# ERGONOMICALLY IMPROVED AZIMUTH CONTROL UNIT

## DESIGN REPORT

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# 2. Introduction

An Azimuth thruster is a propeller that can rotate 360 degrees around a vertical axis providing controlled thrust in every direction. This means that tugboats with azimuth thrusters have a superior manoeuvrability compared to conventional tugboats. (Kongsberg, 2021)
Azimuth thrusters also eliminate the need for rudders and reverse gears as they themselves act as these parts. These thrusters are controlled by control units where each thruster has one related control unit.

The current azimuth control units are made to be functional and only a few control units on the market aim to make the use more comfortable. Smart-Ship is a start-up developing ship controls that include haptic feedback to convey precise information to the operators. As Smart-Ship already has an azimuth control unit in their assortment, a more ergonomically developed one was wanted.

The design project was based on the Double Diamond Design Method (DDD) which is illustrated in image 1 below. The method starts with a discovery phase where research into the topic is conducted. In the case of this study, it was done for azimuth control units to understand the different types, the different features a control unit could include, and health related issues that can arise when using products with a similar interaction as azimuth controls.

The DDD method then states that the Define phase is used to gather and interpret the insights to create a list of requirements.

In the Develop phase ideas were created through, brainstorming, and random image stimulation. These ideas were then developed through sketching and evaluation methods. From those resulting ideas, three were selected, prototyped, and tested with the target users.

After the testing, a form concept was created which had the most comfortable and directional shape. From this form concept, four style concepts were designed to adapt the product to the Smart-Ship style.

These four concepts were then prototyped and tested again to find the overall best shape and style which was then turned into the final concept. The final concept is then explained, and final recommendations were made for the further development of the Azimuth control unit.

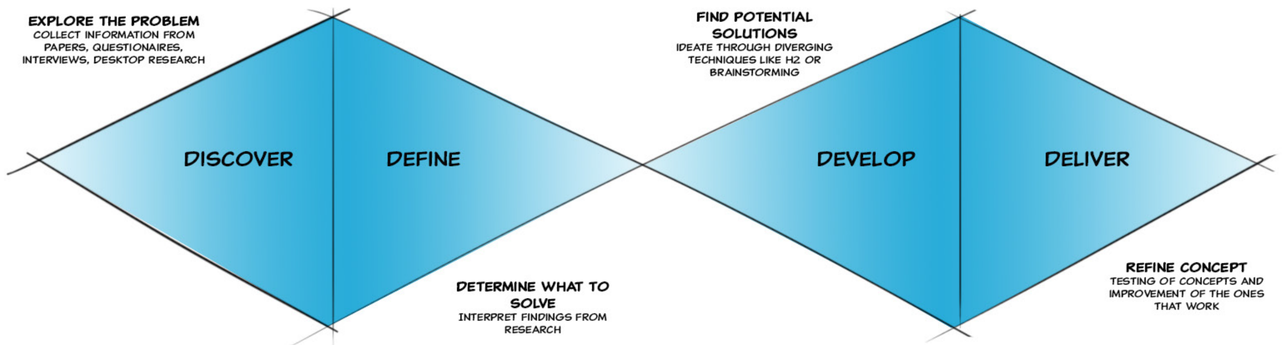


*Figure 1: Double Diamond Desing Method Visualization*

# 3. Problem Definition

Only a few Azimuth control units that are currently on the market are ergonomically developed to increase the comfort of the tugboat operators. Considering that tugboat operators usually work 12-hour days with seven days off in between (Fattori, 2012), they have their hands on the units for very long periods of time which means that uncomfortable controls can cause health issues.

Azimuth control units rotate 360 degrees horizontally to adjust the direction of the thrusters, and a lever attached to the body of the unit rotates 90 degrees vertically. (Carlos A. Pérez Labajos, 2005). If the operator does not directly know where the control unit is pointing, it can cause the operator to apply thrust in the wrong direction leading to dangerous and expensive errors. (Daan Merkelbach, 2021)

Manoeuvring tugboats requires high precision and speed. (GulfCoast, 2020) Therefore operators cannot constantly be looking at their controls to understand where they are pointing.

This project aims at designing an azimuth control unit that improves the comfort of the operator and makes it very clear which direction it is pointing in. The control unit should provide features that aid the comfort, whilst not decreasing the functionality and directional clarity of the control unit.

It is important to have a good understanding of azimuth thrusters as well as the background of this project. This information will be relevant for the rest of the project as a clear understanding of the context determines how the product will look, feel, and be used. In this part of the report the research which the product is based on will be presented.

# Research

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# 3.1 Target Group

**Initial target group from the project:**

When the project was started, the goal was to create an azimuth control unit that could be used on tugboats, and inland ships such as: Dry Cargo Carriers, Tank Vessels, Passenger Ships, Dredging Ships. In addition to this, the control units could also be used in the simulation setup of V-Step.

Whilst doing the research into the different sorts of ships, it became apparent that there are two kinds of azimuth control unit styles: One specifically focussing on tugboats and the other on inland shipping.

By doing a product analysis of the different kinds of control units, it was possible to see the different needs and wants the control units were aiming to solve. In image 2 below, a control unit found on inland ships can be seen. From looking at it, two things become apparent: The control unit is not made to be ergonomic or be continuously used for long periods of time, and there is no focus on making it have a clear directional shape. The control unit shown in image 2 is produced by Kwant and most other azimuth inland ship controls look very similar.

*Figure 2: Kwant Azimuth control unit for Inland Ships*

When comparing azimuth control units for tugboats, there is a large variety in the design of the control units. An example of one of the azimuth control units specifically designed for tugboats can be seen in image 3. The design of this control unit is drastically different and aims to solve tugboat specific needs. The control unit shown is produced by Schottle and clearly gives the operator an insight into where the control is pointing in. Even though the control unit is often used for long periods of time, there does not seem to be much focus on comfort besides the tail of the control unit, where the operator can rest part of his hand palm.

*Figure 3: Schottle Azimuth control unit for Tugboats*



# 3.1 Target Group

After doing an analysis of eight inland ship azimuth control units and six tugboat azimuth control units, a value curve was created (EPM, 2017) for inland ship control units and tugboat control units, as shown in figures 4 and 5.

When looking at the value curves it is clearly visible that when comparing the current Smart-Ship control unit to other inland ship control units, it generally performs very well besides in the category basic information. This is not the same when comparing the Smart-Ship control unit to competing tugboat controls. It's possible to see that the Smart-Ship control unit performs worse in four out of the five categories.

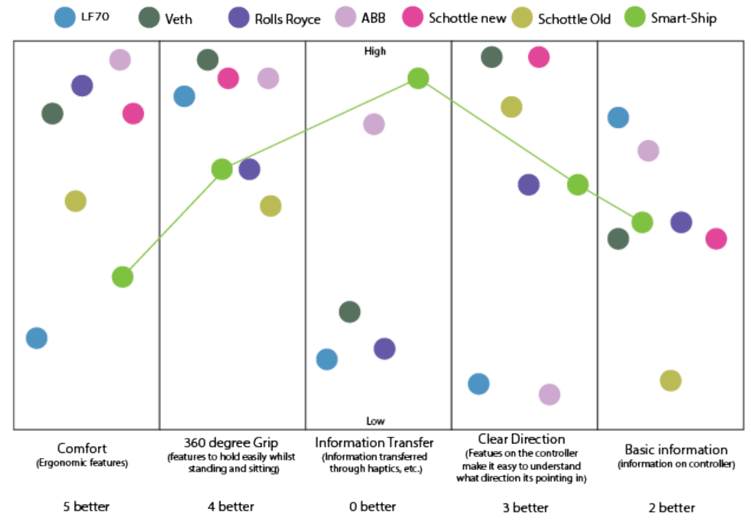



*Figure 4: Value Curve for Azimuth Control Units*

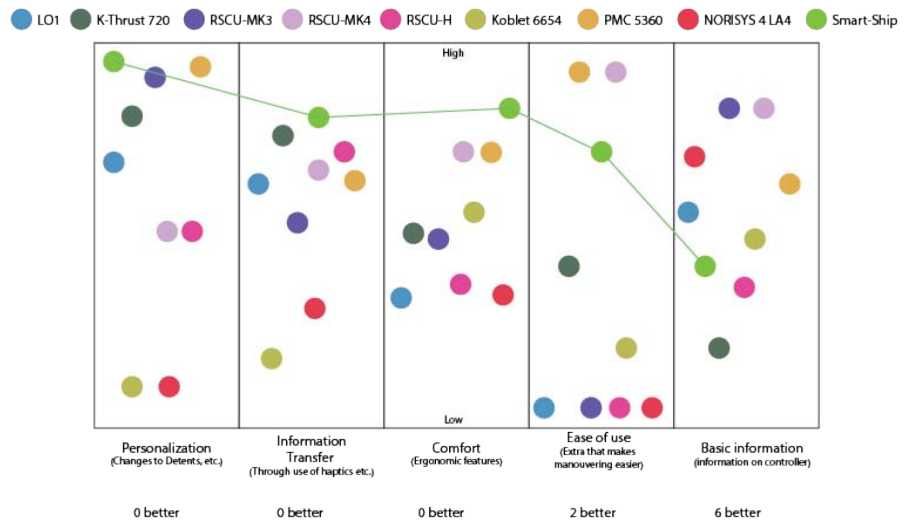



*Figure 5: Value Curve for Inland Ship Azimuth Control Units*

With this information it was possible to get together with Smart-Ship and to discuss whether it would be more sensible to focus only on tugboats as a target group, since the current control unit is already well established for inland ships and more improvements could be made when designing a tugboat control unit. In the meeting it was decided that this would be a wise course of action and therefore the goal and the research of the project was adapted to only focus on tugboats.

# 3.1 Target Group

The idea behind an Azimuth thruster is that the propeller can rotate 360 degrees around a vertical axis providing controlled thrust in every direction. This means that tugboats with azimuth thrusters have a superior manoeuvrability compared to conventional tugboats. (Kongsberg, 2021)

Azimuth thrusters also eliminate the need for rudders and reverse gears as they themselves act as these parts.

An azimuth system consists of 3 different devices: Azimuth thrusters, steering and control unit levers, and shaft lines. The azimuth thrusters are controlled electronically from the bridge of the ship, and each of the thruster's manufacturers has its own characteristic model of the control unit. Generally, tugboat controls consist of two units which each are independent of one another.
The control unit is usually made up of two different parts, a single lever which rotates 90 degrees vertically and is used as the thrust input, and the main body that turns the entire controller 360 degrees horizontally to adjust the direction of the thrusters. Since each thruster has its independent control system, all the azimuth control units can be used with one hand. (Carlos A. Pérez Labajos, 2005)

Through having superior manoeuvrability, it makes the thrusters very useful on tugboats where high manoeuvrability is key. Therefore, azimuth thrusters are useful as they make for a compact propulsion system with the highest degree of movement. (MarineLog, 2016). The concept of the azimuth thruster is the same for each ship class it is installed on, however, the control units for steering and thrust input change depending on the ship class.

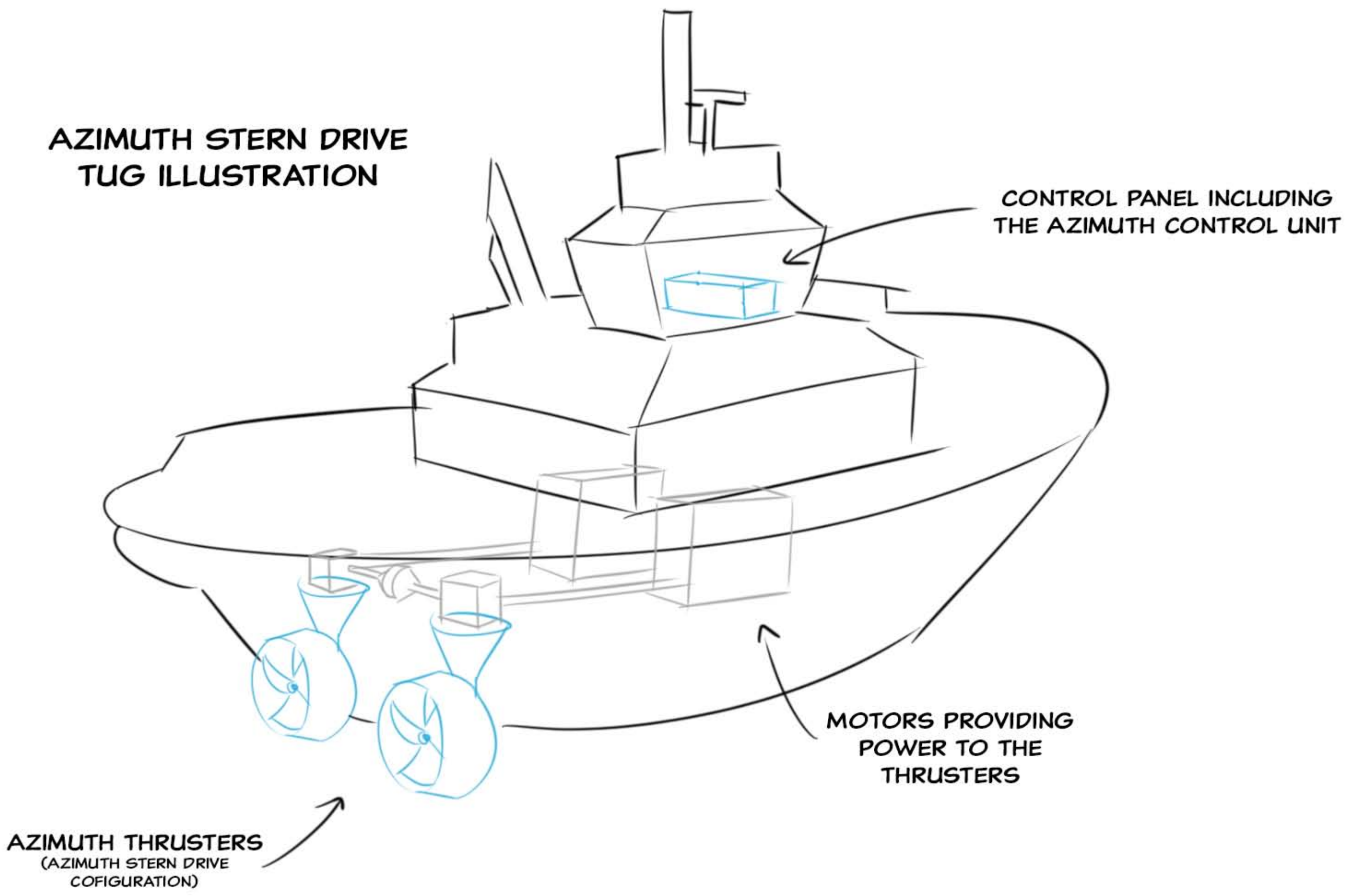



*Figure 6: Illustration of the essential parts of an Azimuth Stern Drive Tugboat*



# 3.2 DESTEP Analysis

To find detailed information about tugboat operators and the tugboat industry, a DESTEP analysis was conducted. Below, the most relevant aspects are listed and the full DESTEP table can be found in appendix 1.

When looking into the demographics of tugboat operators research shows that the majority of tugboat operators is male. As women represent only two percent of the world's 1.2 million seafarers and 94% of those female seafarers work in the cruise industry, there are many more male tugboat operators than female ones. Additionally, it was found that more than 50% of operators are over 40 years of age, with the average age being 42.8 years old. A similar answer was found in the questionnaire which will be explained in section 3.9.

The DESTEP analysis also showed that the tugboat market should not be disappearing any time soon as there is continuous market growth (Ibisworld, 2020). Considering that after COVID-19 the maritime trade is supposed to grow again, this will increase the need for tugboats and therefore azimuth control units. (A. Jadhav, S. Mutreja, 2020)

There were also some important political facts were found. According to the IACS it is required that the azimuth control units can work separately from each other to allow continued control of the vessel in case one of the steering-propulsion systems fails. (IMO 2018)

Trends found connected to environmental factors and tugboats demonstrates a clear development towards an eco-friendlier future in the tugboat industry. Whilst for now the focus is on changing the fuel type to reduce carbon emissions, this might eventually transform into materials used on the ships, including the material of the control units. Therefore, eco-friendly materials and production methods should be chosen.

An interesting development that could shape the future of the tugboat industry is the automatization or remote control of tugboats. Kotug, the leading international towage and maritime company, has already performed tests with remote controlled tugboats. (Kotug, 2021) This however will not be a threat to Smart-Ship as haptic feedback and ergonomic control units will stay relevant even on remote controlled ships.

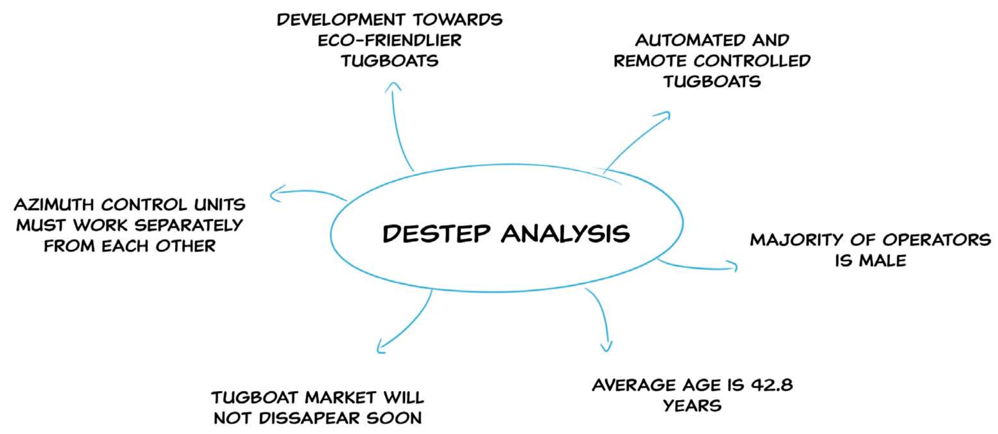



*Figure 7: Illustration of the main outcomes of DESTEP Analysis*

From the DESTEP analysis the following requirements could be made:
- The control unit should be made of eco-friendly materials
- The control unit should be produced using eco-friendly production methods
- The control unit should be designed with male hand anthropometrics in mind
- The control units should not be connected with one another.

# 3.3 Control Unit Analysis

To understand what makes competitive azimuth control units for tugboats good or bad, five control units were analysed in terms of directional feedback, palm rest, overall comfort, throttle actuation and features. The table that shows the results of this analysis can be found in appendix 2. From the analysis, insights were gathered that showed that the throttle is always directly connected to the body of the control unit. Additionally, it was found that some control units have a "swing arm" that operators can hold on to and use to steer the azimuth thruster. Furthermore, most of the control units had a clear difference in their shape which will help the operator understand where the front or back of the control unit is. The analysis also showed that the throttle on most control units slims down towards the bottom, making it more comfortable to use with the thumb and index finger. Lastly it showed that only two of the five control units offer a proper palm and wrist support and that some of the control units had edges which might cause pressure points in the hands.

*Figure 8: Niigata Azimuth control unit*

*Figure 9: Veth Azimuth control unit*

*Figure 10: Rolls Royce Azimuth control unit*

*Figure 11: Schottle Azimuth control unit*

*Figure 12: Aquamaster Azimuth control unit*

From this analysis a set of hard and soft requirements was formed:

- -The throttle lever should be directly connected to the azimuth control unit body
- -The control unit has a clear shape difference in design in the front and back of the control unit
- -The control unit has smooth edges



# 3.4 Ergonomic Mice Analysis

A product analysis was also done for ergonomic mice. Currently there are many ergonomic mice options on the market aimed at making working with a mouse more comfortable and to provide a more natural wrist position. From the research it became evident that there are two main ways that mice manufacturers aim to achieve this. The first one curves the mouse to the hand of the user for better palm support and the other allows the user to use the mouse vertically. The whole mice analysis can be found in the Research Report and in appendix 3.

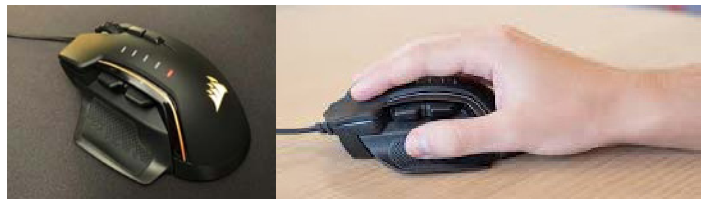
*Figures 13 +14 : Anker Ergonomic Mouse*

*Figures 15 + 16: J-Tech Digital Scroll Endurance Mouse*

*Figures 17 + 18: Logitech MX Vertical Mouse*

*Figures 19 + 20: Logitech MX master 3 Mouse*

*Figures 21 +22: Microsoft Sculpt Ergonomic Mouse*



*Figures 23 +24: Microsoft Sculpt Ergonomic Mouse*

From this analysis more requirements were formed:

- The control unit should follow the contour of the hand for forward driving position
- The control unit should slightly angle the operator's hand in the forward driving position

# 3.5 Video Observation

During the research of the project, video analysis was used to gather insights into how operators work on tugboat bridges and was used as a substitute method for in person observation that could not be done due to tugboat companies not being responsive. In this observation eight videos on YouTube were found that showed operators interacting with different types of azimuth control units. From them it was possible to gain important insights. In the videos one could see that both control units used on the tugboats look the same. The videos also showed that most operators are sitting during operations, however some stand. All the operators have both of their hands on the control units at almost all times. Only sometimes one hand is taken from one of the control units to use a radio. Lastly the videos showed clearly that operators look around a lot during operations as they need to understand what is going on in their surroundings. In figure 25 below one can see a screenshot from one of the videos that was used.
In appendix 4 a table with annotations for the videos can be found.


Figure 25: Rusman Tayang Operating an Azimuth Stern Drive Tugbaot

From the video observation some requirements were formed:
- The control unit should be identical for each thruster
- The control unit can be used whilst sitting and standing
- The control unit can be turned easily

# 3.6 Literature Reseach

An important part of the research process was to find information about possible health related issues that operators could suffer, with a badly designed control unit. In the research, health related issues from computer mice were investigated as the interaction between the computer mice and a computer user are very similar to tugboat operators and the azimuth control units. In both cases repetitive wrist movements are performed over long periods of time.

From the research it became evident that there are health related issues that arise due to poor wrist and forearm posture and repetitive movements. These issues are that the carpal tunnel pressure could rise leading to Carpal Tunnel Syndrome (CTS), and the other issues are musculoskeletal injuries in the upper extremities.

In addition, it was found that there are some features that have been proven to reduce some of the above-mentioned health risks. One of them is having proper palm and wrist support. Another feature that could help, if possible, is that the control unit should be angled to place the wrist in a more natural position. If an angled control unit is not possible, it should be shaped so that it follows the curvature of the hand or is made longer to reduce ulnar deviation.

Based on these insights, additional requirements were created:
- The control unit should slightly angle the operator's hand in the forward driving position
- The control unit should be shaped so the operator can rest his palm
- The control unit should be elongated to reduce ulnar deviation
- The control unit should follow the contour of the hand in the forward driving position

# 3.7 Simulator Testing

During the research phase of the project a test with a tugboat simulator was conducted. Since Smart-Ship works together with V-Step simulations, who make virtual simulations, it was possible to use the simulator to get an understanding of how azimuth control units feel, how certain movements impact the tugboat, and information from Smart-Ship about which movements are performed more often than others.

The testing was not planned and therefore no testing plan was created. However, the testing session was video recorded. During the testing it was possible to obtain a feel for the interaction between the fingers on the throttle and the throttle arms, as well as how the hand is used to rotate the control unit. Additionally, information about the height, and size of the control unit was gained, about which directions the control units are turned in for certain manoeuvres and about the fact that the control units are mainly turned towards each other instead of away from each other to avoid damaging the thrusters.

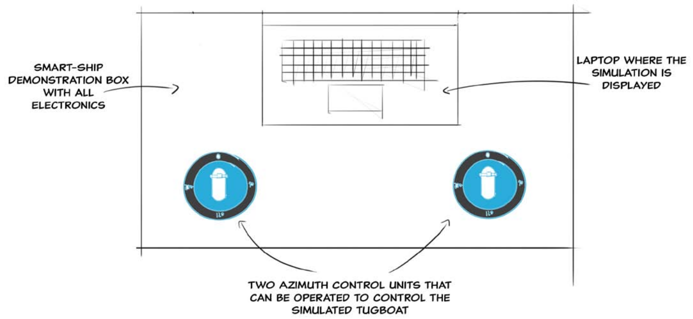
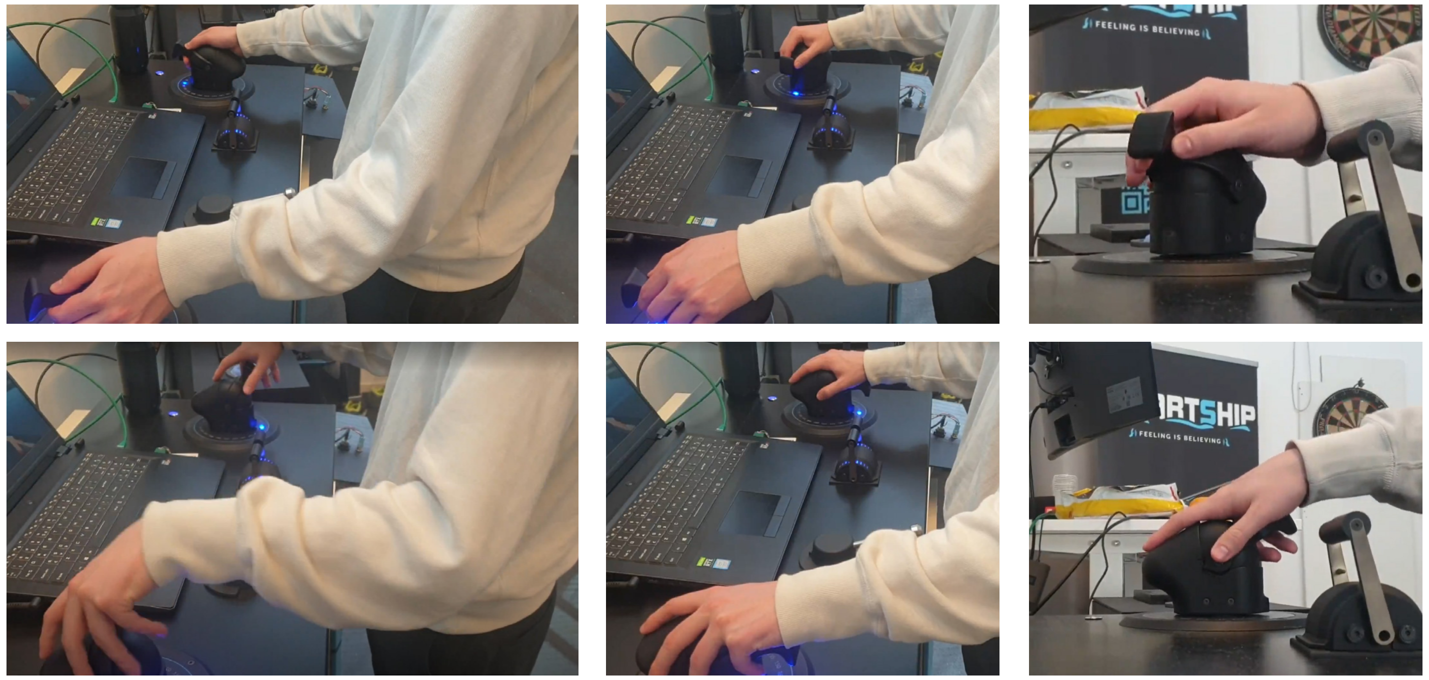



Figure 26: Illustration of the Simulation Box



Figures 27 - 32: Images of the Simulator Testing of an Azimuth Stern Drive Tug on the V-Step Simulator

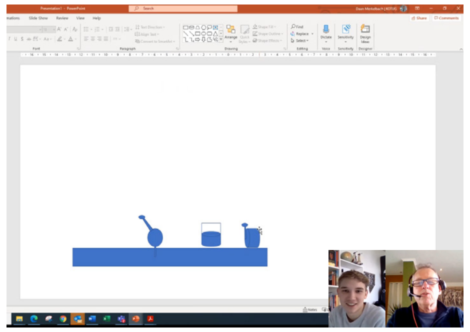
From the testing it was possible to formulate the following design requirements:
- The throttle should be operated through at least the thumb or index finger
- The control unit should be at least 120 mm long
- The control u nit should have a shape that allows the operator to securely hold it
- The control unit should be designed with focus on inwards movements
- The control unit should have smooth edges
- Easy to clean shape and material

# 3.8 Interviews

Over the course of the research phase, three interviews were carried out. All three were conducted online and through different platforms. The first interview was used to get a general overview of the topic. The second interview was used to validate if the research applies to larger tugboats such as AHTS vessels. The third interview was conducted to gain specific information about directional feedback, preferences of features in control units and different interactions between the operator and the control units.

