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Propulsion and Thruster Control for Offshore Vessels

Propell og thruster kontroll for offshore skip

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“PROPULSION AND THRUSTER CONTROL FOR OFFSHORE VESSELS”

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PREFACE

This thesis is written as the concluding work of my master's degree in Industrial Economics and Technology Management at the Norwegian University of Life Sciences (NMBU). The project has been carried out at the Department of Mathematical Science and Technology (IMT) in cooperation with Vard Electro AS (Vard) and Montaag Inc. (Montaag).

Growing up on the west coast of Norway in the heart of the maritime cluster, the maritime industry has always been a big part of my life. Witnessing the rapid innovations and entrepreneurial spirit in my local community is what motivated my choice in education, and later triggered my interest in product development.

Although my interest in product development came at a later stage, I have always been intrigued by the idea of creating great products. I am therefore grateful for the opportunity to learn more about this subject by combining my skills in both engineering and business.

As a participant in the Norwegian Entrepreneurship Program (Gründerskolen) during the summer of 2014 I held an internship at the industrial design firm, Montaag. I was early on put on a project with Vard where I soon was presented with the opportunity to write my thesis in connection to this project.

Being able to work and contribute on a real life project has been very exiting. In addition to the steep learning curve I have achieved during the work on this thesis, I hope that the work I have done also can be of some value to Vard and Montaag.

I want to extend my greatest appreciations to Principal at Montaag, Per Ivar Selvaag, for including me in his project and inviting me to write this thesis. Also thanks to Ove Bjørneseth, Vice President R&D and Technology at Vard Electro AS, for welcoming me into the project. Thank you both for giving me this opportunity.

For valuable advice and insights throughout the project, I would like to thank Associate Professor Jan Kåre Bøe at the Norwegian University of Life Sciences (NMBU).

Ås, May 15th

Ingrid Emilie Pilskog

ABSTRACT

Operating in the maritime supplier industry as a bridge equipment installer focused on the market for offshore and specialized vessels, Vard Electro is developing its own line of control levers. Today Vard procures control levers from subcontractors and implement them into their deliveries. By developing its own line of control levers, the company believes it can create more optimal solutions for today's advanced ship operations.

The primary objective for this project has been to develop specific suggestions and recommendations for product design of Vard's control levers based on ergonomics and operating related aspects of offshore service vessels.

The project follows the method of Integrated Product Development (IPD - initial project), which emphasizes identifying customer needs and market aspects, resulting in a final concept. Research and general literature studies have been performed to map out the human framework, and the operator and marine framework, and data from interviews has been processed to identify stakeholder needs.

Anthropometric measures for the 50- percentile man is established to represent the target segment. In addition is biomechanical restriction pertaining to hand operations, sitting- and standing work positions, and visual characteristics identified. The cognitive ergonomic aspects identifies restrictions and recommendations for optimal human machine interaction in relations to control, displays and placing.

Offshore vessels are usually equipped with a combination of main propellers, azimuth thrusters, tunnel thrusters and rudders. The propulsion units are controlled from the bridge of the vessel using manual thruster control where each propulsion unit has its dedicated control unit. These are better known as control levers. The control levers are located on the bridge's forward, aft and wing workstations. They are operated by the bridge crew, and used during docking, maneuvering, and in transit, both separately and in combination with other systems. The operations can be sitting or standing and for a few seconds up to several hours.

The control lever system usually comprise of physical controls and feedback displays. The system contains a lot of functionality, which can be divided in physical attributes, relating to the actual maneuvering characteristics of the physical levers, and overall system technical functionality, relating more to communication with other systems and start/ stop functionality.

The early specification process presents a list of user needs laying the basis for the development of the product goals. The stakeholder needs clearly stated sound ergonomics as an important quality and further emphasizes the importance of a sound user experience for the overall system functionality. Last, it expressed a need for modularity in order to accommodate the different vessel types.

The functional analysis clarifies that the control levers consist of a total of two main physical functions, "Continuous adjustment control, rotary" and "Continuous adjustment control, linear". The analysis performed of competing products enlightened constructional similarities among the products, typically straining the hand of the operator.

Based on the functional analysis and input from the competitor screening a set of concepts were developed. The concepts were first screened, and then modified before they were taken through a concept scoring, ending with a final concept. The concepts were screened according to a set of criteria developed from the customer needs and product goals. It was further

assigned weights ranging the relative importance of the needs. The final concept is a combination of the three concepts that achieved the highest score in the screening process.

The result of the product development process is a final concept consisting of an azimuth lever, a speed lever, a rudder controller and a feedback display presenting scaling for the control parameters of each individual control lever. In addition to these physical attributes, the final concept is also specified to contain an operator control screen and a set of overall system functionality corresponding with the user needs. It is recommended that the feedback display is also utilized as an operator screen.

As a result of the complete development process the finished concept inhabits much of the identified stakeholder needs, and it is developed to fulfill the established product goals. To limit the scope of this project, some limitations have been set. Most notably, I have not considered rules and regulations, and mechanical and electrical design has not been performed. In order to reach a finished product an operator screen must be developed, and it is also important that the concept undergoes testing for verification.

SAMMENDRAG

Som utstyrsleverandør til den maritime næringen har Vard Elektro AS (Vard) spesialisert seg innen installasjon av bruutstyr for offshore- og spesialfartøy og de skal nå utvikle sin egen serie med manøvreringshendler. I dag kjøper Vard inn manøvreringshendler fra underleverandører og implementerer det inn i sin leveranse til sluttkunde. Ved å utvikle sin egen serie av manøvreringshendler ønsker Vard å skape et produkt som er mer optimalt løsning til dagens avanserte offshore operasjoner.

Målet med prosjektet har vært å utarbeide et konkret forslag og anbefaling til design av Vards nye manøvreringshendler basert på ergonomiske og operasjonelle aspekter ved offshore servise fartøy.

Prosjekter følger den integrerte produktutviklingsmetoden (IPD – initial project). Metoden vektlegger identifisering av kundebehov og markedsaspekter, som resulterer i et ferdig konsept. Undersøkelser og generell litteraturstudie ble utført for å kartlegge menneskelig rammeverk og rammeverk for operatør og marine aspekter, og intervjudata har blitt analysert for å identifisere interessenters behov.

Antropometriske mål for 50-persentilmannen er etablert for å representere målgruppen. I tillegg til er biomekaniske restriksjoner knyttet til håndoperasjon, sittende og stående arbeidsposisjoner, og visuelle karakteristikker identifisert. De kognitive ergonomiske aspektene identifiserer restriksjoner og anbefalinger for optimal menneske- maskin interaksjon i relasjon til kontroll, skjerm og plassering.

Offshorefartøy er vanligvis utstyrt med en kombinasjon av hoved propell, azimuth thrustere, tunnel thrustere og ror. Fremdriftsenhetene er kontrollert fra fartøyets bru ved å bruke manuelle thrusterkontrollere hvor hver enkel propellenhet har sin dedikerte kontrollenhet. Disse er bedre kjent som manøvreringshendler. Manøvreringshendlene er lokalisert i broens arbeidsstasjoner foran, bak og på vingene. De er operert av brumannskapet, og blir benyttet under dokking, manøvrering, og i transitt, både separat og i kombinasjon med andre systemer. Operasjonene kan være stående eller sittende, og kan vare fra noen sekunder opp til flere timer.

Manøvreringshendel systemet består vanligvis av fysiske kontrollere og tilbake-meldingsskjeremer. Systemet inneholder mye funksjonalitet, som kan være delt inn i fysiske egenskaper, relatert til den faktiske manøvreringskarakteristikken for de fysiske manøvreringshendler, og overordnet systemteknisk funksjonalitet, mer relatert til kommunikasjon med andre systemer og start-/stoppfunksjonalitet.

Den foreløpige spesifikasjonsprosessen presenterer en liste over brukerens behov som legger grunnlaget for utarbeidelse av produktmålene. Interessent behovene fastslår at god ergonomi som en viktig kvalitet og videre vektlegges viktigheten av en god brukeropplevelse av hele systems- funksjonaliteten. Til slutt, utrykte listen et behov for modularitet for å kunne akkomodere ulike typer fartøy.

Den funksjonelle analysen tydeliggjør at manøvreringshendlene består av total to fysiske hovedfunksjoner, ”kontinuerlig justeringskontroll, roterende” og ”kontinuerlig justeringskontroll, lineært”. Analysen av konkurrerende produkter viser konstruksjonslikheter mellom produktene, som typisk belaster hånden til operatøren.

Basert på den funksjonelle analysen og input fra konkurrentanalysen ble et sett av konsepter utviklet. Konseptene gikk først gjennom en utvelgelsesprosess, og ble så modifisert før de ble

tatt gjennom en konseptmåling, som endte med et endelig konsept. Konseptene ble valgt ut på bakgrunn av kriterier som ble utviklet fra kundebehov og produktmål. Det ble videre angitt rangeringsvektinger til det relative viktigheten av behovene. Det ferdige konseptet er en kombinasjon av de tre konseptene som oppnådde høyest poengsum i utvelgelsesprosessen.

Som et resultatet av den totale utviklingsprosessen innehar det ferdige produktet mye av de identifiserte interessentbehovene, og det er utviklet for å tilfredsstille de etablerte produktmålene. For å begrense prosjektets omfang har noen begrensninger blitt satt. Viktigst, har jeg ikke betraktet lover og regler, og mekanisk og elektrisk design er ikke gjennomført. For å kunne nå et endelig produkt må en operatørskjerm først utvikles, og det er også viktig at konseptet undergår testing for verifisering.

CONTENT

Page:

Page:

Page:

LIST OF ABBREVIATIONS

Abbreviations used in this paper.

Table 1: Acronyms used in this report.

Acronym	Explanation
NMBU	Norwegian University of Life Sciences
IMT	Department of Mathematical Science and Technology
R&D	Research and Development
IPD	Integrated Product Development
AHTS	Anchor Handling Tug supply
PSV	Platform Supply Vessel
OSCV	Offshore Subsea Construction Vessel
GUI	Graphic User Interface
UI	User Interface
UX	User Experience
HVAC	Heating, ventilation and air- conditioning
CAD	Computer Aided Design
OSV	Offshore Service Vessel/ Offshore Vessel
EOT	Engine Order Telegraph
RPM	Rotations Per Minute
DP	Dynamic Positioning

1. INTRODUCTION

This chapter gives a brief description of the project background before it continues with an historic review ending up in an overall problem description.

1.1 BACKGROUND

Vard Group is one of the major companies operating in the maritime industry delivering services in design and shipbuilding of offshore and specialized vessels used in the offshore oil and gas exploration and production industry, and oil services industries. Vard Group has headquarters in Norway and employs about 10 000 people. In addition to ten shipbuilding facilities located around the world, Vard consist of multiple business units operating as ship's equipment suppliers, the largest of which is Vard Design, Vard Accommodation and Vard Electro. Vard's slogan is "Built on Trust", reflecting their long shipbuilding traditions founded on craftsmanship, fellowship and salesmanship. [1]

Montaag is a multi-disciplinary design agency located in Berkeley, California. It was founded by the company's Principal Per Ivar Selvaag in early 2013. The now 20- strong team consist of designers specializing in product design, User experience/ User interface design, design research, brand, web and service design. Montaag's client list range from small tech- startups to larger more established international companies. [2]

In 2014, Vard Group and Montaag engaged in a collaboration where Montaag was to inform strategic decisions regarding Vard's product development and branding strategies. Vard is operating in a continuously more competitive industry where several of the larger players, including Vard and their major competitors, has put more effort into building a clear brand and identifying their competitive advantage.

Part of the overall project with Vard Group is a closer collaboration with Vard Electro. Vard Electro is a supplier of complete electrical systems for ships, including power and automation, diesel-electric propulsion, switchboards and HVAC systems and a part of this includes outfitting vessel bridges.[1] As an electrical and electronic equipment provider, Vard Electro operates in a market comprised of companies specializing in dynamic positioning, software, specialist hardware, bridge equipment, sensors, etc. As a bridge equipment installer, Vard Electro currently procures products from these suppliers, and implement them into their deliveries.

Today's Vard bridge consist of different equipment from a number of different suppliers. The immediate consequence of this is a bridge environment consisting of several different systems and interfaces. This creates a relative complex and sometimes cluttered environment where the operator has to relate to a number of different interface designs at the same time.

The industry as a whole, and hereunder the bridge equipment and its respective layout, is subjected to strict and rigid rules and regulations which very much dictates the bridge design. With safety as the main driver, this leads to an environment of proven and reliable technology accompanied by redundant systems and solutions. Through the development of new products and solutions, the industry is continuously challenging the classification societies to improve the regulations, adapting them to new technology.

Figure 1: Typical Vard bridge. Wärtsilä control levers located center left with blue light indications on the panel. [3, 4]

In order to achieve greater coherence between their own systems and the ones provided from external suppliers, and to strengthen their presence as a bridge installer, Vard Electro has involved Montaag to perform the overall design of the new Vard bridge. Within this scope lies the development of Vard's own propulsion and thruster controllers. The goal is to develop manual remote controls, so called control levers, for control of the ships main propulsion, thrusters and steering gear that the client and end user can recognize as a Vard product, as part of a Vard bridge.

1.2 SHIP HANDLING

As ships over the years have grown larger, new ways of maneuvering them has been developed and adapted to suit the growing constructions. History takes us from the steering oar up to the electronic remote controllers used to day.

