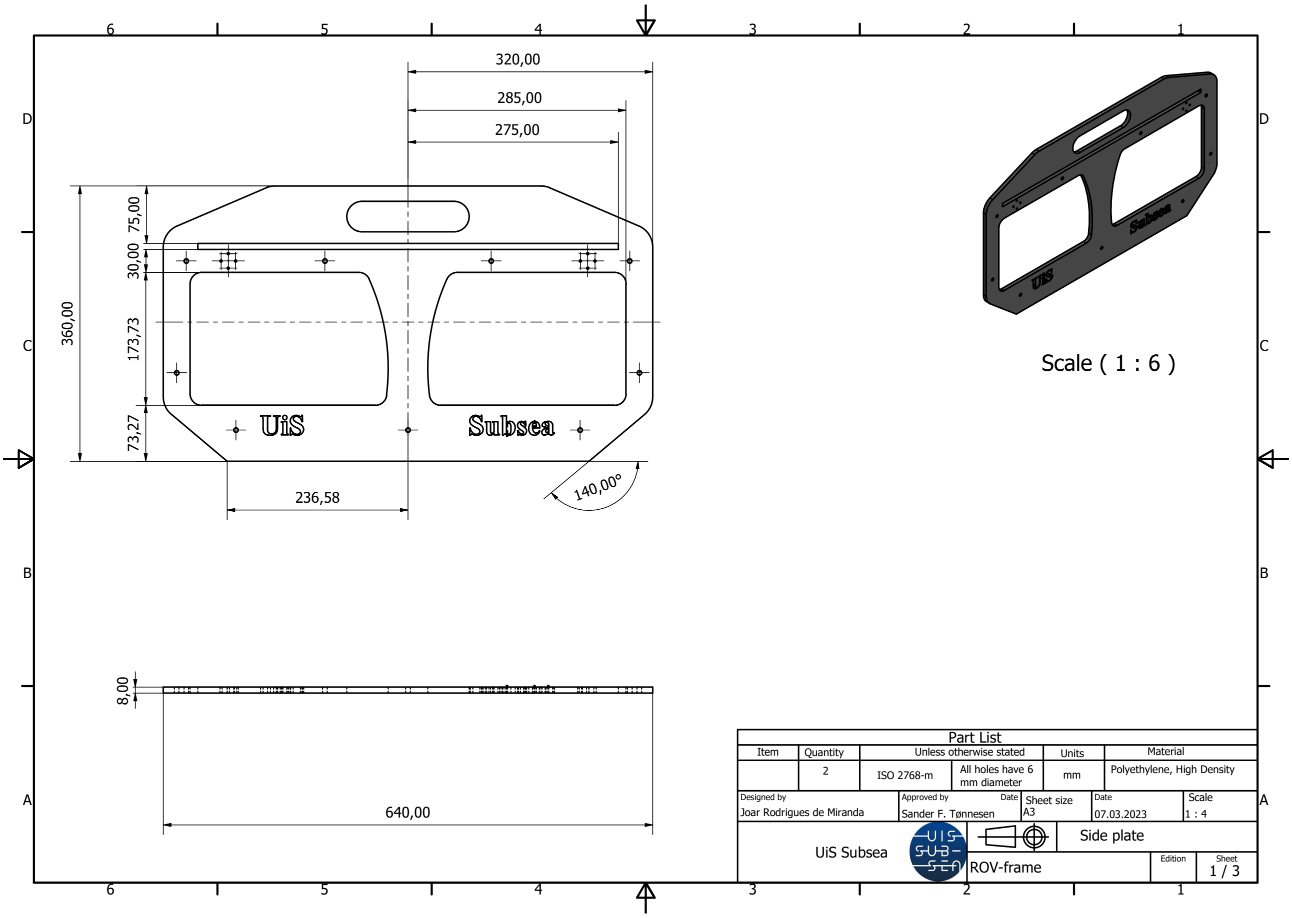


Figure A.4: Techical drawing of the side plate sheet 1/3

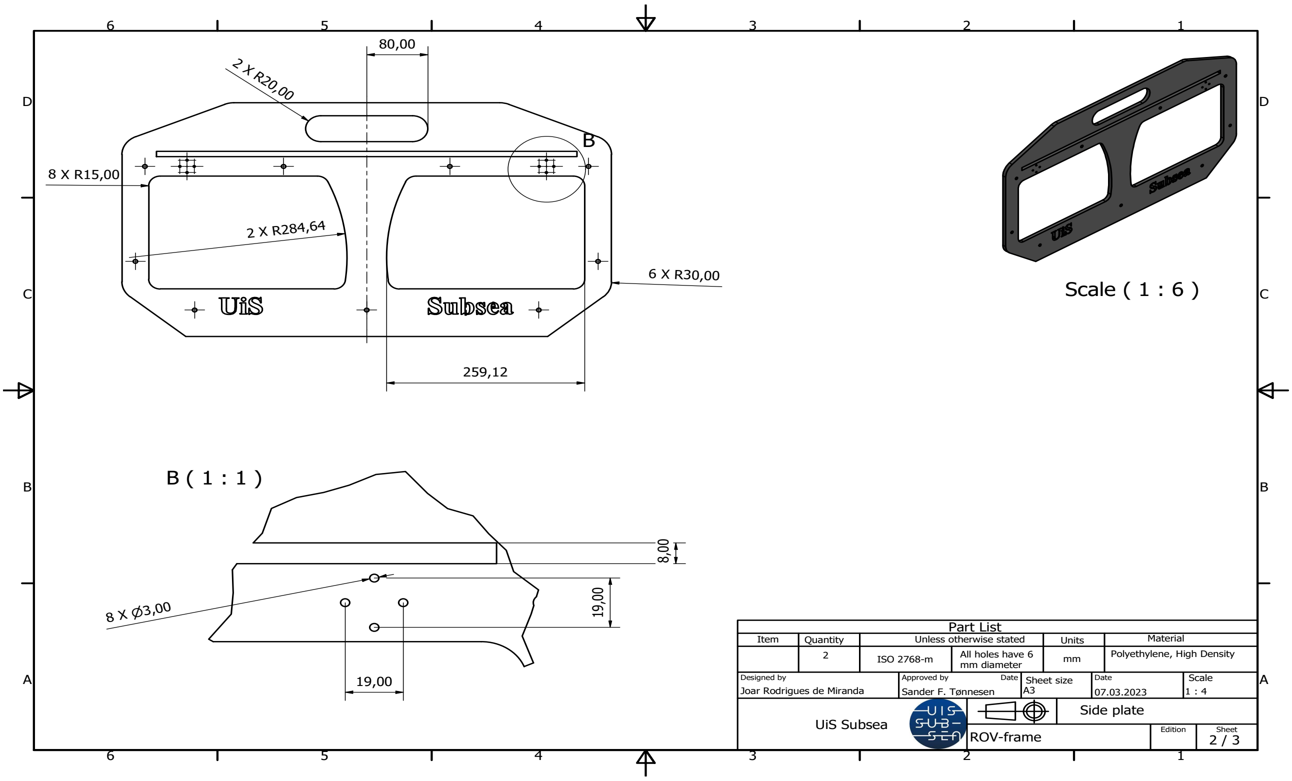


Figure A.5: Techical drawing of the side plate sheet 2/3

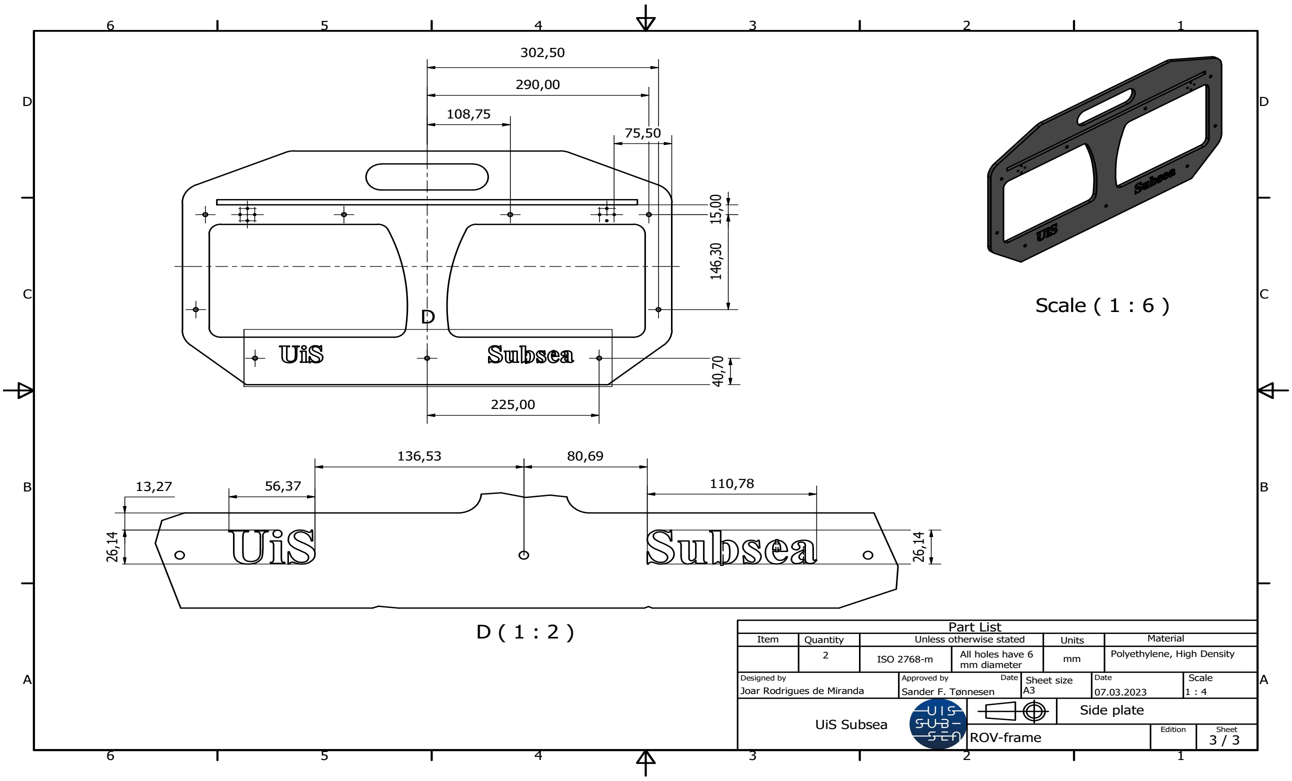


Figure A.6: Techical drawing of the side plate sheet 3/3

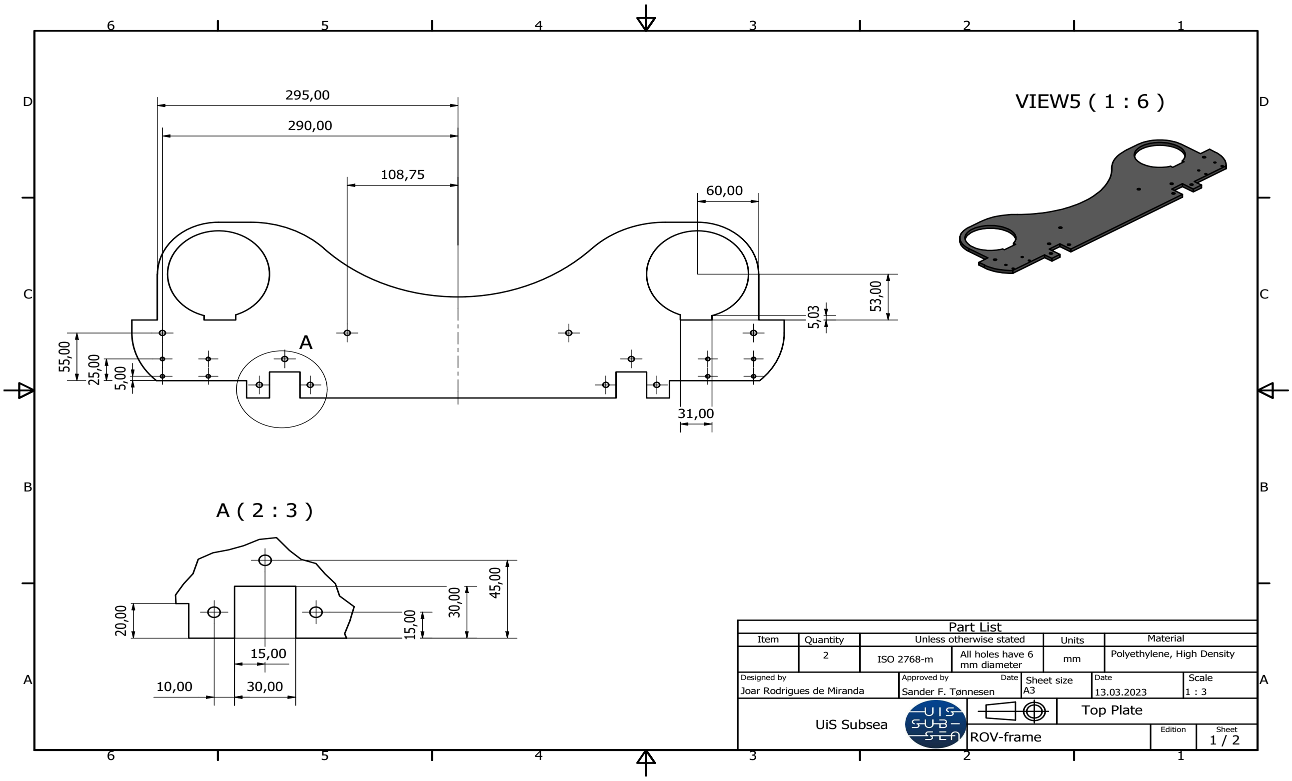