From the interviews useful information was gathered which can be summarized as followed:

-Different types of ships have different azimuth control units
-Tugboat operators have their hands constantly on the controls
-Tugboat operators look outside a lot
-Directional feedback is very important to operators
-The possibility of resting the palms is very important
-Control units are used in simulators for training and testing
-Detents are very nice since they allow for more precise adjustments
-Operators mostly sit but some stand during operations
-During operations both hands are on the control units
-Whilst free sailing one hand on one of the control units
-During autopilot no hands-on are on the control units
-Important to understand if the azimuth thrusters are aligned with the control unit
-It is most comfortable if the throttle can be actuated using the thumb and index finger



*Figures 33 - 35: Interview with Daan Merkelbach on MS Teams (Screenshots)*

From these insights, it was possible to create the following requirements:
- Control unit can be used in simulation environment
- The control unit should be shaped so the operator can rest his palm
- Throttle lever should be operated comfortably from normal hand placement
- The control unit should be able to be turned easily
- The control unit should be identical for each thruster
- The control unit could be used whilst sitting and standing
- The control unit should have a clear shape difference between the front and the back
- The throttle should be comfortable for reversing and using the palm for throttle adjustment
- The throttle should be operated through at least the thumb or index finger

# 3.9 Questionaire

A questionnaire was made for tugboat operators. It consisted of 12 questions. The questionnaire was sent to two tugboat operators, one in the Netherlands and one in New Zeeland. Both forwarded it to their colleagues all over the world. In total 24 tugboat operators answered the questionnaire.

The answers showed that more than half the operators are over 40 years of age, that directional feedback is very important to most of them. In addition to this, it showed that Schottle and Rolls Royce control units are the most comfortable as they have a place to rest their palms. When asked about the interaction during an operation, most of the tugboat operators stated that they sit, however some said that they prefer to stand. One of the most relevant results was that their hands are always on the control units during an operation, and that they use only one hand to steer the tugboat when free sailing.

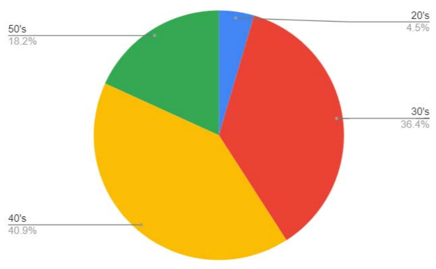



*Figure 36: Age distribution of Operators that answered*

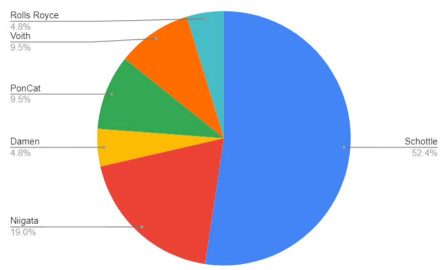



*Figure 37: Current Control Unit used by Operators*

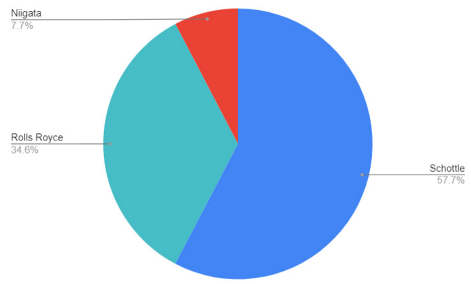



*Figure 38: Preffered Operator's Control Unit from the Examples*

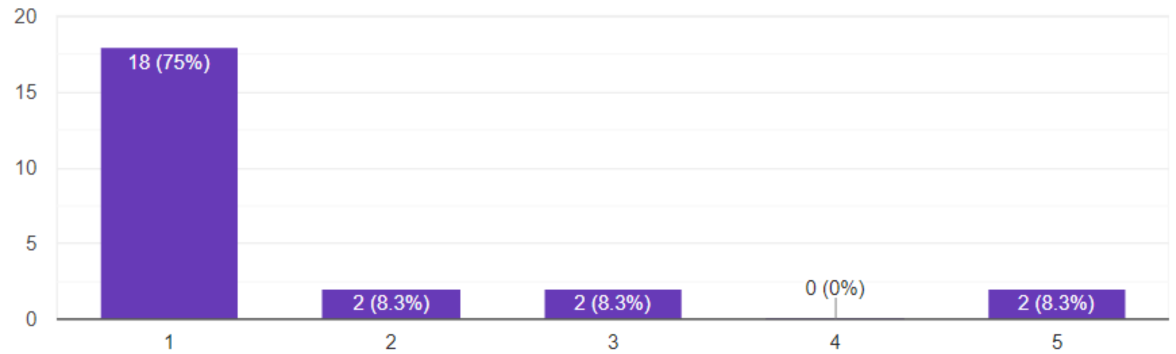



*Figure 39: Importance of DIrectional Feedback ((Very important left --> not important at all right)*

As the questionnaire was very insightful, relevant requirements could be formed:
- The control unit should have a Robust Construction
- The control unit should be shaped so the operator can rest his palm
- The material should be comfortable for the majority of operators
- The control unit should be identical for each thruster
- The control unit could be used whilst sitting and standing
- The control unit should have a clear shape difference between the front and the back

# 3.10 Stakeholders

The final product is aimed at tugboat operators. However, it is important to understand who these operators interact with as they can influence the design of the project.


Figure 40: Stakeholder Map

At the moment, Asia is dominating the global maritime trade. (Unctad, 2020) Therefore, it can be assumed that the control unit that is being developed in this project will be eventually sold to the Asian market. For this reason, it is important to analyse the cultural differences that could impact the understanding of the control unit by tugboat operators.

Because of this, research was done to understand several aspects: How are "Operating condition colours" perceived in Asia? And, if Smart-Ship was to create an instruction manual, which requirements would they have to consider depending on the cultural differences?

When looking into operating condition colours, research shows that there are discrepancies between Asia and Western countries, but also between Asian countries in the understanding of which colour represents which operating condition. (D. Zühlke, M. Romberg, P. Meil, 1998) The research found that in Western and Asian countries there are no discrepancies found for the colours of "Emergency Situation" (Red). In principle it can be said that colours have a similar attention stimulus regardless of what context they are seen in. For western culture this means that the colour red can stand for Anger, Danger, Excitement, Love and Passion. Emotionally the same excitement or attention is created in people. In Japan the colour also stands for the same emotions and therefore it makes sense that it is also seen the same there. For Hindu culture the same can be seen, as red also stands for Energy and Passion. Whilst it does not have negative connotations it is still connected to excitement.



# 3.10 Stakeholders

However, when looking at the operating condition colour for "Warning" the trend in the Asian countries is yellow, except for China and Korea where they do not have a difference between "Emergency situation" or "Warning" and chose red. This is because in these two countries, they only differentiate between a situation where action is required, or no action is required. According to H. Qiang (2011) in China, red indicates that there "may" be an emergency and that it is used as a warning colour. Additionally, the operating condition "Normal State" trends to be represented by the colour green. Except for China where the colour yellow was chosen by 80% to represent "Normal State". This could be based on the fact that according to the colourwheel by David McCandless, Yellow represents healthy in Chinese culture.
This shows that for some Asian countries culture specific particularities must be considered and the international standard cannot just be applied. The colours will need to be adapted by Smart-Ship in order to correctly communicate operating conditions.

Below, the colour of the operating condition can be seen and also which operating condition they would describe depending on the country.

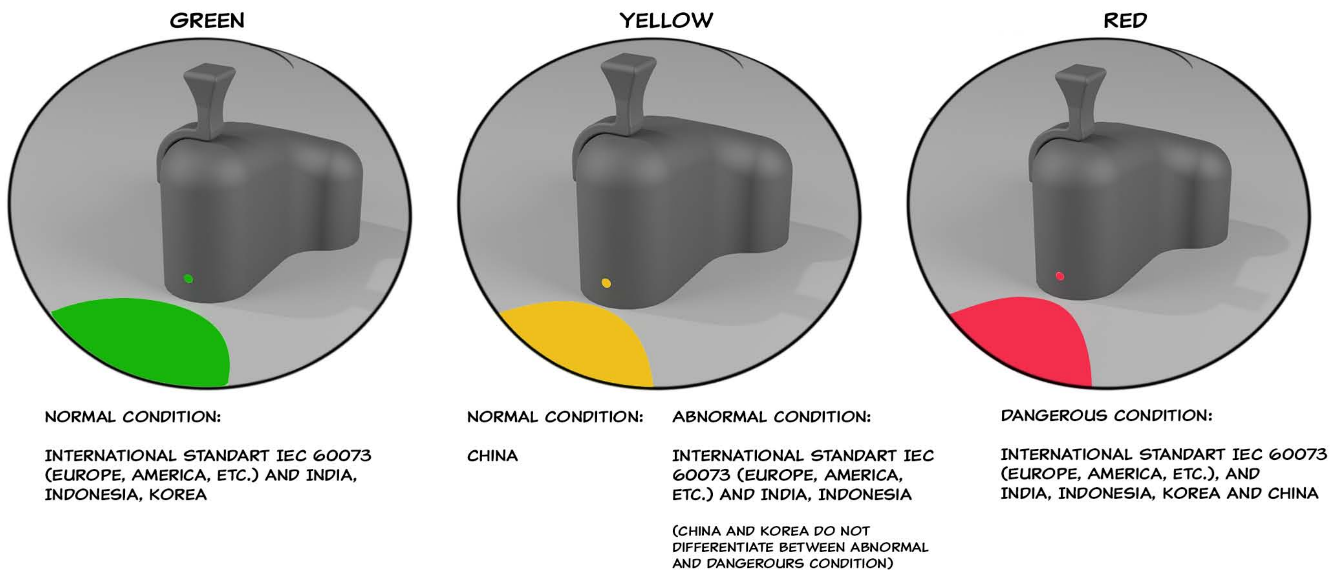



Figure 41: Operation Condition Colour understanding by different cultures

The requirements that were formed on the said wishes are as follows:
- The control unit should not require special tools to be opened
- Operation condition lighting can be changed by Smart-Ship

In appendix 5 a table of criteria is named which Smart-Ship would have to follow to ensure that an instruction manual is understood by stakeholders depending on their cultural background.

# 3.11 Values

Through the insights gathered in the research phase, certain problems could be identified in the contexts: Technical, Human Market and Environment. These problems were based on different values from each context.

**Technical Context:**
- Adaptability
- Quality
- Trust
- Maintainability
- Independence

**Human Context:**
- Human Wellbeing
- Health
- Reliability
- Power
- Cleanliness
- Safety

**Market Context:**
- Versatility
- Competitiveness
- Profitability

**Environmental Context:**
- Disposal
- Sustainability

| Context | Problem | Values | Requirements |
|---|---|---|---|
| Human | No available or small palm rest | Human Wellbeing | The control unit should be shaped so the operator can rest his palm |
| Human | Throttle cannot be actuated precisely | Human Wellbeing, Safety | The throttle should be operated through the thumb or index finger, or with the help of the middle, the ring, and the pinkie finger |
| Human | Many small movements can cause health problems in the lower arms | Health | The control unit should be elongated to reduce ulnar deviation |
| Human | Not all control units have directional feedback which is critical | Trust, Safety | The control unit should have a clear shape difference between the front and the back |
| Human | Control units don't consider wrist position | Health | Control unit should slightly angle the operator's wrist in the forward driving position |
| Human | Control units are shaped uncomfortably | Health | The control unit should follow the contour of the hand in the forward driving position |
| Human | The control unit should have no sharp edges so the operator does not cut himself | Safety | The control unit should have smooth edges |
| Human | Operation condition light does not mean the same depending on the culture | Reliability | Operating condition lighting can be changed by smart ship |
| Human | Control unit needs to be able to be used sitting and standing | Power | The control unit could be used whilst sitting and standing |
| Human | Operators and students sweat on the controls | Cleanliness | Easy to clean shape and material |
| Human | Control units don't have enough grip to hold unit | Safety | The control unit should have a shape that allows the operator to securely hold it |
| Technical | The control unit needs to perform well should not break | Quality | The control unit should have a Robust Construction |
| Technical | The electronics cannot get damaged by water | Quality | The control unit should be Water and Dust resistant |
| Technical | The operator should feel the haptic feedback transferred from the electronics | Trust | The control unit allows for haptic feedback |
| Technical | It should be possible to make quick repairs | Maintaibalility | The control unit should not require special tools to be opened |
| Technical | Due to legislations the control units should not be connected to one another | Independence | The control units should not be connected with one another. |
| Technical, Market | Control unit needs to be used for tugboats and simulators | Adaptability, Versatility, Profitability | Fits onto current mounting mechanism created by Smart-Ship, Control unit can be used in simulation environment |
| Market | The control unit needs to be competitively priced | Competitiveness | Competitive pricing of the unit |
| Market | The parts for each control unit should be the same for easier manufacturing | Profitability | Control unit should be identical for each thruster |
| Environment | The material the control unit is made of should be able to be eco-friendly | Disposal, Sustainability | The control unit should be made of eco-friendly materials |
| Environment | The manufacturing technique should be eco-friendly | Sustainability | The control unit should be produced using eco-friendly production methods |



# 3.12 Requirements

Below the list of requirements can be seen which is based on all the insights gathered from the research phase.

| Context | Hard/Soft | Requirements | Values |
|---|---|---|---|
| Human | Hard | The control unit should be shaped so the operator can rest his palm | Human Wellbeing |
| Human | Hard | The throttle should be operated through at least the thumb or index finger | |
| Human | Hard | Throttle lever should be operated comfortably from normal hand placement | Human Wellbeing, Safety |
| Human | Hard | The control unit should be designed with male hand anthropometrics in mind | |
| Human | Soft | The control unit should follow the contour of the hand in the forward driving position | Health |
| Human | Soft | The control unit should slightly angle the operator's wrist in the forward driving position | Health |
| Human | Soft | The control unit should be elongated to reduce ulnar deviation | Health |
| Human | Hard | The control unit should be at least 120 mm long | |
| Human | Hard | The control unit should be able to be turned easily | |
| Human | Hard | The material should be comfortable for the majority of operators | |
| Human | Hard | The throttle should be comfortable for reversing and using the palm for throttle adjustment | |
| Human | Hard | The control unit could be used whilst sitting and standing | Power |
| Human | Hard | The control unit should have a clear shape difference between the front and the back | Trust, Safety |
| Human | Hard | The control unit should have smooth edges | Safety |
| Human | Hard | The control unit should have a shape that allows the operator to securely hold it | Safety |
| Human | Soft | Easy to clean shape and material | Cleanliness |
| Human | Soft | The control unit should be designed with focus on inwards movements | |
| Human | Soft | Operating condition lighting can be changed by smart ship | Reliability |
| Technical | Hard | The control unit should be shaped so the operator can rest his palm | Trust |
| Technical | Hard | The control unit should have a Robust Construction | Quality |
| Technical | Hard | The control unit should be Water and Dust resistant | Quality |
| Technical | Hard | Fits onto current mounting mechanism created by Smart-Ship | Adaptability |
| Technical | Hard | The throttle lever should be directly connected to the azimuth control unit body | |
| Technical | Hard | Control unit has two degrees of movement | |
| Technical | Hard | The control units should not be connected with one another | Independence |
| Technical | Hard | The control unit should not require special tools to be opened | Maintainability |
| Market | Hard | Competitive pricing of the unit | Competitiveness |
| Market | Soft | Control unit should be identical for each thruster | Profitability |
| Market | Hard | Use of exisitng technology | |
| Market | Hard | The control unit should follow the Smart-Ship design language | |
| Market | Hard | Control unit can be used in simulation environment | Profitability, Versatility |
| Environment | Soft | The control unit should be made of eco-friendly materials | Sustainability, Disposal |
| Environment | Soft | The control unit should be produced using eco-friendly production methods | Sustainability |

With the context and program of requirements defined, ideation can be started. Though the use of diverging and converging techniques, several concept directions were created. After evaluating these directions using the requirements and expert testing, a final concept direction was created.

# Development

4

# 4.1 Iteration 1 - Ideation

**Brainstorming:** Using the insights gathered from the research, ideation started. The process began with Brainstorming. It was used to come up with as many ideas as possible related to the findings of the research. As Brainstorming is based on the principle of ignoring premature criticism, it was a good method to use, in order to allow for free ideation.

**Random Image Stimulation:** In addition to brainstorming, random image stimulation was then used to try to find solutions from a different angle. To each random image generated, the first idea that came to mind was sketched on a piece of paper. This way, a solution was sketched which related to the problems found in the research. Whilst not all ideas were realistic, they were added to the total set, without directly being jugged. To obtain the random set of images, Randomwordgenerator.com was used.

The goal of using Brainstorming and Random image stimulation was to come up with as many ideas as possible which could potentially be interesting, without spending too much time on any of them.

All the initial sketches that were drawn using the two methods can be seen below.

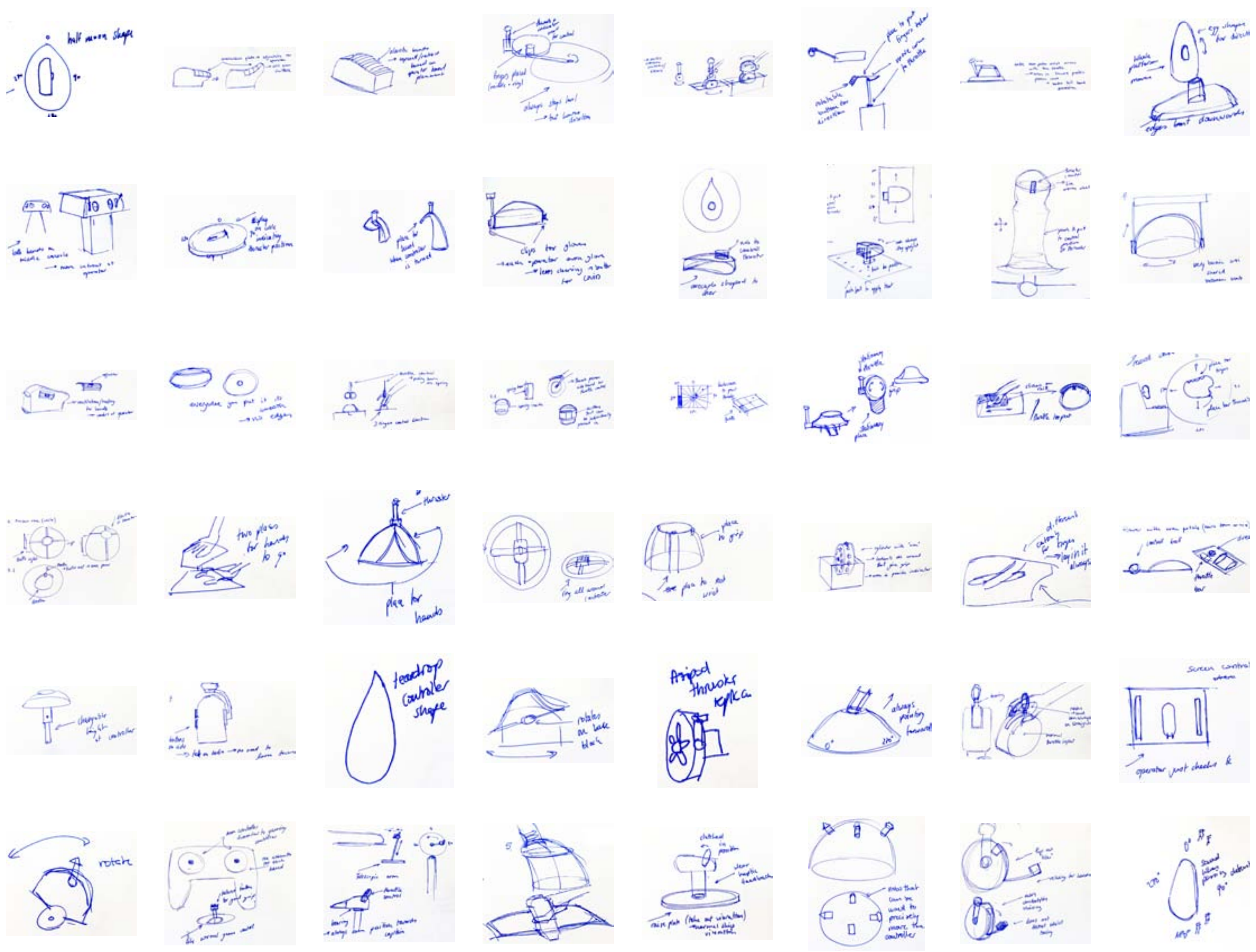


*Figure 42: All sketches from the Brainstorming and Random Image Stimulation*

# 4.2 Iteration 1 - Four-Box Method

**Four-Box Method:** After having sketched 48 ideas, it was necessary to evaluate them in order to find out which of them were the most promising. For the evaluation the Four-Box method was used. As comfort of use and directional feedback are the two most important needs of the project, they were chosen for the two axes of the Four-Box method. The method creates four quadrants where each sketch, depending on how well it scores against the two criteria, is placed inside.

Knowing then which ideas were the most promising ones, it was possible to select them and to drop the rest. The Four-Box method can be seen in figure 43 below.

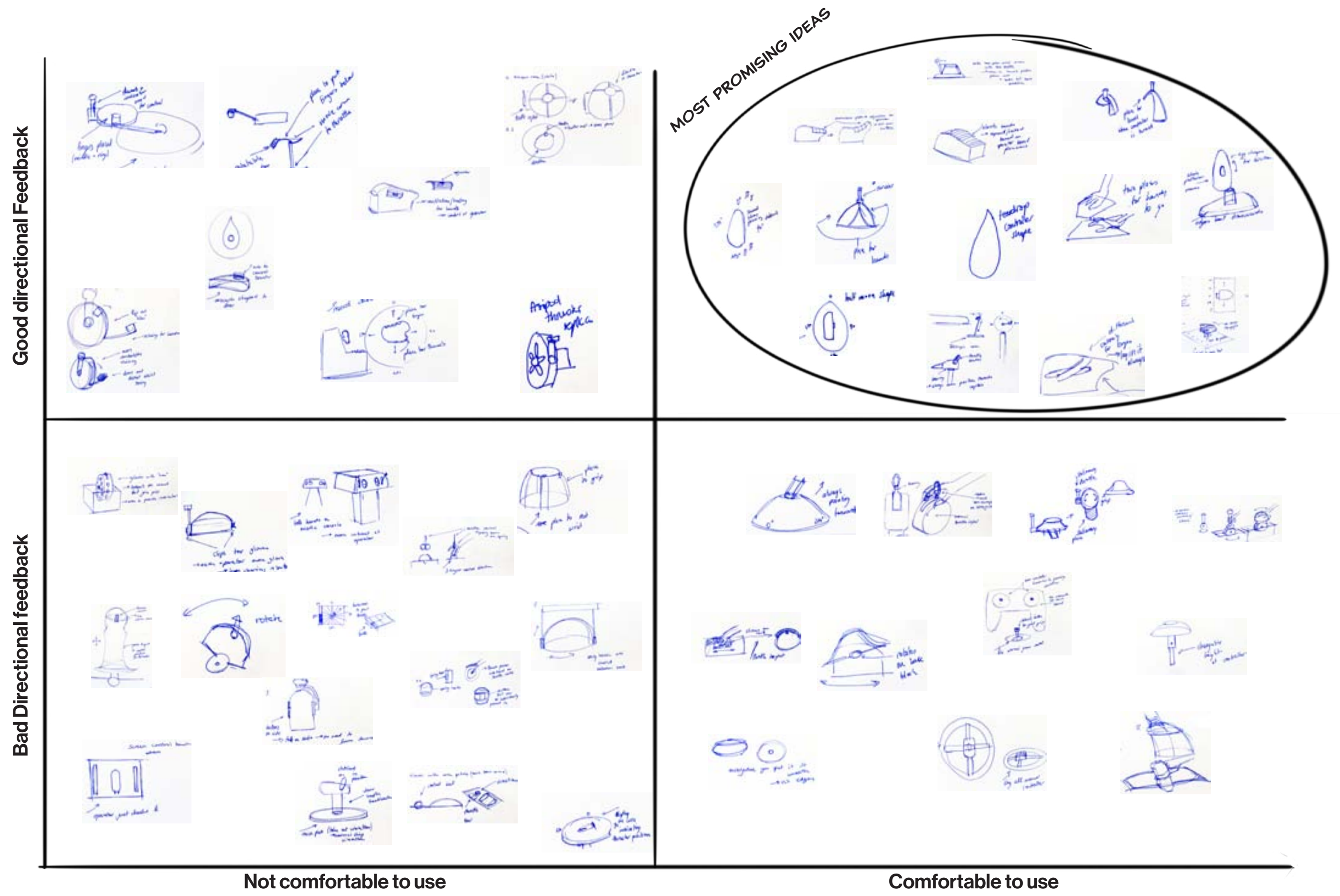



*Figure 43: Sketches placed in the Four-Box table after evaluating them according to comfort and directional feedback*

| | | |
|---|---|---|
| Technical Context: | Considered | Not applicable |
| Human Context: | Considered | Not applicable |
| Market Context: | Considered | Not applicable |
| Environmental Context: | Considered | Not applicable |

# 4.3 Iteration 2 - Update Sketches

As the sketches in the Four-box method were very basic, the most promising ones from the top right quadrant were then re-sketched.

These new sketches contained more detail to offer a better understanding of them to the client, and to make it possible to evaluate them through the PMI method.