1.2.1 HISTORIC SHIP HANDLING

Figure 2: The Oseberg Ship, built around year 820 AD. A steering oar is located on the aft starboard side. A small tiller is mounted for easier maneuvering. [5, 6]

The oldest evidence of boats dates as far back as to the 4th millennium BC to Egypt where the boats steering was commonly performed by utilizing both sails and oars. [7] The steering oar is in other words the oldest and simplest way of maneuvering a vessel. It dominated ship steering for a long time, and was the common steering mechanism of Viking ships. The steering oar was usually situated at the shipside, or occasionally at the stern. By moving the steering oar it interrupts the water flow alongside the vessel, creating forces changing the course of the ship. To ease the operation, steering oars often had a smaller handle or tiller making it easier to operate.[8]

Figure 3: Hinged sternpost rudder with tiller. [9]

After the Viking- ages ships started to grow larger in size and more complex in structure. Around 1180 AD the hinged sternpost rudders appeared and instead of a steering oar, there was now a rudder hinged to the sternpost of the vessel. [10] A tiller operated the rudder, moving the ship towards port when turning the tiller to starboard and vice versa. The hinged sternpost rudder was the main maneuvering mechanism, and is in many ways the same concept still used for rudders. The hinged rudder remained, but the tiller was later replaced with mechanical devices such as the whipstaff and the ships wheel. [11]

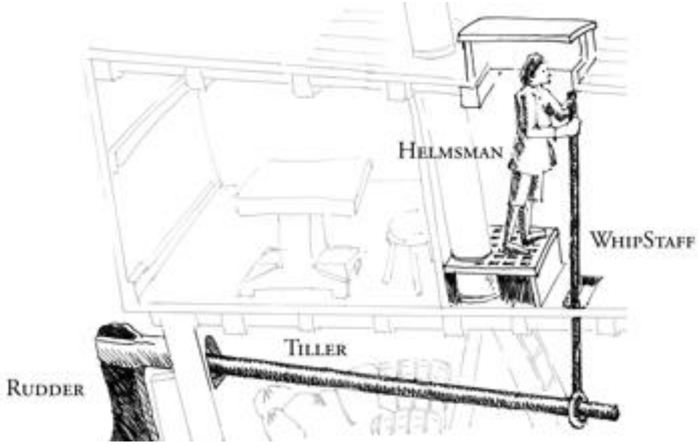

Figure 4: The whipstaff operated by the helmsman. [12]

In time, ships grew larger and ship builders started adding decks to the vessels. To compensate for the increased distance between the bridge and the rudder, a bar was now connected to the tiller. This allowed the helmsman to be situated on the upper decks while steering the rudder located, sometimes, several decks below. This mechanical device was called a whipstaff and was the first steering device where forward- facing operator were able to move the steering device in the same direction as he wants the ship to move. Hereby implementing a new logic for ship steering.[11] As the whipstaff was found heavy to operate, and relative inefficient it was soon replaced by somewhat similar, but more mechanically advanced ship's wheel.

Figure 5: The ship's wheel of the USS Constitution. [13]

The ship's wheel is perhaps the best-known nautical item to this day. This steering mechanism was probably invented in the 1700, but one can not say for sure exactly when.[14] The wheel is connected by a system of ropes to the tiller, which again is attached to the rudder. The intuitiveness of operation models the one of the whip staff, where a forward- facing operator turning the wheel port makes the ship turn port. [15] The ships wheel continues as the main steering device as we enter the new paradigm of motorized vessels.

1.2.2 MOTORIZED SHIPS

The start of modern ship handling is defined by Robert Fulton's development of the first commercially successful steamboat in the beginning of the 1800s.[16] In the 1830s the screw propeller was invented and the traditional rudder mechanics was transferred to the new, modern, steam powered ships.[17]

As ships were now equipped with steam power propulsion, the captain were now able to control the ship's power and speed to a much greater extent and this third control parameter appeared. In order to ensure propulsion, the captain now relied on the skills and duties of the people operating the engine situated below deck. The need for communication between the ships commander on the upper-, and the chief engineer on the lower decks appeared and the engine order telegraph (EOT) was invented. By placing one EOT on the bridge and one in the engine control room the captain could set the EOT to a given order; typically full ahead, ahead, stop, astern or full astern telling the engineer which speed he needed. A bell would go off in the engine room when the order was changed, and vise a versa on the bridge when the engineer confirmed the order given. [18]

Figure 6: Engine order telegraph. [19]

The combination of screw propeller, rudder, and EOT represent the first modern ship handling system and it continued to be dominant as the combustion engine takes over ship propulsion after world war one.[20] As development progresses, the EOT is replaced by the modern remote propulsion control system which directly sets the desired command to the system without the intervening the engine room personnel. [18]

In the 1900s propulsion units advance and the invention of bow thrusters, and the rudder propeller in the 1950s provides the captain with greater maneuvering possibilities, and with this also follow different control units.[21] Today, steering devices are remote controls where both the speed and the direction of power is controlled individually for each propulsion unit. This means that the operator is now also directly in control of the vessels speed. [22] There is therefore a limited need for communication with the engine control room and the EOT is now merely an emergency device in case the remote control system is to break down. [18]

Even though the controls have changed, manual thruster controls still operate from the same order as the ships wheel, and the main propulsion accompanied by rudders is for many vessels still the main steering mechanism. The manual thruster controls have developed from large mechanical installations to today’s electromechanical control units.

Figure 7: Traditional control levers expressing a similarity to the EOT. Lower left there is a rudder controller. [23] [24]

Figure 8: Modern remote propulsion controls. [25]

1.2.3 FUTURE OF SHIP HANDLING

In recent years, there has been an increased awareness directed towards the operating conditions and the importance of the bridge work- environment. Several large innovations projects are underway, most notably the Ulstein Bridge Vision and the Rolls- Royce Future Vision.

Figure 9: Ulstein Bridge Vision. [26]

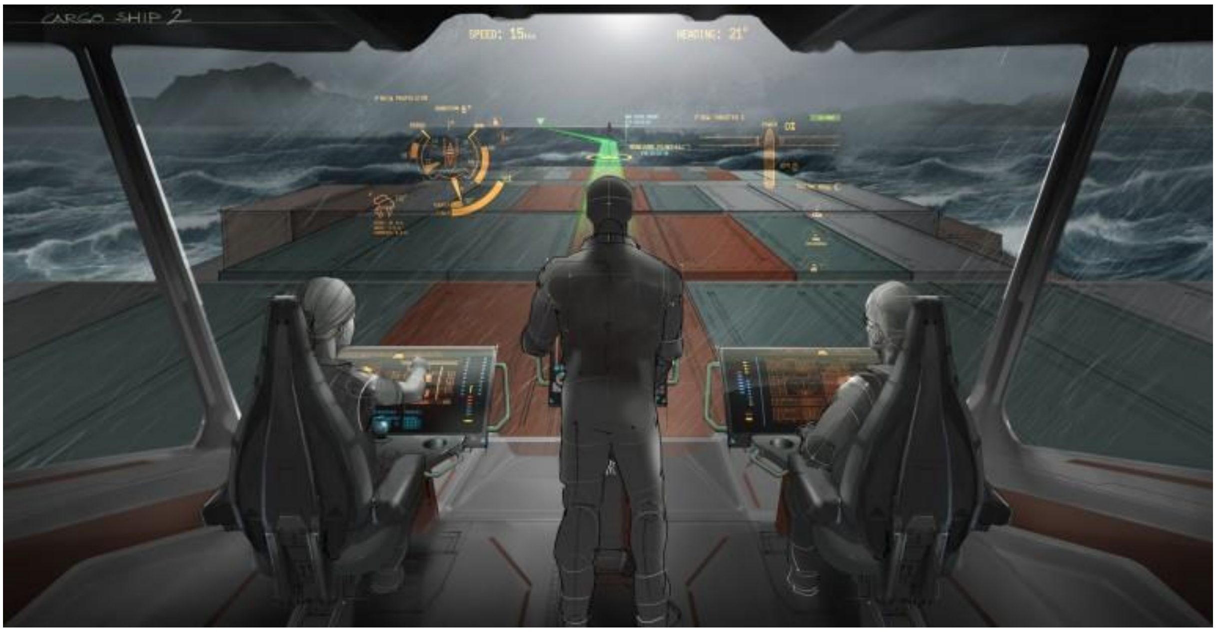

Figure 10: Rolls- Royce Future Bridge. [27]

These projects represent a high tech bridge environment utilizing technology such as heads up displays, eye-tracking technology, augmented reality, gesture controls and advanced computerized systems aimed to ensure optimal and safe operations. [28] Even though these technologies already exist and is present in several industries, it is still a far way to go for the maritime industry.[29]

Statements as "Bring the human back into the loop", and make technology a tool for the operator is in focus in all these projects.[26] Still there are also research projects working on removing humans from the vessels all together. Projects like MUNIN (Maritime Unmanned Navigation through Intelligence in Networks) and DNV- GL's Revolt is exploring the idea of autonomous ships where the operator is all together removed from the vessel.[29, 30] The US Navy's, Project Blue Shark, is exploring the future work environment for these operators. [31]

Figure 11: The US Navy's Project Blue Shark exploring future work environment. The control levers seems to be removed all together and replaced by a touchscreen and gesture controls. [31]

1.3 PROBLEM SPECIFICATION

Looking at the typical Vard bridge one first notice the relative cluttered work environment consisting of many different interfaces and systems. The control levers have a complete different interface and design compared to the rest of the bridge equipment. There is even a difference within the control lever system as the rudder controllers are provided by a different supplier than the thruster and propulsion controls. Studying the bridge a little further one notice the amount of redundancy. Screens are duplicated and functionalities repeated in several different systems creating an information overflow.

Generally looking back in history there seems to have been a natural simplification in technology all the way from the beginning of ship handling, where solutions have been modified to fit the new paradigm. An early example is the whipstaff, which was basically a simple solution to the problem of increased distance. A more recent example is how the remote control levers seems to be a reproduction of the traditional engine order telegraph where its interface have been translated into a smaller speed controller. Just like an EOT, the typical control lever consist of the lever mounted to the outside of a cylinder swinging back and forth. These control levers are found on everything from small boat to large advanced offshore vessels.

Considering the apparently inherent qualities of the control levers, and their relative wide range of application, one wonders if this is really the optimal control lever for todays advanced ship operation. The industry is clearly pushing towards a new paradigm of bridge operations, but the question is based around what this paradigm will be. As humans will still continue to operate ships, a control lever system will have to account for both the human and operational aspects.

2. PROJECT PLANNING

This chapter provides an overview of the projects main objective and subsequent, verifiable subsidiary objectives. It further provides a detailed work plan and progress chart based on the time restrictions of the project. Finally, the project limitations are set.

2.1 OBJECTIVE

The main objective for this master thesis is defined as: ***"Review, identify and analyze ergonomic and operating related aspects of control levers for offshore vessels, and develop substantiated recommendations and specific suggestions for product design of Vard's control levers."***

2.2 SUBSIDIARY OBJECTIVE

The following subsidiary objectives lays a basis for fulfilling the main objective of the project.

1. Establish relevant human framework related to control levers.

2. Identify marine and operator framework related to control levers.

3. Conduct a product development process to develop recommendations for optimal product design.

- Establish product specifications
- Concept generation
- Final concept and recommendations

4. Follow up and establish the project frame by developing a project report documenting and presenting results for all the steps of the process.

5. Prepare presentation for exam.

2.3 TASKS AND MILESTONES

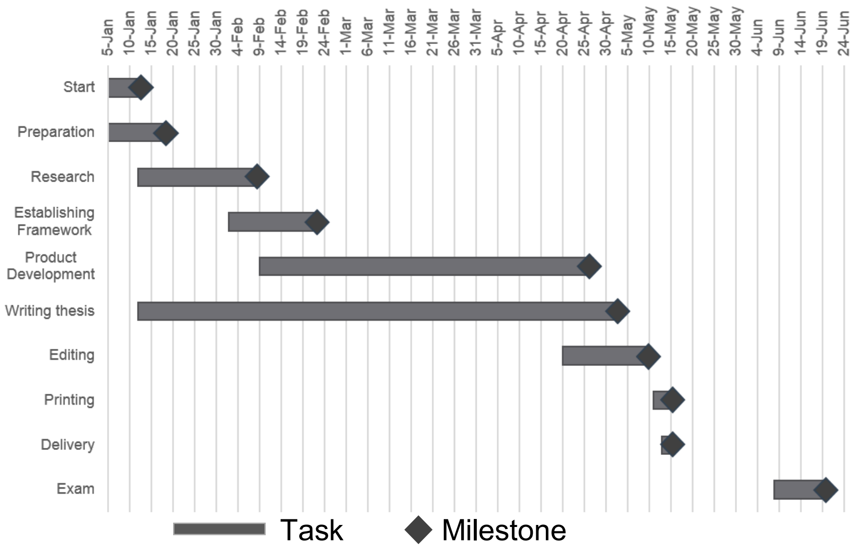

Figure 12: Gantt chart displaying main activities and milestones. (Own illustration)

Table 2: Timeline for milestones in Figure 12.

Task	Start date	Duration	End date
Start	05.01.2015	7	12.01.2015
Preparation	05.01.2015	13	18.01.2015
Research	12.01.2015	27	08.02.2015
Establishing Framework	02.02.2015	20	22.02.2015
Product Development	09.02.2015	76	26.04.2015
Writing thesis	12.01.2015	111	03.05.2015
Editing	20.04.2015	20	10.05.2015
Printing	11.05.2015	4	15.05.2015
Delivery	13.05.2015	2	15.05.2015
Exam	08.06.2015	12	20.06.2015

2.4 DETAILED WORK PLAN

Beneath follows a detailed overview of the subsidiary goals and its process steps. The achievement of a subsidiary goal is defined as a milestone.

1. Establish relevant human framework for control levers:

- Identify anthropometric data for operator
- Identify ergonomic aspects (physical and cognitive)
- Identify which demands must be present concerning accuracy in the control system and same for relevant visual, auditory and muscular input/output.

2. Identify marine and operator framework related to control levers:

- Identify how a traditional offshore vessel is controlled.
- Identify crucial control and information parameters and how they are translated in the interface between operator and the vessels control system.

3. Perform product development process to develop recommendations for optimal product design.

3.1 Establish product specifications:

- Identify stakeholder needs (user and market needs)
- Establish product goals and central requirements

3.2 Concept generation:

- Develop functional analysis
- Review competing solutions
- Ideate

3.3 Final Concept:

- Concept selection
- Detailed design (CAD)
- Make a presentation of recommended concept

4. Follow up and establish the project frame by developing a project report documenting and presenting results for all the steps of the process:

- Background
- Terminology
- Process discussion
- Conclusion
- Literature references
- Relevant attachments

5. Exam presentation:

- Make a presentation
- Hold presentation

2.5 LIMITATIONS

The following limitations are set for this thesis:

- Will not go into detail of the automation system.
- Will not perform mechanical or electrical design.
- Will not develop budget for cost of prototyping.
- Haptics will not be considered in detail.
- Rules and regulations will not be considered in this thesis.
- Detailed production drawings will not be produced.
- Design of screen and GUI, UI/UX is outside the scope of this thesis.
- Technical aspects of the control levers system functionality will not be considered.
- Only a simple overview of the most general propulsion units will be presented, no detailed study on propulsion functionality.

3. METHODOLOGY

This chapter presents the terminology, and chronologically outlines relevant methods used in this thesis. Finally, a list of tools and programs utilized is this thesis presented.

3.1 TERMINOLOGY

Reference coordinate systems and various marine terminology is presented here.

3.1.1 DEFINITIONS

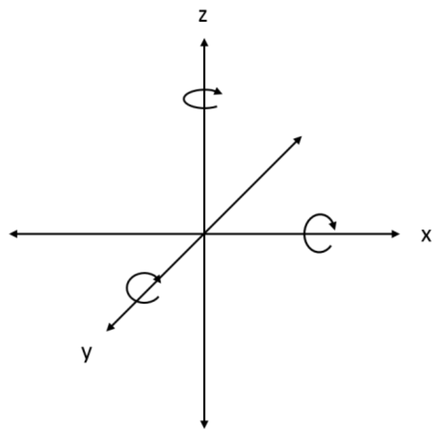

Figure 13: Coordinate system used as reference in this thesis. (Own illustration)

A vessels movement linear and rotary movement along the respected axis is listed in Table 3.