Figure A.7: Techical drawing of the top plate sheet 1/2

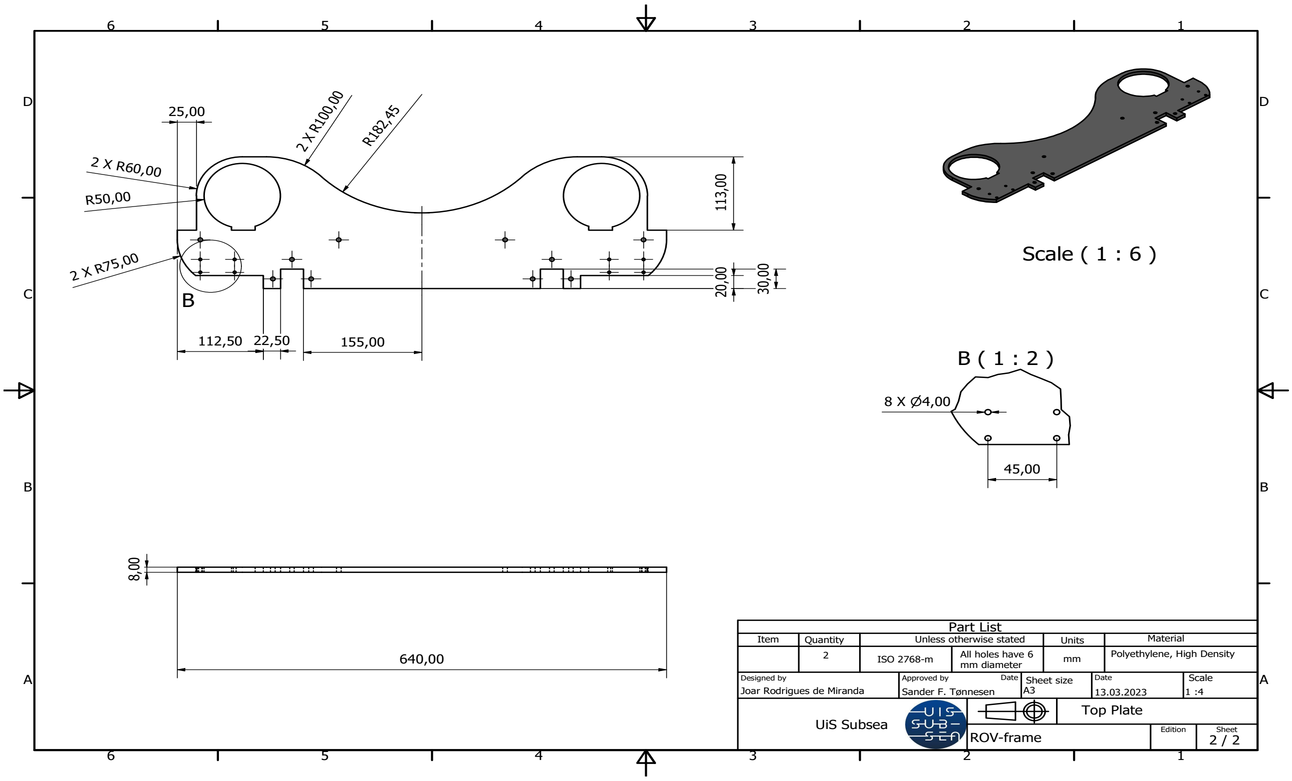


Figure A.8: Techical drawing of the top plate sheet 2/2

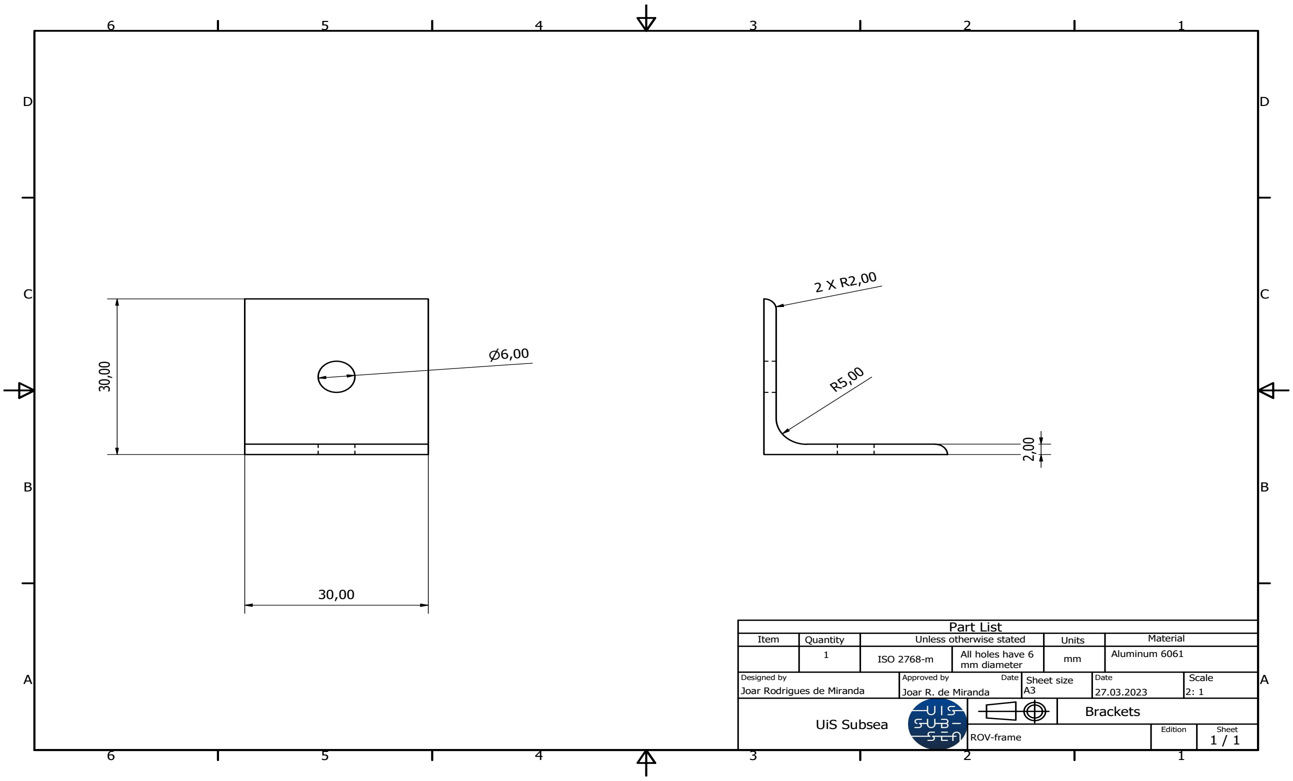


Figure A.9: Technical drawing for angeled brackets

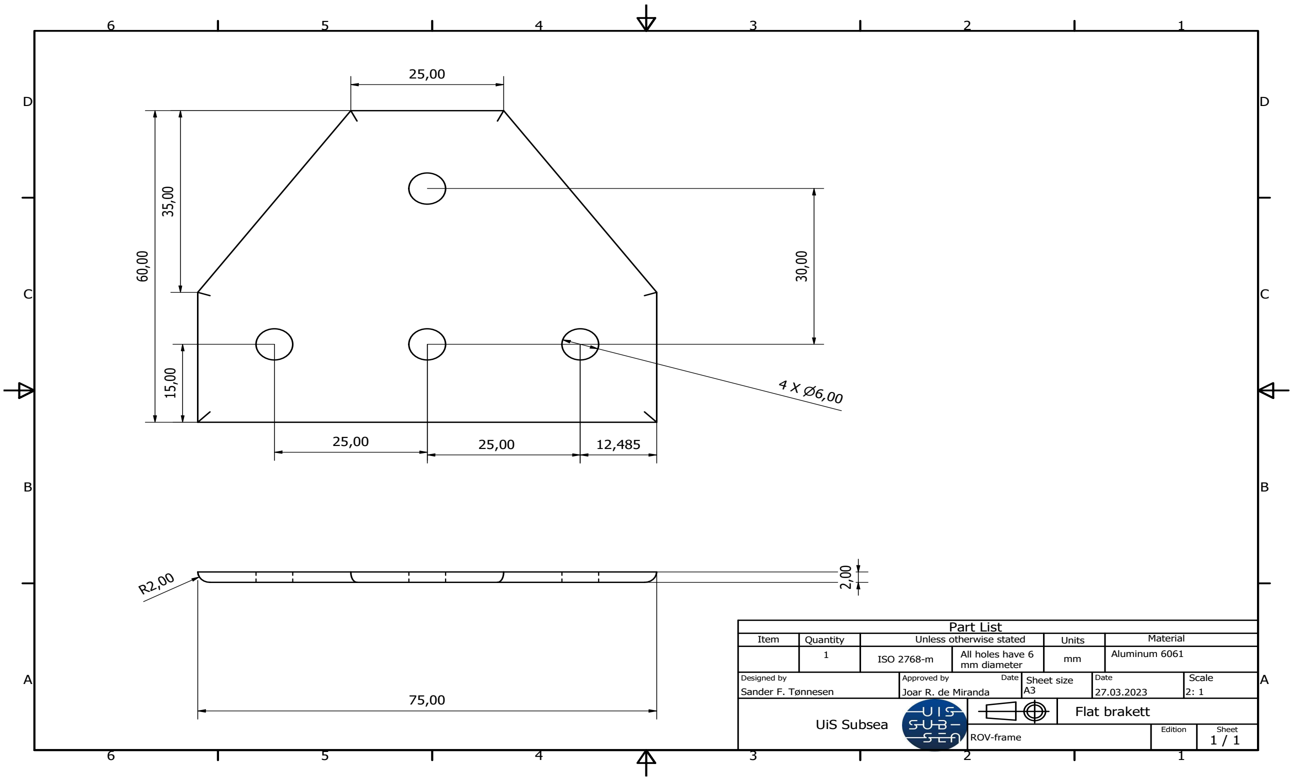
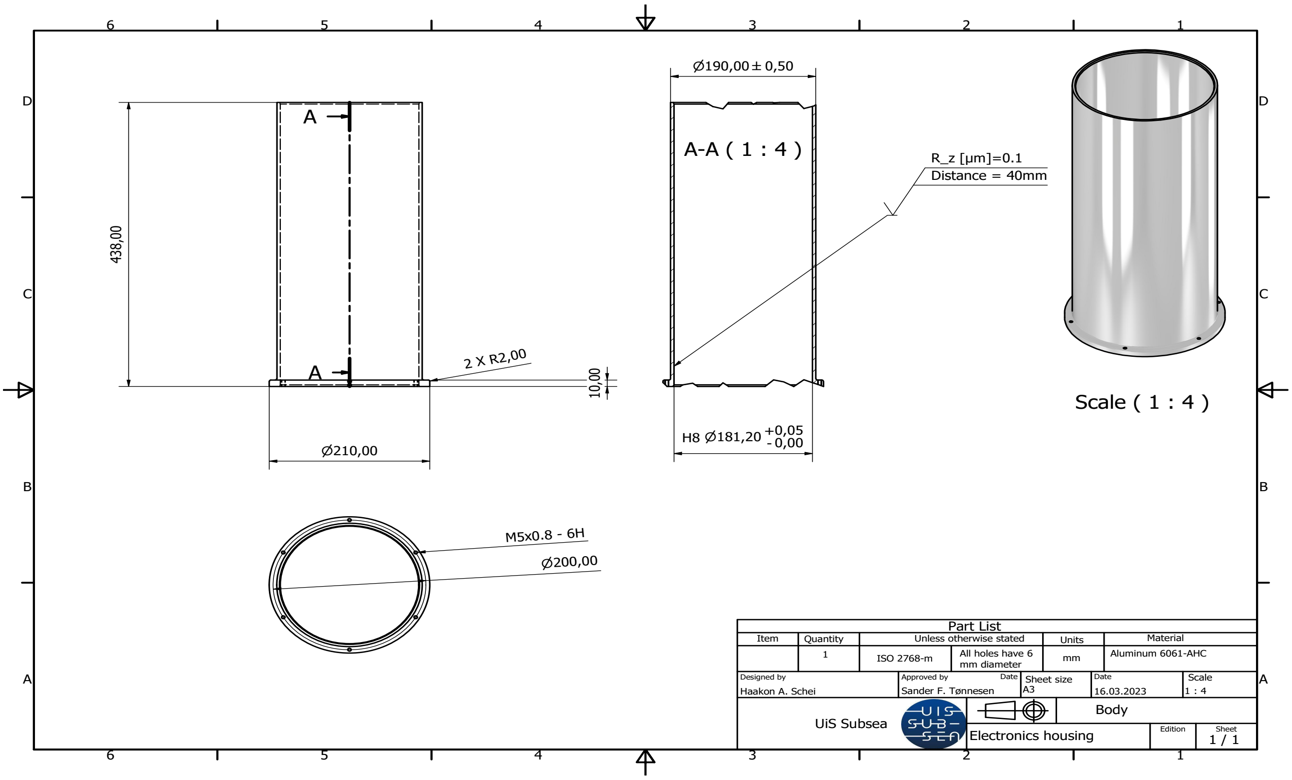


Figure A.10: Techical drawing for flat bracket

B Appendix: Techical Drawings Electronic enclosure



Part List

Item	Quantity	Unless otherwise stated		Units	Material
	1	ISO 2768-m	All holes have 6 mm diameter	mm	Aluminum 6061-AHC

Designed by	Approved by	Date	Sheet size	Date	Scale
Haakon A. Schei	Sander F. Tønnesen		A3	16.03.2023	1 : 4