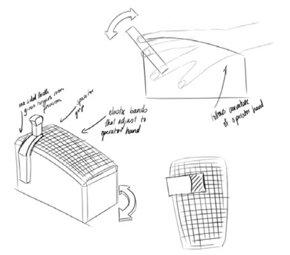


Figure 44: Sketch of idea 1

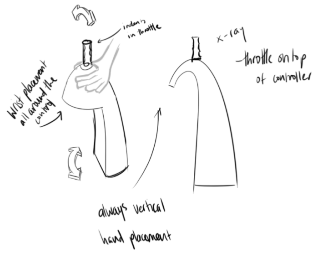


Figure 44: Sketch of idea 2

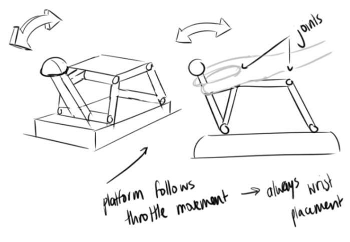


Figure 45: Sketch of idea 3

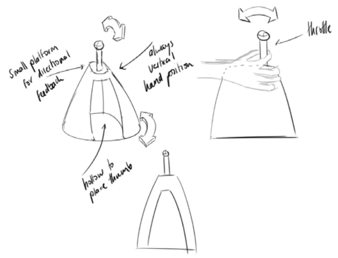


Figure 46: Sketch of idea 4

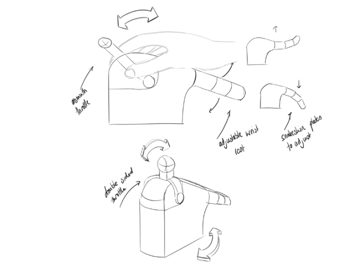


Figure 47: Sketch of idea 5

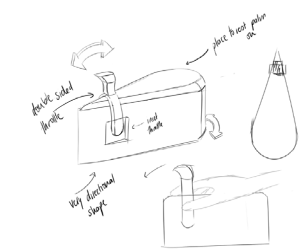


Figure 48: Sketch of idea 6

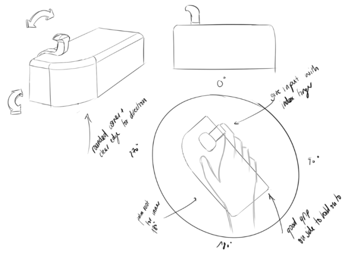


Figure 49: Sketch of idea 7

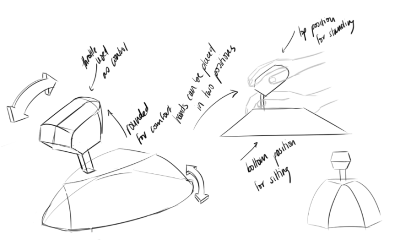


Figure 50: Sketch of idea 8

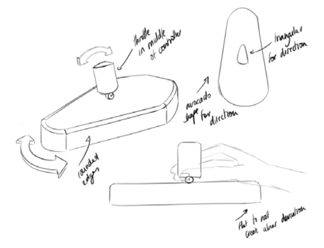


Figure 51: Sketch of idea 9

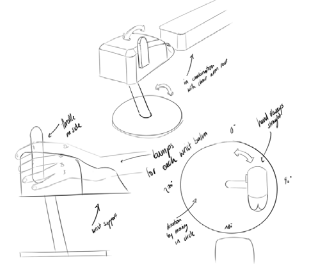


Figure 52: Sketch of idea 10

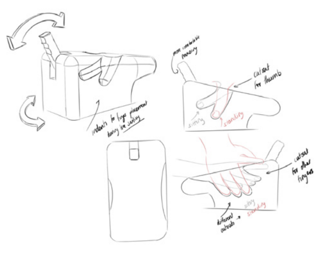


Figure 53: Sketch of idea 11

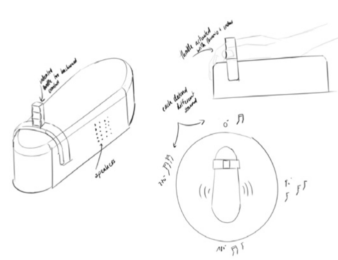


Figure 54: Sketch of idea 12

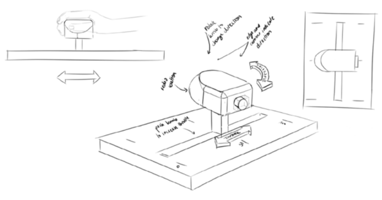


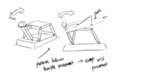
Figure 55: Sketch of idea 13

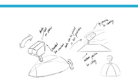
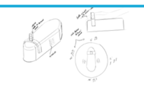
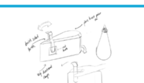
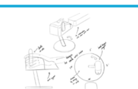


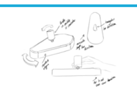
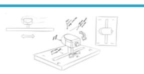
# 4.3 Iteration 2 - PMI Method

**PMI Method:** The PMI method is used to judge ideas intuitively. The method allows the user to first evaluate the ideas critically and to find aspects that the ideas can be creatively improved upon. For each idea, the positive and negative features are listed, and additionally interesting facts about the idea can be named.

After the ideas were evaluated as can be seen in the PMI table below, it became apparent that from the 13 ideas, two did not meet one of the hard requirements (similarity to current Smart-Ship control unit) and were consequently removed from the set. On top of this, it became clear that some of the ideas were very similar and, therefore, it was decided to merge them for further idea development.

| | 1  | 2  | 3  | 4  | 5  |
|---|---|---|---|---|---|
| P | - The elastic bands allow some adaption of the surface to the operators hand, the one sided throttle gives operators more precision and the thumb has more space, direction is clear through the elevation | - Hand of the controller is placed vertically, direction is shown as half of the controller is open on the bottom | - When throttle is applied the body moves forward removing the need to move the hand, direction is clear since throttle is infornt and felt directly | - Vertical shape gives more neutral hand position, slot in the middle allows for it to be grabbed properly, during free sailing thumb can be placed inside for handshake like position | - Clear shape where the front or back is, operator can adjust the wrist position to his liking, can be used with Smart-Ship electronics |
| M | - Open for water to sink in, bands can create pressure points and be uncomfortable over longer time, soft material will dampen vibrations so it is contraproductive | - Not compatible with smart ship electronics, to feel direction operator has to feel downwards to check where the edge is | - Control is open and electronics of smartship are visible, hard to seal against water, shape has rough edges, palm support could create pressure points | - Throttle is placed too far up, open gaps will be uncomfortable and dont offer wrist support, not possible to implement with current smart ship electronics | - Scales make hard to clean areas especially since sweat is involved, involves moving parts which can break, very simmilar to current Smart-Ship controls |
| I | - Surface of the control unit slightly conforms to hand | -hand is always in a vertical position | | | |

| | 6  | 7  | 8  | 9  | 10  |
|---|---|---|---|---|---|
| P | - Has wrist support in the inner 180 degrees, clear directional shape due to camfer and clear edge, one sided throttle makes it possible to use fingers for precise adjustments | - Control can be used comfortably whilst sitting and standing, height change makes wrist position better clear direction as desing becomes smaller towards the front | - Audio cue when controller passes a detent which means they dont have to check, elongated shape means hand can be rested in forward position, slight decrease in size towards the front gives extra direction indicator | - Clear directional feedback, larger backside allows for more room for wrist placement, can be used with Smart-Ship electronics | - Hand of operator is always forward, the wrist support has a place for each wrist balm, throttle can be actuated with index, middle and ring finger |
| M | - Corners are not smooth enough in the inside, little wrist support for movements outwards, control does not follow operators hand | - Hard to switch over the control towards the lower 180 degrees due to the large size of the throttle, no precise input is possible for standing position as whole hand is used for input | - Audio cues can become a nuisance over time as the same sounds are played, especially during towing or intense manouvers | - Front of control is too thin so holding it whilst reversing can become an issue as not enough area can be held with thumb index and middle finger. | - Different direction input to current azimuth controls, does not work with Smart-Ship electronics |
| I | - Wrist support in forward position and most common steering positions | | | | |

| | 11  | 12  | 13  |
|---|---|---|---|
| P | - Palm can be placed all around the control unit, flat shape means less ulnar deviation, avocado shape indicates directional feedback | - Indents for fingers for free sailing whilst standing and sitting, indents allow for fingers to rest | - Clear directional feedback in shape, control can be fully gripped to turn easily, angled wrist support at inner 180 degrees, place to rest thumb in free sailing |
| M | - Throttle in the middle cant be moved 90 degrees forward, flat and very long shape makes it hard to grab and twist | - Create pressure points when rotating the controller, very simmilar to current Smart-Ship control, throttle can only be actuated with thumb and index finger | - Throttle input different to current azimuth control units, does not work with Smart-Ship electronics, Radio button not usefull on control unit |
| I | - Wrist support all around the control unit | | |

| | | |
|---|---|---|
| Technical Context | Considered | Not applicable |
| Human Context | Considered | Not applicable |
| Market Context | Considered | Not applicable |
| Environmental Context | Considered | Not applicable |

**Ideas to combine:**
Ideas 8, 9, 11 have a simmilar shape and could be combined into one good idea with a avocado/peach like shape that offers good wrist support in forward and slight sidwards positions.
Ideas 2, 4 focus on a vertical design and features of both could be used to create a good vertical hand position design.

**Ideas to throw out:**
Idea 5 could be comfortable, however it resembles the current Smart-Ship model and does therefore not pass the Hard requirement.
Idea 12 has upsides for free sailing but no real value to the entire operation range. As the idea also resembles the current Smart-Ship model it also does not meet a Hard requirement

# 4.3 Iteration 2 - Ideation

## CONTROL UNIT 1

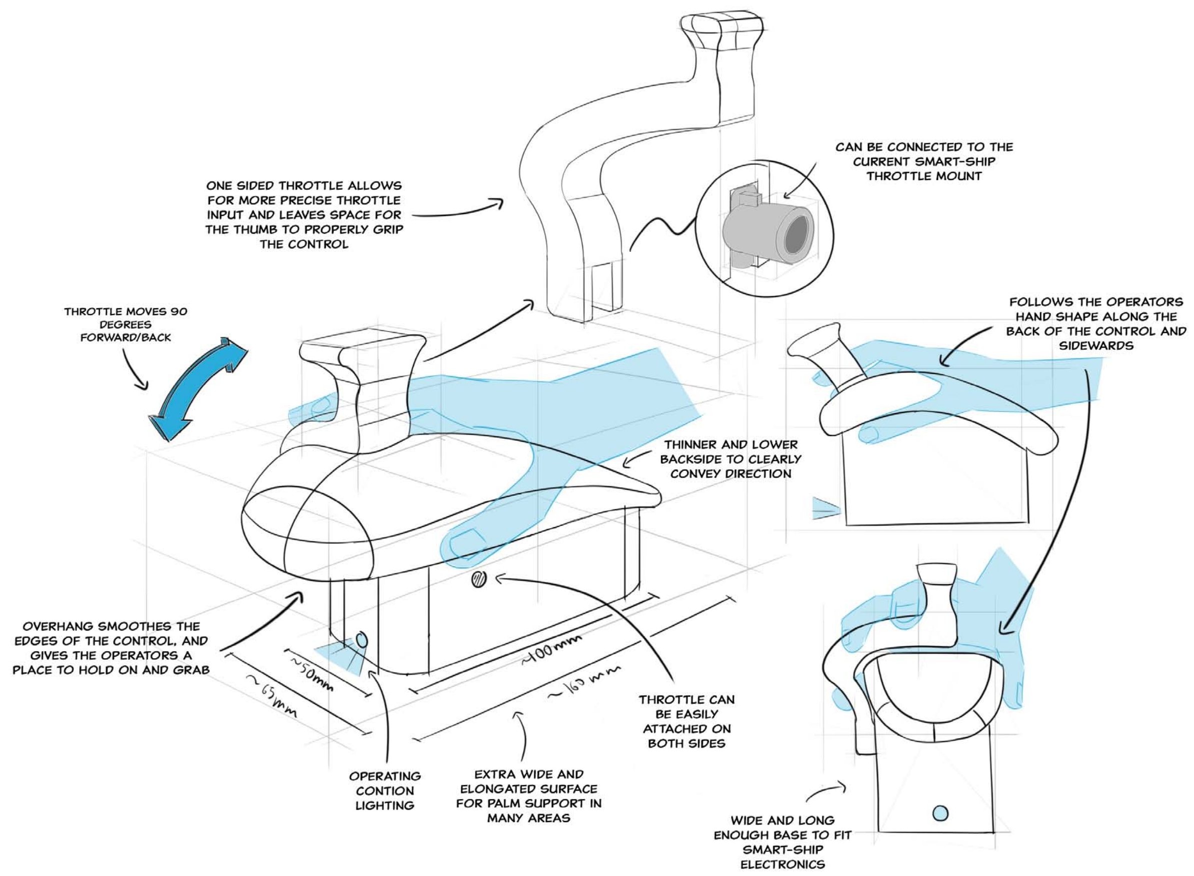



*Figure 56: Illustration of Control unit 1*

Control unit 1 is made up of a relatively large body, with a one-sided throttle attached to it. The large body of the control unit, in combination with the one-sided throttle, will allow the operator to have good palm support in the more often used areas of the turning circle. As the throttle is only placed on one side (on the right for the right hand, on the left for the left hand), the thumb can be used to securely grip the control unit. Therefore, at least two of the remaining fingers will naturally lie on the throttle arm, which makes it possible for the operator to give precise throttle input. Another feature of this control unit is the overhang of the hand placement area. This overhang gives the operator the option to fully grab the control unit to address a sudden manoeuvre or in case of heavy seas. As the body of the control unit is curved to follow the operator's hand in any direction, it will be very comfortable during free sailing, but also whilst performing other manoeuvres. Additionally, as the control unit follows the contour of the hand and the throttle is only on one side, directional feedback would be very clear to the operator.

The lower part of the body is wide enough to accommodate the control converter that is required to connect the control unit with the electronics. And as the throttle is placed on the outside of the body, the current throttle mount can be used. In addition to this, the throttle could be mounted on either side. For that a hole is already inset in the side of the body to easily screw the throttle in.

The operating condition lighting would be placed in the front on the base of the body as it will never be fully covered there. As the control unit can be used for either hand, having it in the front means it will only require one light.



# 4.3 Iteration 2 - Ideation

## CONTROL UNIT 2

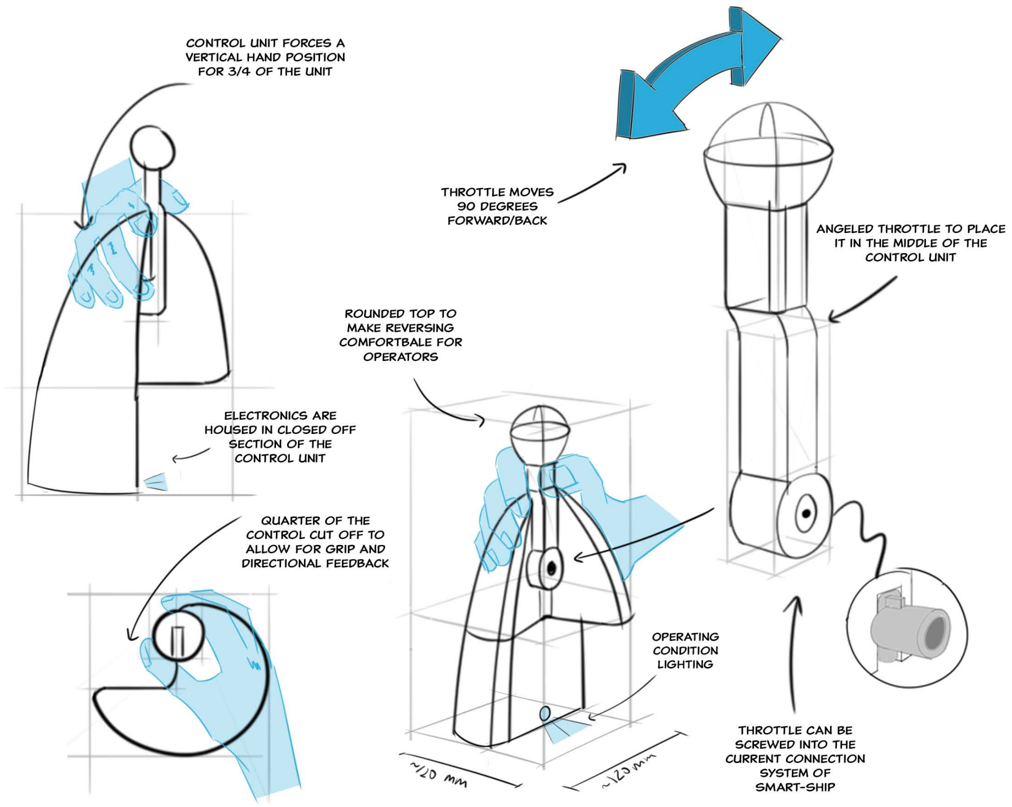



*Figure 57: Illustration of Control unit 2*

The idea for the second control unit originated in ideas two and four from the PMI. Control unit 2 focusses on placing the operator's hand in a more natural position. This is achieved for ¾ of the control unit with one quarter not being present to give directional feedback to the operator and allow space for the throttle.

The throttle itself can be connected to the body with the current throttle mount, and has a bend in the middle, to be placed precisely in the central axes of the control unit. This will allow the operator to use his thumb and index finger to give throttle input. As the throttle has a sphere on the top, it will not create pressure points in the operator's palm.

The half of the control unit that is connected with the ground makes it possible to house and protect the control converter by Smart-Ship. The operating condition light would also be housed there and illuminate the area below the control unit.

# 4.3 Iteration 2 - Ideation

## CONTROL UNIT 3

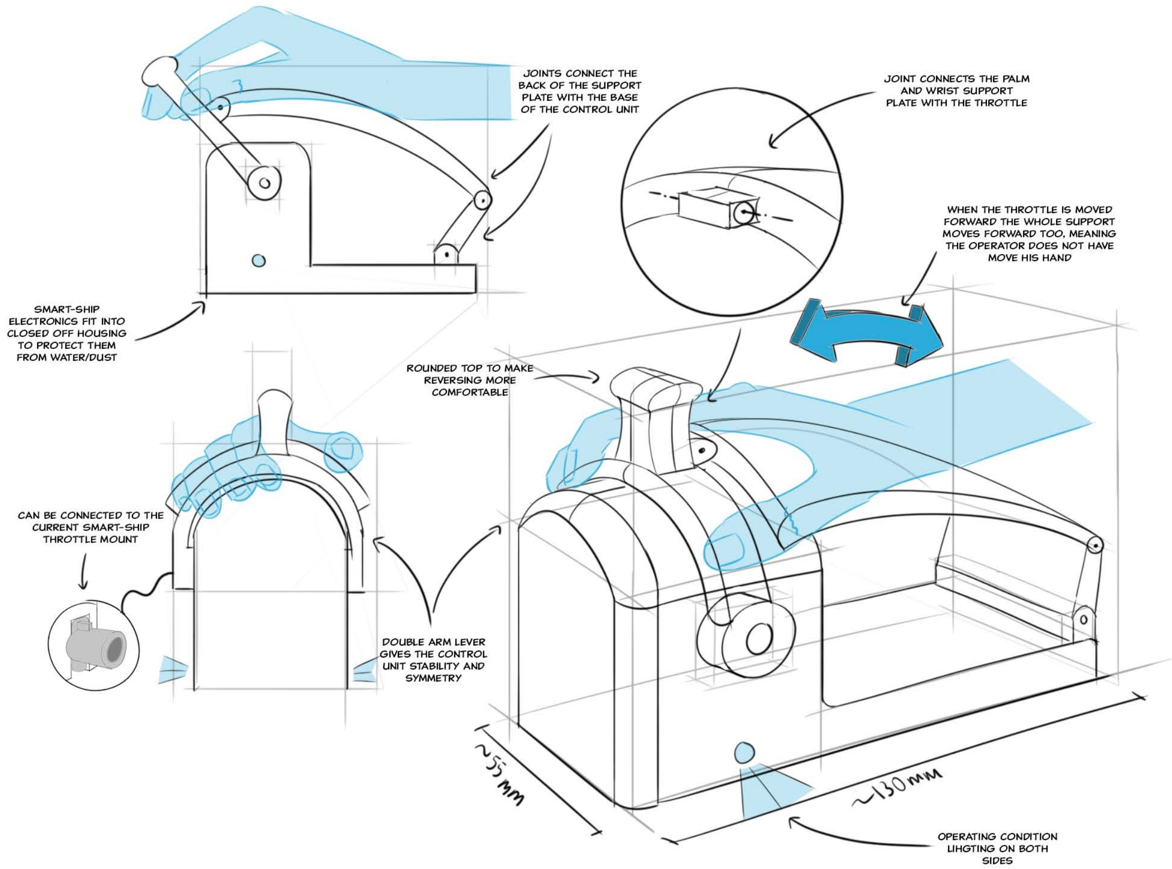



*Figure 58: Illustration of Control unit 3*

The third idea aims at removing the need to move the hand when using the throttle. Currently when the throttle is moved forward, the hand also has to be moved to continuously give precise throttle input. In this idea, the palm and wrist support would follow the throttle forwards. The body of the control unit would consist of a box with rounded corners that houses the control converter of Smart-Ship. The control converter would be connected to the throttle arm with the throttle mount on both sides. The throttle would then connect to the palm support via a joint. At the end of the palm support, another joint would connect it to the body of the control unit again.

Since the throttle is connected via two arms, the operator could actuate the throttle using all his fingers or by using his thumb and index finger at the throttle neck. Additionally, the double-sided throttle arm would give support to the control unit and give it symmetry which would make production easier.

As the whole wrist support moves forward, the operating condition lighting needs to be placed on either side of the control unit to be seen by the operator.



# 4.3 Iteration 2 - Ideation

## CONTROL UNIT 4

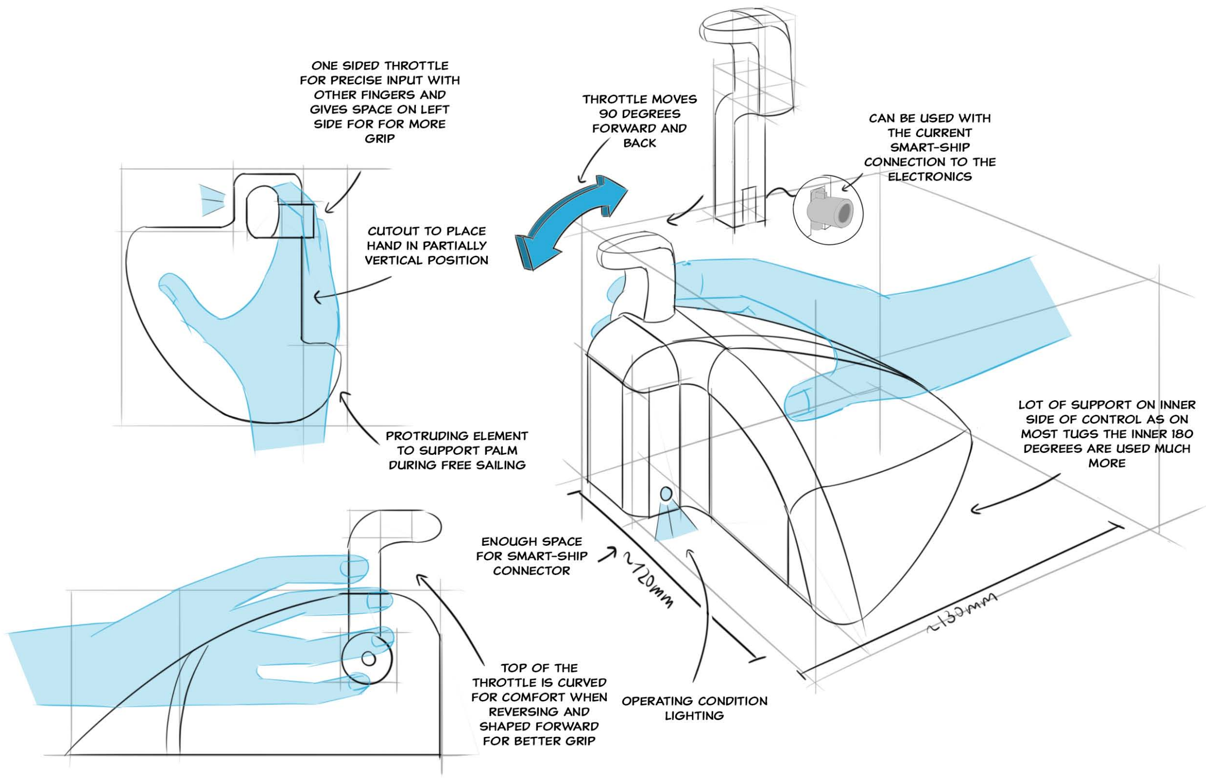



*Figure 59: Illustration of Control unit 4*

Control unit 4 aims to give the operator ample space for proper grip and providing support for much of the inner 180 degrees of turning. (Usually, operators will turn their control units towards each other rather than away from each other as this could cause damage to the tugboat). By also slightly extending the support to the outer side of the control unit, the operator would also have palm support in the forward driving position. However, this extension does not reach over the entire side of the control unit to allow the hand of the operator to get in a more vertical position which reduced the pressure in the carpal tunnel. These features of the design would not only aid comfort but also help with the clear directional feedback of the control unit.

The throttle is placed on the outer side of the control unit to give the operator the option to actuate it using either his thumb or index finger, or his middle and ring finger, according to his preferences. This one-sided throttle also makes it possible for the operator to use his thumb to better grip the control unit. The head of the throttle is curved forward to feel comfortable in the operator's palm, and to be supported by the ring and middle finger.
The control unit is large enough to easily fit the control converter by Smart-Ship.

This control unit not being symmetrical means that production will be complicated as two distinct models have to be made. The operating condition lighting would be placed in the little cut out on the inside of the control unit as there the throttle will not cover it and it can be checked easily by the operator.

# 4.3 Iteration 2 - Ideation

## CONTROL UNIT 5

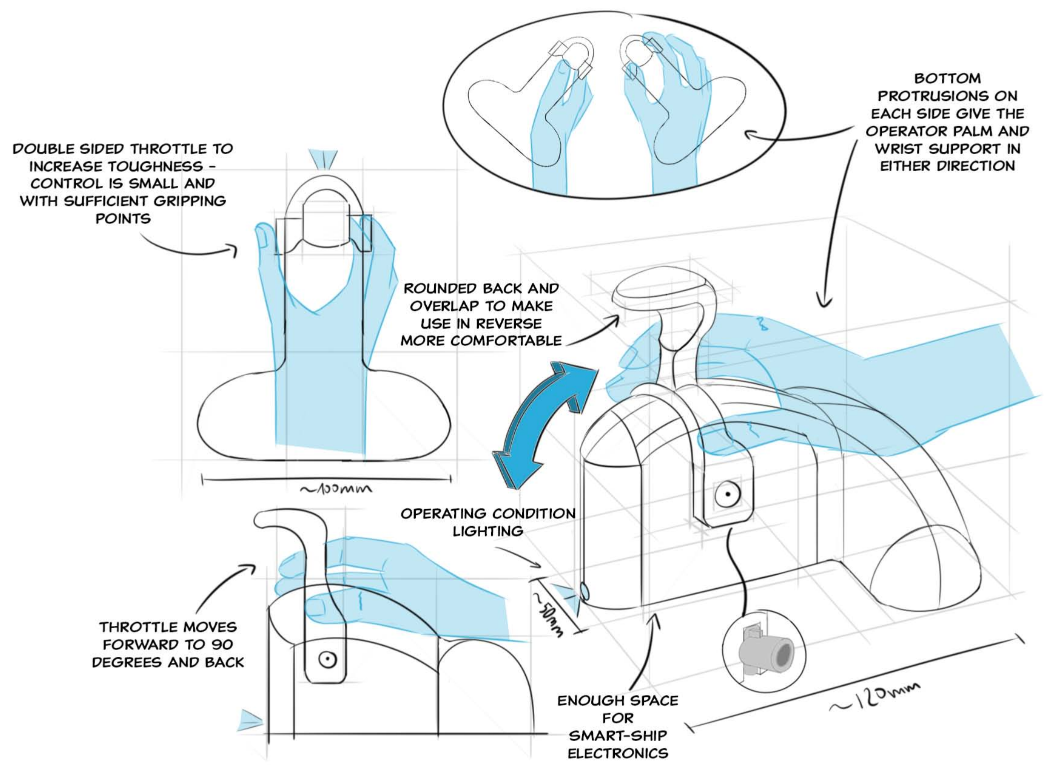



Figure 60: Illustration of Control unit 5

The idea for the fifth control unit was the result of merging ideas 8, 9 and 11. These three ideas had an avocado like shape, which was derived into a reversed T shape. This way, the operator would have suf-ficient palm support for the inner 180 degrees and during the forward driving position, as well as offer-ing enough space for the fingers to grip the control unit. The body of this idea follows the principle of control unit 4 where the operator's hand is placed in a vertical position by offering some support on the outer side of the control unit.

The throttle of the control unit 5 could be attached to the control converter from Smart-Ship on either side of the body. This strengthens the throttle and gives the operator the choice to give throttle input using his thumb and index finger on the throttle neck, or by using the thumb and other fingers on the throttle arms. Being connected on two sides to the control converter would also allow for more pre-cise haptic feedback.

The throttle head is smoothly curved forward to feel comfortable in the operator's palm whilst revers-ing, and to give support to the ring and pinkie finger.