Table 3: Definition of vessel motions. [32]

Axis	Linear	Rotation
X	Surge	Roll
Y	Sway	Pitch
Z	Heave	Yaw

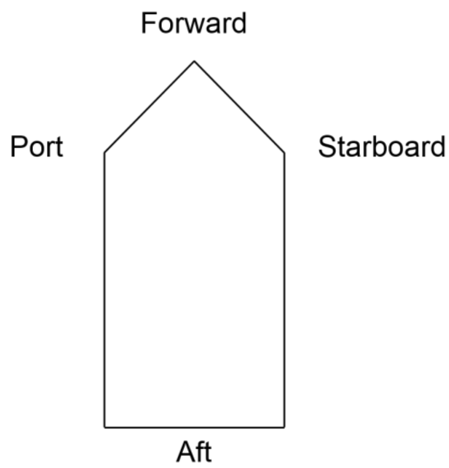

Figure 14: Terminology for referencing vessel directions. (Own illustration)

Table 4. Acronyms, definitions and specialized terms used in this report.

Term	**Meaning**
Haptics	"Describes the sense of touch and movement and the (mechanical) interactions involving these." [33]
Maneuvering	Exposing a vessel to frequent or larger directional adjustments. Usually combined with speed alterations. [34]
Steering	Utilization of rudder or azimuth propulsion to direct the vessel in the, at any time, desired direction.[34]
Manual Thruster Control (MTC)	System providing individual control of propulsion units. [22]
Vessel	"Hollow structure made to float upon the water for purposes of transportation and navigation; especially, one that is larger than a rowboat ".[32]
Ship	"Any large floating vessel capable of crossing open waters, as opposed to a boat, which is generally a smaller craft. The term formerly was applied to sailing vessels having three or more masts; in modern times it usually denotes a vessel of more than 500 tons of displacement."[32]
Dynamic Positioning (DP)	Control system for station keeping and low- speed maneuvering. Designed for simultaneously control of the three horizontal motions (surge, sway and yaw). Dynamic Positioning mainly use thrusters, but can also exploit rudder forces by using the propeller to generate rudder lift forces. [32]
Navigation	"The science of directing a craft by determining it's position/attitude, course and distance traveled. It has originally denoted the art of ship driving, including steering and setting the sails." [32]
Control	"Control, or more specifically motion control, is the action of determining the necessary control forces and moments to be provided by the craft in order to satisfy a certain control objective." [32]
Heading	Rotation about the vertical axis (Yaw). Describes the vessels course.[32]
Superstructure	"Decked structure, not including funnels, which is on or above the freeboard deck." [35]
Docking	The process of maneuvering the vessel alongside a quay and performing mooring operations.[35]
Operations	Conducting assignment in connection to activities in the development and production of oil- and gas. [34]
Tactile	The sense of touch. [36]
Ship Handling	"A fundamental skill of professional seamanship is being able to maneuver a vessel with accuracy and precision." [37]

3.1.2 SYMBOLS AND UNITS

Table 5. Symbols and units (SI) used in this report.

Symbol	Meaning	Units (SI)
x	Coordinate axis, longitudinal direction	m
y	Coordinate axis, transvers direction	m
z	Coordinate axis, vertical direction	m
S_j	Concept Score	Points
r	Radius	m
d	Diameter	m
θ	Angle	Degrees

3.2.3 FORMULAS AND EQUATIONS

Table 6. Formulas and equations used in this report.

Meaning	Formula	Index
Concept score	$S_j = \sum_{i=1}^{n} r_{ij} w_i$	3.1

3.2. RESEARCH AND DEVELOPMENT

Below is a review of the methods that are applied in this thesis.

3.2.1 LITERATURE STUDY

A thorough literature study has been performed in this thesis. Identification of relevant literature started by exploring previous course literature. A key set of titles and persons were identified and explored further using the various search engines and the University library's online search service. The list of references of the books, articles, master and doctoral theses identified has been an important source to further locate relevant literature. The library's online search service has been applied extensively to identify and locate literary resources situated at other institutions than NMBU and/or online. I have also knowingly sought out institutions expert in the respective field, such as NTNU and DNV where specifically literature related to maritime aspects were identified.

The relevant literature in form of books, articles and journals have primarily been collected from the Departmental library at Sørhellinga. In addition, various online services such as google scholar and also other hubs and websites have been utilized. Product brochures, trade publications and various online resources have also been a source for literature. I have also located lecture notes and other published work form respective university professional's websites. For specific information such as competitors and updated industry news, newspapers and specific websites have been used.

The literature has mainly been verified through using publications from recognized institutions such as publishers and universities. The general notion that books used in publications such as doctoral and master theses are acknowledged have also been followed. To avoid utilizing outdated literature, the date of publication have been evaluated for each source considering if type of information is still applicable.

3.2.2 PRODUCT DEVELOPMENT PROCESS

INTEGRATED PRODUCT DEVELOPMENT (IPD)
This thesis utilizes a product development process called Integrated Product Development (IPD). IPD is a development process designed to ensure greater efficiency and a greater learning process of industrial product development projects. It emphasize a multidisciplinary cooperation throughout the development and design phase. And embraces aspects such as

- Identifying customer needs
- Planning and controlling the product development process
- Utilizing product development groups and teams
- Integrating process design
- Control of project costs from the start
- Including suppliers and sub suppliers early in the process
- Developing robust design
- Integrating the use of CAD and other computer aids.
- Computer simulation of product properties

For practical implementation of IPD it is common to divide the development process in two, an initial project and a main project. The main goal of the initial project is to investigate market and customer needs and gain insight in demands and trends. By developing an early concept already in the initial phase you will be able to achieve feedback both within the company, and most importantly from you customer before actual production is started. This will also assist in providing better planning and a more correct financial estimate for the production. For the main project, it is natural to include the market strategy and production teams to start developing parallel to the product. The main project typically has focus on the four main pillars of product specification, conceptualizing, construction and preproduction. Deliverables from a main project is typically a market team ready for launching of the product, a publicly approved product, and a production team ready for production startup.[38]

This thesis models the initial project of the IPD process with focus on investigating market and customer needs before going on to develop a concept ready for testing.

The project process steps:

1. Research
2. Specification Process
3. Concept Development

Below follows a chronological review of the methods used through the product development process.

GATHERING OF ANTHROPOMETRIC DATA
A five- step method for correct use of anthropometric data is to be applied.[39]

Identify all body dimensions relevant for product design

1. Define anticipated user population

2. Select the percentage of users that are to be accommodated
3. Obtain appropriate anthropometric data tables and find the values that are needed.

MISSION STATEMENT
The mission statement specifies the market opportunity and lays out the broad constraints and objectives for the project. It sets the frame for the product development process and help clarifying which areas to focus on.[40]

IDENTIFYING STAKEHOLDER NEEDS
A recommended five-step process is used to identify stakeholder needs.

1. Gather raw data form customers.
2. Interpret raw data in terms of needs
3. Organize needs into hierarchy
4. Establish the relative importance of the needs.

Raw data is collected through interviews with lead users and product experts, and by observing the product in use. Several users has been interviewed both while operating control levers in their own environment i.e. the bridge, and in workshop situations in connection with mockups. Interviews were conducted both to understand the functionality and to map out user aspects. To document the interviews audio recording, video recording, photography and notes where used. [40]

The interpretation of the raw data is to follow the first two recommended guidelines, and to the best of ability meet the following three, resulting in a set of customer needs.

Guidelines:

1. Express the need in terms of what the product has to do.
2. Express the needs as specifically as in the raw data.
3. Use positive not negative phrasing.
4. Express the need as an attribute of the product.
5. Avoid the words must and should.

Redundant needs are eliminated and the standing needs are grouped and labeled.[40]

The relative importance of the needs are established based on the context of the statement and on educated assessments. The importance of the product needs are ranged according to the following scale[40]:

1. Feature is undesirable. I would not consider a product with this feature.
2. Feature is not important, but I would not mind having it.
3. Feature would be nice to have, but is not necessary
4. Feature is highly desirable, but I would consider a product without it.
5. Feature is critical. I would not consider a product without it.

FUNCTIONAL ANALYSIS
To fully understand the functionality of the product a function analysis is to decompose the product functions following the users' actions. This approach is found useful for products that emphasizes user interaction more than complex technical functions.[40] The product is broken down according to function and a function tree is established. Following the analysis downwards, each step answers the question "how?". Following upwards, each step answer the question "why?". [38]

SCAMPER

SCAMPER is a method developed by Alex Osborn and is also referred to as Osborne's checklist. The method provides a structure for building on concepts and developing new ideas. The list presented below is applied to the target which can be for example an object, an idea or a process. SCAMPER is an acronym for [41, 42]:

1. Substitute: What/ Who can I substitute?
2. Combine: Elements, units, ideas, mix, compromise?
3. Adapt: How is the problem solved? More accommodating? More compatible?
4. Modify (also Magnify or Minify): Split up, remove, make lighter, shorter, etc.?
5. Put to other uses: How can it be used? Where else can it be used?
6. Eliminate (also, elaborate): Which alternatives, where, what, when, other ingredients?
7. Reverse (also, Rearrange): Switch parts, reverse functions, change patterns?

PUGH'S METHOD

The concept selection process follows Pugh's method. The selection process consist of two stages; concept screening and concept scoring. Both stages follows the same five steps.

1. Prepare the selection matrix
2. Rate the concepts
3. Rank the concepts
4. Combine and improve the concepts
5. Select one or more concepts

The selection criteria are set from the identified stakeholder needs. The criteria are expressed in a high level of abstraction and typically consist of 5 – 10 dimensions. The criteria should be of roughly the same level of importance. The concepts are then ranked against a benchmark concept, or reference concept. Usually an industry standard, commercially available product, best-in-class which the team has studied.

For the concept screening stage the concepts are rated by + = "better than", 0 = "same as", - = "worse than" the reference concept for all the criteria and ranked according to the total score. The results are verified, and in light of the process, the concepts can be adjusted or combined to achieve improved concepts. The concepts preferred, usually those with the highest score is taken further to the next stage, concept scoring.

For the concept scoring stage, weights are added to the selection criteria leading to a more quantitative evaluation of the concepts. Hundreds percentage points are divided between the selection criteria, often subjectively by the ones performing the selection. The concepts are then rated against the reference concept by:

1 = Much worse than reference

2 = Worse than reference

3 = Same as reference

4 = Better than reference

5 = Much better than reference

The total score is then calculated for all the concepts by:

$$S_j = \sum_{i=1}^{n} r_{ij} w_i \tag{3.1}$$

r_{ij} = raw rating of concept j for the *i*th criterion.

w_i = weighting for the *i*th criterion.

n = number of criteria.

S_j = total score of concept *j*.

As for the screening stage, concepts are adjusted or combined in light of the process. A final concept is then chosen. [40]

3.3 COMPUTER AND DESIGN TOOLS

SolidWorks (x64) Student Edition 2014- 2015. CAD used to create, edit and visualize 3D models and 2D drawings of the final concept.

TOOLS FOR WRITING REPORT AND EDITING
Microsoft Office Home and Student Edition 2013, hereunder:

Microsoft Word 2013 is used to write and edit the report.

Microsoft Excel 2013 is used for tables, and for developing the Gantt chart.

Microsoft Power Point 2013, Paint and Photo Editor is used for photo editing and to generate figures.

Adobe Reader

EndNote X7.3 is used for referencing sources.

4. HUMAN FRAMEWORK

The purpose of this chapter is to establish the human framework for the product development. Ergonomics aspects such as physical- and cognitive ergonomics, including biomechanics, anthropometrics and human- machine interactions are presented here.

Ergonomic comes from the words *ergos* meaning work, and *nomos,* meaning natural law. Initially ergonomics builds on the knowledge of how the human body and our senses acts during interaction with external elements. [41] Today ergonomics also includes elements from several other disciplines and is regarded synonymous with the expression human factors. [43] Ergonomics concerns principles from biomechanics, utilize anthropometric data and considers the humans cognitive capabilities.[44]

4.1 ANTHROPOMETRICS

Anthropometrics is the study of the human measurements.[41] The word derives from “anthropos” meaning human and “metricos” meaning, or pertaining to measuring and it establishes the physical geometry, mass properties, and strength capabilities of the human body. [43]

Both static and dynamic anthropometric data is useful for product design. Static data is measures performed while the body is fixed, while dynamic measures involve some sort of body movement.

The relevant user segment for this product are both male and females aged 20- 65 years, from all over the world. In lack of segment specific data it is hard to generalize about the measurements of the typical user. To best accommodate the potentially wide segment, data from the 50th percentile man, age 20-65 years is utilized.

Relevant body dimensions for the product is presented below.

STATIC DATA

Table 7: Measures of 50-percentile man. All measures in mm.[43]

Body Measures	**50 Percentile Man**
Stature	1755
Shoulder width	465
Shoulder height	1440
Shoulder- elbow distance	366
Max seat height	457
Top of head to eyes	112

Table 8: Selection of Hand Data for 50- percentile man. All measures in mm.[43]

Hand Measures	**50 Percentile Man**
Grip width (Hand width without thumb)	89
Hand width (Hand width with thumb)	104
Hand length	191
Palm length	104

Table 8. continues: Selection of Hand Data for 50 percentile man. All measures in mm.

Hand Measures	50 Percentile Man
Grip circumference	216
Thumb length	59
Middle finger length	86
Thumb width	23
Index finger length	76
Palm thickness	23
Wrist thickness	43
Hand joint to grip line	76

DYNAMIC DATA

Table 9: Hand movements. All measures in degrees. Read in reference to Figure 17. [43]

Hand Movements	General Comfort Ranges
Wrist flexion	45
Wrist extension	25
Wrist radial deviation (adduction)	0
Wrist ulnar deviation (abduction)	10

Table 10: Vertical visual measures. [43]

Visuals Measures Vertical (Sitting)	Degrees
Horizontal sight line	0
Max eye rotation up	25
Max eye rotation down	35
Upper visual limit brow cut off	50 - 55
Lower visual limit cheek bone cut- off	70 - 80
Relaxing sight line (down)	15
Easy eye rotation optimal display range up	0
Easy eye rotation optimal display range down	30
Acceptable range up	5
Acceptable range down (with head tilt forward)	45

Table 11: Horizontal visual measures. [43]

Visuals Measures Horizontal (Sitting)	Degrees
Horizontal sight line	0
Max eye rotation left	35
Max eye rotation right	35
Easy eye rotation left	15
Easy eye rotation right	15
Eye rotation acceptable for secondary display left	30
Eye rotation acceptable for secondary display right	30

4.2 BIOMECHANICS

Biomechanics is the study of the how the body, specifically how the muscular and skeleton works and moves. [41]

4.2.1 HAND FUNCTION

The hand is one of the body's most intricate parts and is able to exercise both precision and power. It is a sophisticated device sensible to touch, temperature and vibrations. With several vulnerable anatomical structures, it is exposed to injuries if overstressed.[39]

GRIPS
Hand movements are usually considered either *prehensile* or *non-prehensile*. Prehensile movements are those where the object is wholly or partially within the grasp of the hand. [39] Non- prehensile movements describe movements that does not involve grasping, such as pushing or lifting. The two distinctions gives a good reference when designing hand held operation instruments that consists of both gripping exercises and buttons.