UiS Subsea

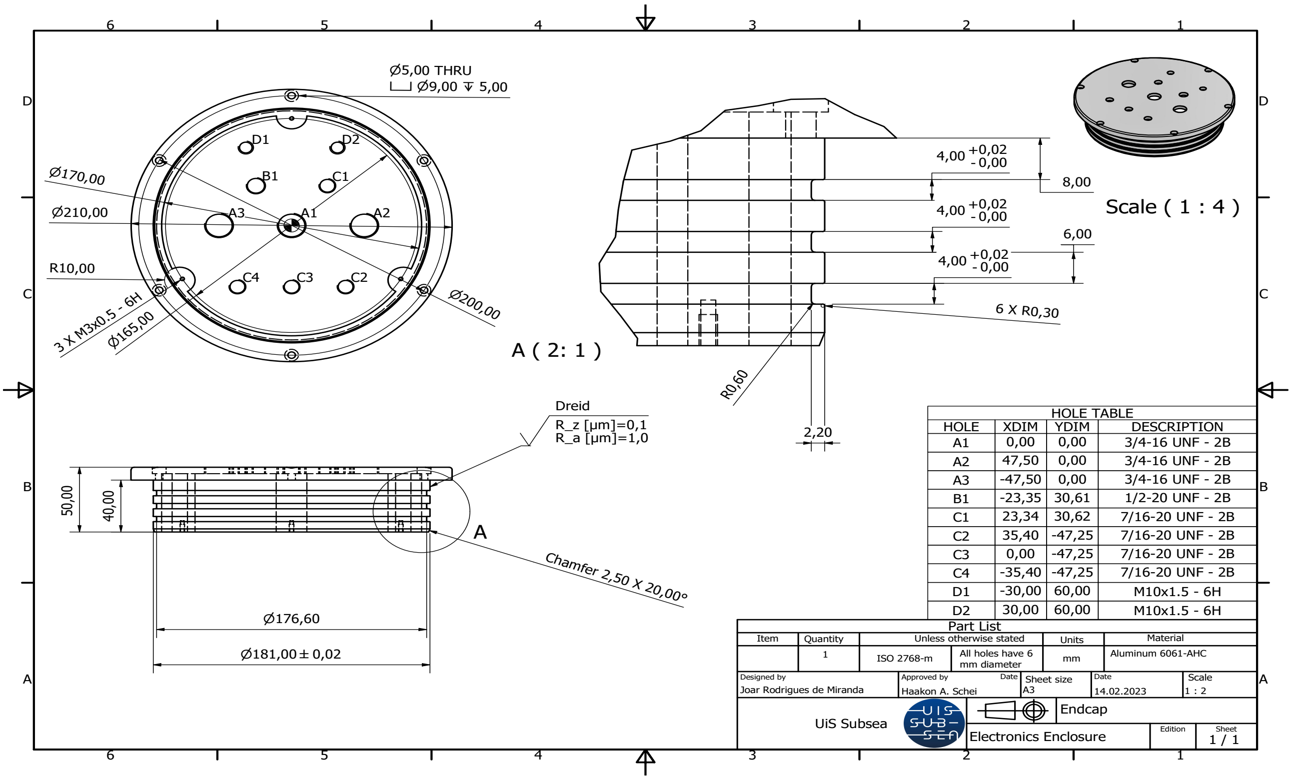
Body

Electronics housing

Edition

Sheet 1 / 1

Figure B.1: Techical drawing for electronic enclosure body



HOLE TABLE

HOLE	XDIM	YDIM	DESCRIPTION
A1	0,00	0,00	3/4-16 UNF - 2B
A2	47,50	0,00	3/4-16 UNF - 2B
A3	-47,50	0,00	3/4-16 UNF - 2B
B1	-23,35	30,61	1/2-20 UNF - 2B
C1	23,34	30,62	7/16-20 UNF - 2B
C2	35,40	-47,25	7/16-20 UNF - 2B
C3	0,00	-47,25	7/16-20 UNF - 2B
C4	-35,40	-47,25	7/16-20 UNF - 2B
D1	-30,00	60,00	M10x1.5 - 6H
D2	30,00	60,00	M10x1.5 - 6H

Part List

Item	Quantity	Unless otherwise stated		Units	Material
	1	ISO 2768-m	All holes have 6 mm diameter	mm	Aluminum 6061-AHC

Designed by	Approved by	Date	Sheet size	Date	Scale
Joar Rodrigues de Miranda	Haakon A. Schei		A3	14.02.2023	1 : 2

UiS Subsea

Endcap

Electronics Enclosure

Edition

Sheet 1 / 1

Figure B.2: Techical drawing for electronic enclosure end-cap

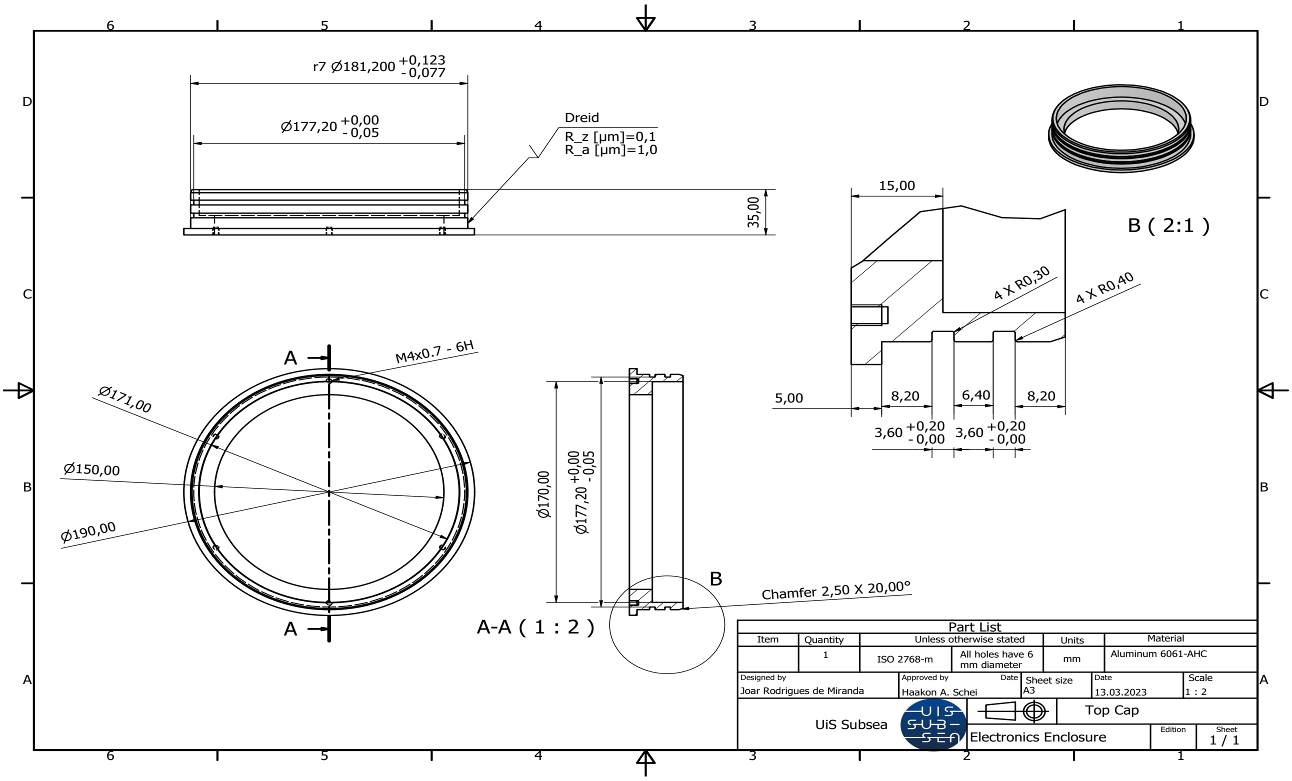
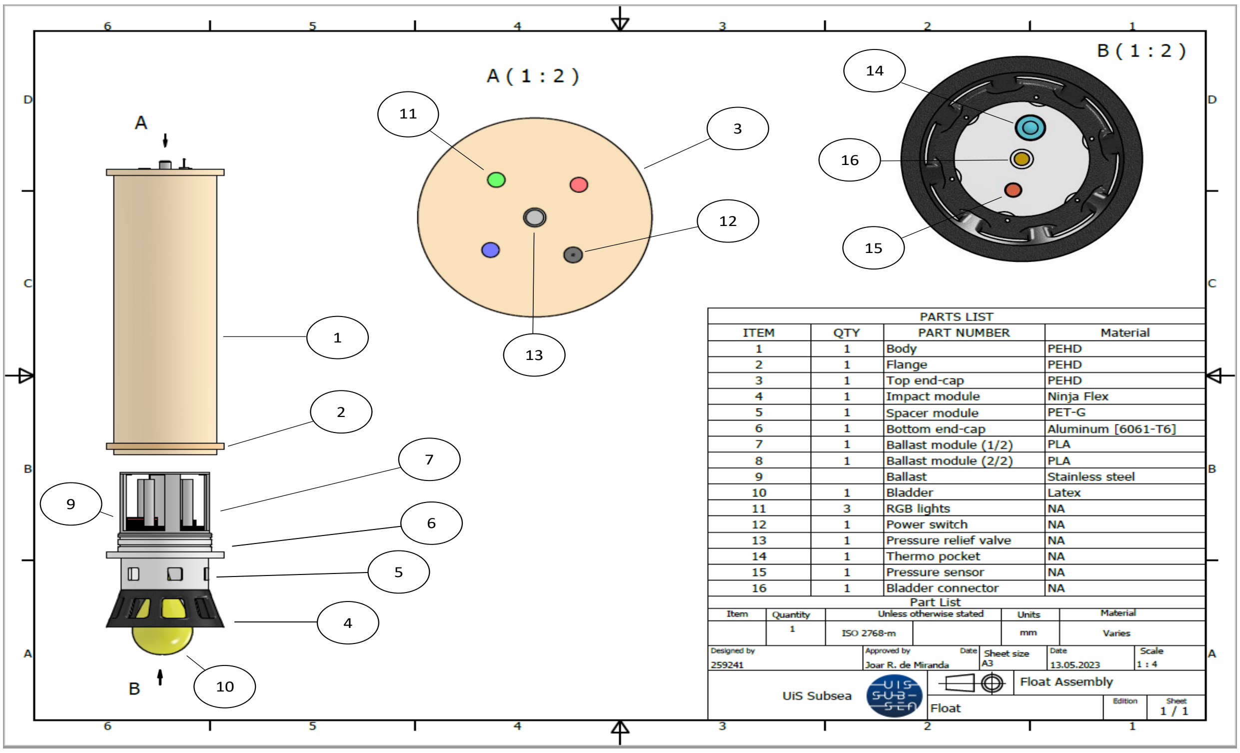


Figure B.3: Techical drawing for electronic enclosure top-cap

C Appendix: Technical Drawings Float



PARTS LIST			
ITEM	QTY	PART NUMBER	Material
1	1	Body	PEHD
2	1	Flange	PEHD
3	1	Top end-cap	PEHD
4	1	Impact module	Ninja Flex
5	1	Spacer module	PET-G
6	1	Bottom end-cap	Aluminum [6061-T6]
7	1	Ballast module (1/2)	PLA
8	1	Ballast module (2/2)	PLA
9		Ballast	Stainless steel
10	1	Bladder	Latex
11	3	RGB lights	NA
12	1	Power switch	NA
13	1	Pressure relief valve	NA
14	1	Thermo pocket	NA
15	1	Pressure sensor	NA
16	1	Bladder connector	NA