As the control unit is symmetrical, the production would be simplified as the same model could be used by either hand. However, this also means that the operation condition lighting will have to be placed in the front of the control unit, to be easily visible for the operator.



# 4.3 Iteration 2 - Ideation

## CONTROL UNIT 6

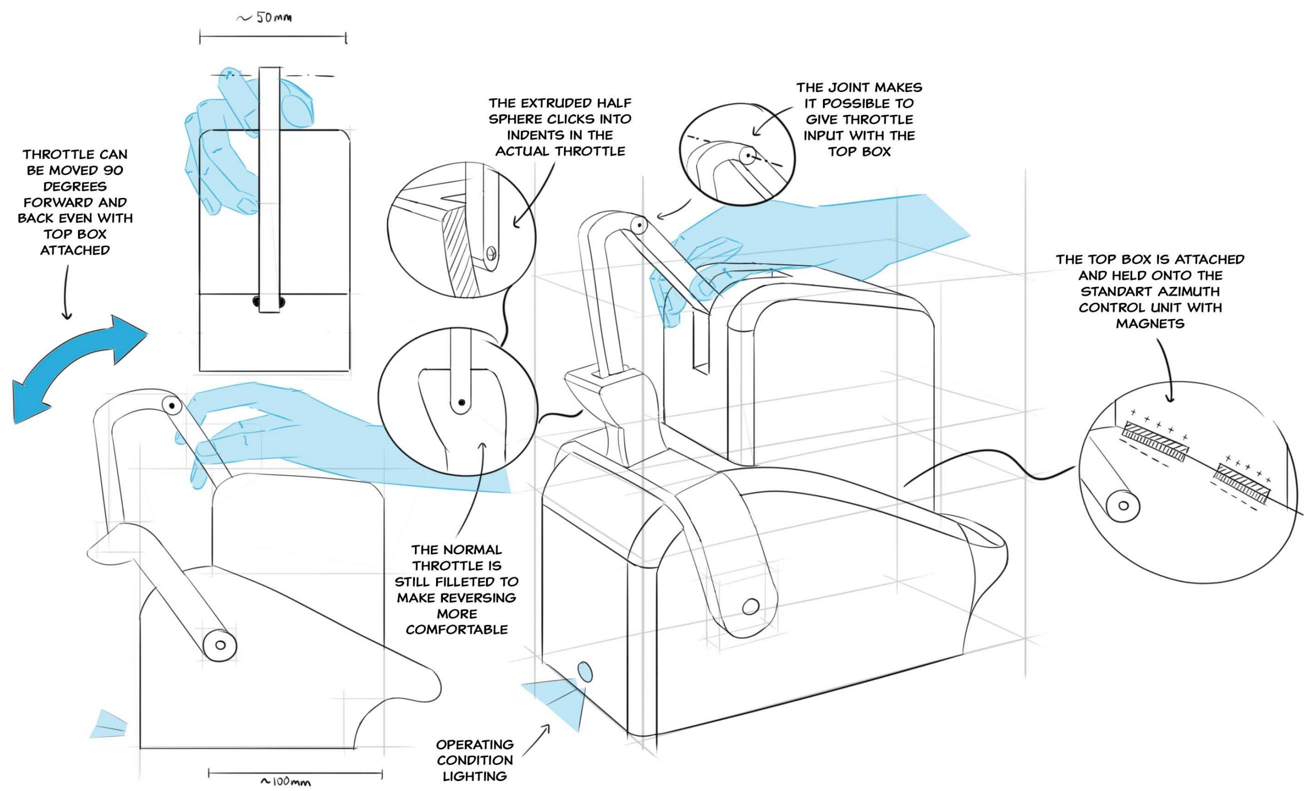



Figure 61: Illustration of Control unit 6

Control unit 6 is not an idea for an entire control unit, but an attachment that operators could use to be more comfortable whilst operating standing up. This attachment would connect to the current Smart-Ship control unit using magnets and a clip-in system in the throttle. The magnets attach the body to the actual control unit, whilst the clip-in system makes sure that the throttle can be actuated. The attachment is made of the body and a throttle arm connected to a joint. This throttle arm would clip into the actual control unit throttle. The body of the attachment would have rounded edges to prevent pressure points in the operator's palms.

As it is only an attachment and not connected to electricity, the operating condition lighting would need to be installed on the actual azimuth control unit.

# 4.3 Iteration 2 - Ideation

## CONTROL UNIT 7

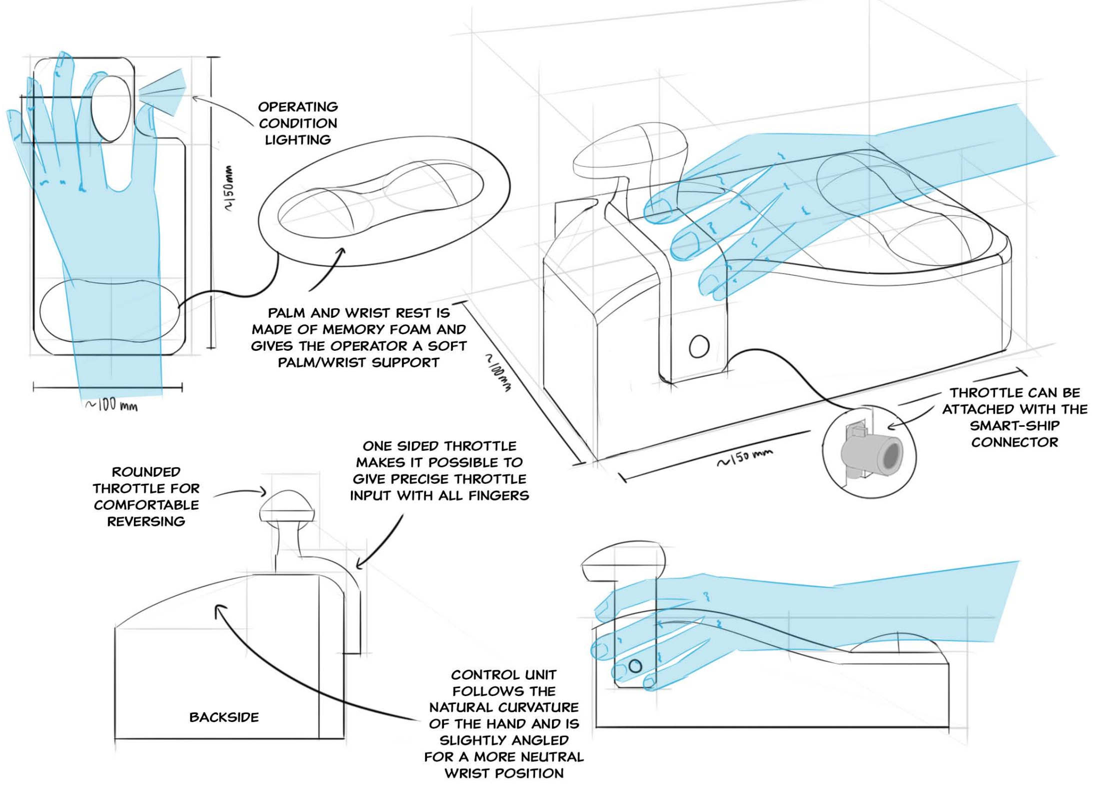



*Figure 62: Illustration of Control unit 7*

The idea for control unit 7 was based on idea 10 of the PMI method. There it could be seen that the idea does not work with the Smart-Ship electronics and the directional input would be completely different to what operators are now used to. As the basic shape of the control unit could be comfortable it was mainly kept, however a small cut out on the inner side was added. This cut out would allow the operator to properly grip the control unit with the thumb. As the control unit has a one-sided throttle, the throttle could be operated with the other fingers. Contrary to the initial idea, the throttle now contains a bend that places the throttle neck more in the centre of the control unit so that it could also be actuated with the thumb and index finger if the operator so chooses.

In the back of the control unit a pad with memory foam would make free sailing or driving in the forward position very comfortable. The difference in height between the front and back of the control unit, the one-sided throttle, and the memory foam on the bottom of the control unit, would make it very clear to the operator where the control unit is pointing to.

The throttle head would be rounded to make operation comfortable, and the elongated shape would allow the operator to hold it with the ring and pinkie finger when going in reverse.

The operating condition lighting would shine out of cut out on the inner side so the operator could easily glance at it to check if everything is working fine.



# 4.3 Iteration 2 - Ideation

## CONTROL UNIT 8

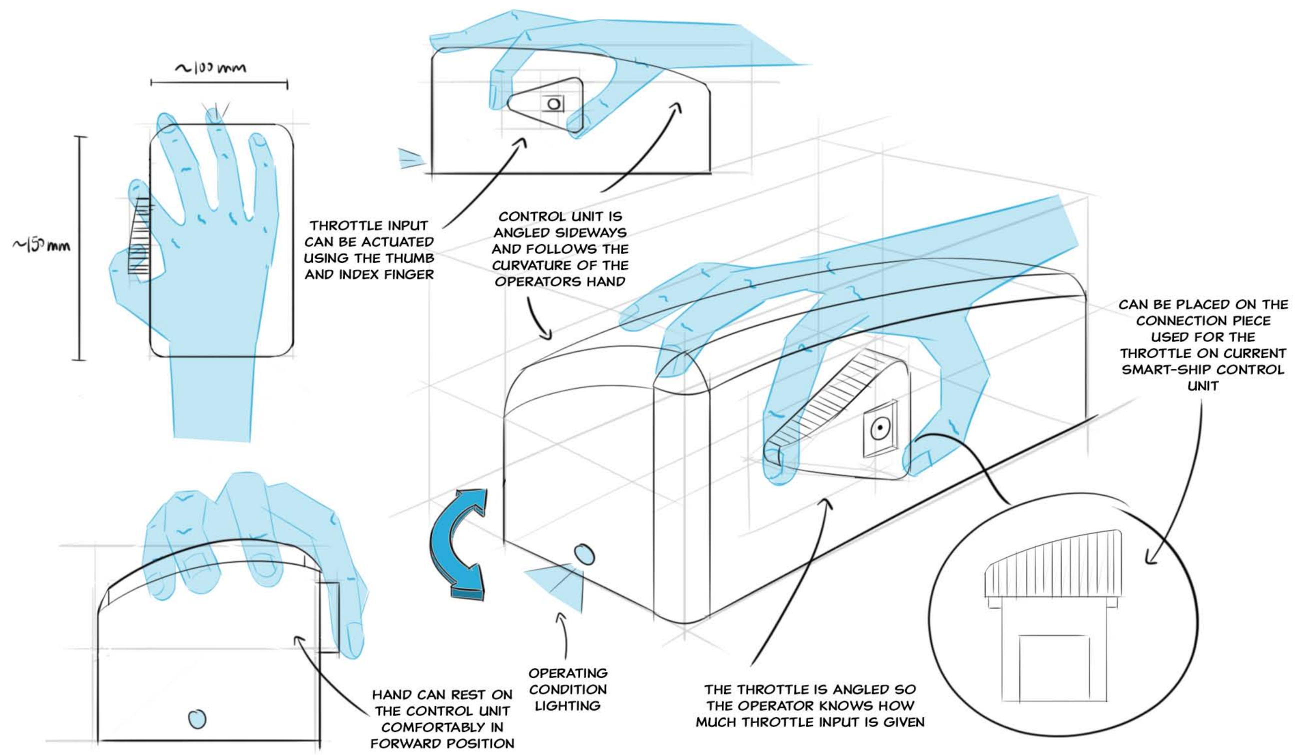



*Figure 63: Illustration of Control unit 8*

The initial idea control unit 8 is based on idea 13 of the PMI. The original idea would have also not worked with the current Smart-Ship electronics. The placement of the radio button inspired the small triangular throttle which is now present on the new developed idea. The throttle itself is shaped to be an elongated triangle so the operator can easily feel how much throttle input is given. The body of the unit is curved down towards the outside of the hand to place the wrist in a more natural position. Additionally, the control unit follows the curvature of the hand towards the wrist.

The throttle itself can be attached to the control converter using the Smart-Ship connector. The throttle could only be actuated by the thumb and index finger of the operator.

This control unit not being symmetrical, it means that production would be more complicated as two distinct models would have to be made. The operating condition lighting would be placed on the front of the control unit as this would make it easy for the operator to quickly check if the unit is working properly.

# 4.4 Iteration 2 - Weighted Objectives

**Weighted Objectives Method:**

The ideas created during the ideation have been developed based on the requirements found in the research. Over the course of the ideation these requirements were refined, and some new ones were found by talking with Smart-Ship. As each of the eight control unit ideas were developed, it was made sure that they comply with the hard requirements.

To evaluate the eight control unit ideas, the method Weighted Objectives was used. In this method, each requirement is given a specific weight (from 1-10) that corresponds with their importance for the final concept. This weight is determined based on the insights gathered from the research. Each hard requirement was given a weight of 10 as they are crucial to the project. Nevertheless, as not all requirements could be used to evaluate the ideas, a selection was made of the ones that could be evaluated.

After that, each control unit was ranked on a scale from 0-10 based on how much they fulfil the respective requirement. By multiplying the ranking with the weight of the requirement and adding the results together, a final score for each control unit was created.

Technical Context:
Considered | Not applicable
Human Context:
Considered | Not applicable
Market Context:
Considered | Not applicable
Environmental Context:
Considered | Not applicable

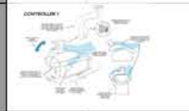
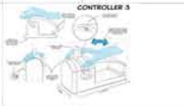
| | Requirement | Specs/Statement | Weight of Req. | Idea 1 | Idea 1 weighted score | Idea 2 | Idea 2 weighted score | Idea 3 | Idea 3 weighted score | Idea 4 | Idea 4 weighted score | Idea 5 | Idea 5 weighted score | Idea 6 | Idea 6 weighted score | Idea 7 | Idea 7 weighted score | Idea 8 | Idea 8 weighted score |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | |  | |  | |  | |  | |  | |  | |  | |  | |
| Desirability | Palm rest in most used positions | The control unit should give operators a place to rest their palm in the inner 180 degrees | 10 | 7 | 70 | 8 | 80 | 6 | 60 | 8 | 80 | 8 | 80 | 5 | 50 | 5 | 50 | 5 | 50 |
| | Control unit has a clear shape difference in design in the front and back of the control unit | The control unit has a clear shape that creates understanding of direction | 10 | 9 | 90 | 5 | 50 | 9 | 90 | 9 | 90 | 9 | 90 | 6 | 60 | 8 | 80 | 5 | 50 |
| | Control unit should have smooth edges | The controls should have rounded edges to not create pressure points in the operators hand/wrist | 10 | 7 | 70 | 6 | 60 | 6 | 60 | 8 | 80 | 9 | 90 | 7 | 70 | 8 | 80 | 8 | 80 |
| | Practical design | All design elements have a function and these functions are intutitive | 8 | 9 | 72 | 7 | 56 | 9 | 72 | 8 | 64 | 8 | 64 | 6 | 48 | 8 | 64 | 4 | 32 |
| | Control unit should follow the contour of the hand for forward driving position | The control unit follows the curvature of the operators hand | 8 | 10 | 80 | 9 | 72 | 9 | 72 | 9 | 72 | 9 | 72 | 1 | 8 | 9 | 72 | 7 | 56 |
| | Control unit should have a shape that allows the operator to securely hold it | In order to have enough grip to turn it easily the control unit should have space to securely be held | 6 | 9 | 54 | 6 | 36 | 2 | 12 | 7 | 42 | 9 | 54 | 8 | 48 | 4 | 24 | 6 | 36 |
| | Easy to clean design | The design should be simple and it should be easy to clean it from sweat, etc, | 7 | 7 | 49 | 8 | 56 | 2 | 14 | 8 | 56 | 7 | 49 | 4 | 28 | 5 | 35 | 8 | 56 |
| | Control unit should slightly angle the operator's hand in the forward driving position | The desing should place the operators hand in a slightly angled position to reduce carpal tunel pressure | 8 | 4 | 32 | 9 | 72 | 4 | 32 | 8 | 64 | 6 | 48 | 7 | 56 | 7 | 56 | 6 | 48 |
| | Control unit should be elongated to reduce ulnar deviation | The control unit is elongated to prevent the operator from twisting his hand a lot | 8 | 9 | 72 | 3 | 24 | 5 | 40 | 5 | 40 | 5 | 40 | 3 | 24 | 7 | 56 | 7 | 56 |
| | Throttle should be operated through the thumb or index finger, or with the help of the middle, the ring, and the pinky finger | The throttle can be acurately be adjusted with thumb and index finger, or the throttle arm can be moved with the other fingers | 10 | 8 | 80 | 6 | 60 | 7 | 70 | 8 | 80 | 8 | 80 | 5 | 50 | 8 | 80 | 4 | 40 |
| | Throttle lever should be operated comfortably from normal hand placement | The operator can actuate the throttle without moving his entire hand | 10 | 8 | 80 | 8 | 80 | 9 | 90 | 8 | 80 | 9 | 90 | 7 | 70 | 9 | 90 | 4 | 40 |
| | No pressure points when going backwards | The throttle is rounded and does not create pressure points on the palm of the operator | 7 | 6 | 42 | 9 | 63 | 8 | 56 | 8 | 56 | 8 | 56 | 2 | 14 | 8 | 56 | 10 | 70 |
| | Large enough to be supported by middel finger in reverse | The throttle is able to be supported by the index finger when reversing | 5 | 7 | 35 | 0 | 0 | 7 | 35 | 0 | 0 | 8 | 40 | 0 | 0 | 6 | 30 | 7 | 35 |
| Viability | Control unit should have an easy construction | The product should be constructed easily so part changes can be made instead of a new controler being bought | 10 | 9 | 90 | 9 | 90 | 2 | 20 | 9 | 90 | 9 | 90 | 3 | 30 | 5 | 50 | 9 | 90 |
| | Control unit should be identical for each thruster | Identical parts make production cheaper | 7 | 8 | 56 | 0 | 0 | 10 | 70 | 0 | 0 | 10 | 70 | 10 | 70 | 0 | 0 | 0 | 0 |
| Total | | | | | 972 | | 799 | | 793 | | 894 | | 1013 | | 626 | | 823 | | 739 |
| Place | | | | | 2 | | 4 | | 6 | | 3 | | 1 | | 8 | | 5 | | 7 |

*Figure 64: Weighted Objectives Table*

The result of the evaluation showed that **Control Unit 5** scored the highest with 1013 points. In second place came **Control Unit 1** with 972 points.
In third place came **Control Unit 4** with 894 points.
As these were the three highest scoring ideas, it was decided to prototype them and to test them with tugboat operators.

# 4.5 Prototyping

To prototype the 3 ideas, it was decided to use modelling clay. The option of materials was between foam models or clay. Whilst for foam models more detail could have been achieved, clay was chosen instead since it allowed for a more realistic feel. When dried, the clay has weight and a solid feel to it. This would be hard to achieve with foam. Additionally, as the goal is to find the most comfortable form, which is also very directional, therefore high precision models were not needed at this stage.

Furthermore, as the clay is very solid, it would give more accurate results in the testing, as operators would not have to be afraid of being very delicate with it. The modelling clay was supported by wood and wire which made it possible to have "functioning" throttle levers which could be moved 90 degrees forward and backwards as a real control unit would. For the testing, a separate board with a stick was created, where the prototypes could be mounted on to rotate on one axis.

Pictures that were taken during the making of the prototypes can be found in appendix 6.

## PROTOTYPE 1


Figure 65: Prototype 1 Front


Figure 66: Prototype 1 Perspective


Figure 67: Prototype 1 Top


Figure 68: Prototype 1 Side

Modelling clay, wood, hot glue, and a screw were used.

The base consists of a wooden block to which clay was attached using water. The top of the body was first formed separately and then attached to the body using water. The overhang was formed with the help of a small wooden board. The rough shape of the throttle was first cut from wood, and after noticing that it did not exactly fit, it was cut in half and glued into the right shape. Subsequently, it was covered in modelling clay and the form of the throttle was reproduced. Lastly, the created throttle was attached to the body of the model using a screw.

The angle at which the body slopes downwards from the highest point to the lowest point is 20 degrees.

## PROTOTYPE 2


Figure 69: Prototype 2 Front


Figure 70: Prototype 2 Perspective


Figure 71: Prototype 2 Top


Figure 72: Prototype 2 Side

Modelling clay, wood, wire, hot glue, and screws were used.

The main body has a base of wood to reduce the amount of clay needed. Using water, clay was added to the wooden base to make sure that it sticked together. For the throttle, wire was used to first form the general shape, and after clay was used to give it volume and a more representative form. Lastly, two screws were used to attach the throttle to the body on either side.

The angle at which the body slopes downwards from the highest point to the lowest point is 45 degrees.

## PROTOTYPE 3


Figure 73: Prototype 3 Front


Figure 74: Prototype 3 Perspective


Figure 75: Prototype 3 Top


Figure 76: Prototype 3 Side

Modelling clay, wood, hot glue, washers, and a screw were used.

The body of the prototype is made entirely of modelling clay. The general shape of the throttle was cut with wood to which modelling clay was added to represent the idea more accurately. The throttle was then attached to the body using a screw and two washers. The washers helped with a more controlled forward movement.

The angle at which the body slopes downwards from the highest point to the lowest point is 35 degrees.

# 4.6 Testing

**Scope of the Testing:**

The testing  focussed on the shape of the three prototypes. Each of the prototypes has a different shape and a different throttle form.
The testing will focus on comfort, wrist support, functionality, and size.
The testing did not consider stress that can be placed on the unit, materials that could be used or haptic feedback that could be felt by operators.

*Figure 78: Daan Merkelbach testing*

**Testing Logistics:**

Daan Merkelbach and Cees Aalbers tested the three prototypes for around one and a half hours.
Daan is the manager for tug training and consultancy from Kotug. He has worked with a lot of different tugboats and can be considered an expert in the field. He also has experience with simulators and has tried many different azimuth control units.
Cees has been a tugbaot operator for his entire life and has over 50 years of experience in the field.

*Figure 80: Daan Merkelbach and Cees Aalbers testing*

*Figure 77: Cees Aalbers testing*

**Testing Objective:**

Entire prototype:
- Hand placement in different positions
- Throttle usability in different positions
- Directional feedback from the prototype

Body:
- Size, Shape, Comfort, Angle and Height

Throttle:
- Size, Shape, Comfort and Placement

*Figure 79: Daan Merkelbach testing*

**Testing Setup:**

-The three prototypes explained before
-Simulation board where each prototype can be mounted on to simulate roation over one axes
-Phone camera to record the testing
-Tripod to place the camera in the desired location
-Mask and hand sanatizer to follow sanitary conditions due to COVID-19



# 4.6 Testing

**Test 1:** During the first test one of the three prototypes was placed on the black simulation board, and the two operators were asked to move the prototype from marker to marker (each at 45 degrees from another), and to move the throttle from 0 to 90 degrees at each marker.
This procedure was repeated for all three prototypes and the questions asked afterwards were:

- What are your initial thoughts?
- How is the comfort of the prototypes in the different sections?

The most important answers for each prototype were:

**Prototype 1:**
- The angle and height are very nice whilst standing and sitting, however, the throttle should be mounted on the left side of the body when using the right hand to operate the control unit.
- When using the prototype like in practice, the throttle is too large, and switching from a forward position to a backwards one is not smooth
- The overhang is very good as it allows for a lot of grip, but it should be extended some more.

**Prototype 2:**
- The angle and height of the unit are not as nice as prototype 1 as it is too steep
- The shape of the throttle is very good as smooth transition between forward and backward driving is possible, and for every position it feels comfortable to use
- The space between the throttle and the outward extensions needs to be enlarged and an inverted T shape would be better

**Prototype 3:**
- The prototype is more comfortable to use when standing than sitting
- Both operators preferred to use the prototype made for the right hand, with the left hand as it felt more natural to place the whole palm on the support.
- The prototype was okay when turning the prototype outwards, but inwards, it was quite tricky to move the hand due to the large throttle head.
- The operators mentioned that the throttle arm should be used on prototype 1

(A document with the complete answer report can be found in appendix 7)

*Figure 81: Daan Merkelbach using prototype 1*

*Figure 82: Daan Merkelbach using prototype 2*

*Figure 83: Daan Merkelbach using prototype 3*

# 4.6 Testing

**Test 2:** The second test was aimed at getting the operators feedback on the shape of the body. They were asked to use the prototypes and play around with them for one minute and to only focus on the body.
After the three prototypes were freely tried, Daan and Cees were asked the following questions:

- What do you think about the size of the prototypes?
- How comfortable was each prototype?
- How good is the palm support offered by each prototype?
- Which prototype has the best angle and height?
- How is the grip on each prototype?

The most important answers for each prototype were:

**Prototype 1:**
- Hand placement area is slightly too large
- The hand placement itself is very comfortable
- Angle and height of the hand placement are very good whilst standing and sitting
- Palm placement is okay, but the axes need to be moved back as currently it moves the body of the prototype away from under the hand
- Grip is good but the overhang could be extended for even better grip

**Prototype 2:**
- Extrusions make it comfortable even when the prototype is turned
- The grip is good as you can place your fingers on either side to turn in quickly
- The angle is too steep whilst standing and decent when sitting (should be like in Prototype 1)
- The space between the throttle and the outward extensions needs to be enlarged and an inverted Y shape instead of an inverted T shape would be better

**Prototype 3:**
- The size of the body is okay, however the operators preferred to use the prototype (made for the right hand) with their left hand
- For forward position it is very comfortable, but when turning inwards there is no palm support
- The grip of the body is not as good as the others as the large palm support makes it hard to hold on to with all fingers.
- The angle of the body is good, however the height of prototype 1 was better

(A document with the complete answer report can be found in appendix 7)

*Figure 84: Daan Merkelbach using Prototype 1*

*Figure 85: Daan Merkelbach giving feedback on Prototype 2*

*Figure 86: Cees Aalbers using Prototype 3*



# 4.6 Testing

**Test 3:** The third test was very similar to the second one, however this time Daan and Cees were asked to put their attention on the throttle of the prototypes.
After the test the following questions were asked:

- What was your impression of each throttle "neck"?
- What do you think about the throttle "head"?
- What do you think about the size and form of the connection arm?

The most important answers for each prototype were:

**Prototype 1:**

- The throttle arm of the prototype is too thick and not comfortable to operate and grip with the thumb
- The one-sided throttle on the right-hand side (for the left hand) is comfortable as it gives good support when reversing
- The throttle "head" is comfortable but not necessary
- The thickness of the "neck" is very good

**Prototype 2:**
- It is nice that the throttle arm can be used to actuate the throttle, but a one-sided throttle where the outer arm is gone would be better
- Size of the whole throttle is very nice as its not in the way when turning it to the reverse position
- The "neck" is a bit too thin
- Throttle "head" is comfortable but not necessary

**Prototype 3:**
- The throttle is very nice and better than from prototype 1
- Overall thickness is good, and the "neck" is also a good size
- The throttle head is too large, and it gets in the way when turning the prototype

(A document with the complete answer report can be found in appendix 7)

*Figure 87: Daan Merkelbach using Prototype 1*

*Figure 88: Daan Merkelbach using Prototype 2*

*Figure 89: Daan Merkelbach using Prototype 3*

# 4.6 Testing

**Additional Questions:** Next to testing the prototypes, the opportunity was used to ask questions that will help with the development of the upcoming steps of the project. These questions were about potential features that could be added to the control unit, and the material. The questions, and the answers can be found in appendix 7.

**Final Testing Conclusion:**

When asked to rank the prototypes after the testing was done, both operators agreed on the same ranking if certain features were adjusted:

The best prototype regarding usability and comfort was prototype number 2. However, the prototype should integrate the angle and height of prototype 1 to give more comfort whilst operating standing and sitting. The outer throttle arm should be removed to allow for better grip, and the length should be slightly adjusted as it is too short right now.

As second-best prototype they chose prototype number 1. The prototype was overall very good however there were some aspects that they did not like. The first was the large throttle arm which was hard to grab and the second was the turning axes which is too far in the front.