Prehensile movements further divides into two categories: *precision grips* and *power grips*. Whereas a precision grip is defined by an object being pinched between the flexor aspects of the fingers and the opposing thumb. A power grip is defined by and object being held by partially flexed fingers towards the palm where counter pressure is being applied by the thumb lying more or less in the plane of the palm.

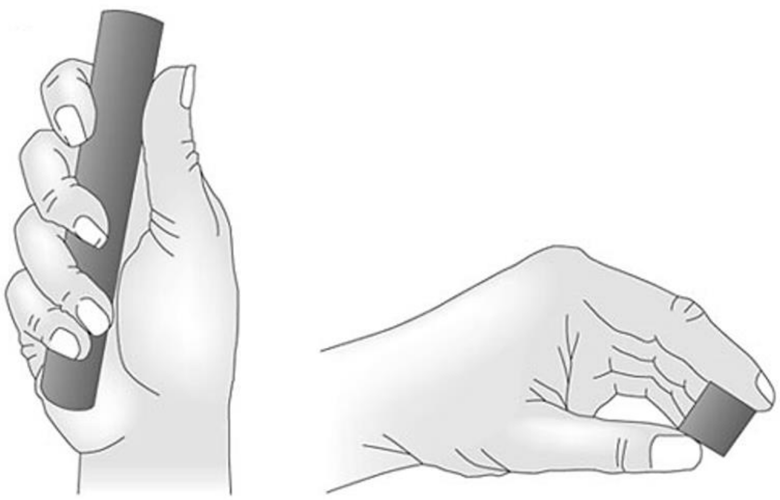

Figure 15: Power grip to the left and precision grip to the right. [45]

Either separate or in combination, these two grips provide the anatomical basis for all prehensile activities. The nature of grip chosen clearly depends on the nature of the intended activity where some activities appears as predominant for either precision or power. Looking at a wooden rod, one find that as a pencil it is griped by a precision grip and as a hammer one will naturally use a power grip. It is also recognized that the physical form of the object may under certain conditions influence the choice of grip. [46]

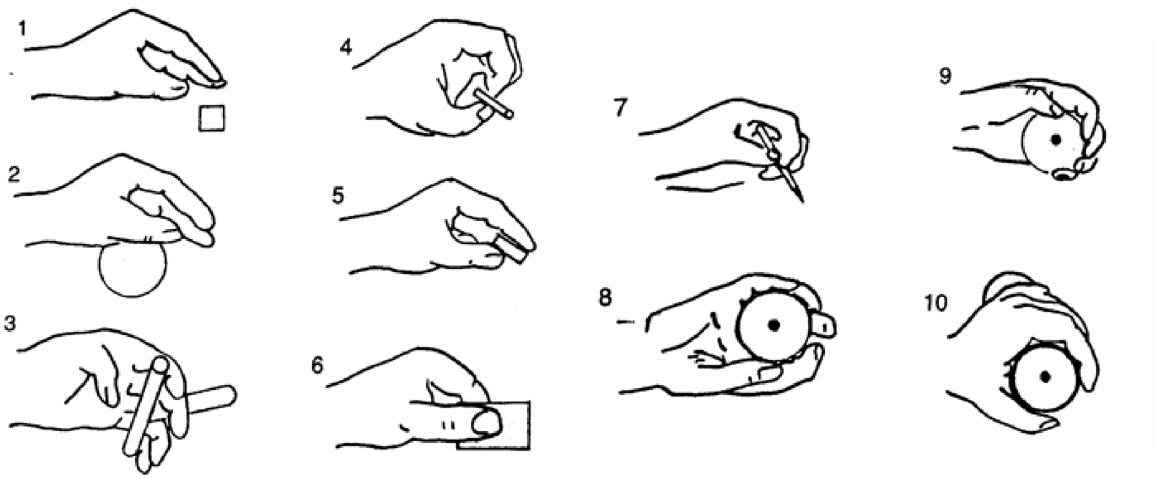

Figure 16: Different grip types. [39]

Grip types illustrated in Figure 16:

1. Finger touch
2. Palm touch
3. Finger palmar grip (hook grip)
4. Thumb- fingertip grip (tip grip)
5. Thumb- finger palmar grip (pinch grip)
6. Thumb- forefinger side grip (lateral grip)
7. Thumb and two- finger grip (writing grip)
8. Thumb- fingertips enclosure (disk grip)
9. Finger- palm enclosure (prehensile)
10. Power grip (prehensile)

The most common grips are the tip grip, pinch grip, lateral grip and power grip.[39]

MOVEMENTS
The movement of the hand and wrist can be described as illustrated below.

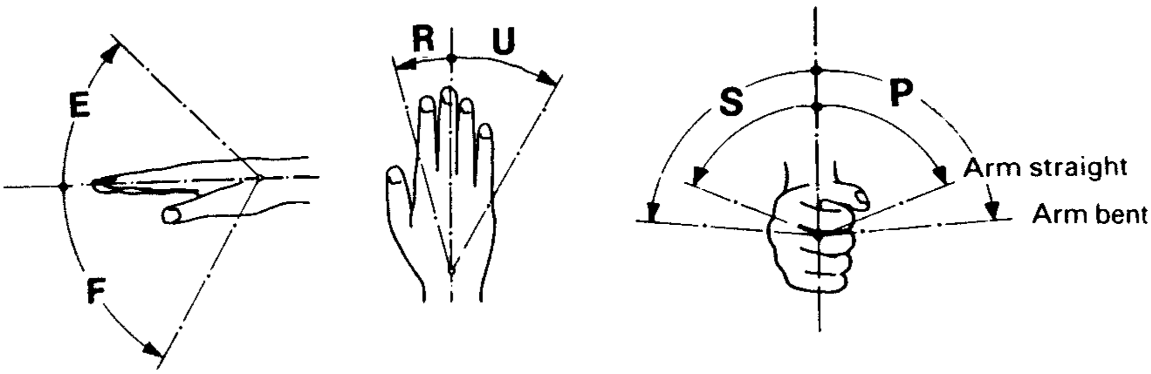

Figure 17: Hand movements [47]

Table 12: Hand movements in reference to Figure 17. [47]

Picture reference	Movements
F	Wrist flexion
E	Wrist extension
R	Wrist radial deviation (adduction)
U	Wrist ulnar deviation (abduction)
S	Forearm supination
P	Forearm pronation

To minimize the biomechanical stress put on the user's hand the wrist should be kept as straight as possible, as close to the neutral relaxed position as possible. This means holding the hand within its flexion range and avoiding forces applying a large amount of torque about the wrist. [47] The comfort range for flexion and extension is respectively 45 degrees and 25 degrees from the neutral position. A general recommendation for working with keyboards and monitors is to keep the wrist and forearm in a position as close to a straight line as possible.[43]

4.2.2 WORK POSTURES

STANDING
Too high workstations lead to the operator lifting his shoulders, which may again cause pain in neck and shoulders. If the workstation on the other hand is too low, it will lead to the operator continuously bending over initiating back pains. The optimal work height reference the persons elbow height, which defines as the distance from floor to the underside of the elbow when bent at right angle with upper arm vertical.[47]

Further, one must account for the type of work executed. Normally one distinguish between *precision work* (e.g. drawing), *light work* where you typically need room for instruments, and *heavy work* where the bodyweight is needed to perform the task. The preferred height specifies in relation to floor- elbow height.

Precision work: Delicate work, e.g. drawing. Preferred working height is 50 – 100 mm above elbow height.

Light work: Need space fir tools and materials. Preferred working height is 100-150 mm below elbow height.

Heavier work: Involves much effort and upper body weight. Preferred working height is 150 – 400 mm below elbow height.

Platform can be provided for shorter people; therefore, you should accommodate max height in the segment. [47]

SITTING
The same problem as with standing workstations also applies for sitting workstations. If it is too high, the shoulders will experience stress and if it is too low, back pain will occur. For working with computers, the general rule is to keep the hand as close to the body as possible, with an elbow angle of 90 degrees. The forearm is to be parallel with the floor and relaxed.[41]

Standard recommended table- heights for men and women in cm are:

Precision work: Men: 90-110, women: 80-100

Light Work: Men: 74-78, women: 70-74

Heavier Work: Men: 68, women: 65

A work position varying between sitting and standing is to recommend both from a physiological and orthopedic point of view. [41]

REACH/ ROOM TO GRASP
To avoid excessive movement of the trunk, making the operations less accurate and more energy consuming it is important that controls be within reasonable reach of the operator. The grasp is determined by the sweep radius of the arms, with the hands in a grasping or reaching attitude.[47]

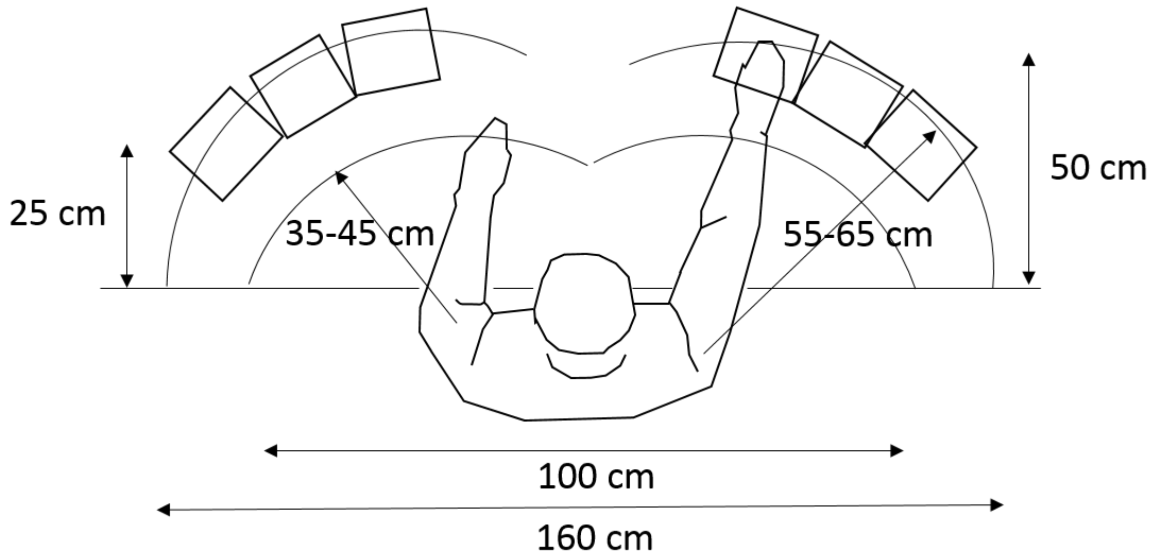

Figure 18: Grasp and working area of tabletop height.[47]

The optimal work area is within a radius of 350-450 mm and 550-650 mm for the 5th percentile. The grasp area is set from the shoulder to hand, while the work distance is set from elbow to hand. An occasional stretch up to 700-800 mm is not harmful, but the convenient and comfortable work area is located closer to the operator as illustrated.[47]

4.2.3 VISUAL CHARACTERISTICS

Directly related to the visual characteristics are a persons head and neck posture. It is important to meet the limitations of sight to avoid stressing the neck. The head and neck should not be bent forward more than 30 degrees making the “eye- ear” line not be more than 15 degrees below the horizontal.[47]

The line of sight is defined as the connection between the pupil and visual target. Given that the head is held upright, the optimal direction for sight is straight ahead when looking at objects far away. The line of sight is gradually tilted downwards as the target get closer to the eye. The visual specter is defined from the horizontal sight line. To avoid visual fatigue regular viewing tasks should happen within the acceptable sightline ranging from about 5 degrees above the horizontal sight line to about 30 degrees below. A person’s normal, relaxed line of sight is by most literature found to be located between 0 and 15 degrees below the horizontal sightline.[47] Data for visual characteristic is located in Table 10 and Table 11.

4.3 COGNITIVE ERGONOMICS

Cognitive Ergonomics concerns mental processes such as perception, memory, reasoning and motor response during interaction among the human and other elements of a system. Relevant topics include mental workload, decision- making, skilled performance, human computer interaction, human reliability, work stress and training as these may relate to human- system design.[44]

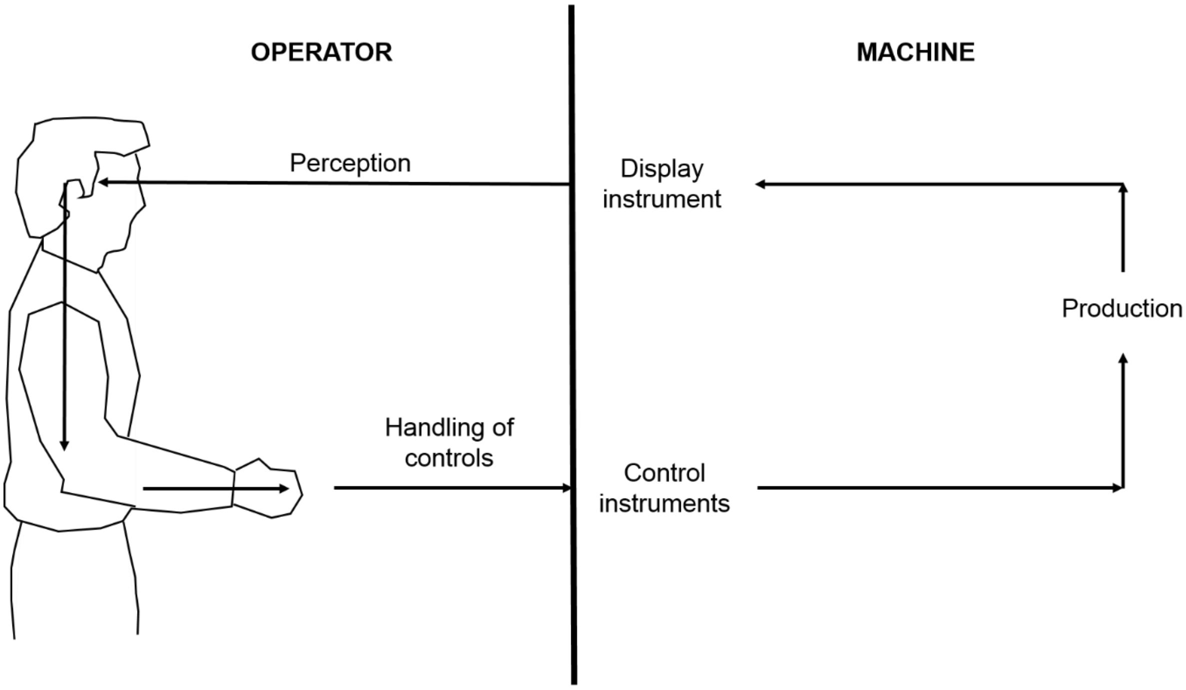

Figure 19: Human- machine system. [47]

A Human- Machine System is a system where the human and an external mechanical or electrical system interacts with each other in a reciprocal relationship. [41] The interface is where the operator communicates with the machine, it consist of displays and controls. [47]

4.3.1 CONTROLS

Controls constitute the feed forward between human and machine. The user manipulate the controls to achieve a desired response from the machine. There are generally two types of controls. [47]

1. Controls that require little manual effort, in other words, they can be operated with the fingers.
2. Controls that require muscular effort, in other words, they involve major muscle groups of arms and legs.