Figure C.1: Techical drawing of the finished float assembly

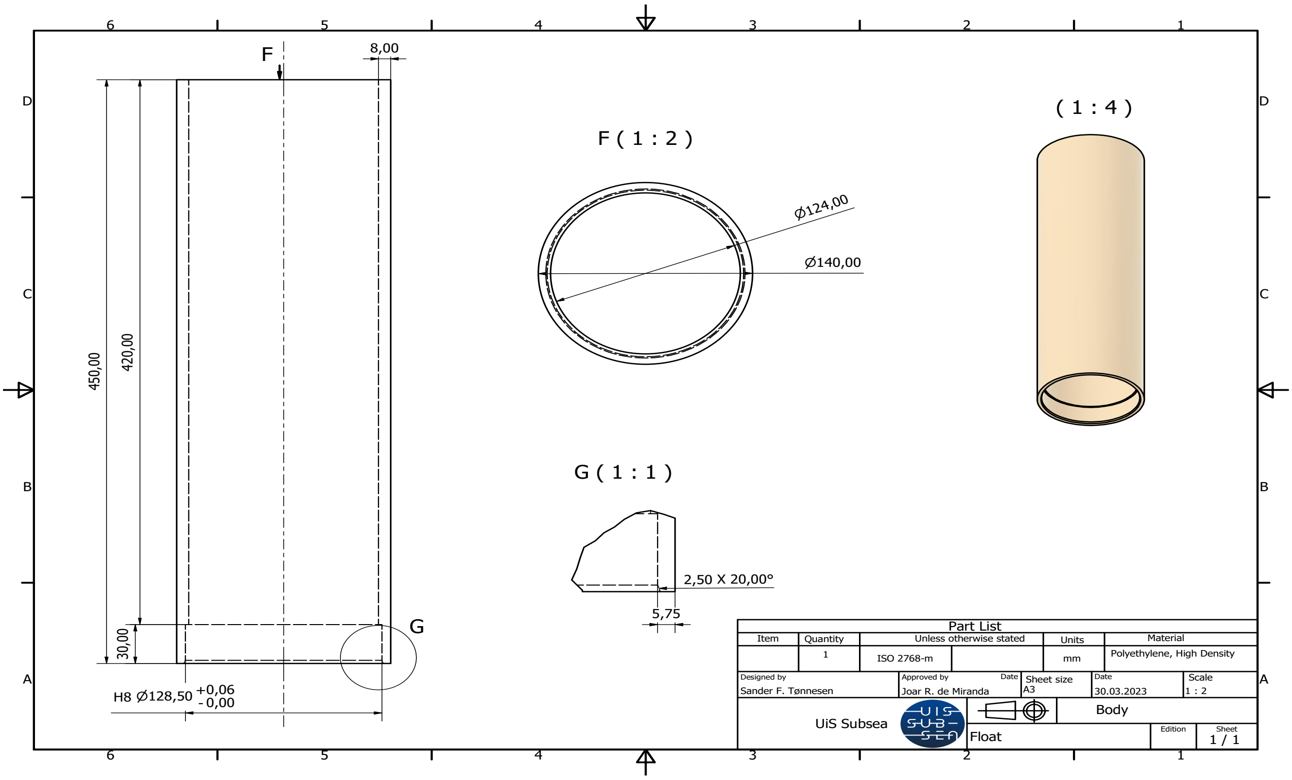


Figure C.2: Techical drawing of the float body

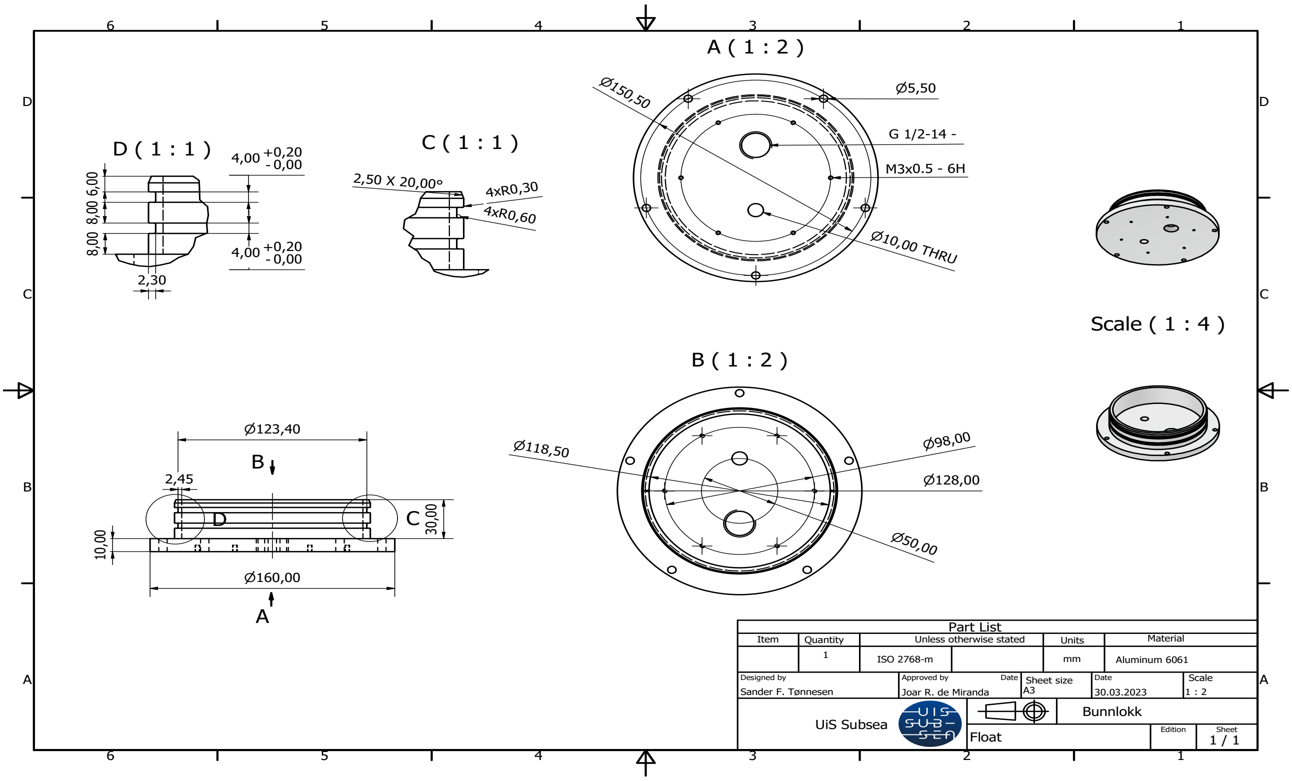


Figure C.3: Techical drawing of the float end-cap

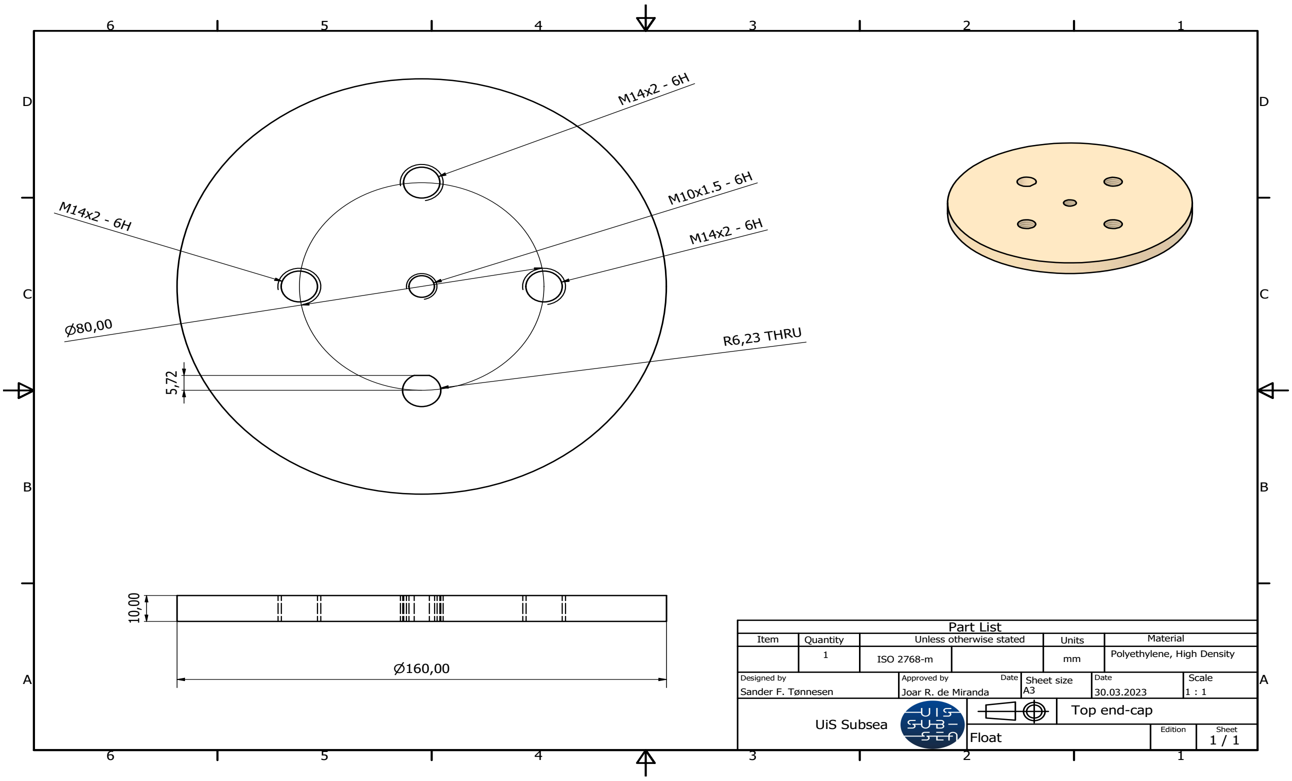


Figure C.4: Techical drawing of the float top-cap

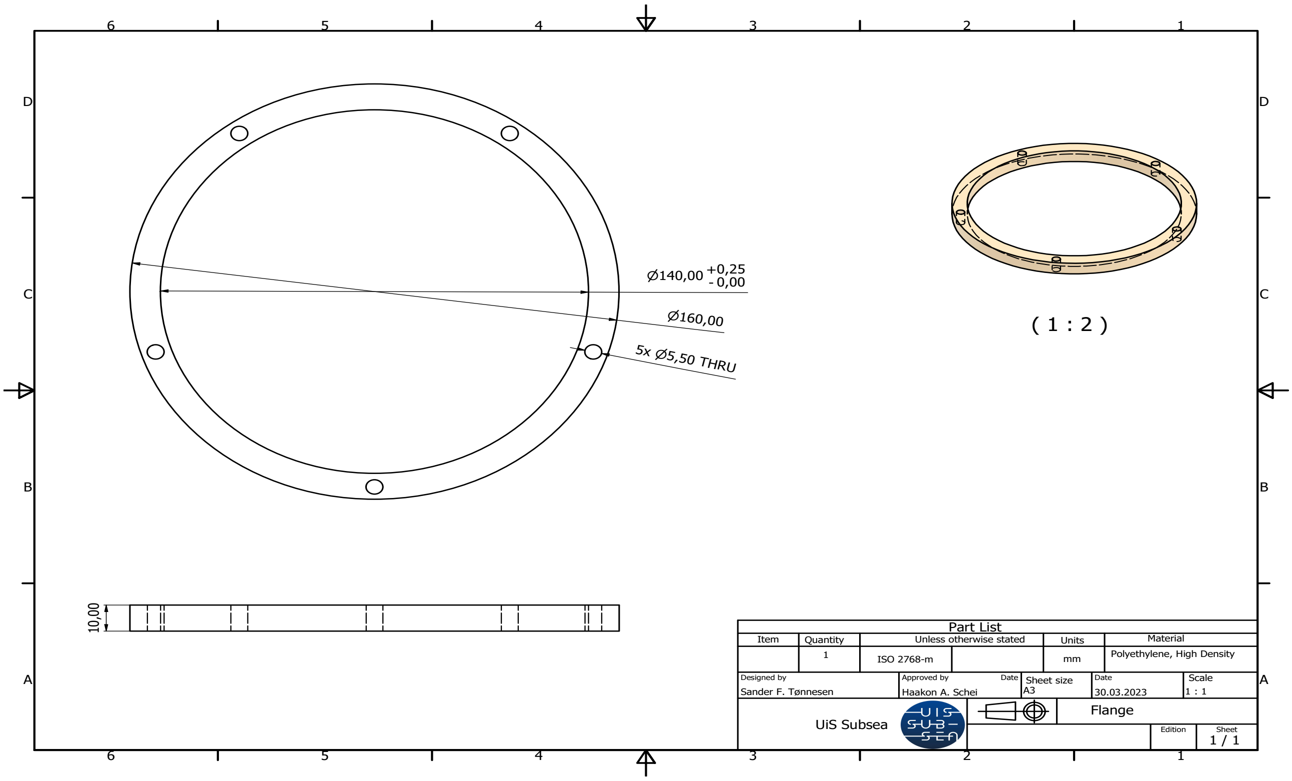


Figure C.5: Techical drawing of the float flange

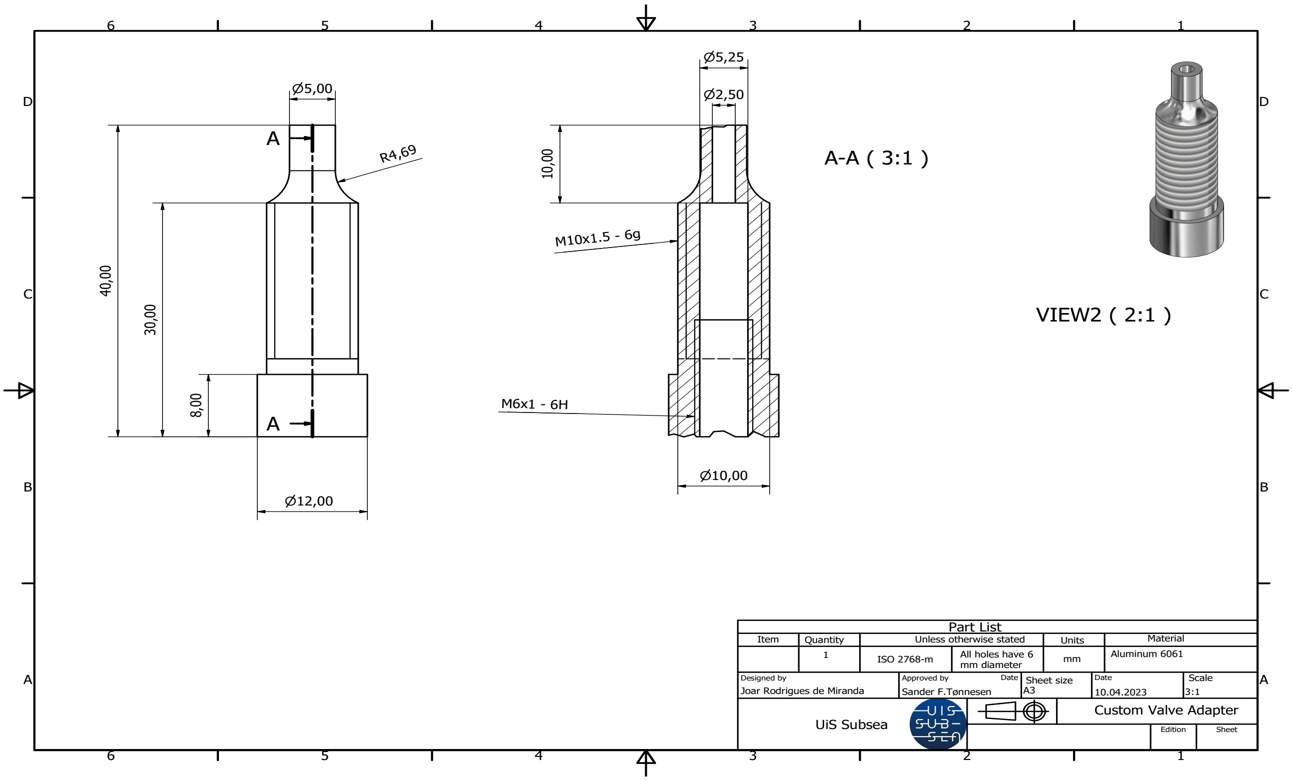


Figure C.6: Techical drawing of custom float adapter