The third best prototype was number 3. As the body shape was designed to be used by the right hand, and the operators to use it with the left hand, it did not have many features that were very useful. It does however have the best throttle arm, which should be installed on prototype 1.

Overall, they preferred prototype 2 as it felt most comfortable whilst simulating practical operation movements.
After presenting the information to Smart-Ship, it was decided that control unit 5 (prototype 2) should be developed into a concept considering the feedback from Daan Merkelbach and Cees Aalbers.

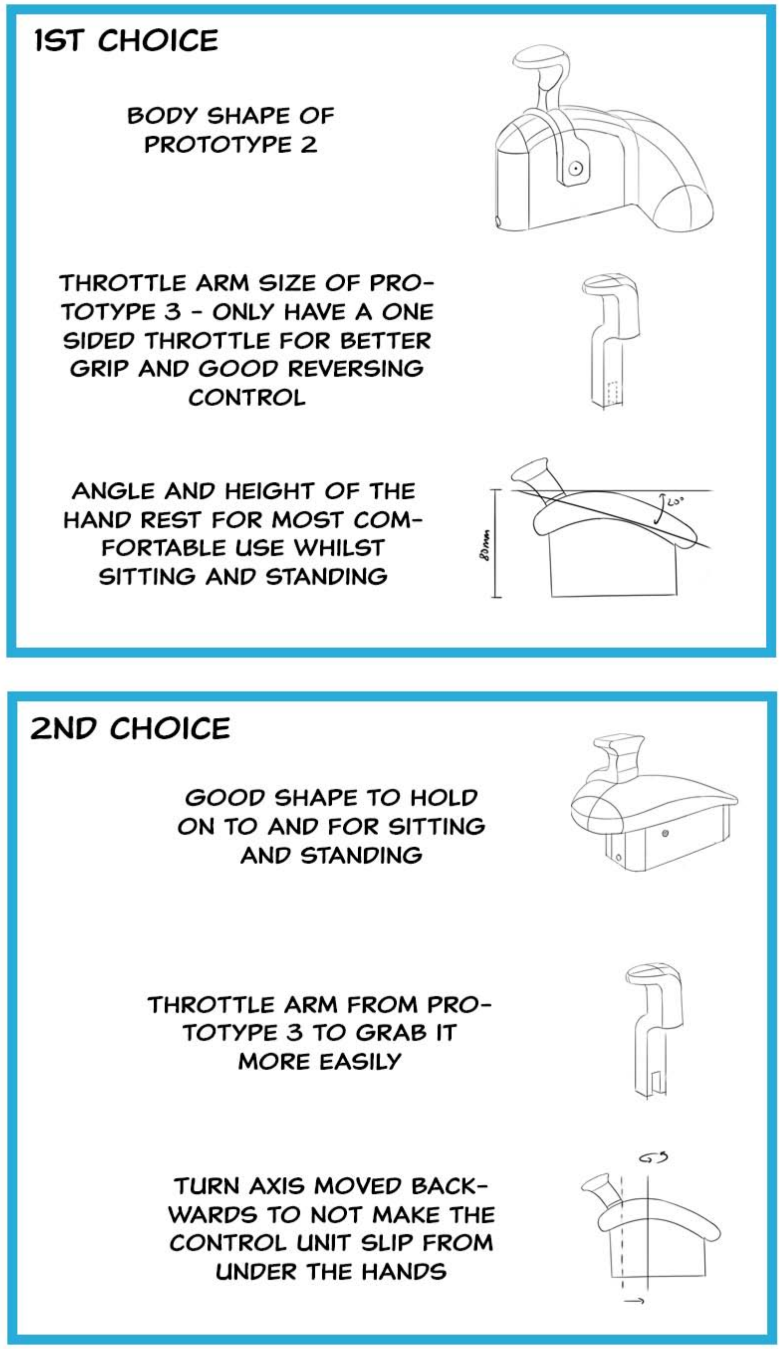



*Figure 90: Testing conclusion visualized*

Based on on the testing results a set of new requirements was formulated and some existing requirements had to be modified.

These requiremnts are:

- Palm rest in form of inverted rounded T shape
- The control unit has an elevated Front and an distint inverted T shape
- The control unit cuves down at an angle of 20 degrees from the highest point to the lowest palm rest point
- No metal element touches the operators hand
- Material should be plastic that does not feel cheap
- There is an at least 50 mm gap between the throttle and the extrusions
- Throttle should be operated with the thumb and index finger
- Control unit has a one sided throttle
- The throttle "neck" is 15*15 mm for comfortable operation

| | | |
|---|---|---|
| Technical Context: | | |
| | Considered | Not applicable |
| Human Context: | | |
| | Considered | Not applicable |
| Market Context: | | |
| | Considered | Not applicable |
| Environmental Context: | | |
| | Considered | Not applicable |

# 4.7 Form Concept

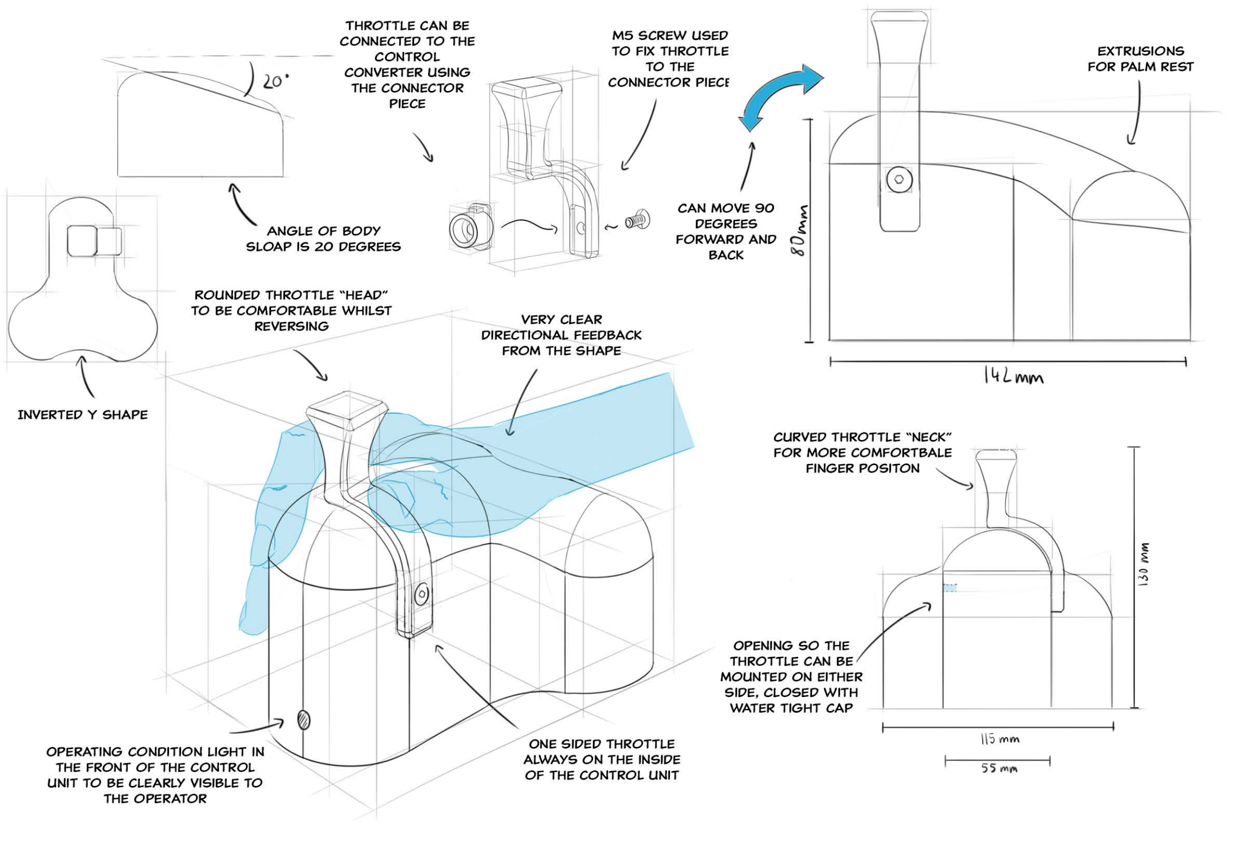



*Figure 91: Illustration of the form concept and its features*

The form concept is based on control unit 5 from the ideation and can be seen in figure 91. By using the feedback from the testing, improvements were made on control unit 5. The form concept consists of the main body piece, the throttle and it includes the operating condition light.

The body of the concept is shaped like an inverted T. This shape gives the operators a place to rest their palms in both directions of the turning circle. The entire topside of the unit is filleted to prevent pressure points in the operator's palm. The body is also curved downwards from the front to the back of the control unit to follow the curvature of the operator's hand. The angle of this slope from the highest to the lowest point of the hand placement area is 20 degrees.

The front part of the body gives the operators a large amount of space to properly grip it and turn it quickly if needed. Additionally, by having an inverted T shape, the body has a very clear directional feel through which the operator can directly know where it is pointing at and does not have to check.

*Figure 92: Form concept control unit perspective view*

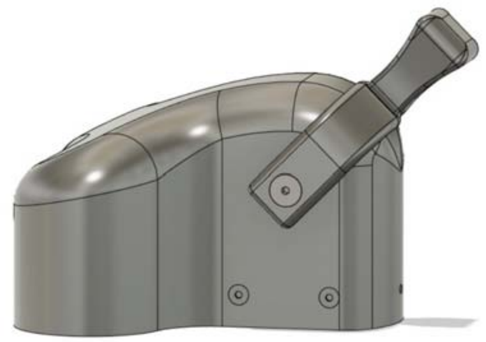


*Figure 93: Form concept control unit with throttle engaged at 45 degree*



# 4.7 Form Concept

The throttle is only connected on one side of the control unit. As determined during the testing, the throttle should always be connected on the inside of the control unit, as can be seen in figure 94. This gives the operators space on the outer side of the control unit to comfortably place their middle, ring, and pinkie finger. This one-sided throttle also makes operating in reverse more precise and comfortable, as the entire throttle lever "lays" in the palm of the operators. Therefore, it can be easily adjusted. As the throttle can be installed on either side of the control unit, the throttle "head" has a rounded neutral shape that does not favour a driving direction and does not create pressure points in the palm of the operators. The throttle "neck" is curved to give the operators more comfort whilst holding it.
The throttle is connected to the body of the control unit, using the connector piece, which also directly connects it with the control converter of Smart-Ship.

*Figure 94: A pair of the concept control unit in the neutral position*

The throttle is connected to the body of the control unit using the connector piece from Smart-Ship, which also directly connects it with the control converter housing a pulley to all the electronics. These pieces are held together by an M5 screw. Since the throttle can be mounted on either side of the body, there will be an open hole on one of the sides. On the side with no throttle, a cap is needed to close it off to ensure water proofing. This cap is also connected to the control converter using an M5 screw. In addition to the two M5 screws, four M4 screws connected the body to the control converter to make sure that it does not move anywhere.

*Figure 95: Explosion of the throttle and its connecting pieces*

Lastly, the control unit has an operating condition light in the front of the body to always inform the operator if the control unit is working as it should. The colour of this light can be adjusted by Smart-Ship depending on which country the tugboats containing the controls will be used in. This will make sure that the operators do not misunderstand the meaning of the colour. The light is placed at the bottom in the front of the control unit so it illuminates the area Infront of the control unit.

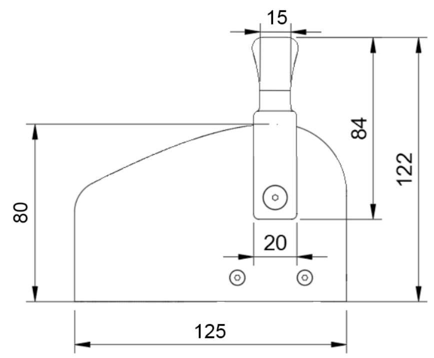



*Figure 96: Dimensions form concept side*

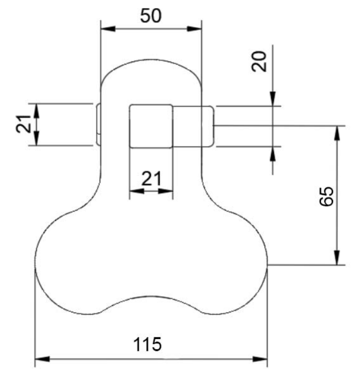



*Figure 97: Dimensions form concept top*

# 4.8 Form Concept Evaluation

During the ideation phase several new insights were gained and some of the requirements were refined as more information on certain aspects was found. Especially for the technical context, as the electrical components were explored, better insight was gained into which requirements the products must follow to accommodate these electronics. Additionally, new requirements were created in the Human and Market context.

With this new research two new values were added which had not been considered before. One was in the Technological context: Utility. This value was added as the control unit had to be usable with the Smart-Ship electronics. And for the Human context, the value Innovation was added as Smart-Ship's desires had to be considered. An evaluation of the form concept was done to understand which values it incorporates, and which are still missing.

| Context | Values | Requirements | Included in concept |
|---|---|---|---|
| Human | Human Wellbeing | The control unit should be shaped so the operator can rest his palm | Yes |
| Human | Human Wellbeing, Safety | The throttle should be operated through the thumb or index finger, or with the help of the middle, the ring, and the pinkie finger | Yes |
| Human | Health | The control unit should be elongated to reduce ulnar deviation | No |
| Human | Trust, Safety | The control unit should have a clear shape difference between the front and the back | Yes |
| Human | Health | Control unit should slightly angle the operator's hand in the forward driving position | Yes |
| Human | Health | The control unit should follow the contour of the hand in the forward driving position | Yes |
| Human | Safety | The control unit should have smooth edges | Yes |
| Human | Reliability | Operating condition lighting can be changed by smart ship | Yes |
| Human | Power | The control unit could be used whilst sitting and standing | Yes |
| Human | Cleanliness | Easy to clean shape and material | Not yet investigated |
| Human | Safety | The control unit should have a shape that allows the operator to securely hold it | Yes |
| Human | Innovation | Different shape to current azimuth control unit | Yes |
| Technical | Quality | The control unit should have a Robust Construction | Not yet investigated |
| Technical | Quality | The control unit should be Water and Dust resistant | Not yet investigated |
| Technical | Trust | The control unit allows for haptic feedback | Yes |
| Technical | Maintaibalility | The control unit should not require special tools to be opened | Not yet investigated |
| Technical | Independence | The control units should not be connected with one another. | Yes |
| Technical | Adaptability | Fits onto current mounting mechanism created by Smart-Ship | Yes |
| Technical | Utility, Adaptability | Throttle screws to the control converter | Yes |
| Technical | Independence | Throttle and direction input are not given with the same movement. | Yes |
| Technical | Trust | The body is securely connected to the control converter | Yes |
| Market | Versatility, Profitability | Control unit can be used in simulation environment | Yes |
| Market | Competitiveness | Competitive pricing of the unit | Not yet investigated |
| Market | Profitability | Control unit should be identical for each thruster | Yes |
| Environment | Disposal, Sustainability | The control unit should be made of eco-friendly materials | Not yet investigated |
| Environment | Sustainability | The control unit should be produced using eco-friendly production methods | Not yet investigated |



# 4.9 Four Style Concepts

After the form concept was created and presented to the client it was decided that it was a good concept and that the project can continue. The next step was to think about how this shape could be made more attractive and more in line with the other products that Smart-Ship is offering.

In order to do this a style analysis of the Smart-Ship website, the logo, and the existing products in the product line-up was conducted. From the analysis it was possible to gather the representative colours that are used, and it was also possible to see that from the 4 products in the line-up, two are based on geometric shapes, and the other two are based on organic shapes. The full style analysis can be found in appendix 8.

Before starting the ideation on the style, the requirements were updated and specified to match the form concept. As not all requirements had to be considered during the creation of the style concepts, the relevant requirements were selected as they had to be considered to prevent a new form and to only allow slight changes.

For the creation of style concepts, the first step was to brainstorm on how some details of the body shape could be changed to be more interesting and to fit with the Smart-Ship style, whilst also still fulfil the above-mentioned requirements. The second step in the ideation was the throttle. The throttle had to follow the same styling as the stylized body shape whilst again following the requirements set by the form concept. The next part of the ideation focussed on how the throttle input could be displayed on each of the different style concepts. From the previous testing it became apparent that this was an important part of the control unit as it can be very helpful, especially to tugboat trainees and trainers. The fourth step focussed on how certain highlighting features could be used to make each style concept more interesting, and the fifth step considered the styling of the covering cap of the open side.

In the illustrations on this page the above explained steps can be seen for the four created style concepts.

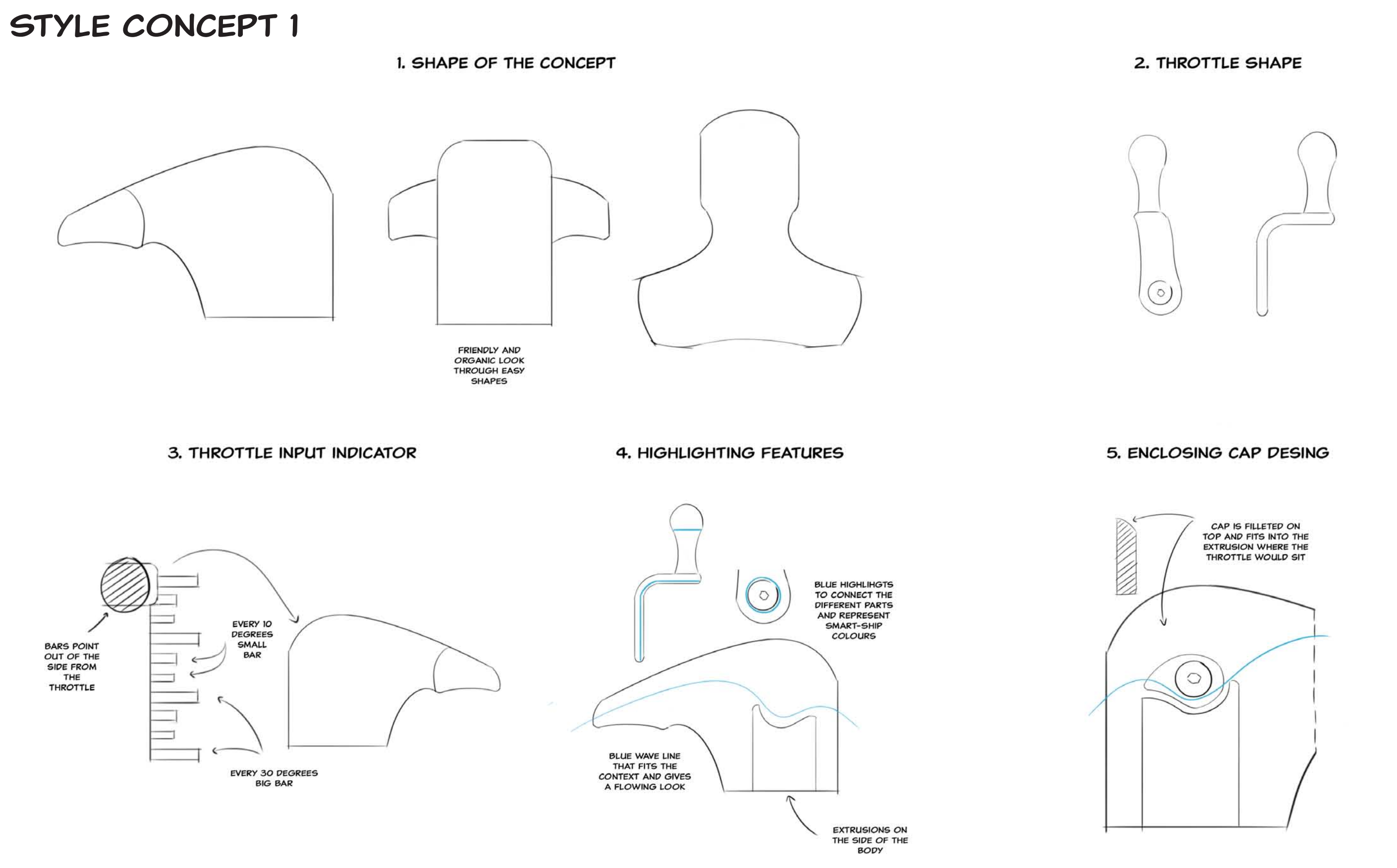


*Figure 98: Style concept 1 process sketch*

# 4.9 Four Style Concepts

## STYLE CONCEPT 2

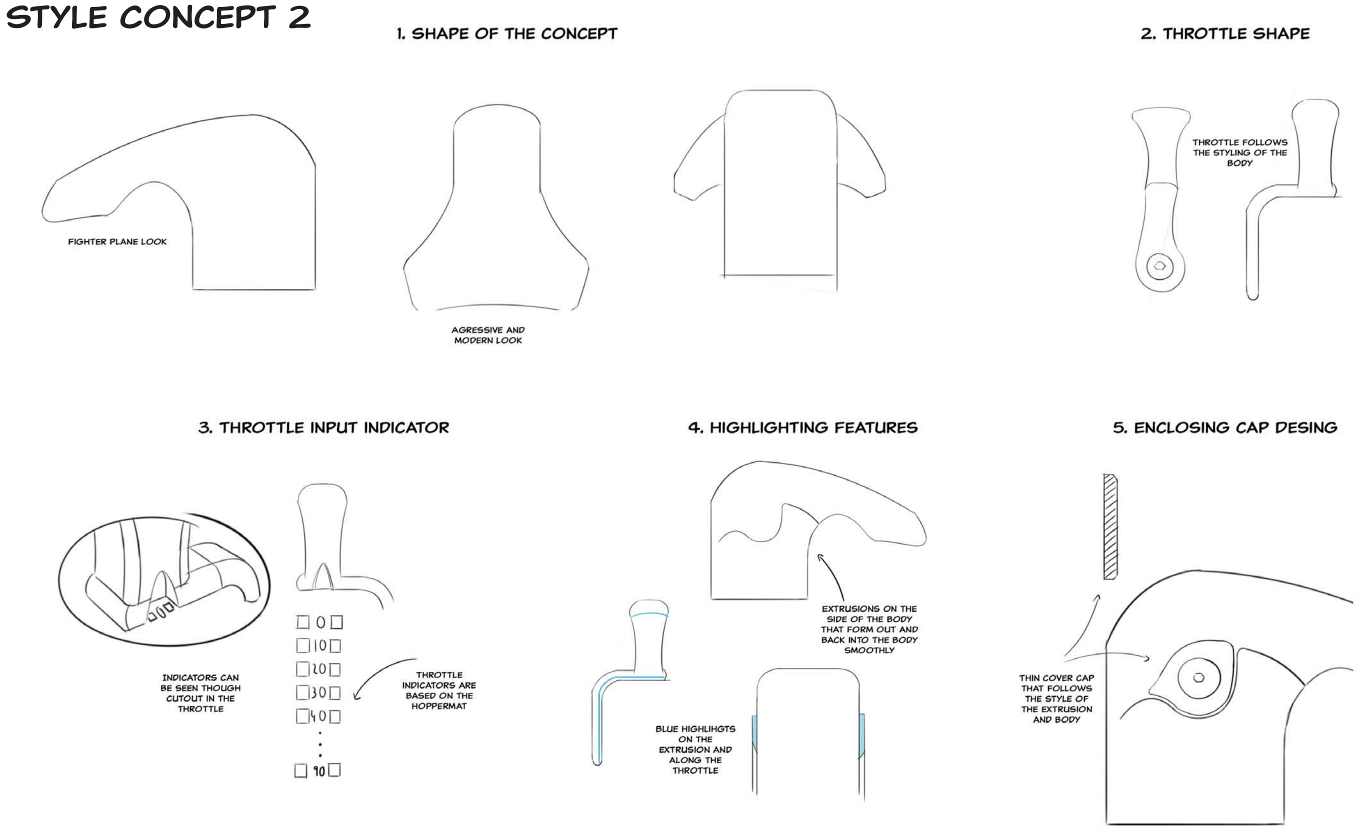



Figure 99: Style concept 2 process sketch

## STYLE CONCEPT 3

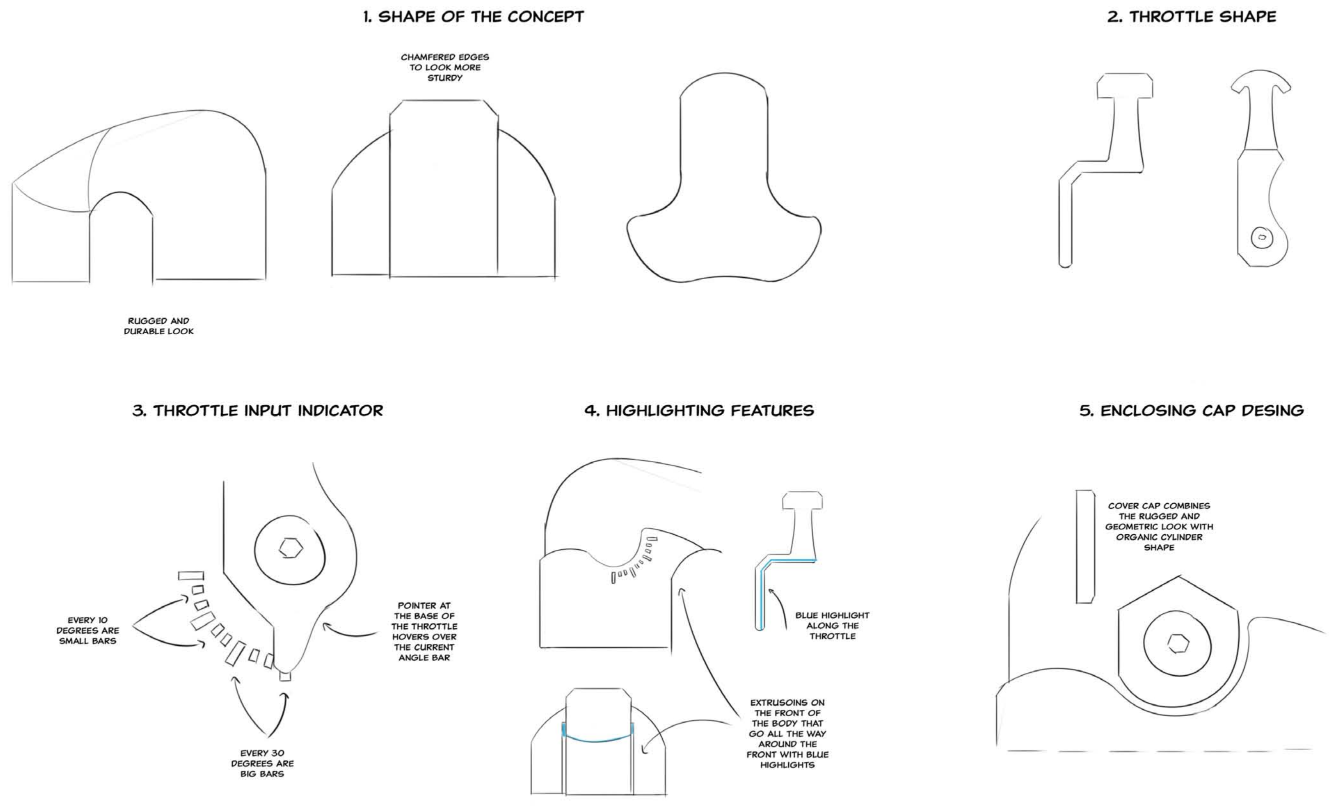



Figure 100: Style concept 3 process sketch



# 4.9 Four Style Concepts

## STYLE CONCEPT 4

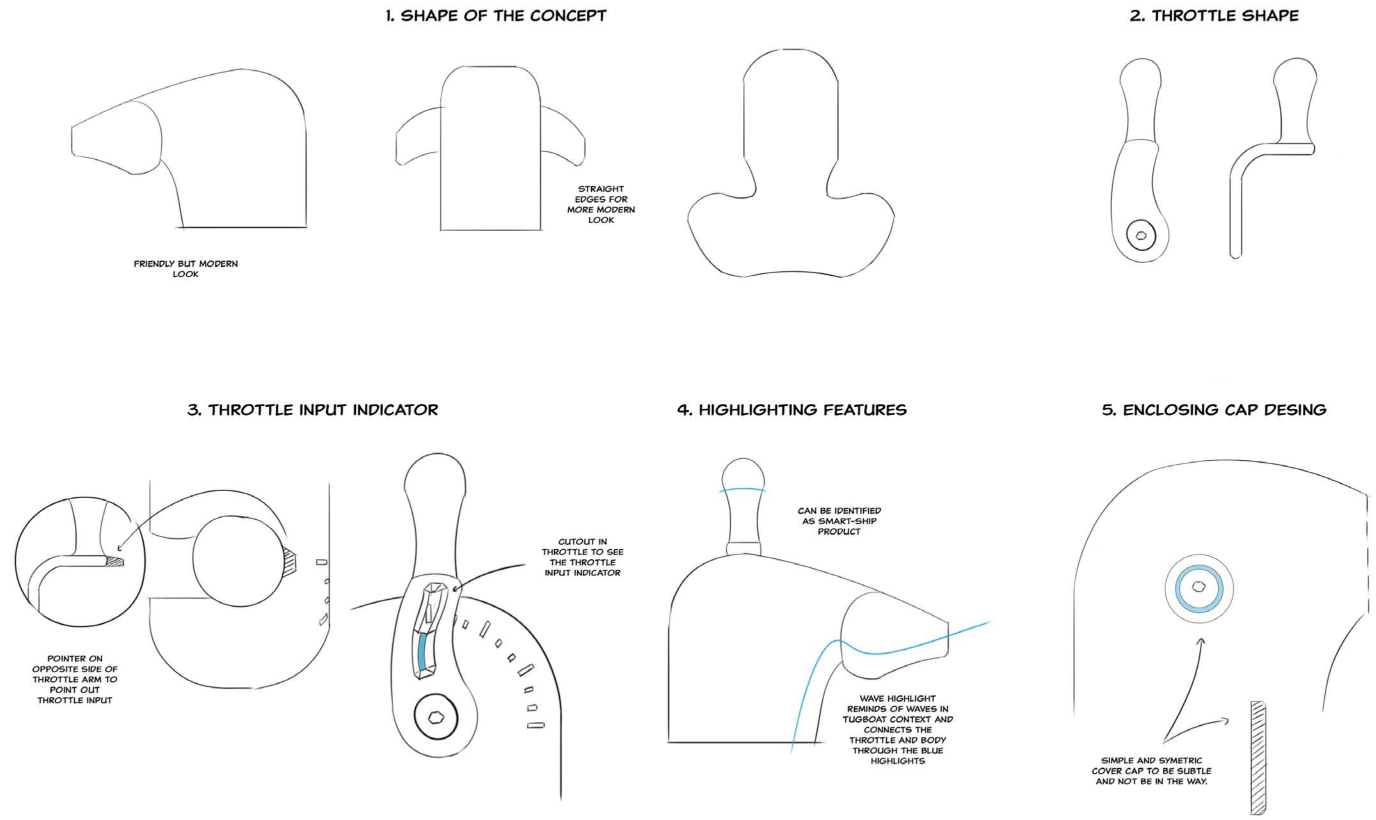



Figure 101: Style concept 4 process sketch

After the style concepts were created, a 3D model was made for each of them to better visualize these styles, and to see if all of them could work with the space requirements the control unit needs to consider. These renders were also used during the testing, which is explained in section 5.2.