There are mainly two factors significant for deciding which control type is applicable. One is the capability of the user, such as physical and cognitive ergonomics, the other is the requirements based on the tasks that are to be performed.[39]

The task characteristics greatly dictates the type of controls applicable. Below there is an overview of potential tasks.

1. Single discrete tasks. (Turning a device ON, or selecting between several operating modes)
2. Selection of a quantitative value. (Setting a thermostat)
3. Adjusting output to a desired level. (Volume of a radio)
4. Serial task, in specific order. (Programming a VCR)
5. Data entry. (Dialing a phone number)
6. Continuous motor tasks. (Steering an automobile)

In addition to the actual nature of the tasks, one also have to consider the speed of the operation and the degree of accuracy in both control input and general feedback.

The scope can be narrowed down further based on if the task includes discrete – or continuous adjustment, number of positions or range, activation force, or preference for linear or rotary control movement. [39]

Controls categorized in five groups.

1. Two- position discrete controls – Small activating force.
2. Multiposition discrete controls – Small activating force.
3. Two- position and multiposition discrete controls – Large activating force.
4. Controls for making continuous adjustments – Small activation force.
5. Controls for making continuous adjustments – Large activation force.

Some commonly used controls are:

- Push buttons
- Switches
- Rotary knobs
- Cranks/ levers
- Wheels
- Pedals
- Trackball
- Keyboard

On a more general level aspects of labeling and coding, resistance in controls, arrangements of controls, control – display relationship, and standards and expectations must be considered. [39]

GUIDELINES FOR CONTROL DESIGN

Controls has to take into account the anatomy of the limbs. For quick, precise movements fingers and hands should be used. For activities requiring force, arms and feet should be used. Buttons, switches and rotary knobs are therefore suited for activities that require precision, small travel and little movement and muscular effort. For activities requiring little precision, long travel and muscular efforts, long radius levers, cranks, wheels and pedals are recommended.[47]

Generally controls should be easily reached and grasped and be in full view. Controls operated by fingers should be 50 mm apart, and controls operated by the whole hand should be 50 mm apart. [47] Rotary knobs has a recommended diameter between 38 mm and 76 mm, and a height between 13 mm and 25.4 mm. Sliding switches has a recommended length of minimum 6 mm to maximum 19 mm. Minimal width is given at 6 mm and maximal width at 25 mm. The height is recommended between 6 and 13 mm. Knurling is recommended to ensure a good grip.[43] Common travel for levers are 45 degrees to each side, resulting in a travel of 90 degrees. [47]

4.3.2 DISPLAY

Displays convey information that cannot be directly sensed or easily inferred. [39] They provide feedback to the human about the status of the machine or the behavior of the whole system. [47] One distinguish between visual displays and auditory displays.

VISUAL DISPLAYS
There are mainly four categories of displays. Each of which has its advantage in certain circumstances. [41, 47]

1. Digital displays (Readouts and counters). Can be either mechanical or electronic.
2. Analog: Moving pointer with fixed scale. (This can be either quantitative or qualitative.)
3. Analog: Fixed pointer with moving scale. (This can be either qualitative or quantitative.)
4. Column bar display. (Level indicator)

Digital displays are recommended for reading off exact values. If it is necessary to register an ongoing process and register the change of a value the moving pointer over a fixed scale is recommended. This type of display is also ideal when controlling from a desired and an actual value. Two pointers are then facilitated so the process can be controlled until the two pointers come together. Displays with fixed pointer has the same range of application as for scales with moving pointer, but they are not as intuitive when it comes to observe change.[47] The fourth version is column bar displays which are suited for reading of qualitative information such as level indications.[41]

In addition to these four display categories, there are status indicators, e.g. indicator lights for on/off. There is also labels, such as warning labels or pictograms.[39] Pictograms are often good for special applications like aircraft altitude, pitch and roll and they can greatly assist in the interpretation of special relationships.[43]

It is important that the displays only provide the information required by the operator and that only the smallest unit the operator is likely to read off is displayed. Meaning that if the operator reads off values to the nearest 100 N, the smallest division should be 100N. Displays should be designed to reduce reading errors.[47]

SCALE GRADUATIONS AND READABILITY
The size of numbers and the scale graduation is often considered even more important than the type of display. A display should only provide the information necessary for the operator and you should never use a finer grading than what is necessary to perform adjustments.

Recommended size for the scale graduations are given by a ratio based on the straight-line distance from eye to display. Where “a” is the greatest viewing distance to be expected in mm, the minimum dimensions are as follows. [47]

Table 13: Scale graduations. [47]

Height of biggest graduations	a/90
Height of middle graduations	a/125
Height of smallest graduations	a/200
Thickness of graduations	a/5000

Table 13 continues.: Scale graduations.

Distance between two small graduations	a/600
Distance between two big graduations	a/50

As seen in table 13, if “a” is the greatest viewing distance to be expected in mm, the minimum height is given by:

Height = a/ 200

Following this, recommended proportions of letters and numerals are:

Table 14: Recommended proportions of letters and numerals. [47]

Breadth	2/3 of height
Thickness of line	1/6 of height
Distance apart of letters	1/5 of height
Distance between words and figures	2/3 of height

Figure 20, below, show recommended proportions. H = height of capital letters, h = height of lowercase letters.

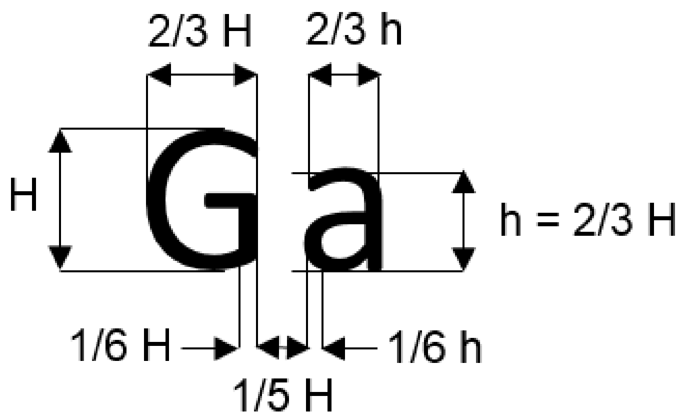

Figure 20: Proportions for letters and figures. [47]

Literature says that in general, black letters on a white background provides the best readability since white characters seems to blur. On the other hand, white symbols are easier to read under poor lighting. In other words, in the ideal situation the display will be black on white during the day, and white on black during nighttime. The most important thing is to ensure a clear contrast between the letters and the background. [47]

Capitals and lower case letters are easier to read than all of the same size.[47]

AUDITORY DISPLAYS
If the purpose of the message is to attract the attention of the user, auditory displays are to prefer before visual displays. They are suitable when the message is short and simple. They are widely used as warning devices. Auditory signals can consist of tone, complex tone or spoken message. [39]

4.3.3 CONTROL PANEL ARRANGEMENT

To ensure that each controller is operated safely, it is important to provide a suitable distance between controllers and a sensible placing in relation to displays. Further, clear coding can greatly assist in reducing the risk of misinterpretation of controls and false actions.[47]

CONTROL- DISPLAY RELATIONSHIP
The most important aspect of control- display relation is correspondence in movements between the two and the operator's stereotypes. This entails that the display show the same movement as the controller. The general stereotype states that for increasing a value you either push forward, to the right or turn clockwise. The display will then follow respectively moving clockwise, upwards or to the right. Vice versa for decreasing. [47]

Generally the display should be placed as close to the relevant controller as possible. It is further recommended that displays be placed over the related controller. If this is not possible it can be placed to the right of it. Potential identification labels is also to be placed above the controller and above the corresponding display. [47]

If the controllers are operated in a specific sequence, they are to be arranged accordingly. If not the controls can be arranged according to functional groups such as color, shape or size. [47]

Even though this might seem trivial, it is important to ensure a logical layout of controls as a weary operator performing automated work will fall back upon conditioned reflexes if a critical situation suddenly appears.[47]

CODING
When operating controls without looking at them, it is important that the operator is able to identify the correct controller. To avoid confusion controllers located at the same control panel must be designed so they distinguish from each other. The most efficient alternative is to vary the shape of the controller and combine different structures and materials. This is also effective at nighttime. Colors and labeling is also suitable, but only useful if the operator is looking at, and can actually see the controller. Arrangement can also provide some indication. [47]

5. MARINE AND OPERATOR FRAMEWORK

This chapter is dedicated to identifying the control levers use- situation and general functionality. The purpose is to map out control and operating aspects of offshore vessels focusing on the bridge environment and aspects related to the thruster and propulsion control units.

5.1 OFFSHORE SERVICE VESSELS

Offshore service vessels (OSVs) operate in harsh and demanding environments, such as the North Sea, under strict rules and regulations where there are great expectations to precision in terms of both environmental and operational aspects. They all operate in open oceans, but also in close action with other vessels and marine constructions.[35]

OSVs carry out offshore service missions involving cargo supply, towing, cable/ pipe laying, firefighting, oil recovery, subsea activity, and wind turbine installation, to name a few. The variety of missions carried out by OSVs leaves each vessel to be highly specialized and advanced and the vessels are therefore built to detailed specifications and each specialized to perform a certain set of tasks.[35]

There are mainly three types of OSVs, categorized by which operations they are designed to execute. As each vessel is different, the definitions are somewhat inconsistent, but the three main vessel groups are Anchor Handlers, Platform Supply Vessels and Multipurpose Offshore Vessels. Anchor handlers and Platform Supply are the most known and clearest defined types. Multipurpose offshore vessels are tailor- made solutions that can carry out several different types of operations, and therefor considered more complex. [34] Vard divides their OSV types into Platform Supply Vessel (PSV), Anchor Handling Tug Supply (AHTS) and Offshore Subsea Construction Vessel (OSCV). [48] A common characteristic of these vessels is that the deck is located aft of the super structure, and they all have a dedicated operational bridge overlooking the deck.

ANCHOR HANDLING TUG SUPPLY (AHTS)

Figure 21: Anchor handling tug supply (AHTS). [48]

AHTS's main duties is to assist offshore drilling units and floating production units with anchor handling and towage. In addition, due to their generally free deck area, they also perform supply duties, and those who have tanks installed below deck can carry bulk. [34, 48] An AHTS goes in transit form the harbor area out to the rig where it goes into operation, and anchor handling and rig moves are performed. The operation usually last a few days depending on if it is a simple move or if it entails towing of an offshore drilling unit. [4]

PLATFORM SUPPLY VESSEL (PSV)

Figure 22: Platform Supply Vessel (PSV). [48]

PSVs are designed to transport cargo to and from offshore oil rigs and platforms, and are commonly referred to as the “trucks of the sea”. They are designed with focus on cargo capacity and precise maneuvering capabilities, as they are to operate close to other marine constructions.[48] A PSV spends most of its time in transit between shore and platforms, before going into DP mode during on- and offloading at oil rigs and platforms.[4]

OFFSHORE SUBSEA CONSTRUCTION VESSEL (OSCV)

Figure 23: Offshore Subsea Construction Vessel (OSCV). [48]

Offshore Subsea Construction Vessels are so called multipurpose offshore vessels and are outfitted and arranged to perform a number of different operations. Typically, subsea construction and installation, pipe laying, well intervention, diving support, or inspection, maintenance and repair. Most of these operations involve operating in DP- mode and they are therefor designed with focus on station- keeping, maneuverability and sea-keeping.[48]

5.2 SHIP HANDELING AND MANEUVERING

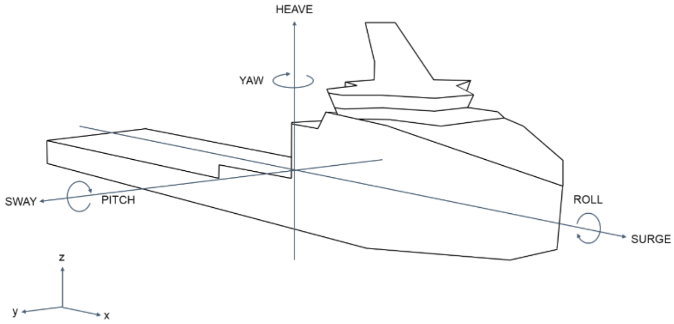

Figure 24: Vessel degrees of freedom. (Own illustration)

During maneuvering, a vessel experience movement in a total of six degrees of freedom (DOF). Surge, sway, heave, yaw, pitch and roll.