D Appendix: FEA-Analysis Results

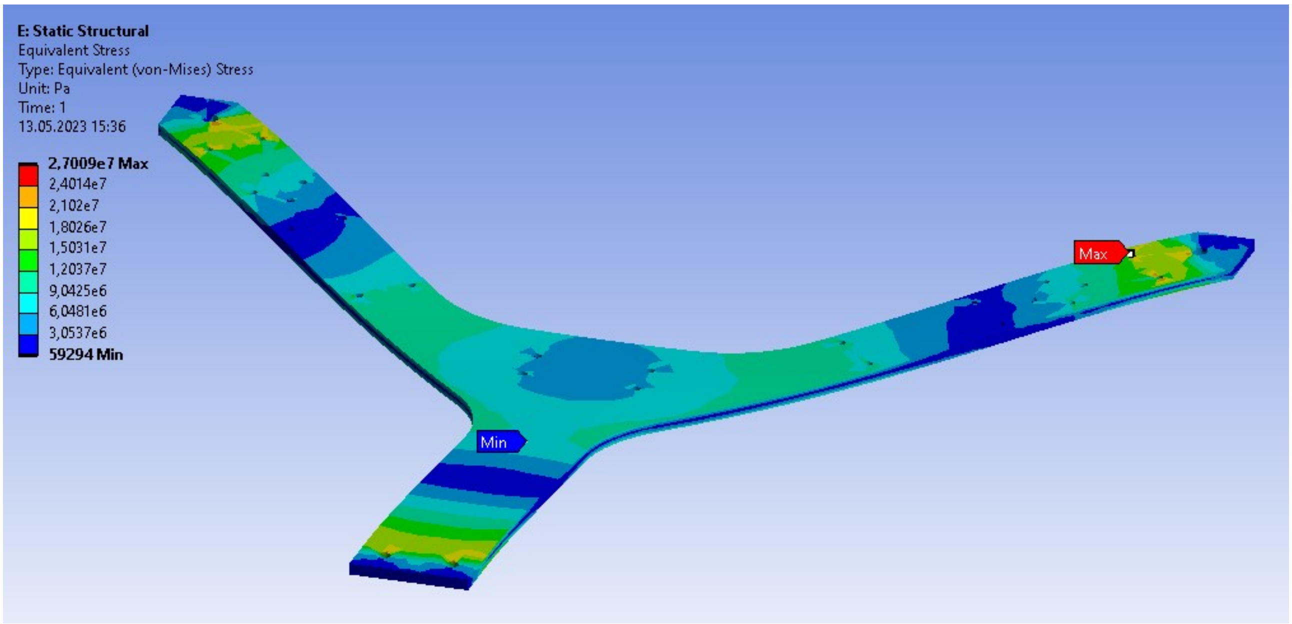


Figure D.1: Equivilant stress on back cross stiffener

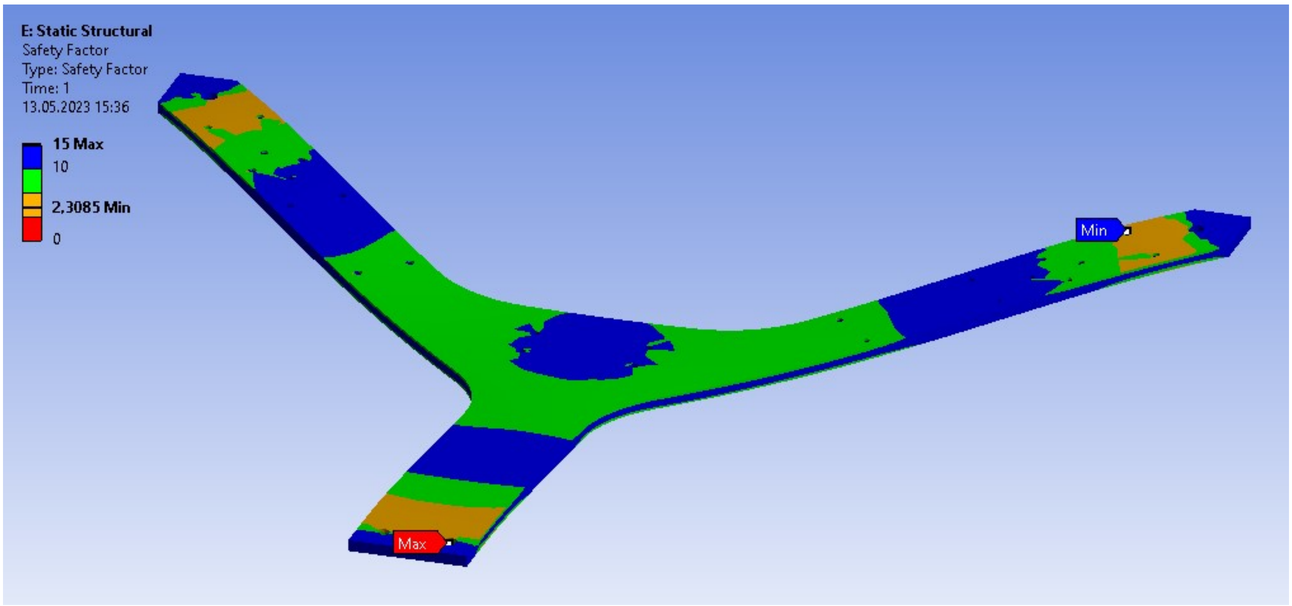


Figure D.2: Safety factor for back cross stiffener

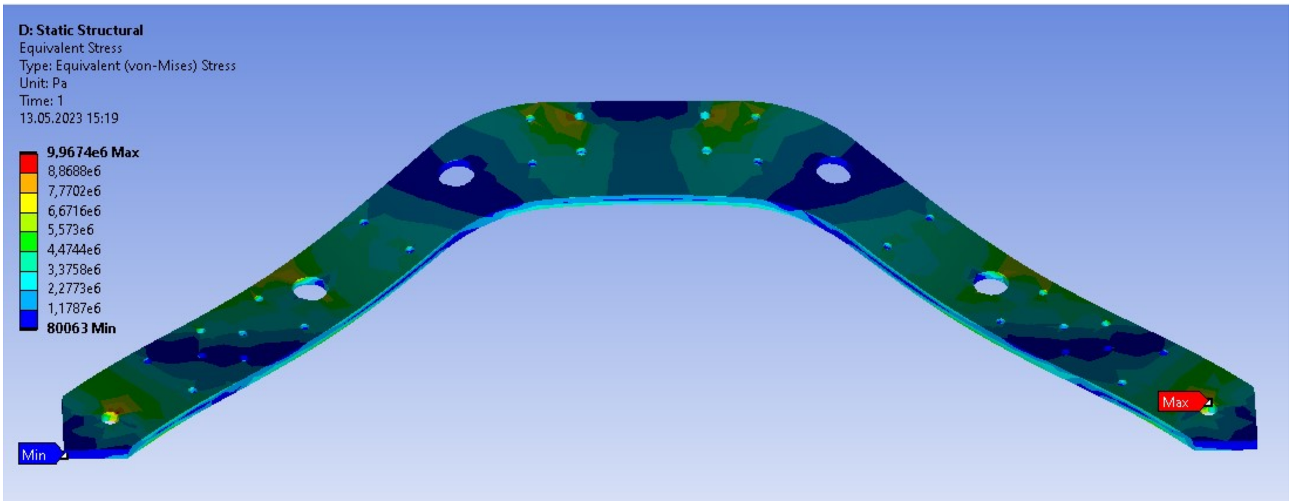


Figure D.3: Equivilant stress on front cross stiffener

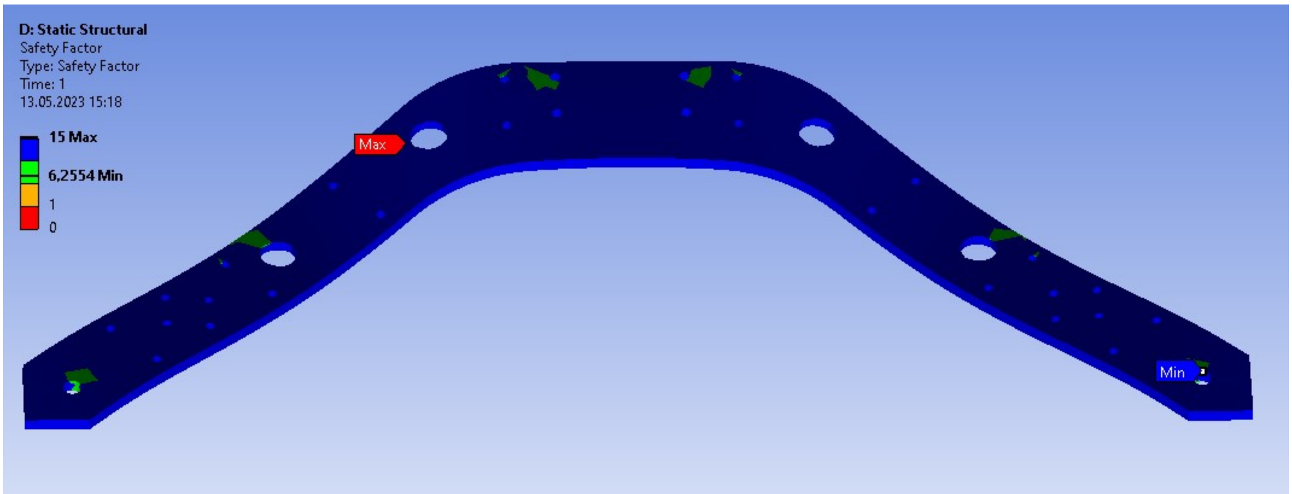


Figure D.4: Safety factor for front cross stiffener

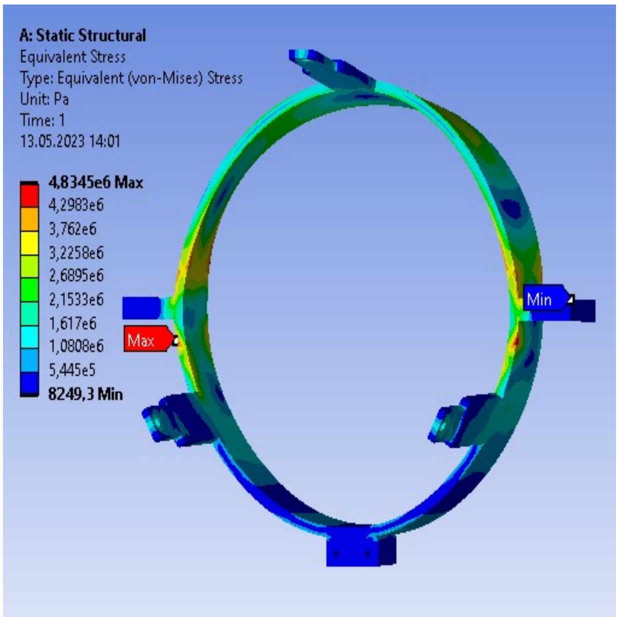


Figure D.5: *Equivilant stress on bands*

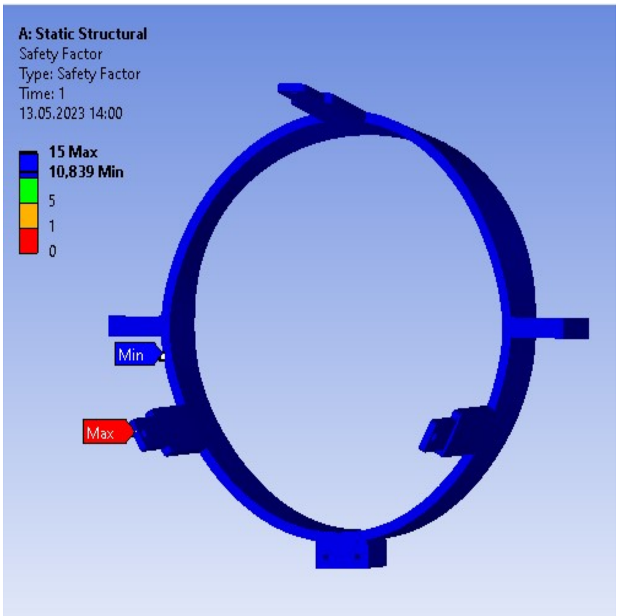