As can be seen in the next pages, every concept uses the same colour scheme. This colour scheme was decided upon as dark grey (#363d43) and light blue (#29acd9) are the main colours of the Smart-Ship logo and website, which will make the product recognisable as a Smart-Ship one. On top of this, a dark base colour will hide potential scratches, sweat stains or other imperfections better than a light colour.

# 4.9 Four Style Concepts

## Style Concept 1

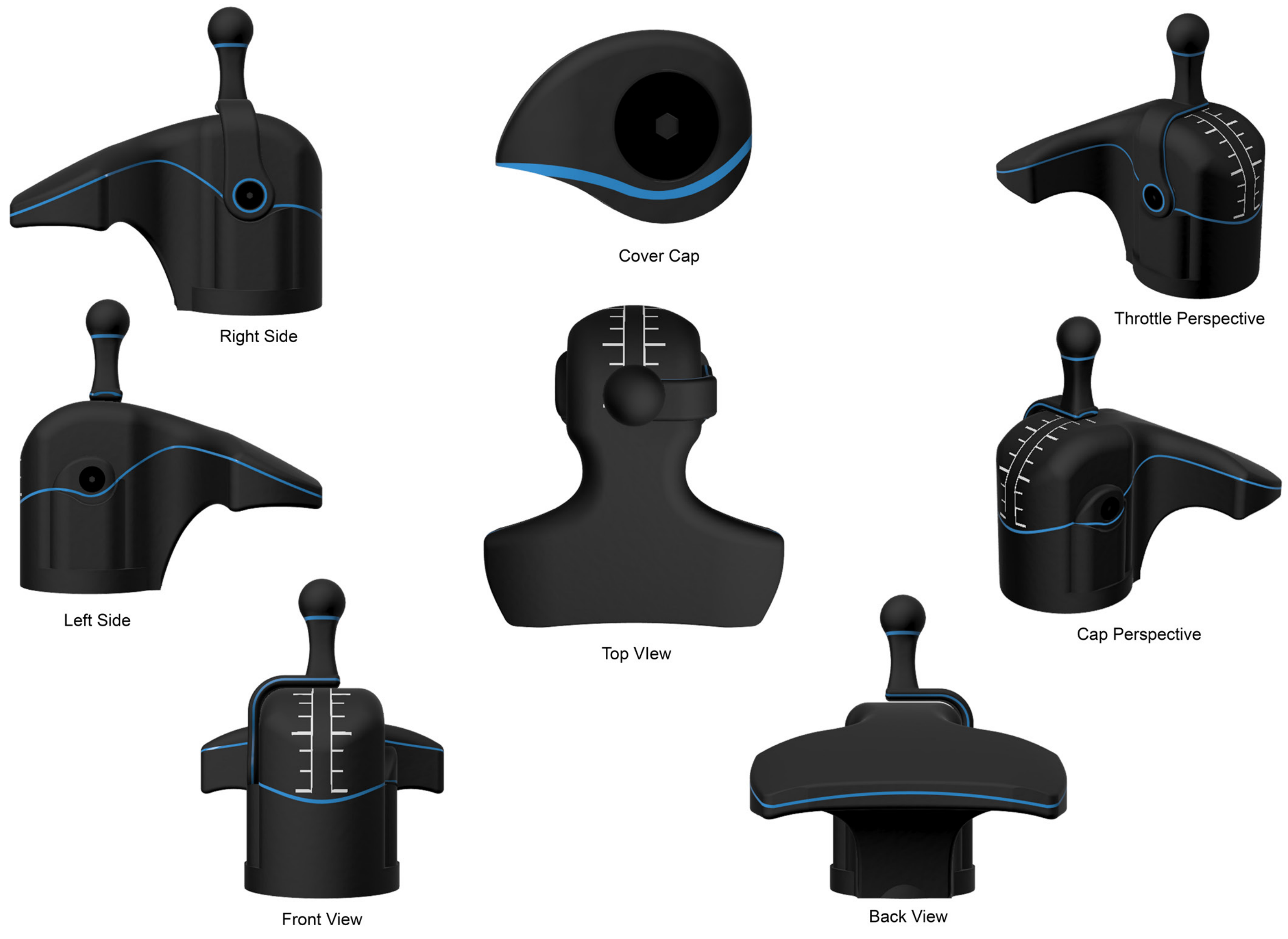



*Figure 102: Renders of the first style concept from different perspectives*

The first style concept has a friendly and organic look. The main detail that sets it apart from the form concept is the "floating" palm rest. As the support is removed the whole control unit does not look as bulky as before. The second detail that is supposed to help with this "floating" palm rest, are the two indentations between the front of the body and the palm rest.

The throttle follows this friendly organic look by having a spherical throttle "head" which flows into the throttle arm. To combine the throttle and the body there are two 5mm extrusions below the attaching point of the throttle.

The throttle input indicator is very clear and visible on the front of the control unit and it can be read as the tips poke out of the side of the throttle. The lines vary in size, where a large line is placed at every 30 degrees and a small line indicates every 10 degrees.

To highlight the shape of the control unit, a blue pinstripe is placed around the entire unit following its shape. The blue pinstripe also goes around the throttle arm and creates a connection between the body and the throttle.



# 4.9 Four Style Concepts

## Style Concept 2


*Figure 103: Renders of the second style concept from different perspectives*

The second style concept aims to have a more aggressive and modern look than the first concept. As can be seen in the renders above, it also has a "floating" palm rest, however there are no indentations between the front of the body and the palm rest. As the body gradually curves outwards to the widest point, it creates a fighter plane look. This styling is reflected in the throttle as the throttle "head" has a sportier look to it. The throttle has a small cut out in the back to give the operator a chance to read out the throttle input which is placed in the front in the middle of the body.
The indicator consists of two squares with a percentage number in the middle, that is based on the hoppermat design from Smart-Ship.

On each side of the body, there are 2mm extrusions which form out of the back and flow into the front of the unit. These extrusions also follow the shape of the body and help merging the throttle and the body together. As they are only 2mm, they are less obtrusive as in style concept 1. The edge of these extrusions is highlighted and so are the throttle arm and the throttle "head".

The covering cap follows the same principle as in style concept 1 where it fits into the cut out where the throttle would be placed and follows the shape of the body.

# 4.9 Four Style Concepts

## Style Concept 3


*Figure 104: Renders of the third style concept from different perspectives*

The third concept aims to have a more rugged and durable look. For this reason, the palm rest is supported by two pillars below the palm rest extrusions and the edges are chamfered. The throttle also follows this styling by having a squared throttle "neck" and a throttle "head" which aims to provide comfort through a curvature whilst still having chamfered edges. As comfort still needs to be considered, each edge created by the chamfer is filleted slightly to prevent pressure points or cuts. The part of the throttle where it connects to the control unit also aims at including some of the geometric style that can be found in two of the Smart-Ship products, as half of it is made from a hexagon and the other half from a circle.

The rugged look is completed as this style concept also has a highlighting extrusion, however, instead of smoothly flowing into the front of the body, it goes all the way around. The extrusion is also painted blue to highlight this feature and as the throttle also has a blue pinstripe around the base. It connects the two.

The throttle indicator is another feature that merges the throttle and base together, as the base of the throttle has a pointer, which rotates with the throttle. The pointer moves over a set of lines, which like in style concept 1 are larger for every 30 degrees and smaller for every 10 degrees.

The throttle cap, similarly to the throttle, is made of part hexagon and part circle to create a rugged and also geometric look, which still fits the design.



# 4.9 Four Style Concepts

## Style Concept 4


*Figure 105: Renders of the fourth style concept from different perspectives*

The fourth style concept is like the first style concept as it also aims to have a friendly but also modern look. This is achieved by having almost only rounded and organic forms. In order to still give the concept a modern look, the back of the palm rest is straight instead of fully rounded. This concept also has two small indentations between the front and the back of the body to create a visual separation making the pam rest look like it is "floating".

The throttle follows the style of the body with its spherical throttle "head" which flows into the cylindrical throttle "neck". The throttle has a small pointer on one side of the throttle "neck" and an indent and whole in the throttle arm. Both of these features will allow the operator to see the throttle input and therefore connects the throttle with the body. The indicator lines are placed on either side of the front of the body and follow the same principle as style concept 1 and 3.

To keep the design simple, the highlights are only a pinstripe along the back of the unit, which merge into the ground before the front of the body begins. Besides this, there are blue highlights around the large screws of the throttle and covering cap, and between the throttle "head" and "neck". This way the body and throttle are connected visually through blue highlights. On top of this, the blue line can represent waves in the context of tugboats in addition to creating a visual identification as a Smart-Ship product, through their brand blue. The converging cap is kept very simple and symmetric to be as subtle as possible, as a 2 mm high cylinder.

As the main form was decided upon, and the four style concepts were created, they had to be prototyped and tested to understand if they are good concepts. Additionally, this stage was used to select the final concept.

# Prototyping & Testing

5

# 5.1 Prototyping of Style Concepts

As the style concepts had slightly different shapes to the form concept through their different styles, they had to be tested to understand if they remained comfortable and clear in directional feedback, or if some style features made them better or worse in either aspect. For this reason, a prototype was made for each of the style concepts.

Since more detail was needed for this testing, in order to have the right dimensions as the 3D models had, hardfoam was used. This material can be first cut to the rough dimensions via a saw or cutting knife, and then sanded to the right dimensions. To get the most accurate models, the 3D models were used to print outlines on a 1:1 scale to verify if the height, width, etc. of the foam models was right.

Hardfoam would be a good material to use for the body of the concepts, however the throttles would be too fragile if made from the same material. Therefore, the decision was made to 3D print the throttle levers using a Prusa i3 mk3 printer with PLA. Printing the throttles would make them the exact dimensions whilst making the levers more rigid so that during testing the operator would not have to worry about breaking it. As 3D printing the entire concept would have taken around 23 hours for each of the concepts, it would have taken too long, and it would not have been done before the testing.

In order to connect the 3D printed throttles with the hardfoam bodies, an M4 x 50mm screw was used. This way the throttle would be "functional" and real-life use scenarios could be recreated.

Additionally, as the hardfoam was very light, the prototypes were connected to wooden bases using double sided tape to give them some weight and to make it easier to turn them on one spot.

Since the hardfoam has a beige colour, it was decided to spray paint the bodies black for two reasons. The first was to make the prototypes look more uniform as the throttles were 3D printed in black. And the second reason was to prevent abrasion of the hardfoam, as it could have caused frustration during the testing.

In the images below, pictures of the four concepts can be seen, and on the right, an image during the making of the prototypes.

Figure 2: Making of Prototypes

## PROTOTYPE 1

Figure 106: Prototype 1 Front

Figure 107: Prototype 1 Back

Figure 108: Prototype 1 Side

Figure 109: Prototype 1 Top

## PROTOTYPE 4

Figure 118: Prototype 4 Front

Figure 119: Prototype 4 Back

Figure 120: Prototype 4 Side

Figure 121: Prototype 4 Top

## PROTOTYPE 3

Figure 114: Prototype 3 Front

Figure 115: Prototype 3 Back

Figure 116: Prototype 3 Side

Figure 117: Prototype 3 Top

## PROTOTYPE 2

Figure 110: Prototype 2 Front

Figure 111: Prototype 2 Back

Figure 112: Prototype 3 Top

Figure 113: Prototype 2 Top

# 5.2 Testing of Style Concepts

**Scope of the Testing:**

The testing focussed on the styling of the four style concepts. As for each concept some details of the body shape were changed, and each concept had a different throttle, these had to be tested to understand how good or bad they were. Additionally, the testing was used to understand which throttle input indicator would be most useful to operators and trainees.

The testing did not consider the stress that can be placed on the prototype, materials that could be used or haptic feedback that could be felt by operators.

Figure 122: Daan Merkelbach testing

**Testing Logistics:**

Daan Merkelbach tested the four concepts for 25 minutes. Daan is the manager for Tug training and consultancy from Kotug. He has worked with a lot of different tugboats and can be considered an expert in the field. He also has experience in simulators and tried many different azimuth throttles.

Figure 124: Daan Merkelbach testing

Figure 121: Daan Merkelbach testing

**Testing Objective:**

Entire Prototype:
- Comfort and usability of control unit in different positions
- Comfort and usability of throttle in different positions

Body:
- Feel of the body shape

Throttle:
- Feel and use of throttle shape

Figure 123: Daan Merkelbach testing

**Testing Setup:**

- The four prototypes mentioned in part 5.1
- Laptop to show the renders with the styling
- Phone camera to record the testing
- Tripod to place the camera in the desired location

# 5.2 Testing of Style Concepts

For the testing one of the prototypes was placed on a table like it would on a tugboat, and the opera-tor was asked to use the prototype for around 2 minutes as if he was using a functional control unit on a tugboat during an operation. During this part the prototype was rotated multiple times and used in different positions, and whilst sitting and standing. After the initial use some questions were asked, and this procedure was repeated for the other three prototypes to gain the first impression on each one.

Following the first impressions, a series of questions were asked to gain a more in depth understanding of how good or bad each of the concepts was. Whilst asking these questions, the prototypes were constantly used by the operator.

Below the questions that were asked with the answers that were given can be seen:

**What are your initial thoughts to the prototype?**
**Concept 1:** There should be an overhand in the front of the body where the fingers can hold onto or fit into. This would make it easier to work with the throttle.
**Concept 2:** The body feels too wide. As the palm rest gradually gets bigger the entire body is very wide and hard to hold on to, when standing it is okay but when sitting its very uncomfortable, this goes for the forward and backwards position.
**Concept 3:** The part below the throttle is in the way like in concept 1. Changing this will also improve going backwards as the fingers have space to slide comfortably and there wont be a barrier in the way.
**Concept 4:** Comfortable and nice to sail astern through the indents between the main body and the palm rest as they feel "very nice", one automatically start using the indent in the throttle arm which is good but it's also because there is no overhang below the throttle in the front.

**What do you think about how front of the prototype connects to the palm rest?**
I dislike the way the front connects with the back on concept 2. When sailing astern the indents on prototypes 1 and 4 are nice, this in combination with the open back(floating palm rest) allows the fingers to properly hold onto the main body, Concept 4 does this very well as it creates nice finger placement, the grip is very good through the little indents, important that the floating palm rest is rounded on the bottom as fingers will wrap around to grip onto it.

**Which prototype do you feel is most comfortable?**
When free sailing and resting concept 1 and concept 4 are the most comfortable as the hand can very comfortably lay on it. When it comes to giving power and making manoeuvres concept 4 is also the most comfortable with concept 3 close behind. Overall concept 4 is the most comfortable.

**What is better: the gradual form to the palm rest, or a clearer cut to the palm rest?**
The clear-cut palm rest is significantly better. The gradual form makes the body too wide. On top of that, the indents offer better grip. With the clear-cut palm rest the hand can lay on the control unit nicer.

**Which throttle do you think is best? Is there a shape that you prefer?**
**Concept 3:** The throttle is quite bad. When giving throttle, it hits the operator in the finger and when taking throttle away it also hits the operator in the finger. Too bulky and not nice
**Concept 1 + 4:** They have a good shape; however, they are not so easy to control with the fingers. It is easy to slip off the throttle. The indent in the throttle arm of concept 4 can be quite useful to actuate the throttle without having to pinch the throttle head. This was also seen as he directly started to use it when moving the prototype.
**Concept 2:** This is the most comfortable and best shape; it is easy to control and gives good grip. And it is easy to control with thumb and index finger.

# 5.2 Testing of Style Concepts

After asking the questions relevant to the form and feel of the prototypes, the renders of each of the concepts were presented to Daan through a Laptop screen. After going through the four concepts and their features, Daan was asked another set of questions regarding the style of the concepts, the throttle input indicators, and two wrap up questions to get his final feedback.

Below the questions that were asked with the answers that were given can be read:

**Which style do you prefer the most?**
The best style would be for concept 4 as it looks the best, and the least favourite style is concept 2.

**Which throttle input indicator do you think is the best?**
**Concept 1:** I like this one as it is large and clear how much throttle input is given. Confusion can be prevented.
**Concept 2:** This is a nice indicator which is subtle and looks good.
**Concept 3:** This is a very bad indicator. It is not helpful as it can't be seen by the operators.
**Concept 4:** The indicators are fine and show the required information.

**Best style as trainer:** Concept 1 as one can directly understand what the trainee is doing.
**Best style as student:** Concept 1 as its most clear to see what is going on. As they are big and clear it is easy to apply and understand adjustments.

**Which style concept do you find the best in terms of usability and style?**
Best concept is concept 4: The body is the preferred one as it is comfortable, the floating palm rest is very nice as it allows the operator to grab the main body, to make it better the throttle head from concept 2 should be used as it was easier to give throttle input with it, however the indent on the side should be kept so easy throttle adjustments can be made

Second place is concept 3 however this one should have an open palm rest and also the throttle from concept number 2 and the indent on the side.

**What would you still improve of the control unit to make it better?**
I cannot think of something else besides what I have already said, and I like them right now.

*Figure 125: Style Prototype 2 during testing*

*Figure 126: Style Prototype 2 during testing*



# 5.2 Testing of Style Concepts

**Final Testing Conclusion:**

The conclusion of the testing is that the final concept should use the form of concept 4. Doing so the indent between the front and the back of the body is included. These indents were found to not only be a stylistic design feature, but also a functional one. Additionally, a section below the throttle should be removed to allow the operator to actuate the throttle more easily.

The body from concept 4 should be coupled with the throttle head of concept 2, as it could be used the best in different throttle positions, and the throttle arm should include an indent like on concept 4. This indent could help operators actuate the throttle using their thumb without having the need to pinch the throttle head.

*Figure 127-129: Daan Merkelbach during the testing*

| | | |
|---|---|---|
| Technical Context: | | |
| | Considered | **Not applicable** |
| Human Context: | | |
| | **Considered** | Not applicable |
| Market Context: | | |
| | Considered | **Not applicable** |
| Environmental Context: | | |
| | Considered | **Not applicable** |

Using all the information gathered from the previous stages, a final concept was created that aimed to solve all the requirements set in the beginning, and those that were added and changed over the course of the project. The final concept is described in this chapter.

# Final Concept

6

# 6.1 Explanation of Parts and Features

The final concept is an azimuth control unit for tugboats, which is focussed on making operating it more comfortable and safer. With this control unit, tugboat operators can operate comfortably for longer periods of time, and by having a very directional design, they will always know where the control unit is pointing to.

The control unit can be 3D printed and used with the electronics from Smart-Ship to be installed in whichever context it is needed, be it on a tugboat, or in a tugboat simulator from V-Step.

Figure 130: Final Concept rendered in a tugboat bridge mounted onto the Smart-Ship hardware.

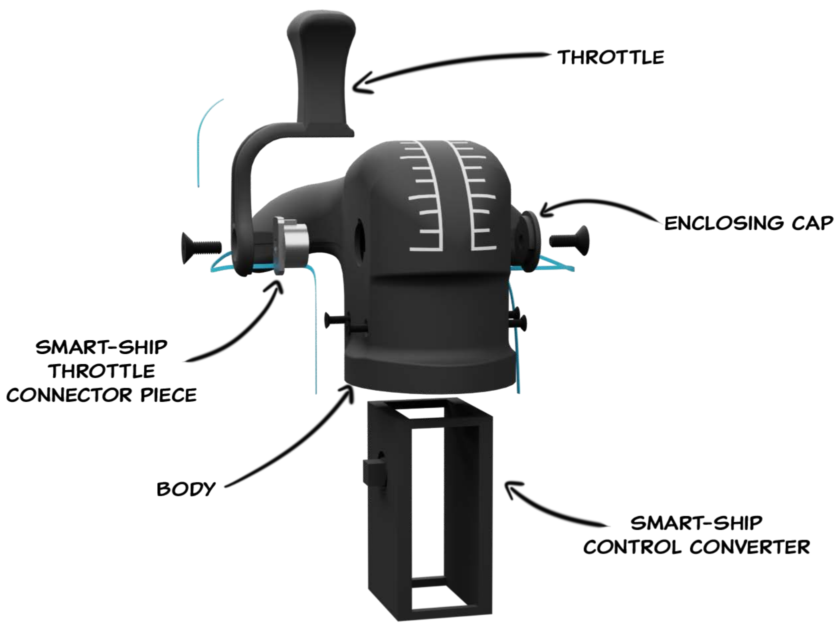



Figure 131: Exploded view of the final concept (with Smart-Ship parts)

The concept consists of three main parts. The body, the throttle, and the enclosing cap. Together these parts give the control unit functionality. The body is the basis of the control unit which everything connects to. It is also the part that is screwed onto the control converter and when twisted dictates the direction of an azimuth thruster.

The throttle is connected to the body and control converter using a connector piece and allows the operator to give thrust input to the azimuth thruster.

Lastly, as the throttle is only connected on one side of the body, a cap is needed to close of the other side to ensure protection of the electronics.



# 6.1 Explanation of Parts and Features

## Body

If the body is viewed from the top, it resembles an inverted T shape. By having the two extrusions on the back, the palm rest area is extended from only being available in the forward position to a larger area, which reduces pressure on the wrist as it is now supported on the palm rest. Towards the outer sides, the extrusions curve downwards which additionally angles the operator's wrist in the forwards position, placing the wrist into a more natural position and further reducing pressure. When looking at the body from the side, it is also possible to see that the palm rest is "floating". This makes it possible for the operators to wrap their fingers around the back part of the unit when reversing, allowing for a more precise throttle input. When looking at a side view, it is also possible to see that the body curves downwards from the front to the back. This is done so that the body follows the curvature of the hand in the forward position. In the renders it can also be seen that there is a blue highlighting line around the back of the body. This line is a style feature that highlights the form of the control unit and connects the body and throttle visually (as it also has a blue highlight). On top of this this, as the highlight comes out of the base of the body, it visually connects the control unit with the mounting plate as can be seen in figure 130.

Between the front part of the body and the palm rest, there are two small recesses which give space for the operator's fingers when reversing, and add small gripping points to make the turning of the control unit easier during quick manoeuvres.

Figure 132: Body from a side

When looking at the front of the body, one can see a cut-out below the throttle. This cut-out serves the purpose of making throttle actuation more comfortable for the operator, as it gives space to his space to his middle, ring, and pinkie finger. Alongside more comfort, the cut-out also offers a better grip of the control unit.

Figure 133: Body from the top

Figure 134: Body from the front

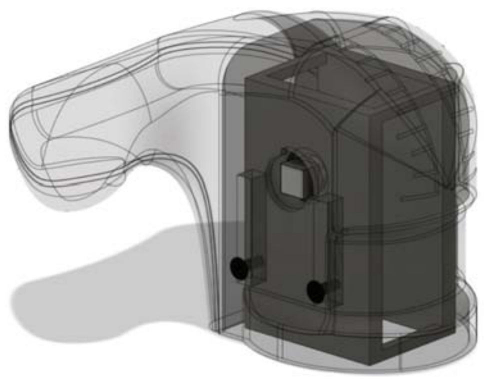


Figure 135: Transparent body shows how it is attached to the control converter using 4 M3 screws

When looking at the base of the body, a protruding element can be seen which is necessary to house a 58mm v-ring for waterproofing.

On the front of the body the throttle input indicators are located. These give the operator information about how much throttle is given at the moment and are also very important to tugboat operator trainers and trainees. For this reason, the indicators are designed to be large and clear and they can be read as the lines stick out of the side of the throttle.
The second aspect, besides comfort, that the inverted T shape tackles is directional feedback. Through the clear shape difference between the front and the back, operators will instantly know which way the control unit is pointing. When combined with the one-sided throttle this becomes even clearer.

On each side of the front part of the body, three holes can be found. The larger one on top makes room for the throttle connector piece of Smart-Ship, and the two lower ones are openings for two M3 screws, which secure the body against the control converter. As all screws on the concept use standard Alan keys to be tightened, it means no special tools are needed to remove the body and throttle.

# 6.1 Explanation of Parts and Features

## Throttle

As can be seen from the renders, the throttle is connected to the body and the control converter on the inner side by a single throttle arm. This is done to give operators space on the outer side of the control unit to properly grip the body. By having the throttle arm on the inner side of the control unit it also makes it very easy to actuate the throttle when reversing as the throttle arm can be held very easily by the whole hand and more precision of the inputs is possible.

As operators like to give throttle input with their thumb and index finger when possible, the throttle "neck" is squared with filleted corners. This gives the operators the required grip for precise throttle actuation whilst also being comfortable. To give the operators an additional grip point for throttle actuation, there is an elongated cut-out along the throttle arm, which allows them to give throttle input without having to always pinch the throttle neck. This indent also fits the blue highlight that was mentioned earlier which visually connects the throttle to the body and mounting plate.