An offshore vessel operates in this horizontal plane, and is from a control perspective described as a 3-DOF model where surge, sway and yaw can be controlled. Surge and sway represent the ships longitudinal and sideways motion, and yaw represents the ship course, and is often referred to as heading. For course and station keeping these three DOFs are stabilized by the vessels propulsion units.[32]

5.2.1 PROPULSION UNITS

Traditional offshore vessels are usually equipped with a combination of main propellers accompanied by rudders, tunnel thrusters and azimuth thrusters, depending on their operational profile. The propulsion units generate forces in the horizontal plane, providing movement in surge, sway and yaw. Fixed pitch propellers are only controlled by speed (rpm), while controllable pitch propellers are also controlled by propeller blade pitch. [49]

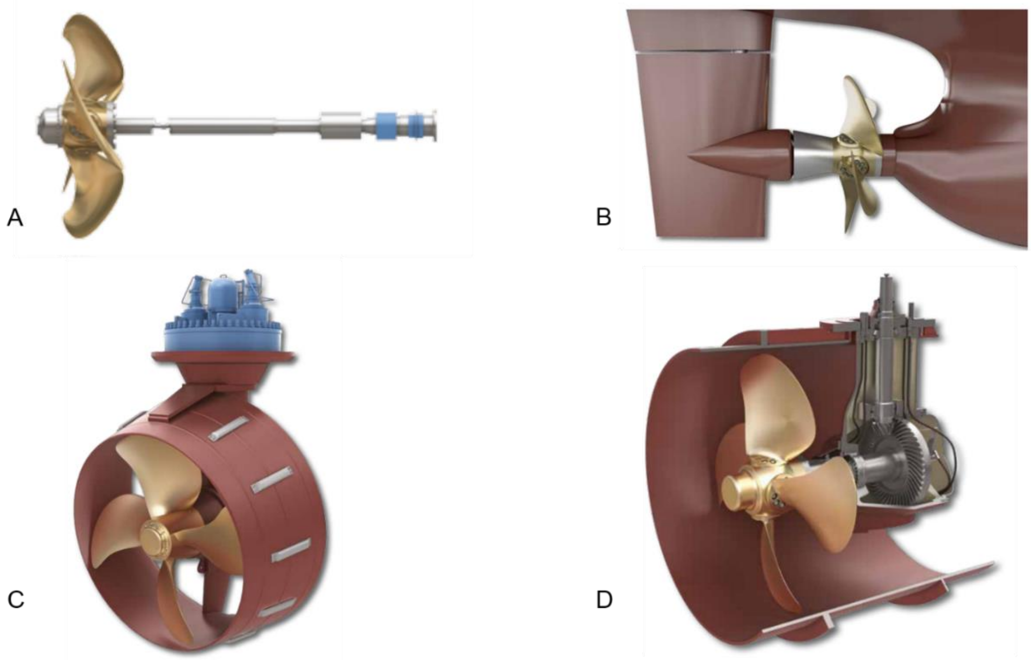

Figure 25: A: Main propeller, B: Rudder, C: Azimuth thruster, D: Tunnel thruster. [50]

MAIN PROPELLER
The main propeller is situated aft of the vessel always in combination with rudders and have either fixed pitch or controllable pitch propeller blades. [22] Main propellers often appear in pairs where one is placed towards starboard and the other port. The main propellers provide force in surge needed during transit. [32]

RUDDER
Rudders are situated aft of the main propeller and is the vessel's primary steering device directing the thrust produced by the main propeller. A rudder force in sway will provide a yaw moment which can be used for steering control. [32] Rudders are delivered to different specifications, with varying degrees of rotation. By example at standards of 35, 45 or 75 degrees.[51]

TUNNEL THRUSTER
Tunnel thrusters, or so called transverse thrusters are situated inside the hull in a transverse tube crossing through the vessel. They exert force in sway and appear forward and aft of the vessel, often in pairs with controllable or fixed pitch. They are only effective at low speeds and therefore mostly used during docking and for dynamic positioning.[32]

AZIMUTH THRUSTER
Azimuth thrusters, or so-called steering propellers, rotate 360 degrees around its z- axis and therefor provides force in all directions. Azimuths are designed with an optimal thrust direction, but also have thrust capacity in the negative direction to avoid continuous azimuth rotation. [22] Azimuths are frequently used for dynamic positioning. There are usually several azimuths on offshore vessels, and some only have azimuths and tunnel thrusters. Azimuth thrusters are mounted under the hull, and some more advanced types are swing- up and retractable.[32]

5.2.2 PROPULSION AND THRUSTER CONTROL SYSTEM

The total vessels propulsion control system normally consist of Manual Thruster Control system, Autopilot system and Dynamic Positioning system. These systems are connected to the vessels prime movers, controlling typically, diesel engines, generators, transmissions and propulsion units. [22]

These three systems are all present on the vessel bridge as separate systems, and the operator switches between using these systems depending on the type of operations that is to be performed. The systems are interconnected making it possible to operate them in combination. By example can the Manual Thruster Control unit for main propulsion be used in combination with the autopilot system where the speed is set from the control unit, and the heading from the autopilot system. [3, 4]

The propulsion units are controlled manually by the manual thruster control system. The manual thruster controls provides individual control of the propulsion units from the bridge commanding forces in surge, sway and moment yaw. The low- level thruster controllers will then control the propeller pitch, speed, torque and power satisfying the desired thrust command. For azimuth thrusters the direction is also set. [22] The propulsion units are controlled by respectively azimuth lever, tunnel thruster lever, main propulsion lever and rudder controller, all located on the bridge.

5.3 THE BRIDGE

An OSV bridge have two primary workstations, the aft and the forward bridge, also referred to as the navigational and operational bridge. Additional workstations include the wing bridges with workstation for docking/ rescue, firefighting station, station for safety monitoring and emergency operation and workstation for communication as applicable. [35]

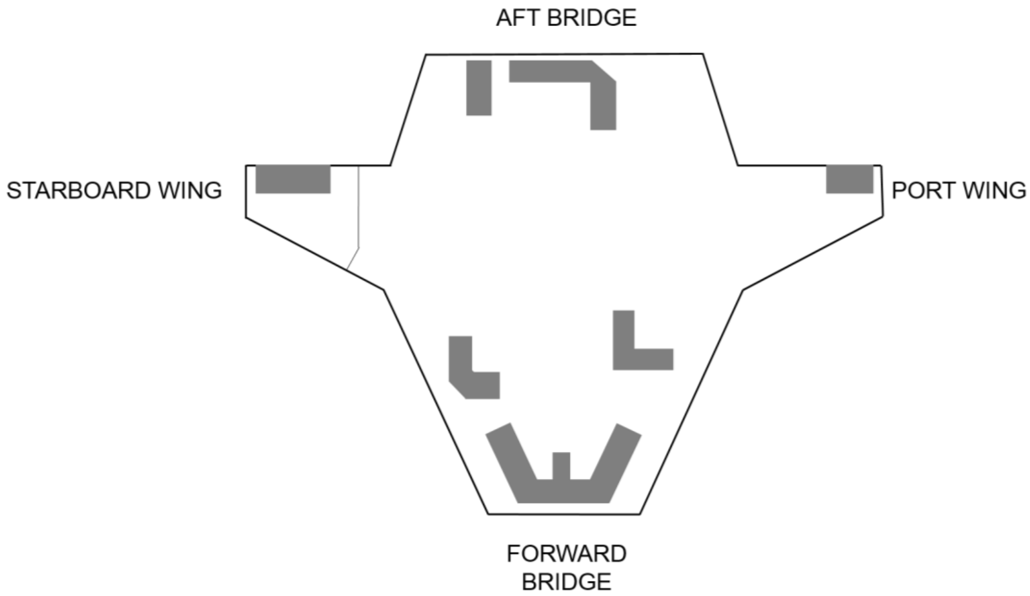

Figure 26: Offshore Service Vessel Bridge. (Own illustration)

The bridge consists of different areas depending on the type of operations the vessel is designed for. In addition to the specified workstations presented below, there can be a planning station, bathroom and a kitchenette/ coffee station. Some bridges also have the client's stations such as shift supervisor desk and survey area located on the bridge.[35]

5.3.1 FORWARD BRIDGE

The forward part of the bridge is also known as the navigational bridge. This is the largest workstation on the bridge and is regarded the main station for navigating and maneuvering. In other words, this is the workstation used when the ship is in transit. The navigational bridge facilitates activities such as:

- Navigation and Maneuvering
- Monitoring
- Route planning
- Docking/search/rescue operations.

These tasks are executed by one person, but often in pair. The bridge facilitates operation for two operators and the most important equipment should be reached by both operators, but most closely be oriented to the navigation chair. Radar and chart is what is used in navigation. [35]

The forward bridge is the workstation used when the vessel is in transit. Even though this traditionally is the main bridge of the vessel, it is generally not the workstation where the operators spend the most of its time for an OSVs. That is the aft bridge/ operational bridge. The use frequency of the forward bridge vary from vessel to vessel. Generally, it more frequently used by PSVs and AHTS than OSCVs, which roughly uses it 10 % of the time. [3, 4]

5.3.2 AFT BRIDGE

The aft bridge is also known as the operational bridge and it is here that the other functions, special for OSVs, not usually carried out on conventional ships are facilitated. The operational bridge overlooks the vessel deck and the offshore vessels multi- roles are carried out from here. The operational bridge consists of one workstation for ship handling and one workstation for aft support where efficient positioning/ maneuvering of the vessel, as well as operations and monitoring of all deck equipment needed for the operation is performed. The bridge also usually have a full DP station. [35]

For an OSCV the operational bridge is in use roughly 90 % if the time. The vessel usually approach the platform going astern. AH perform anchor handling from this bridge, and PSVs perform loading and unloading from here. [3, 4]

5.3.3 WING BRIDGES

An OSVs bridge usually have two wing bridges, one port and one starboard. The wing bridges are mainly used during docking, but also facilitate rescue operations and firefighting. They have a full vertical and horizontal view of the shipside making it easier for the navigator to go quayside. Docking includes maneuvering and controlling the mooring operations.[35]

5.3.4 BRIDGE PERSONNEL, ROLES AND TASKS

Only authorized personnel is permitted on the bridge. There are always four navigators and one Captain on board the vessel, and there is always two navigators on the bridge. Normally one is controlling the vessel and the other is doing administrative work. Rank and culture along with traditions is important on any ship. The titles used vary between ship owners, but generally this is the titles of bridge personnel/ navigators, in order of hierarchy:

- Captain
- Chief Officer
- 1st Officers
- 2nd Officers
- 3rd Officer
- (DP- Operator)

The bridge personnel operate in fixed pairs according to rank, where typically the Captain is off duty when the Chief Officer is on duty, leaving Chief Officer and 2nd Officers on the same shift, and Captain and 1st Officer and/or 2nd officer on the same shift. This ensures that qualified and experienced operators are always in charge. As the captain is usually not steering the vessel, but doing administrative work, there is often two others together with him on his shift. [3, 4]

The navigators performs tasks connected to:

- Route Planning
- Navigation
- Maneuvering/ Steering
- DP operating
- Winch operations
- Docking

The Captain is the commander of the vessel and responsible for everyone on the ship. He has an administrative role and does not necessarily spend much time performing actual maneuvering tasks. The largest part of the captain's daily work is administrative. Depending on the situation, the captain does not necessarily follow the traditional 6- or 12-hour shifts. He might be on a cycle where he works day and sleeps night.

The Officers main task is to maneuver the vessel on command from the captain and/or the Chief Officer depending on which of them is on shift. In addition to operating the ship, officers also have daily, weekly and monthly tasks. They are responsible for e.g. checking all fire extinguishers and checking all the equipment in the lifeboats. The Chief Officer is in addition responsible for purchase of spare parts and supplies for able seaman such as tools and paint.

The bridge is supervised at all times and bridge personnel works either 6- or 12-hour shifts. If you work 6 hours on/off you typically start at 6 o'clock when you have finished breakfast. You work until 12 o'clock when you go to lunch and then return to post after dinner at 6 o'clock. Depending on the operations, a shift can vary from sitting and drinking coffee looking out the window, barely touching the equipment, too operating the levers for 6 hours straight without taking your hands off them. Continuously concentrating and looking outside. When changing shifts you typically overlap each other with 5 minutes to get a short briefing in ongoing activities. You do a quick status update checking the chart, heading, ETA and look at the IAS for power status. [3, 4]

5.3.5 ENVIRONMENT

The bridge environment is dominated by a lot of equipment and operators moves between workstations to reach the desired equipment. Safety railings are mounted along consoles and walls, ensuring bridge personnel to move safely between workstations in bad weather. The bridge environment can easily change from relative relaxed to very hectic and there are many alarms going off with varying importance. Noise and vibrations of different scales is part of every- day life on a vessel. [3, 4]

COMMUNICATION
The communication on the bridge is continuous and very important. The bridge communicate with external parties such as other vessels, platforms, rigs and harbors. There is also internal communication between the navigators on watch and leaders of the operating crew.

Both of the navigators on watch share the responsibility and need to communicate closely in order to ensure safe operations. The work is dynamic, making the one closest to the radio usually answer it. Short messages like "Have you taken command now?" are essential to ensure that one of them is always in control of the vessel.[3, 4]

VISIBILITY
The bridge is surrounded of windows, ensuring a 360 degree view of the vessels surroundings. This is highly necessary, but it also creates light challenges. During the day strong sunlight cause glare and even tough measures like angling the windows and providing alternatives for

blending is applied, it is not optimal. Because of this, navigators often use sunglasses to ensure adequate vision. Equipment and consoles usually have a matte, low- reflecting surface in order not to interfere with the operator's vision.

At night, the lighting conditions on the bridge change drastically. Operating in adjacent areas means operating in complete darkness. To ensure that the navigators vision is adequate the bridge is also darkened and the equipment is illuminated. [3, 4]

Figure 27: Dark bridge with illuminated equipment. [3, 4]

5.4 THE WORKSTATIONS

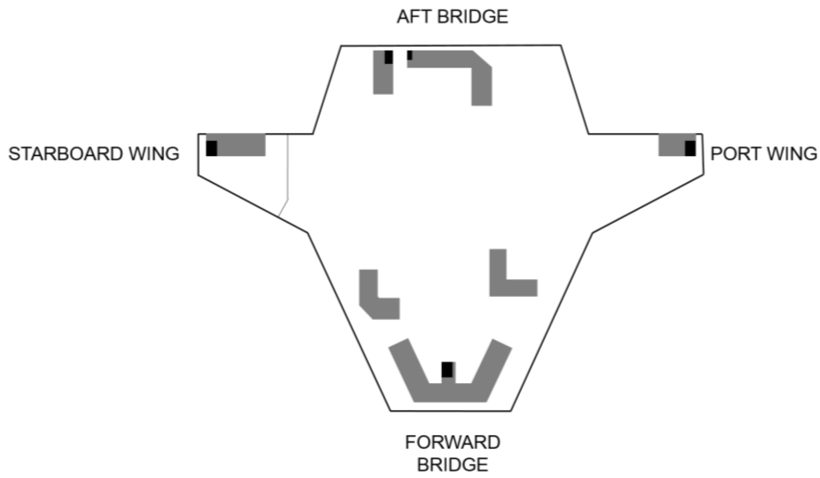

Figure 28: Potential location of the control levers on the bridge workstations. (Own illustration)

Control levers are located on all of the main bridge stations. There are complete sets forward, aft and on the wings, making it possible for the operator to choose location depending on the type of operation to be performed. The operator often has the choice between sitting and standing while operating the control levers. A chair is usually provided at the stations, with the possibility to move it away from the console if preferred. In addition to operating the levers, the operator exploits and relate to information from other systems simultaneously.[3, 4]

5.4.1 FORWARD BRIDGE

Figure 29: Forward Bridge of an OSCV. The forward bridge station usually consist of a wraparound console with two chairs, where equipment is placed according to importance. Mounted from the ceiling is monitoring and display equipment. [3, 4]