Figure D.6: *Safety factor of bands*

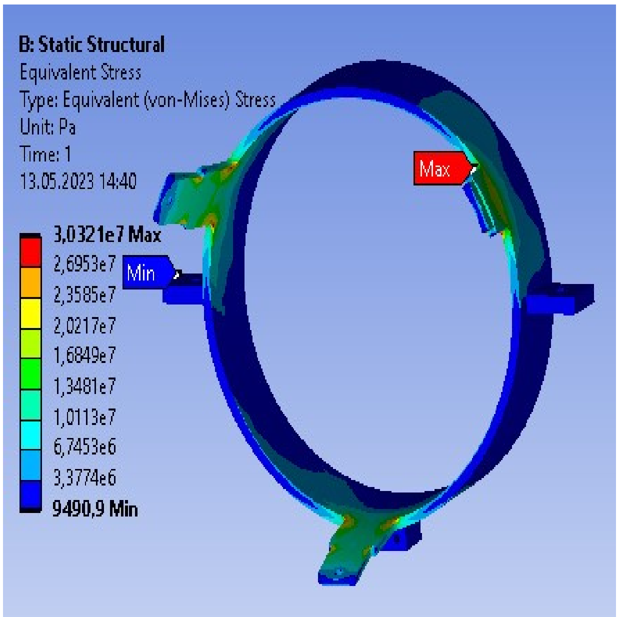


Figure D.7: *Stress from exteranl forces on new iteration bands*

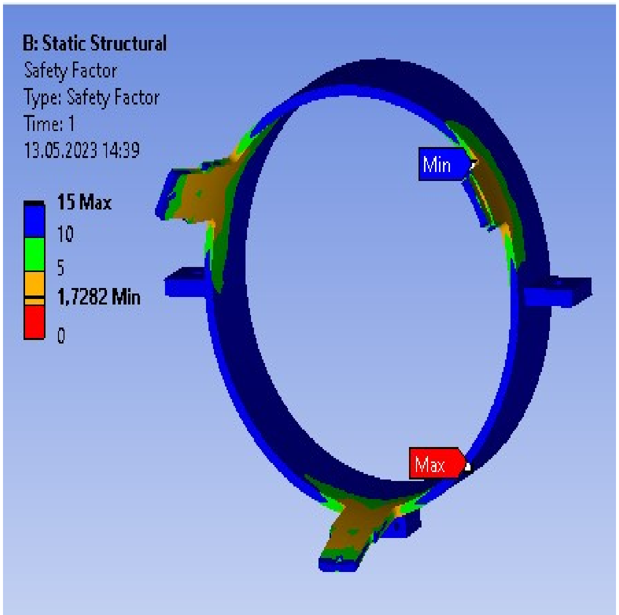


Figure D.8: *Safety factor of new bands*

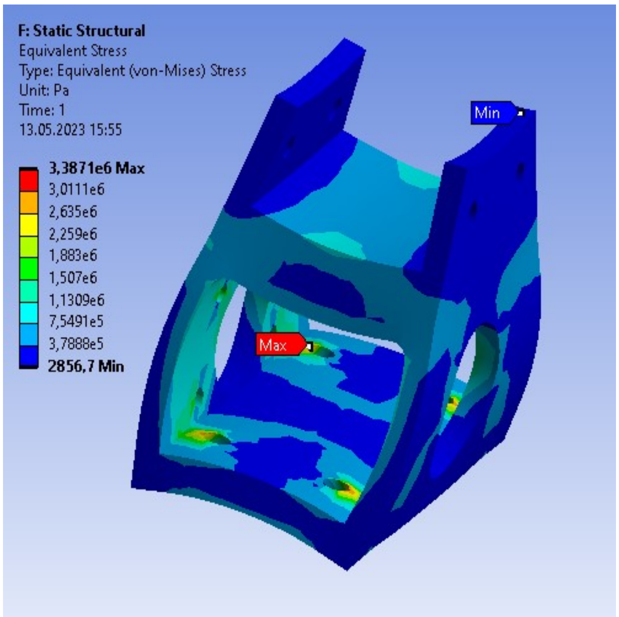


Figure D.9: *Equivilant stress on cross stiffener bracket*

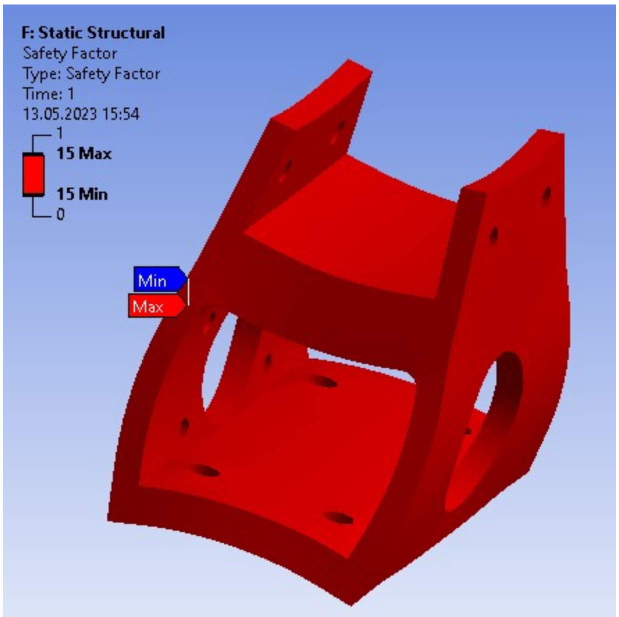


Figure D.10: *Safety factor of cross stiffener bracket*

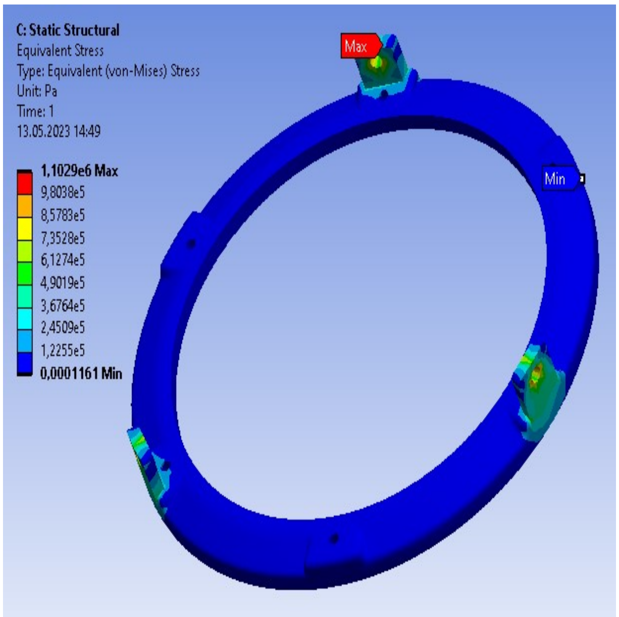


Figure D.11: *Equivilant stress on 3D-printed flange*