Figure 136: Throttle from the front

Figure 137: Throttle from the side

Figure 138: Throttle from an angle with the M5 screw in place

Figure 139: Body with throttle attached from the side

Figure 140: Hand on a quick prototype of the final concept

Figure 141: Hand on a quick prototype of the final concept

The throttle "head" is rounded on top to give comfort whilst reversing. However, it looks modern from the side to fit the style of the entire control unit. By being narrow in the forward position, it is easier to turn the entire control unit over when going from a forward driving position to a backward driving position.

The throttle is connected to the control converter and body with the throttle connector piece by Smart-Ship. This piece acts as a stopper to only allow the throttle to travel 90 degrees and transfers haptic feedback into the throttle. The Smart-Ship connector piece also seals the hole and ensures water proofing. An M5 screw is used to attach the throttle and uses a simple Alan key to be tightened.



# 6.1 Explanation of Parts and Features

## Enclosing Cap

The enclosing cap is designed to cover and hide one of the large open holes on the side of the body which the throttle would usually be designed for. The cap has the same shape as the opening in the body and therefore fits into place nicely.
From the outer side of the body, it is visible as a simple cylinder with filleted edges, which is subtle and does not disturb the operators. The filleted edges make sure that the operators do not get hurt by getting cut. The cap is attached to the control converter using an M5 screw which also uses a simple Alan key to tighten. An O-ring could be used on the wider part to provide waterproofing as it is pressed against the body. However, this would have to be tested and explored first.

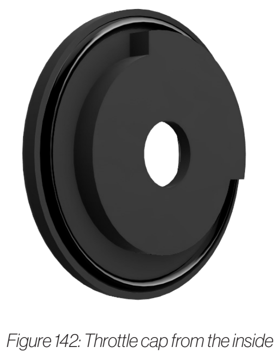


Figure 142: Throttle cap from the inside

Figure 143: Throttle cap mounted on the control unit

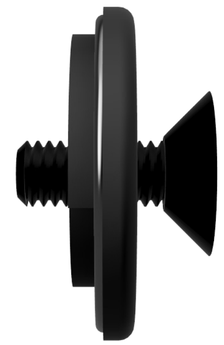


Figure 144: Throttle cap from the side with an M5 screw

## Highlight Features

As mentioned before, there are blue highlighting features on the body around the palm rest, and on the throttle. These highlights will be printed as separate bodies and then glued into place in their respective parts.

To make this possible, along the line of the highlight, the body and throttle have 0.3 mm cut-outs into which the highlights are placed. The throttle highlight is made of one single part and the highlight for the palm rest is split in two and is made of two separate bodies to be printab

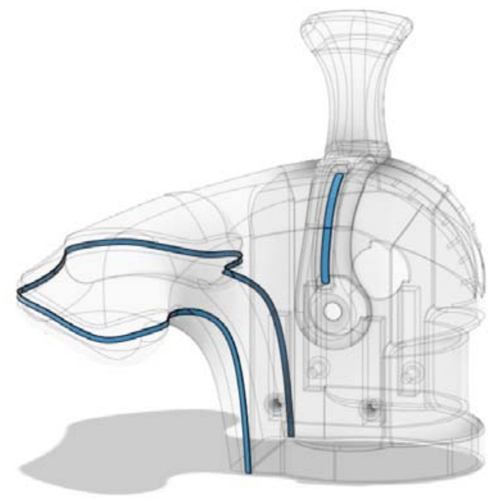


Figure 145: Transparent control unit to show the highlighting feature parts

# 6.2 Material Selection

As Smart-Ship will be doing the manufacturing in house using a Formlabs "Form 2" SLA printer, the material that is chosen should be able to be printed with this printer. SLA printers use Stereolithography to produce high-accuracy and watertight prints which have a smooth surface finish.

Formlabs offer a variety of different resins with different use cases such as engineering cases, dental applications, medical applications and others. From the offered resins, the ones that fall under the category of engineering are the most promising and were therefore compared to find the best one for the product. These engineering resins are specifically developed as they have specific mechanical and thermal properties which can come in very useful.

In the table below the five different resins which are most promising are evaluated according to their pros and cons, and also production costs are considered. For the production cost only the material cost is considered.

| Material | Pros | Cons | Production |
|---|---|---|---|
| **Rigid 10 K** | Can withstand a significant load without bending, has a tensile strength of 65MPa, solvent capability is very low (0.1) | Stiffest material, Brittle material meaning it can chip, Very expensive (285 €/L) | Print time: 26h 11m<br>Layers: 1765<br>Volume: 257.48 ml<br>Cost: 73.38 € |
| **Rigid 4000** | Creates very strong parts, Highest tensile strength of 69MPa | Made for stiff and strong parts, solvent capability is higher than ABS (0.7), second most expensive (220€/L) | Print time: 28h 25m<br>Layers: 1755<br>Volume: 248.83 ml<br>Cost: 54.74 € |
| **Grey Pro** | Moderate elongation, low creep, good for parts that are handled repeatedly, tensile strength of 61MPa, Cheapest material cost (199€/L) | Solvent capability slightly higher than ABS (0.6) | Print time: 25h 4m<br>Layers: 1755<br>Volume: 248.84 ml<br>Cost: 49.51€ |
| **Tough 2000** | Strongest and stiffest material, strong and sturdy parts that should not bend easily, Tensile strength very similar to ABS (46MPa), cheapest material cost (199€/L) | Solvent capability slightly higher than ABS (0.6) | Print time: 22h 44m<br>Layers: 1820<br>Volume: 250.58ml<br>Cost: 50.90€ |
| **Tough 1500** | Resilient prototyping, cheapest material cost (199€/L) | Stiff and pliable parts, bend and spring back quickly, High solvent capability which is higher than ABS (0.7), Lowest tensile strength of 33MPa | Print time: 21h 16m<br>Layers: 1840<br>Volume: 260.37ml<br>Cost: 51.81€ |



# 6.2 Material Selection

**Material Selection for the base components:**

The material that could be chosen to produce the product using resin printing is "Grey Pro". The material has several good attributes such as moderate elongation, low creep, and it is good for parts that are handled repeatedly which is the case with an azimuth control unit.

Additionally, the material has the lowest cost per control unit with 49.51€, and it has a relatively high tensile strength. As the production time is also the third fastest, it has overwhelming good attributes that will make sure the product works well. Additionally, Smart-Ship is currently using "Grey Pro" as a resin, which means that it is already proven to work well for the intended application.

**Material Selection for colour parts:**

As the final concept will include two blue highlights, one on the throttle, and one going around the palm rest, these will be made as separate parts. As these parts won't aid the structural integrity of the entire control unit, it is not necessary to make them from the Grey Pro material. Instead, the colour kit resin material by Formlabs can be used to print these parts in the desired colour (Blue: #29acd9).

The colour kit resin material is said to be strong and precise with high detail and smooth surface finish, which will be necessary as they must fit into the 0.3mm cut-out in the body and throttle. Additionally, the colour kit resin material has a relatively high tensile strength of 65MPa.

Printing these parts will take 5 hours and 5 minutes and use 7.42ml of resin. As a litre of the resin can be purchased for 184 euros, this will result in a total cost of 13,65 euros per control unit for the colour parts.

**Conclusion Material Selection:**

In total the entire control unit will cost 63.16 euros if the material "Grey Pro" is used in combination with the "Color Kit" resin for the colour highlights. As the colour of the body will be dark grey, and the printed material comes out as a dark grey, it means that a surface finish might not be required, reducing the amount of material used.

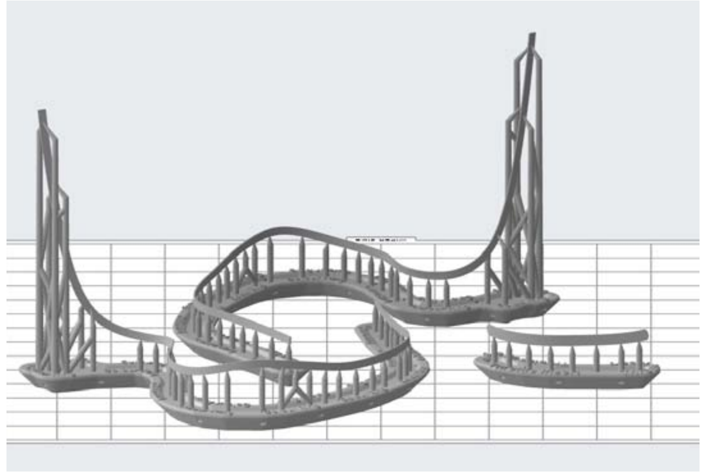


*Figure 146: Highlight parts on the PreForm software*

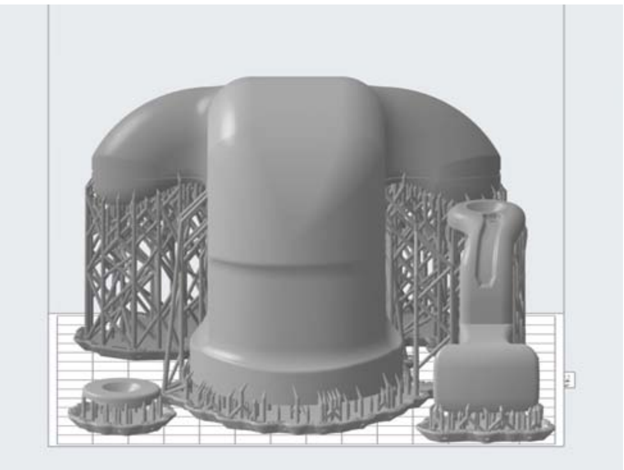


*Figure 147: Body, throttle and cap on the PreForm software*

# 6.3 Dimensions

## Azimuth Control Unit (in mm)

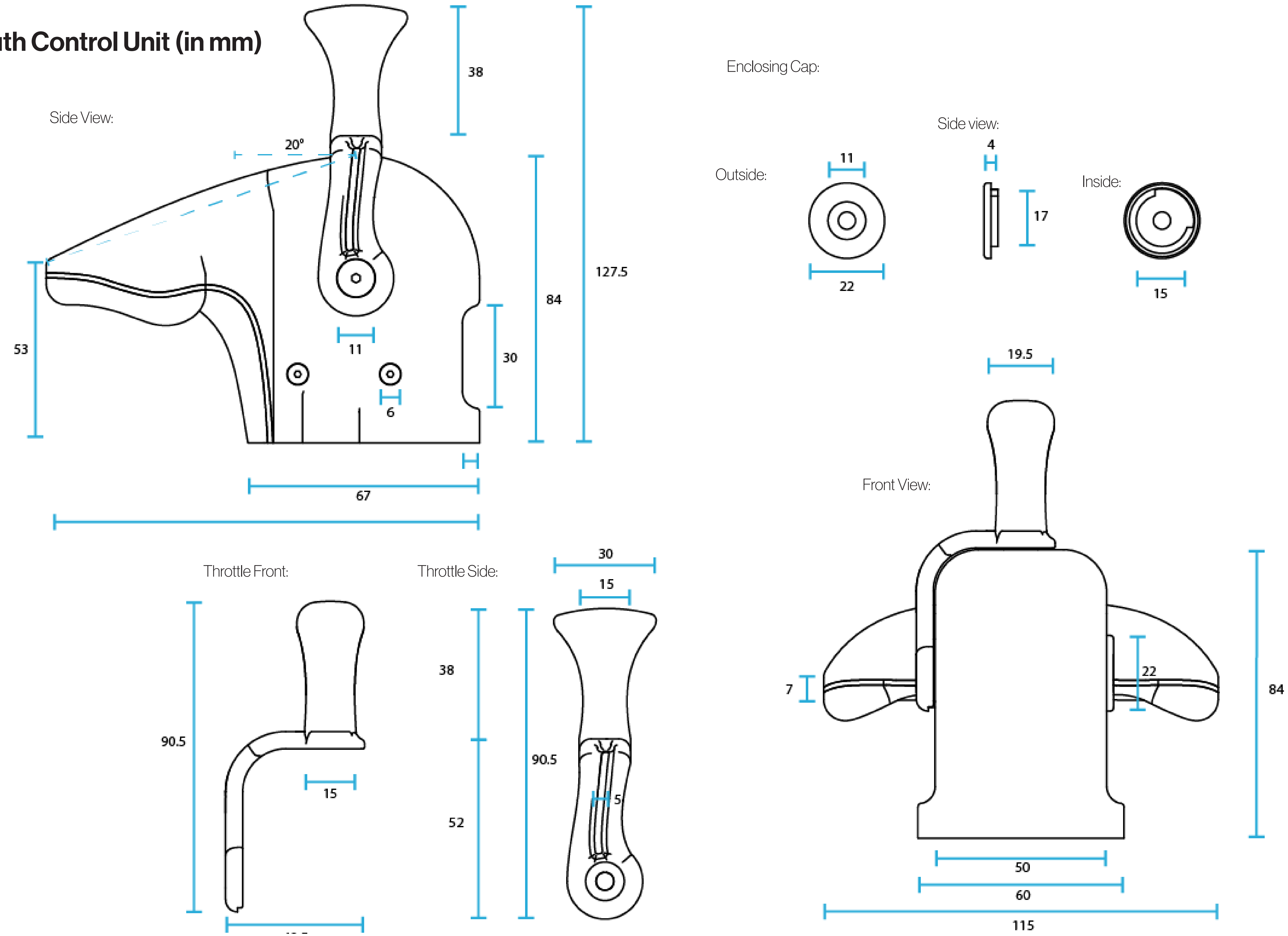



*Figure 148: Dimensions of the main parts from the final concept*

In this section the final concept is evaluated according to the initial values that were found for this project, the requirements that were set in this project, and also recommendations are made if the project is continued.

# Evaluation

7

# 7.1 Evaluation of Requirements and Values

## Evalaution of Human Values:

### Health (Pass)
The control unit is specifically shaped so pressure on the wrist of the operator is reduced.
By curving downwards and sidewards, the palm rest places the operators wrist in an angled position reducing strain.

### Human Wellbeing (Good)
The control unit is heavily focussed on being as comfortable as possible.
With features such as the back extrusions, the rounded edges, and the ability to precisely give throttle input, the operator shoudl feel very comfortable using it.

### Safety (Good)
By making sure that the shape of the control unit is directly understandable, directional feedback is provided.
Additionally all edges that can be touched are filleted to prevent the operators from cutting themselves.

### Reliability (Bare pass)
The control unit is properly secured to the control converter, and includes design features to make it waterproof.
Therefore the operator can be sure that it will work well.
However there is no integrated operating condition light to indicate this.

### Innovation (Pass)
The shape of the body is quite different to the current model and does not resemble it.

### Power (Pass)
The operators can use the control unit as they feel most comfortable.
The 20 degree angle allows them to feel comfortable whilst sitting and standing.
Additionally the small recesses in the middle of the body and the cutout below the throttle offer ample grip to be able to turn it quickly.
Furthermore, the cutout in the throtlte gives the operators annother way of giving throttle input.

### Cleanliness (Pass)
As the control unit does not have very intricate shapes and parts, and the surface finish is smooth, cleaning it allows for easy cleaning.
Therefore sweat stains can be removed easily.

# 7.1 Evaluation of Requirements and Values

## Evalaution of Technical Values:

### Trust (Pass)
As the body is connected to the control converter in the same way as the current azimuth control unit, therefore, the haptic feedback should feel just as good.
However, as there is only one throttle arm, the haptic feedback in the throttle could feel slightly less powerfull.

### Utility (Pass)
The control converter from Smart-Ship fits into the front part of the control unit.
Therefore the body and throttle can be mounted wherever the Smart-Ship hardware is installed, for example on any tugbaot, but also a simulator.

### Quality (Pass)
The control unit will be printed with the "Grey Pro" material which should be as strong as required.
Additionally, the O-ring in the enclosing cap and the V-ring in the bottom in combination with the Smart-Ship throttle connector should make sure that it is properly water sealed.

### Maintainability (Good)
All the screws which are used to attach the body or throttle to the control converter use Alan keys, which are widely available.
Additionaly, as the materials can be 3D printed, replacement parts can be quickly made.

### Adaptability (Pass)
The throttle can be mounted on either side of the body making it possible to have the same body for either hand.
On top of this, the control converter from Smart-Ship fits into the front part of the control unit.
Therefore the body and throttle can be mounted wherever the Smart-Ship hardware is installed.

### Independence (Good)
Each control unit is an independent object and does not connect to annother control unit on the same tugboat.
Also as throttle and direction inputs can be given separately, they are independent of one annother.

## 7.1 Evaluation of Requirements and Values

### Versatility (Pass)

As the control unit can be connected to the Smart-Ship hardware whereever it is needed, the control unit can be sold to more customers.

### Evalaution of Market and Environmental Values:

### Competitiveness (Not fully investigated)

Since the control unit will be sold in combination with the electronic hardware from Smart-Ship, it could not be determined if the product will be competitively priced as this hardware is still under development and therefore no price is known yet.
For this project only the material could be determined as the manufacturing technique is already chosen to be SLA printing since the final production numbers will be low.

### Sustainability (Fail)

For the same reason as for the Disposal value, the sustainability value cannot be fulfilled since SLA printing does not offer environmentally friendly resins at the moment.
However, as there is constant development of resins, this could change in the near future.

### Profitability (Pass)

The body of the control unit is identical for whichever is it used by. The throttle however needs to be mirrored and can therefore only be used on either the right control unit or the left control one. As the throttle will be 3D printed, this is no problem since the production cost does not increase.

### Disposal (Fail)

Since the production technique is required to be SLA printing, this value cannot be fullfilled because there are currently no biodegradable or compostable forms of resin.

# 7.1 Evaluation of Requirements and Values

Human Context   Technical Context   Market Context   Environmental Context

● Good   ● Pass   ● Bare Pass   ● Fail/Not testetd   ● Not Relevant

| Hard/Soft: | Requirement: | Grade: | Grade Explained: |
|---|---|---|---|
| Hard | The control unit should be shaped so the operator can rest his palm | ● Good | The control unit gives the opertator palm support in form of an inverted T shape with rounded contours. |
| Hard | Different shape to current Smart-Ship azimuth control unit | ● Pass | The control unit does not resemble the current azimuth control unit by Smart-Ship |
| Hard | The control unit should have a clear shape difference between the front and the back | ● Good | The control unit curves downwards to the back and a distinct inverted T shape. |
| Hard | Control unit should have smooth edges | ● Good | The controls has rounded edges to prevent the operators from cutting themselves |
| Hard | Control unit should be designed with male hand anthropometrics in mind | ● Pass | The control unit is designed with the average male hand size of 193mm in mind |
| Hard | The control unit can be used whilst sitting and standing | ● Pass | The control unit cuves down at an angle of 20 degrees from the highest point to the lowest palm rest point |
| Hard | The control unit should be at least 120 mm long | ● Good | Control unit is 126mm long |
| Hard | The control unit should have a shape that allows the operator to securely hold it | ● Good | The control unit cuves down at an angle of 20 degrees from the highest point to the lowest palm rest point |
| Hard | Gap between the throttle and the widest part of the extrisons is at least 50mm | ● Pass | The gap is 53mm and therefore bigger than the minimum space |
| Hard | The throttle should be operated through at least the thumb or index finger | ● Good | The throttle is actuated with thumb on the throttle arm or by the throttle neck with the thumb and index finger |
| Hard | Throttle lever should be operated comfortably from normal hand placement | ● Good | Throttle has indent in the side for easy throttle actuation |
| Hard | Control unit has a one sided throttle | ● Pass | The throttle is attached on the side where the thumb is depending on the hand. |
| Soft | The material should be comfortable for the majority of operators | ● Bare Pass | "Grey Pro" is a material that feels comfortable to the hand and no metal parts touch the operators hand |
| Soft | Material should be plastic that does not feel cheap | ● Bare Pass | "Grey Pro" is a material that feels comfortable and solid to the hand but has not been tested yet |
| Soft | Operating condition lighting can be changed by smart ship | ● Fail/Not testetd | The operating condition lighting was removed as it was not wanted in the concept by Smart-Ship |
| Soft | Control unit should follow the contour of the hand for forward driving position | ● Pass | The shape offers easy grip points andthere is small cutouts between the front and back and below the throttle |
| Soft | Control unit should slightly angle the operator's wrist in the forward driving position | ● Pass | Operators wristare slightly angled through the curvature of the body. |
| Soft | Control unit should be elongated to reduce ulnar deviation | ● Fail/Not testetd | This was only a potential feature that could have been included to increase comfort, however it did not make it. |
| Soft | No pressure points when going backwards | ● Pass | Throttle head is rounded and comfortbale when going backwards |
| Soft | The throttle "neck" is 15*15 mm for comfortable operation | ● Pass | The thinnest part of the neck is 15 * 15 mm and curves upwards. |
| Soft | The throttle is large enough to be supported by middel finger in reverse | ● Good | The throttle neck and head are 38 mm which are large enough to be held |
| Soft | Easy to clean shape and material | ● Bare Pass | Simple shape and smooth surface finish, The material was not tested |

# 7.1 Evaluation of Requirements and Values

Human Context | Technical Context | Market Context | Environmental Context

Good | Pass | Bare Pass | Fail/Not testetd | Not Relevant

| Hard/Soft: | Requirement: | Grade: | Grade Explained: |
|---|---|---|---|
| Hard | Allows for haptic feedback | Pass | The body is is solid and screwed onto the control converter so haptic feedback can be transferred precisely |
| Hard | The control unit should have a Robust Construction | Fail/Not testetd | The control unit has a strong shape that can withstand pushing and pulling forces |
| Hard | Fits onto current mounting mechanism created by Smart-Ship | Good | The body accomodates control converter through gap in bottom of body of 48mm x 44mm |
| Hard | Control unit should be Water and Dust resistant | Pass | The body houses a v-ring on the base and uses the cap to seal it from water |
| Hard | Control unit has two degrees of movement | Good | The control can give throttle and directional input on two axes throttle in vertical, direction in horizontal |
| Hard | Control units should not be connected with one another. | Good | The control unit is an independent unit and not connected to any others. |
| Hard | Throttle and direction input are not given with the same movement. | Good | Control unit is 126mm long |
| Hard | The body is connected to the control converter with 4 M3 screws. | Pass | The body is attached properly it is attached to the control converter using 4 M3 screws in the front of the unit. |
| Hard | The throttle screws to the Control converter | Pass | The throttle is actuated with thumb on the throttle arm or by the throttle neck with the thumb and index finger |
| Hard | Throttle lever moves its full range | Good | The throttle moves forwards and back a full 90 degrees |
| Soft | Control unit should not require special tools to be opened | Pass | The control unit only uses Alan key screws which are common |
| | | | |
| Hard | Competitive Pricing | Not Relevant | Could not be determined as this can only be one once the total cost with the electronics components is known |
| Hard | Control unit can be used in simulation environment | Pass | The control unit can be mounted onto the electronics so it can be used wherever they are placed |
| Hard | Use of exisitng technology | Good | The parts are manufactured using SLA printing on a Form 2 printer which Smart-Ship already owns |
| Soft | Control unit should be identical for each thruster | Fail/Not testetd | The body has the same shape for either hand, the throttle however has to be mirrored to fit |
| Soft | Follows Smart-Ship design language | Pass | The body uses organic shapes which can be found in the other products, and it uses the blue highlights |
| Soft | Control unit should be made of eco-friendly materials | Fail/Not testetd | There are currently no eco-friendly SLA printer resins which could be used. |
| Soft | The control unit should be produced using eco-friendly production methods | Fail/Not testetd | As SLA is the required production technique this could not be fullfilled as the choice was already made |

# 7.2 Recommendations

The final concept has been designed to fulfil all the requirements that were obtained throughout the research phase. However, as not all requirements were fulfilled or not fully fulfilled, this part will name some recommendations of how to proceed to pass all the requirements that were set.

**Material Selection:**

Since the material that was chosen had to be able to be printed using an SLA printer, the choice was very limited. There are currently no environmentally friendly resins on the market, so the values of sustainability and disposal failed. As the technology develops, there is a high possibility that these environmentally friendly resins will be created. However, if these values and requirements are to be fulfilled immediately, research should be conducted into alternative manufacturing processes which make use of environment friendly materials.

If "Grey Pro" is the material that will be used further, testing is recommended to understand whether the material will perform well over longer use times, and during different temperatures. This could potentially influence if a different material needs to be chosen, or if the parts need to be coated with another material.

**Identical Shape of every part:**

One of the requirements that was barely passed is the one that states that the components should be identical for all control units. This was a requirement that failed as the throttle cannot be used on either side of the body and needs to be mirrored first. The requirement was created in the beginning of the project when the production technique was expected to be a technique like moulding. For the current production method, this does not matter, as it has no impact on material cost, production cost, or manufacturing time.

However, if the production method was changed, it could mean that two moulds are needed for the throttle, which raises the costs. Therefore, the recommendation is that the throttle shape should be changed depending on whether the production method changes.

**Highlight features:**

In the concept, the highlight features are separate bodies which are glued into place on the control unit. For future development of this concept, it is recommended to investigate other methods through which these highlights can be displayed on the body and throttle. This could potentially save production time and material that is spent on the print of these parts.

**Elongated control unit:**

The requirement of the elongated control unit failed as it was not included in the final concept. This was since it was contradicting with other requirements about the size of the control unit. To be sure that it could not aid the operators, it is recommended to make a prototype which is a more elongated version of the final concept, to test if it could potentially aid the operators.