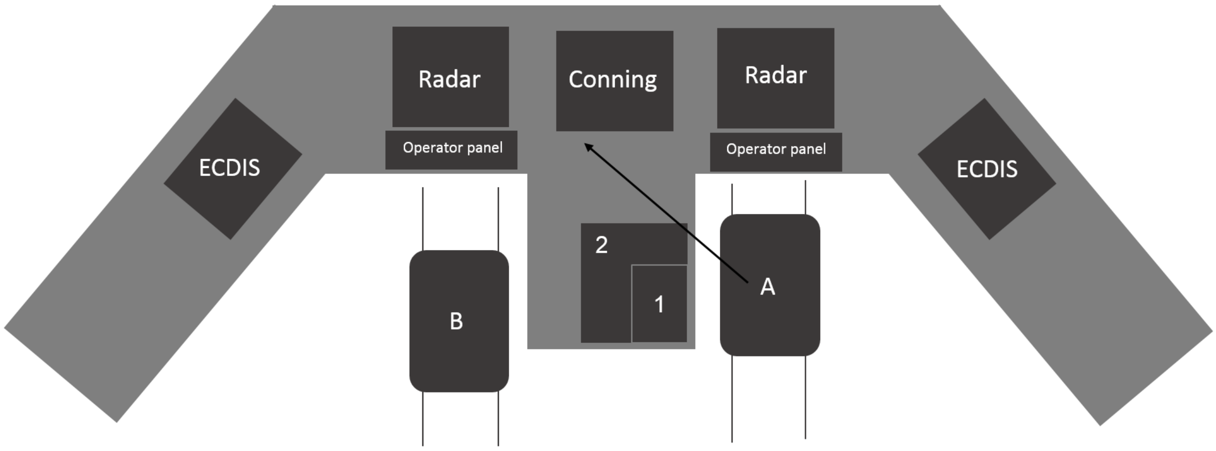

Figure 30: Forward bridge setup. A: Workstation for monitoring and navigation & maneuvering, B: Workstation for monitoring. 1. Control for heading and speed. 2. Thrusters for maneuvering. [35]

The navigational bridge is divided into workstation for navigating & maneuvering and workstation for monitoring. Workstation for navigating & maneuvering is favored as this is the main work area. Here the navigator operate the autopilot (radar) where he plot ship's position, heading, track and speed. He also alter heading, change speed and carry out change of operational steering modes while monitoring time, heading, speed, track, propeller revolutions, thrust indicators (when available), pitch indicator (if the ship is equipped with pitch propellers), rudder order and rudder angle. The operator also monitors traffic with all available means, acknowledges alarms and communicate internally and externally. [35] Equipment on workstation for navigating & maneuvering:

The control levers are located to the left of the operator of the navigation & maneuvering station. As the forward bridge is mostly used during transit, the levers for heading and speed, i.e. main propulsion and rudders are placed closest to the operator. Next to them are the thrusters for maneuvering, i.e. azimuth thrusters and tunnel thrusters. Right in front of him is the autopilot and the radar.

Information feedback for the control levers is usually located in display indicators beside the levers, in the ceiling and it can also be represented on other systems such as the conning screen.

5.4.2 AFT BRIDGE

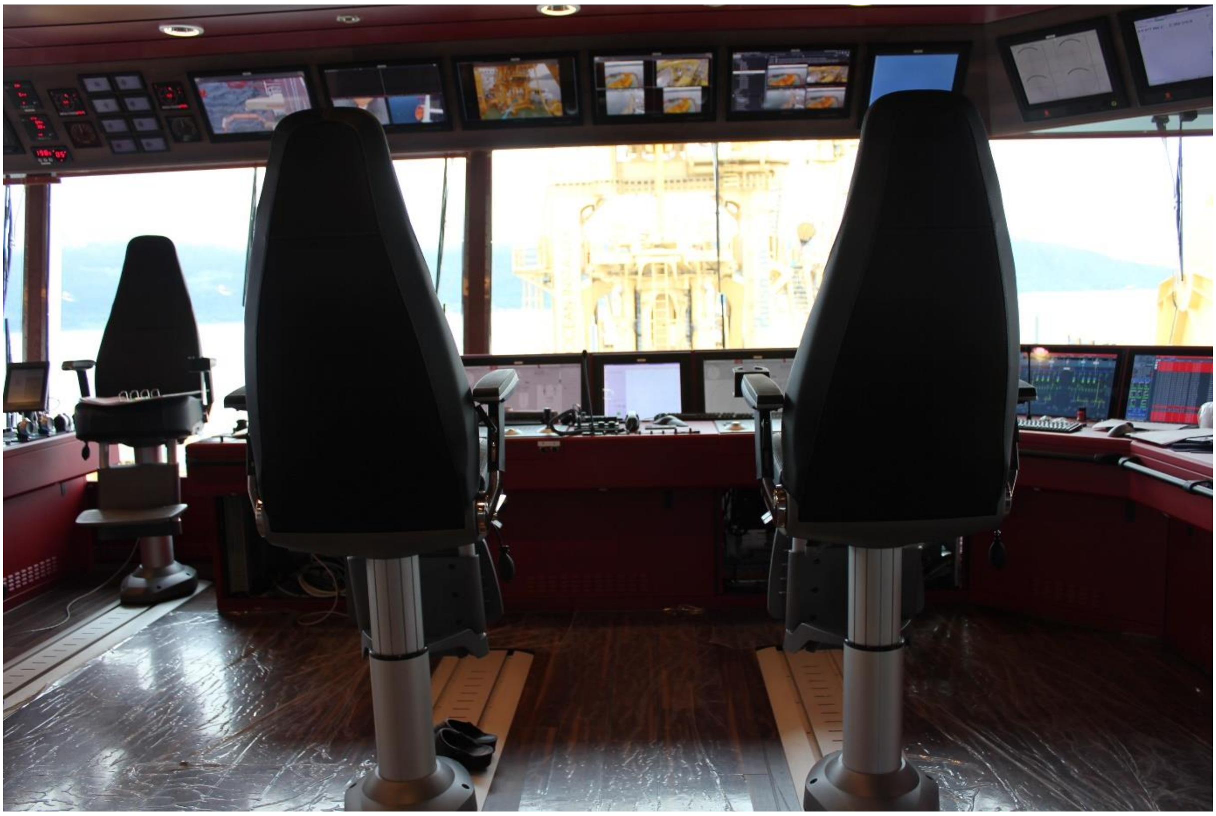

Figure 31: Aft bridge of OSCV. Workstation for ship handling is located to the left and workstation for aft support to the right. [3, 4]

The aft bridge is as mentioned divided into workstations for ship handling and aft support. With respect to control levers, the workstation for ship handling is of greatest importance. The workstation for ship handling facilitates control of main propulsion, thrusters, DP system and monitoring status of main propulsion and auxiliary machinery. Here the operator have “on hand”, as applicable, control of main propulsion, azimuths, tunnel thrusters, rudder controls and joystick, as well as communication systems. [35]

The workstation for aft support also have this equipment within reach, but the intent is that workstation for aft support should be able to take over the maneuvering function from workstation for ship handling only if necessary. The main functions for the aft support station is to perform tasks related to operations, e.g. anchor handling and cargo loading/ offloading.[35]

For AHTS and PSVs, this equipment is often placed in the chair, known as the DP- chair. The control levers are then placed on the armrest of the chair allowing the operator to rest his hands horizontally when operating the levers. If it is not placed in the chair, it is placed on the console close to the operator chair. Operations performed on AHTSs and PSVs can be rather intense and it often requires the operator to be operating the control levers for several hours consecutive. [3, 4]

5.4.3 WING BRIDGES

Figure 32: Starboard wing bridge of an OSCV. [3, 4]

Levers on the wing bridges are used frequently during docking of the vessel. Operators often use several instruments simultaneously. Operating the levers while communicating with i.e. an able seaman at the mooring station, harbor, pilots or with the co- captain on the other side of the bridge. [3, 4]

5.5 THE CONTROL LEVERS

The control levers are remote controls providing individual control of each of the thrusters and propellers. [22] The systems usually comprise of four different types of controllers, one representing each type of propulsion unit, i.e. main propulsion lever, rudder controller, tunnel thruster lever and azimuth lever.

Figure 33: A typical setup of control levers. To the left two tunnel thruster levers, lower center a rudder controller (plus one out of sight), to the right a main propulsion lever and in front of it, two azimuth levers. displays are located to the right of the levers. [3, 4]

For the tunnel thruster, power is initiated by pulling the handle sideways. As tunnel thrusters often appear in pairs, as illustrated here, the lever is split in two handles allowing the operator to control each thruster either synchronized with the other, or separately. Two sets of tunnel thruster levers result in a total of four tunnel thrusters.

The rudder angle is set by rotating the knob. The rudders are either operated separately or synchronized.

For the main propulsion lever power is initiated by pulling the handle back and forth. Main propulsion levers are often split, as shown here, in order to control the set of two main propellers from one lever. Each propeller is initiated power separately or synchronized.

The azimuth lever initiates power by pulling the handle back and forth and the angle of the thruster is set by rotating the controller.

Each control lever have distinct technical qualities corresponding with the characteristics of the propulsion unit, commanding thrust vectors in surge, sway or yaw, as applicable. Generally, the system consist of the same number of levers as the number of propulsion units, but in some cases one control lever control two propulsion units, as illustrated in Figure 33. [3, 4]

The control lever system contains feedback displays present relevant information for the respective controller such as power, rpm, pitch and azimuth angle. [52] It also provides input screens or buttons for additional functionality such as:

- "Emergency stop" for diesel engine/ electro motor or propeller clutch.[52]
- "Start/stop" of motors and oil pumps.[52]
- "Command transfer" moving command of the control levers between stations.[52]
- "Alarms confirmation" [3, 4]
- "Light dimmer" [3, 4]
- "Synchronized/ independent steering" allowing each power handle of a split control lever, e.g. a main propulsion lever to move synchronized or independently. (Vard)
- Retract or swing- up command for azimuth.[3, 4]

Additionally the system as whole can include functionality such as [52]:

- "Electronic shaft system" enabling the control levers on the different workstations to automatically move to the position it was placed in by the workstation in command, as master and slave units.[52]
- "Haptic feedback" providing force feedback to the operator.[52]
- "Status indication" presenting the current operational mode of the control levers. [52]
- "Backup system" which is a redundant system in case of main system failure.

OPERATING THE CONTROL LEVERS

When operating the control levers you always have in mind that everything moves slow. During maneuvering you typically increase power in the direction you want the vessel to move and then set it back to zero. You then observe the vessels motions, before you potentially increase power again, or choose to slow down. If you choose to slow down the initiated movement, you simply initiate power in the opposite direction. [3, 4]

The main propellers are sometimes controlled in combination with the autopilot. The autopilot than has control of the ships rudders, while the operator controls the speed through the main propulsion lever. Its not operated very frequently, it typically just moves from 70% power to 80 % power to shorten the ETA. During this time, the operator is constantly checking screens and most importantly his outside surroundings, through the windows for anything closing inn. [3, 4]

6. EARLY SPECIFICATION PROCESS

This chapter starts with the development of a mission statement and continues by mapping out the stakeholder needs.

6.1 MISSION STATEMENT

Table 15: Mission Statement, ref. chapter. 3.2.2.

Mission Statement: Vard Control Levers	
Product Description	• Manual Thruster Controls for offshore service vessels
Key Business Goals	• Entering the market for manual thruster controls. • Strengthen Vard's presence as a bridge installer. • Achieve greater design coherence between Vard's systems.
Primary Market	• Offshore service vessels
Secondary market	• Merchant vessels, cruise vessels.
Assumptions	• Has to be implemented in console. • Must be modular.
Stakeholders	• User (Operator: Captain and Officers) • Customer/ Client (Offshore shipping companies/ Ship-Owners or Shipyards/ Equipment suppliers) • Equipment provider (Vard Electro) • Technology provider/ producer/ manufacturer • Classification Societies • Sales/ Marketing department • Service/ aftermarket department

6.2 IDENTIFYING STAKEHOLDER NEEDS

The raw data extracted from the gathered data is interpreted in terms of needs and a list of user needs is presented below. The needs are given a score of importance ranging from 1, where feature is undesirable to 5, where the feature is critical.

Many of the expressed needs recorded, more closely relates to the operational and technical aspects than to the physical design of the control levers. In order to sort out the most relevant needs for further application, the customer needs are organized in four categories.

1. Lever: Needs directly relating to the physical design of the control levers.

2. Display: Needs regarding information presentation and possible in- screen- functionality.

3. Placing: Needs directly related to the placing and layout of the operator stations.

4. Technology: Needs referencing programmable aspects and system- cooperation- functionality.

The needs marked (!) indicates that it is a latent need, interpreted from the context.

Table 16: List of user needs. [3, 4]

No.	User Needs	Imp.	Category
1	The levers have clear, informative indications.	4	Lever
2	The levers have haptic feedback.	4	Lever
3	The azimuth lever clearly states what is forward and aft of the propeller.	5	Lever
4	The levers are user-friendly.	4	Lever
5	The levers are numbered in reference to the propulsion units, placing on the vessel and position on the lever control screen.	3	Lever
6	The distance between each scale relates to the massive powers the user is operating with (longer travel).	4	Lever
7	Levers have good tactical qualities and clear coding.	4	Lever
8	Levers can be operated while user is using communication equipment.	5	Lever
9	Levers accommodate both sitting and standing operations.	5	Lever
10	Azimuth levers have a shape easy to rotate.	4	Lever
11	The levers are operated with precision; hand and fingers.	3	Lever
12	The levers put as little strain on the hand and arm as possible.	4	Lever
13	The levers are comfortable to grip and have good tactile qualities.	4	Lever
14	Levers are small enough to not obstruct operation of other equipment.	3	Lever
15	The main propulsion lever is designed for speed. The thrusters are designed for maneuvering and are good to grip. (!)	4	Lever
16	The levers are movable in x, y and rotates in z as fit.	5	Lever
17	The levers has feedback screens on/ or next to them.	3	Lever
18	The levers allows for fine and easy power adjustments and maneuvering.	4	Lever
19	Control lever system does not disrupt view.	5	Lever
20	The levers are something more like a joystick, good to grip (ball) and have power adjusting with thumb and middle finger.	3	Lever
21	The levers have good ergonomics and bring something new.	3	Lever
22	The lever control is integrated with a personalized iPad that you move around from station to station. (!)	3	Lever
23	Levers are modular.	5	Lever
24	The levers are small (to more easily accommodate installation).	2	Lever
25	The lever system should be as good as Helicon X3.	x	Lever
26	The control lever system is designed to accommodate the different ship types and operations in the market segment.	5	Lever
27	The levers inherit some tradition. (!)	3	Lever
28	Levers have a shape that is possible to grip and hold onto.	2	Lever
29	The levers have physical push buttons.	3	Lever
30	The tunnel thruster lever, main propulsion lever and rudder controller allows for easy connection/ disconnection of split-mode.	4	Lever/ Tech.
31	The lever control system is fail-safe.	5	Lever/ Tech.