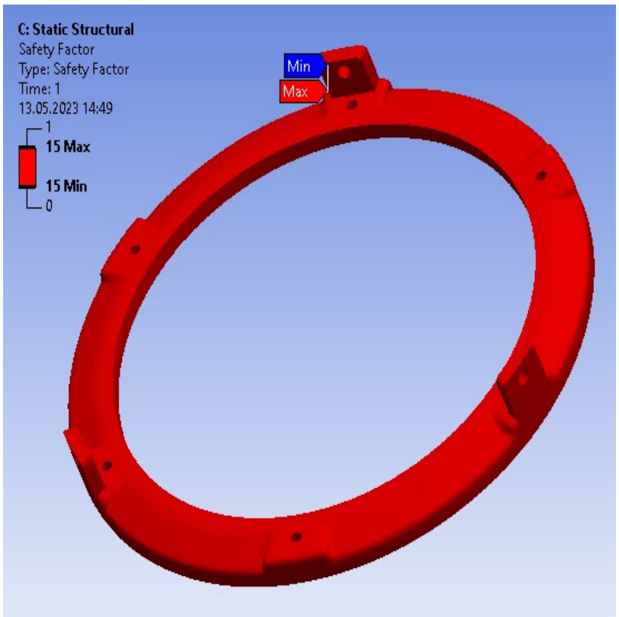


Figure D.12: *Safety factor of cross stiffener bracket*

E Appendix: Float chart | Project

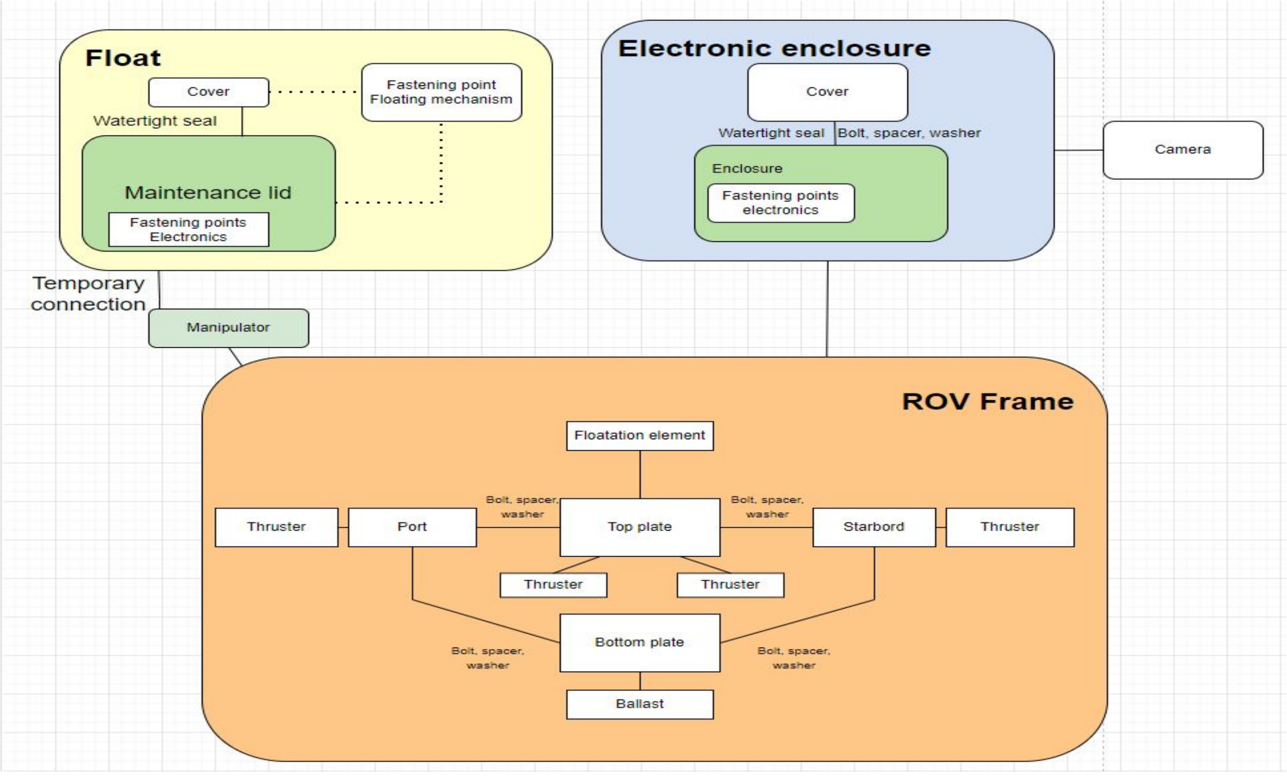


Figure E.1: Pre-project float chart

F Appendix: Hyperlinks to relevant files

- **Link to STL files of products and minutes of meeting:** https://1drv.ms/f/s!Ak_879P7mz4hsFVygmeG-ZiV3OVN?e=QFvNrj
- **Link to Gantt chart:** https://1drv.ms/x/s!Allx5PxNYzTrjPoqNahW1zenMC0TXQ?e=DFdeL9
- **Link to original needs matrix:** https://1drv.ms/x/s!Allx5PxNYzTrjLtpkV0Lm4WjOdNjoA?e=jmbN3a