# References & Appendix

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# 9. Appendix

## 1. DESTEP Analysis

| Factor | Trends | Relation to Company | Sources |
| --- | --- | --- | --- |
| **Demographics** | Ship operators in Japan are becoming Older (56% of 20 000 operators were 50 or over) | As is clear from these factors the main demographic for Tugboat operators is male and over 40 years old.<br><br>This is very useful since the controllers can be specialized for this target group and they can be adapted to suit this target group especially well instead of having to suit a large number of different people. | https://www.rina.org.uk/Could_unmanned_ships_solve_Japans_population_crisis.html<br><br>https://www.imo.org/en/OurWork/TechnicalCooperation/Pages/WomenInMaritime.aspx<br><br>https://www.zippia.com/marine-captain-jobs/demographics/ |
| | Women represent only two percent of the worlds 1.2 million seafarers | | |
| | 94% of female seafarers are working in the cruise industry | | |
| | more than 50% of captains in the US are 40+ years old, with the average age being 42.8 y/o | | |
| | 20-30y/o 16%, 30-40y/o 27%, 40+ y/o 56% ages of the operators | | |
| | 81% of captains in US are white, with 8% being black, 7% being hispanic or latino | | |
| | | | |
| **Economics** | Autonomous ship market will be 165 billion by 2030 | From this research it is clear that the market for Tugboats will not disappear any time soon. With continued market growth more tugs will be needed with better controls.<br><br>Considering that after COVID the maritime trade is supposed to grow further this will also increase the need for tugs and hence good controllers to steer these tugs. | |
| | every month roughly 100.000 seafarers reach the end of their employment contract | | |
| | Asian market will drive growth of autonomous ships market | | https://www.alliedmarketresearch.com/autoNomous-ships-market |
| | Unemployment rate of captains steadily dropping in US from 11% in 2011 to around 4% in 2018 | | |
| | approximately 1.68 billion tons of cargo transported every year | | https://www.ibisworld.com/united-states/market-research-reports/tugboat-shipping-navigational-services-industry/ |
| | global shipping index continued to rise in Feb 2021 by further 9.6% to 131.82 points | | |
| | The eventual widespread administration of a COVID-19 (coronavirus) vaccine is anticipated to enable a return to normal, and thus, aid the economy in a steady path of recovery. | | https://globalmaritimehub.com/report-presentation/global-shipping-index-february |
| | Trade activity expanded strongly during the period, with more barges and ships entering and exiting US ports | | |
| | Trade activity expanded strongly during the period, with more barges and ships entering and exiting US ports | | https://www.ics-shipping.org/shipping-fact/on-the-brink-of-a-revolution/ |
| | A return to positive conditions in the US economy is expected to drive waterborne trade levels higher, stimulating greater demand for tugboat and navigational services as a result | | |
| | ICS, along with a consortium of international associations, has proposed a dedicated $5 billion R&D Fund to research sustainable and viable solutions | | https://www.maritime-executive.com/blog/the-future-of-tugs-in-a-changing-world |
| | UNCTAD expects that seaborne trade will triple by 2050 compared to 2016 | | |

# 9. Appendix

| Factor | Trends | Relation to Company | Sources |
|---|---|---|---|
| **Technological** | using shore power whenever possible | Automation is the main trend that will shape the tugboat industry in the coming years. It has already started with Kotug doing tests of remote controls tugs. This will be important for Smart ships since it is a potential market they could step into and sell their controls too. By tweaking the electronics of the controls it should be able to connect them via satellite connection to the tugs at sea. Smart Ship could sell ready control units to larger companies such as Kotug which are ergonomically better and can be directly implemented into the simulator. | http://www.tugmasters.org/wp-content/uploads/2014/07/BTA_Jack-gaston.pdf |
| | Use of 5g to help autonomous and remote control navigation technologies | | |
| | Maritime Autonomous Surface Ship (MASS "a ship which to a varying degree can operate independently of human interaction" | | http://www.businesskorea.co.kr/news/articleView.html?idxno=39109 |
| | Advanced technologies can be used for insightful information for alerts that will help to reduce accidents | | |
| | The emergence of advanced technologies such as Artificial Intelligence (AI), machine learning, cloud computing, big data, and augmented reality have brought the idea of autonomous vehicles to reality | | https://maritimecyprus.files.wordpress.com/2018/09/dnv_gl_autonomous_ships_2018-08.pdf |
| | For a remote operator to gain adequate situational awareness sufficient information must be transferred from the sensors on the ship to a remote control center in a timely manner. | | |
| | RT Borkum was controlled from the international Tug Salvage and OSC convention and exhibition(ITS) in marseille with the RT Borkum was in Rdam | | https://safety4sea.com/first-remote-controlled-tugboat-sails-over-a-long-distance/ |
| | Cameras and controls of the tugboat were used on the demo console in marseille | | |
| | The real time sensor technology makes it possible to give the remote control captain the situational awareness that is needed for safe operation | | https://maritimecyprus.files.wordpress.com/2018/09/dnv_gl_autonomous_ships_2018-08.pdf |
| | | | |
| **Environmental** | Based on future trade growth estimates, shipping will have to improve its carbon efficiency by some 90% in order to achieve IMO's target of a 50% reduction in global GHG emissions by 2050 | These trends are very important since they show a clear development towards a more eco friendly future in the tugboat industry. Whilst for now the main focus is on changing the fuel type to reduce carbon emissions, this will eventually transform into general materials used on the ships. Including the controller. Therefore eco friendly materials and production methods should be chosen. | |
| | ICS believes if the 2050 reduction target is to be met commercially viable low emission ships need to appear on the market by the early 2030s. | | https://www.ics-shipping.org/shipping-fact/on-the-brink-of-a-revolution/ |
| | Natural gas takes over as the biggest energy source in 2026. This includes a decrease of crude oil and other oil products to be transported after 2020 and an increase of natural gas. | | https://www.maritime-executive.com/blog/the-future-of-tugs-in-a-changing- |
| | lower carbon fuels such as LNG, methyl-Alcohol and bio-oil | | https://www.ics-shipping.org/shipping-fact/shipping-and-new-technologies/ |
| | Hybrid solutions and duel-fuel solutions (LNG-based) | | https://www.wartsila.com/wst-tug-campaign/video |
| | requirement to have an International Energy Efficiency (IEE) certificate and to provide an energy efficiency management plan | | https://www.greenport.com/news101/energy-and-technology/green-tugs,-serving-green-ports |
| | LNG-fuelled, or dual fuel (LNG/diesel). All have the advantage of fuel savings and a reduction of emissions over conventional tugs. | | |
| | Kotug refitted its Rotortug RT Adriaan to become Europe's first true hybrid tug with early reports of fuel reductions of 15% and emission reductions of 44% hydrocarbon, 33% NOx, and 38% SOx. | | |



# 9. Appendix

| Factor | Trends | Relation to Company | Sources |
|---|---|---|---|
| **Polititcal** | IMO code on Noise Levels on Board Ships MSC.337 will establish mandatory noise level limits | The last two legislations are probably some of the most important since they consider the azimuth thrusters. It is important that they can work separately from each other, but in case something goes wrong at least one has to be able to stay in control of the ship. A clear indication of which controllers are doing what can assist with this. | https://marine-digital.com/article_maritime_transport_technology_outlook_for_2030 |
| | If the limitations of drones could be overcome and no legal restrictions are in force for the use of them, it might become a good system to make a connection between tug and ship. | | |
| | Starting and control of the speed must be provided and performed by a single starting lever or a dedicated push button switch. | | https://www.swzmaritime.nl/news/2019/07/11/the-road-towards-autonomous-ship-handling-with-tugs/?gdpr=accept |
| | Remote control failure must be indicated with an alarm and still allow the machinery control from local control. | | |
| | Consequently, IACS considers the requirement for a main and auxiliary steering gear should be applicable for each of the steering gears in a multiple steering-propulsion unit installation. Alternatively, each of the steering gears is to comply with the interpretation of SOLAS regulation II-1/29.6.1. | | https://www.marineinsight.com/maritime-law/solas-requirements-for-remote-control-of-propulsion-machinery-of-ships/ |
| | IACS considers that redundancy should be required in the steering gear for each steerable propulsion unit based on the understanding that, in particular for passenger ships | | |
| | 1 a reduced steering capability after a single failure is not acceptable; and . | | http://www.iacs.org.uk/media/5698/sse-6-12-draft-revision-of-iacs-unified-interpretation-sc242-relating-tosolas-regulations-ii-128-i-iacs.pdf |
| | 2 a failed steering gear on a ship with multiple steerable propulsion units may impair the steering capability of the ship, either due to lift effect on the underwater part of the failed unit or due to the uncontrolled direction of the propulsion thrust from the failed unit. | | |

# 9. Appendix

## 2. Azimuth Control Unit Analysis

| Controller | Positive Aspects | Negative Aspects | Picture of controls |
|---|---|---|---|
| **LF 70 - Lilaas** | - rounded throttle control to change with palm<br>- throttle gets slimmer to be adjusted with thumb and index finger<br>- the throttle can be actuated with more fingers | - no indication of direction (besides visual arrow)<br>- no place to rest palm<br>- controller not adapted to hands<br>- edges can create pressure points |  |
| **Veth Control** | - throttle lever in centre of controls for better adjustment with thumb and index<br>- "swing arm" for quick grab<br>- clear sense of direction | - edges on the cylinder can cause pressure points on the hands<br>- throttle lever square<br>- no indentation to place thumb and index comfortably<br>- throttle cannot be actuated with all fingers |  |
| **Aquapilot - Rolls Royce** | - modifiable cheek and palm pads<br>- indentation on side of controller to palace fingers<br>- throttle rounded for comfortable control with palm<br>- clear directional feedback | - make throttle slimmer on the bottom for more comfortable input<br>- throttle cannot be actuated with all fingers |  |
| **Schottle control** | - clear directional feedback through design and throttle head<br>- palm rest for comfort<br>- "swing arm" to grab easily<br>- slim throttle for precise input<br>- throttle arm on either side to use all fingers for input | - relatively sharp edge on throttle when going backwards and operating with palm<br>Palm rest is quite narrow |   |



# 9. Appendix

## 3. Ergonomic Mice Analysis

| Mouse Name | Features | Image |
|---|---|---|
| **Logitech MX Ergo Wireless Trackball Mouse** | Adjust height of the mouse ?  perfect if you want to elevate your wrist to certain levels<br>Place for pinkie to lay on<br>Thumb is supported on trackball/outstretched<br>Curved to fit the form of a hand<br>Can be tilted upward to suit the normal wrist placement tilt it up to 20°<br>"instantly improves the position of your wrist and forearm" |  |
| **Anker 2.4 G Wireless Vertical Ergonomic optical mouse** | Vertical mouse<br>Hand is positioned similar to if you're holding a cup<br>Build of the mouse curves up with your hand so that instead of having the thumb on the side and the index finger on top of the mouse ?  thumb on one side of the control and fingers on opposite side of the controls<br>Alleviates pressure on the wrist joint<br>Its designed to use with a palm grip though through its large size people with smaller hands might have difficulties reaching the buttons |   |
| **J-Tech Digital Scroll Endurance Wireless Mouse** | Added grip for where you position your thumb and rest your fingers<br>Has a specific groove for the wrist to go<br>Not hanging wrist directly on the tabletop<br>Palm rest is removable if not liked<br>Follows hand curve better than anker<br>Thicker gripping point than the anker ?  not as good for smaller hands |  |
| **Microsoft Sculpt Ergonomic Mouse** | Mouse is contoured like water<br>Halfway between a slightly vertical mouse design and a traditional mouse<br>Indented area on left side of the mouse for thumb placement<br>No placement for pinky finger or wrist<br>Does not support the full palm ?  not long enough |  |
| **Logitech MX master 2S** | Long mouse that follows contours of hands<br>Large place for the thumb to rest on<br>Expands towards the back to follow the palm<br>No placement for pinky or index finger<br>Tilted towards the right ?  not quite normal mouse which is flat but follows normal movement of the hand |  |
| **Logitech MX Vertical Wireless Mouse** | Textural grip surface where palm is placed<br>Place for thumb to be placed<br>Other fingers are just Resting on pinky finger since there is no support for them<br>"reduces muscle strain by 10% and promotes a more ergonomic posture"<br>unique vertical angle of 57° which reduces pressure on the wrist |  |
| **Corsair GLAIVE PRO** | Slight curve for right hands<br>Textured grips<br>Comes with 3 swappable side panels that can be exchanged to make it more comfortable<br>One of them has thumb rest<br>Other two have different grip patterns |  |

## 4. Video Observation

| Video Description | Operator Standing/Sitting: | What control is used: | Interaction between hand and control: | Other observations: | Source |
|---|---|---|---|---|---|
| Operator is filmed from the top and side whilst he tows and berths a vessel. | Sitting between the controls | Niigata type control | Both hands are constantly on the controls besides when he uses his right hand to use the radio. | Footage of him using the controls is 291s long and in that time, he makes adjustments around 135 times. | https://www.youtube.com/watch?v=4Mct7EbL0xo&ab_channel=RusmanTayang |
| Tugboat is towing a large vessel and the operator is filmed by a second person. Controls are not constantly visible. | Operator is standing during the entire video. | Rolls Royce controller | Whenever the controls are in the frame the operator has both hands on the controls. | The operator looks around a lot whilst it looks like he has both hands on the controls. The operator communicates with the large vessel a lot. | https://www.youtube.com/watch?v=OLo_yrd6q6w&ab_channel=RobinsonDaLobeira |
| Tugboat is manoeuvring very close to a large ship. The operator is filmed by a camera on the left. | The operator is sitting throughout the entire video | Aquamaster control head | The operator has both hands on the controls whenever he is in the frame. He takes his left hand off to use a radio hanging from the ceiling. | The operator looks around a lot to orientate himself. | https://www.youtube.com/watch?v=11xflkvYZZ0&ab_channel=KristianMangampa |
| Video describing tugboats and how they work. During the video it is possible to see how the tugboat is operated | The operator is standing in the parts of the video where she is visible. | Unknown control unit. Similar to the Aquamaster control head. | In the frames that she is visible both hands are laying on the controls. | The video is very short and only a few frames show how the operator uses the controls. | https://www.youtube.com/watch?v=a1iKboDo6go&ab_channel=Techsploration |
| Video of a tug operator manoeuvring towards a larger vessel and moving around the vessel. The camera is first behind the operator filming above him and the controls and then pans to his left. | Operator is sitting throughout the entire duration of the video. | The control is a Niigata controller. | In the first part of the video where both hands are visible both of them stay on the controls the entire time. When it pans right only the right controller is visible and the right hand is still on the controls constantly. | The operator makes quite a few adjustments with the controls on approach of the larger vessel. Towards the end the right hand is used to use a radio hanging from the ceiling. | https://www.youtube.com/watch?v=_lHysOibcq4&ab_channel=RollesCha |



# 9. Appendix

## 5. Criteria for Instruction Manual

When looking into requirements that Smart-Ship would have to consider when developing an instruction manual for the Asian market, interesting and important aspects to acknowledge were found. Depending on the country the manual is written for, culture impacts the way the manual should be written. One critical aspect that needs to be addressed per country is the use of pictograms. For example, in China numbers under 10 can be counted with one hand and therefore pictograms using hand symbols might not mean the same for them as for someone with a different cultural background. (C. Song, 2021)

The second critical aspect that needs to be looked at is the language of the instruction manual itself. Whilst in some Asian countries, the manual is preferred in the national language, this is not a valid assumption for all of them. In countries like India with no official national language, it is hard to create a manual that will suit every state. (PTI, 2010) Therefore, the manual should be written in English as it is used for interpersonal communication among workers. (D. Zühlke, M. Romberg, P. Meil, 1998)

Based on insights from the different cultures, a list of aspects that Smart-Ship would have to consider, when writing an instruction manual for the Azimuth control unit was created.

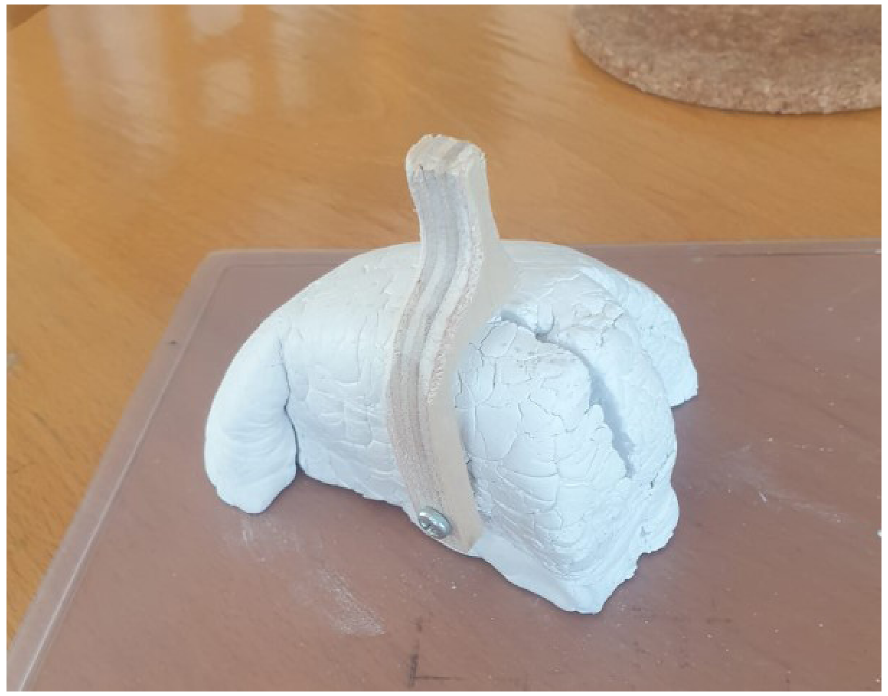
Aspects for China:
- Instruction manual written in a more chronological and context-based form compared to western manuals
- Little use of imagery especially not heavily abstract pictograms
- Careful use of hand sign pictograms
- Instruction manual written in Chinese

Aspects for Korea:
- Elaborate Manuals with a detailed explanation for every problem
- Manuals are written in Korean
- Should include visuals such as pictograms

Aspects for India:
- Instruction manual written in English
- Use of pictograms cannot be copied from western manuals
- Use of sufficient illustrations
- Use of simple structure

Aspects for Indonesia:
- Instruction manual should be written in Indonesian as it builds a basis for their multicultural background
- Instruction manual should be kept basic and simple

## 6. 1st Prototyping Images





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## 7. 1st Testing Answers

| Step | Action | Questions |
|---|---|---|
| **Test 1: Hand placement in different position** | Prototype 1:<br>- Turning axes needs to be moved back<br>- Sitting: Turning between 0 and 180 degrees over outside (90*) is not nice<br>- Sitting: From 315 to 45 degrees is nice<br>- Standing: forward 180 degrees is okay<br>- Standing: Switch from 0 to 180 over inner (270*) is good<br>- Smaller throttle arm should make it more comfortable<br>- Prefer to use the prototype with the left hand when throttle is mounted on the right and with the right hand when throttle is mounted on the left<br>- → surprise as when I tried it at the simulator I experienced it more comfortably the other way around<br>Prototype 2:<br>- Sitting: turning between 315 to 45 is very nice, and between 270 and 90 is nice<br>- Switch over the throttle between forward and backward is comfortable and easy both sides<br>- Backwards is very nice in all positions (90 to 270)<br>- Space between throttle and extension needs to be enlarged (three fingers between throttle and extension)<br>Prototype 3:<br>- Sitting: Forward between 330 and 30 degrees is comfortable<br>- Standing: forward 330 to 30 is more comfortable<br>- Standing: backwards its okay with 90 to 270 being decent<br>- For inside 180* (270*) its not nice as the throttle is in the way when switching over<br>- Throttle head is in the way<br>- Prefer to use the prototype with the left hand, which means the purpose of the idea is gone, as it designed for the right hand→ only use in forward position | After each controller:<br>- What are your initial thoughts?<br>- How is the comfort of the controls in the different sections?<br>- How comfortable is the throttle in the different positions?<br>Repeat for all 3 control units |
| **Test 2: Directional Feedback of controls** | - The directional feedback Is clear for all three control units<br>- Directly understand which way the units are pointing<br>- The way the throttles are placed in combination with the shape of the body, clearly see which way they point<br>- Yes, for all three prototypes it is very clear which way to place the hands on it. | - How clear is the directional feedback?<br>- Is it clear which way the prototype is supposed to be held? |

| | | |
|---|---|---|
| **Test 3: Usability of controls** | Prototype 1:<br>- The hand placement area, is too large in the front and needs to be slightly reduced to allow for better grip<br>- The hand placement itself is very comfortable<br>- Angle and height are very good<br>- Palm placement is okay → axes need to be moved more to the back as the control unit rotates away from below hand<br>- Grip is very nice, overhang could be extended on the sides some more to improve grip<br><br>Prototype 2:<br>- Size is good but the extrusions on the bottom are too close to the throttle → they need to be moved back slightly → three fingers should fit in between the throttle and the extrusion<br>- Extrusions make it comfortable when the throttle is turned when sitting, → hand can rest on it nicely<br>- The angle is too steep when standing, when sitting it is okay but prototype one was better<br>- The grip is good as you can place your fingers on either side to turn in quickly<br>- Extrusions could be made with less of a sharp angle – less of a T more of a Y<br><br>Prototype 3:<br>- Size of the body is okay → right hand design preferred for left hand<br>- Control unit is comfortable but when turning inward it feels awkward (left hand on righthand control)<br>- Palm support is very good in forward position but not for inward movement, for outward movement it gets in the way<br>- The grip of the unit is quite bad. The large palm support makes it hard to hold on to the body with all fingers → slip of the side when necessary to make sudden change<br>- The angle is good but a bit too low prototype 1 was better height | - What do you think about the size of the control unit?<br>- How comfortable is the control unit?<br>- How good is the wrist support that it offers?<br>- Is the angle and height of the unit comfortable?<br>- How is the grip of the unit? |
| **Follow up questions - Body** | - prototype 2 is best as it is most comfortable in both directions, very easy to rotate the control unit and to switch over the throttle<br>- Prototype 1 is second best as the grip is very good and the angle and height are the best of all three prototypes<br>- Prototype 3 is last as the large palm support makes it hard to grip as the whole palm is resting on a curved surface (different to the intended use with the right hand)<br><br>- Control unit does not need to be symmetrical, but the one-sided throttle is preferred to be on the side where the thumb is placed (not where all fingers are placed) | - Which of the 3 did you find the best and why?<br>- Is a symmetrical control unit better than a one-sided control? |



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| | | |
|---|---|---|
| **Test 4: Usability of Throttles** | Prototype 1:<br>- slimmer throttle the throttle is too thick and is hard and not comfortable to grip with the thumb<br>- one sided throttle on the right is comfortable in reverse as it offers support<br>- form of the throttle arm is good and can be gripped but too large<br>- Top of the throttle is not important but it is comfortable as its rounded off<br>- thickness of the neck is very good<br><br>Prototype 2:<br>- throttle arms can be used with thumb and other fingers are nice<br>- would be more comfortable if the outer arm could be gone (better grip with full hand)<br>- size of the throttle is very nice as its not in the way when turning the control back<br>- neck is a bit too think<br>- top of the throttle not too important but this one is very comfortable<br><br>Prototype 3:<br>- throttle is very nice → better than the prototype 1 throttle<br>- nice thickness and throttle neck is also nice<br>- throttle head is too large so it gets in the way when turning the control unit | - What are your initial thoughts?<br>- What is your impression of the handle?<br>- What do you think about the top of the throttle?<br>- What do you think about the size and form of the connection arm? |
| **Follow up questions – Throttle** | - a one sided throttle arm would be nicer as it gives more room to hold onto the control unit<br>- its best if the left throttle arm stays on the right control unit and the right control arm on the left control unit<br>- the thinner throttle was a lot nicer as it could be handled easier | - Would you prefer a one-sided control arm or a two sided one and why?<br>- Was the thinner control arm or the thicker control arm more useful/ comfortable? |
| **Additional Features** | - the control unit should not have a built-in radio switch as the control unit spins and finding it would be hard and it could be accidentally turned on<br>- a screen Infront of the control unit would not be very useful since having one along the windows is of much more use and less distracting<br>- important to feel clutch in point and the full engagement point<br>- no the control unit should stay very basic | - Would you like it if the control unit had a built-in radio switch?<br>- If a screen was added, would you like it and what type of information would you like to see on it?<br>- Are there features that are missing on current controls that you would like to add? |

| | | |
|---|---|---|
| **Summarizing questions** | - preferred prototype 2 the most from all after simulating actual use on a tugboat → very comfortable, can be turned very nicely and offers good grip → one sided throttle would be better, and a Y shape instead of T shape would be preferred<br>- Second best was prototype 1 however after testing it practically it was not as good as originally thought → very good with the grip it offers and the angle and height are the best → shape is not as good as prototype 2, if its used then with the throttle of prototype 3<br>- Last was prototype 3 → it had the best throttle arm→ more comfortable for the operator to use it with the left hand instead of the right, throttle head is too large and when turning it gets in the way | - Which of the shapes did you prefer the most and why?<br>- Which throttle did you prefer the most and why?<br>- What were the main features you liked the most overall? |
| **Extra questions** | - very bad to use steel or any metal as it gets incredibly cold and uncomfortable<br>- if metal is used it needs to be coated with something<br>- plastic is a good idea as it does not get too cold or too warm → important to select the right plastic as it can't be a plastic where the operator begins to sweat<br>- veth control unit is made of comfortable material<br>- not usually but on the simulator, students sometimes sweat very much so it should be easy to clean<br>- they are only important to trainees as in simulators there is no screen to check on, so being able to check how much 30 degrees turning is very important, also for the trainers to check on the students | - What is the preferred material you would like to see on the control unit?<br>- Do operators sweat a lot when operating tugboats?<br>- are the visual indicators on the throttle and direction important? |





# 8. Style Analysis Smart Ship

**Style Analysis Smart-Ship**

1. **Understanding who Smart-Ship (SS) is**

SS Mission:

- Bridge the gap in information transfer they want to create a more sustainable maritime future

SS Values:

- Innovation – revolutionary way of information transfer
- Sustainability – control units transfer optimal speed, and other information
- Safety – transfer any type of information e.g. shallow water, engine status etc.
- Efficiency – increase operational efficiency as it makes it easier and less demanding to perform tasks

SS Brand Personality:

- Attention to Detail
- Relaxed and Flexible
- Open

Ss Unique Positioning:

- Haptic feedback is not very developed in the maritime sector and especially not as modifiable as the one SS is making

2. **Colour Pallet:**

Logo:

Grey: Grey:

Blue: # 29acd9

White: # ffffff

Website:

#363d43

Blue: # 29acd9

White: # ffffff

Light Grey: # dadadb

Black: #000000

Product Range:

Grey (metallic): # 8F8F8F

Blue: # 29acd9

White: # ffffff

Black: # 000000

Bronze: # 685539

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Blue: most universally appealing colour in the spectrum, can help branding appear more stable and trustworthy, fits with the maritime industry (99designs, 2017)

Grey: communicates some strength and mystery of black, sophisticated colour which lacks the negativity of colour black (Bourncreative, 2010)

White: communicates purity and innocence, but also cleanliness, freshness and simplicity (Verywellmind, 2021)

Black: Modern and Sophisticated, Classic (99designs, 2017)

**3. Form/ Shape:**

Logo: Combination of Rounded shapes and straight edges. The combination prevents the logo from seeming impersonal, however conveys strength and efficiency. The two arcs along the top left and bottom right of the logo, give insight into what it is smart ship does. With the outer edges being squared it keeps the feeling of being robust and safe.

Website: The website uses squares everywhere to display images, textboxes and other things. It is split up by straight blue lines. This gives the website a very robust look which could also show strength and efficiency. Combined with the light blue, it does not come across as very impersonal.

**4. Font**

- Font family: Sans-Serif – Sleek and modern feel
  - Font: itc-avant-garde-gothic-pro
- Header: Size: 53.6px
- Sub-header: Size: 37.2px
- Text: Size: 17.1px

**5. SS product line up:**

1. Hoppermat – Throttle Control Lever
   - Simple design with only 3 colours: Bronze, Black, and White
   - Hexagons along the surface of the body of the unit
   - Throttle arms in elongated octagonal shape
   - Throttle knobs hexagonal shape
   - Throttle input indicators have squares on both sides of the number

2. Classic Tiller – Rudder Control Lever
   - Chamfered body cylinder and lever knob
   - Filleted direction indicator "nose"
   - Direction indicator lines, every 30 degrees larger indicator
   - Smart-Ship logo inset into the top of the cylinder

3. Azimuth – Azimuth control unit
   - Filleted edges on throttle "head" and direction indicator "nose"
   - Filleted edge on throttle "arm" front side and chamfered in the back
   - Base plate chamfered along the side
   - Throttle indicators white squares, every 30 degrees one is larger
   - Numbers of direction are written on the base plate in white



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   - Blue circle on the base plate around the control unit – indicates that it can turn 360 degrees
   - Base of the throttle has a rounded extrusion which points at how much throttle is given
4. The Heptune – Fast Craft Throttle Lever
   - Most edges are filleted
   - No chamfer on any part of the product
   - Blue lines highlight buttons and overall shape of the product
   - Extrusion on the back of the body for extra grip which is not filleted or rounded

Overall product evaluation conclusion:

- No real consensus on whether to use smooth design with filleted edges or a rougher style with chamfered edges
- The only control that uses the hexagonal shape is the hoppermat and it is not reflected in any of the other products
- Direction indicator "nose" is very similar on the azimuth and the tiller
- Clash between more organic design of the heptune and azimuth, compared to the geometric forms of the tiller and hoppermat

How can I continue the Brand Identity?

- Think about designs that are focussed on organic shapes and also geometric shapes
- The best ideas can be presented made in foam prototypes and tested, and also presented to Smart-Ship

References:


https://www.bourncreative.com/meaning-of-the-color-grey/#:~:text=The%20color%20gray%20is%20an,formal%2C%20conservative%2C%20and%20sophisticated.&text=Dark%2C%20charcoal%20gray%20communicates%20some,negativity%20of%20the%20color%20black.

https://www.verywellmind.com/color-psychology-white-2795822#:~:text=White%20represents%20purity%20or%20innocence.&text=Some%20of%20the%20positive%20meanings,stark%2C%20cold%2C%20and%20isolated.

https://en.99designs.be/blog/tips/brand-identity/

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DE HAAGSE HOGESCHOOL