Table 16 continues.: List of user needs.

No.	User Needs	Imp.	Category
32	The levers are recognizable without looking at them, and they have a logical placing.	4	Lever/Placing
33	Lever system displays RPM as a secondary information parameter.	4	Display
34	The lever control screen presents only necessary information clearly and simply, without duplication, all in one place.	4	Display
35	The levers clearly states ordered and actual value of power and angle.	4	Display
36	The lever control screen is easy to navigate.	4	Display
37	The levers display load.	5	Display
38	The levers have electronic scaling.	3	Display
39	Lever control screen contains secondary functions. (!)	4	Display
40	Levers are placed logically according to nautical terms and operators training/ common practices.	5	Placing
41	The levers are located close to the conning screen.	4	Placing
42	The levers are easy to reach, located within close proximity of the operator whether standing or sitting.	4	Placing
43	Levers are within reach for both operators.	4	Placing
44	The levers are placed close to other necessary external systems.	5	Placing
45	The levers are placed close to the operator, displays further away.	4	Placing
46	The control lever system allows for ergonomic placing of the control units and screens. (!)	4	Placing
47	It is possible to easily switch from using levers to using DP system.	4	Tech.
48	The lever control system provides function for command transfer of all controls to other stations with one click. Also allows for every single lever.	4	Tech.
49	Levers can automatically synchronize between workstations.	4	Tech.
51	The levers are single thruster controls.	4	Tech.
52	The control levers are separated from the emergency engine room telegraph.	5	Tech.
53	The control lever system is context and user sensitive.	3	Tech.
54	Levers work in combination with other necessary external systems.	5	Tech.
55	Levers do not have to be duplicated.	4	Tech.

In addition to the list of user needs, a set of overall needs has been identified by Vard and the customer. For Vard it is important that the design is representative for the overall bridge environment and correspond with the Vard brand. The product should also be different from existing systems in a way that makes it exciting and innovative.[3, 4]

6.3 PRODUCT GOALS

In order to meet the key business goal the overall product goal is to ensure that the Vard brand is well represented throughout the product, in all aspects. This entails the product reflecting aspects such as reliability, quality and functionality. On a product level this means ensuring that the technology is reliable, there is quality in every aspect of the product and production process, and most important for this paper, ensure that the product has good functionality corresponding with the users expectations. The product should also be different from existing systems in a way that makes it exciting and innovative.

The needs list clearly emphasizes ergonomics as an important quality. In summary, it is stated that the lever should be good to hold and it is preferred to operate it with fingers, and avoid extensive use of hand and arm. Further, the user wants to be able to operate the control levers from both a sitting and standing position. It is also expressed that any indications are to be clear and information overflow and too much redundancy is not desired. As the levers are often operated without the operator looking at them there is also a wish for implementing haptic feedback in the control levers.

In addition to the physical aspects, the overall system functionality is also addressed as important. A need for a smooth user experience with easy access to system functionality such as command transfer between workstations, synchronized and split mode of i.e. tunnel thruster lever, easy change from DP mode to manual control lever mode is stated. The aspects of context and user sensitive control lever systems was mentioned as a possibility and the user generally expresses a wish for a more technologically updated product.

The third aspect identified is modularity. As the control lever system is to be used on several different vessels, all with individual propulsion and thruster setups, the system needs to be modular. The customer expects at some level to be able to customize the product according to technical specifications of the vessel. It is also desired that it does not take up any more room than necessary. Modularity also affects how the product is manufactured, which again addresses the joint market expectations of production costs and retail price.

To ensure a good product, the product is to:

- Represent the Vard brand.
- Have sound ergonomic qualities.
- Consist of modern technology.
- Be modular.

7. CONCEPT GENERATION

In this chapter the product goals are taken under investigation. The functionality of the product is outlined and the market space is explored ending in a competitor screening. The process ends with a set of concepts emphasizing different aspects of the identified stakeholder needs and product goals.

7.1 FUNCTIONAL ANALYSIS

The primary function of the control levers are identified as controlling the vessel. From this a set of secondary functions are identified. The function analysis is presented in Figure 34.

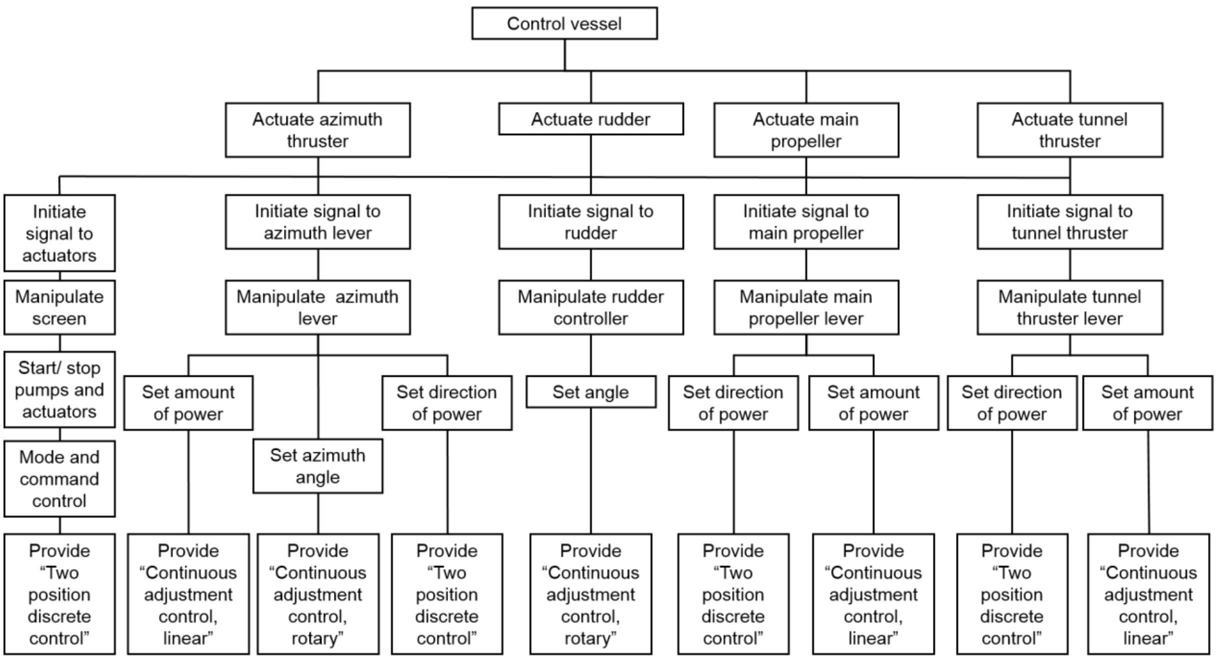

Figure 34: Functional Analysis. Moving downwards answers "how?" and upwards answers "why?".

The analysis has identified all the basic functions connected to the levers control of the vessel. Each branch of the analysis has identified what functionality is required for each control unit. In addition to these physical functions, there is also some necessary functions for startup and mode control outlined on the left. These functions are considered secondary, and are more related to the system functionality then the design of the physical control levers. They are set aside for now and brought back in the detailed development of the final concept.

The result of the analysis clarifies a total of three different physical functionalities represented in different combinations in each of the control units. Respectively "Continuous adjustment control, linear", "Continuous adjustment control, rotary" and "Two position discrete control".

To minimize the number of functions "Continuous adjustment control, linear" and "Two position discrete control" are combined. The two functions derives from the activities "Set amount of power" and "Set direction of power". "Set direction of power" comes from the fact that many propellers work in both directions, allowing the operator to initiate power in the propellers positive or negative direction. The two functions can be combined by defining the power adjustment function with a scale ranging from e.g. -10 to 10 utilizing the 0 position as an indication of direction. Meaning that which side of zero the indicator is placed determines the direction, and power is set along the scale of the chosen side. If these two functions were to remain split, it would require a two- step process for something that only really need to be one. This is also how other control lever systems work, and there is therefore the extra benefit that the control levers applies the same logic as other systems.

The task characteristic of continuous control is determined based on user interviews and other control lever systems exhibiting that the movements of the control levers are mainly continuous. As the functions of “Continuous adjustment control, linear” and “Two position discrete control” are combined, the control levers are left with a total of two main physical functions, “Continuous adjustment control, rotary” and “Continuous adjustment control, linear”. These functions corresponds with the control type “Controls for making continuous adjustments – small activating force”. In addition there is ”Two position discrete control” functionality for the secondary functions, set aside for now.

In light of the functional analysis, a natural component to focus on during concept generation is the azimuth lever as this is the only lever containing both “Continuous adjustment control, linear” and the “Continuous adjustment control, rotary” functionality.

7.2 COMPETING PRODUCTS

Below is a review of a selection of competing products. Presented first is an ingoing analysis of a selection of the most prominent, direct competitors offering complete control lever systems. After I look into some indirect competitors offering somewhat different products, notable for either form or function.

7.2.1 ROLLS- ROYCE MARINE

Royce Marine is a leading company in the maritime supplier industry, and within the segments of automation and bridge installation regarded as one of Vard Electro’s largest competitors. Rolls- Royce offers their clients the complete product range throughout the vessel from control lever, down to propulsion units and rudders.[53]

Rolls- Royce Marine was among the first to set focus on control lever design with their Helicon X3 control system. Because of the Helicon X3 Rolls- Royce is by many regarded as the market leader and preferred provider of control levers. As part of their new bridge, “Rolls- Royce Unified Bridge”, a complete set of new levers have recently reached the market.

HELICON X3

Figure 35: The Helicon X3 installed on the aft bridge DP chair. Also displayed is the Poscon DP solution. [48]

Helicon X3 is the latest model in a long series of propeller and thruster control system. It consist of a larger touch based operator display, speed- and azimuth levers. The Helicon X3 has a coherent design language with the entire integrated bridge system, which makes it consistent with Poscon; a DP solution with an independent joystick control system for manual vessel positioning and low speed maneuvering.[51]

Helicon X3 is designed by Hareide Design and manufactured by Lilaas AS. [54] It was awarded “Merket for God Design” in 2003. [55]

PRODUCT DESCRIPTION

All the levers consists of the same oval shaped main component. The main component is attached to a platform mounted to an oval base plate. On top of the main component, there is a handle for adjusting power. Power is initiated by pushing the handle back and forth. For the azimuth lever, the azimuth angle is set by rotating the main component.

On the baseplate of each lever there is an integrated display presenting relevant feedback for the respective controller and there are integrated pushbuttons for key functionality. The larger operator display is touch based and works as an operator panel providing control of overall system functionality, as well as for each individual thruster. The screen present feedback to the operator and it contains overview of alarms, start/ stop of thruster and oil pumps, mode and command control, status of thrusters and warnings. [3, 4]

EVALUATION

Helicon is by many regarded as the best on the market. Levers are described as ergonomically sound as they fit in the operators hand. The screen is characterized as user friendly, easy to navigate and it had the right type and amount of information displayed. It also provides easy access to useful features such as alarm confirmation button. It further has a consistent user interface with other bridge systems, but it does not provide a rudder controller.[3, 4]

Figure 36: Demonstration of Helicon X3. A setup containing a split tunnel thruster lever and three azimuth levers. (Own photo)

Figure 36 demonstrates the use of a split tunnel thruster lever. The first image shows the operator using his thumb to initiate power towards port for one of the tunnel thrusters. He is using his thumb, while supporting his hand by resting his fingers on the side of the lever. The next two images shows how he uses a pinch grip initiating power towards the port side. He has now gathered his fingers, but is still using them to support his hand to achieve accuracy in the power adjustment.

It is clear that the operator naturally approached the adjustment alternatives with his fingers, not his hand, which indicates a wish to achieve precision.

UNIFIED BRIDGE

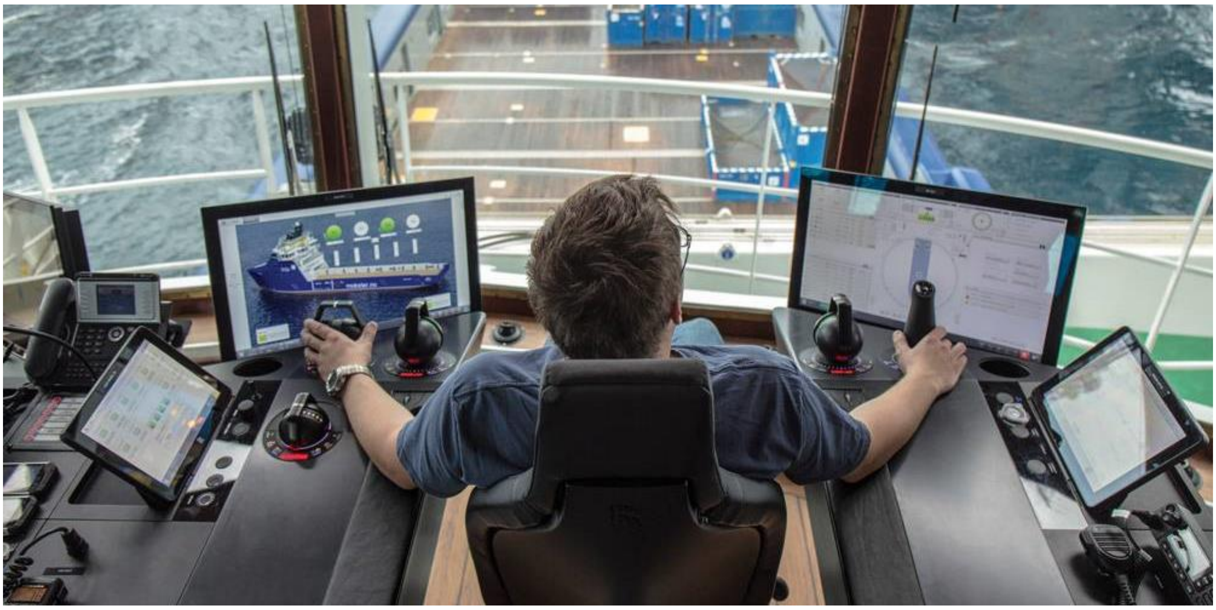

Figure 37: Rolls- Royce Unified Bridge. Operations on the aft bridge.[56]

A new control lever system, part of the Unified Bridge. The system consist of larger touch based operator display, speed- and azimuth lever. As for the Helicon X3 here is a coherency with the overall Unified Bridge and an independent joystick system for DP. [57] The components are designed by Hareide Design.[58]

PRODUCT DESCRIPTION
There is a greater difference between the forms of the components in this system. The azimuth levers consists of an oval main component attached to a platform mounted to a circular baseplate. Attached to the main component is a handle for initiating power. The speed lever is a hemisphere mounted to a circular baseplate with a handle for initiating power.

Integrated in the baseplate for all the components is a display presenting relevant information for the respective controllers. In addition, there is pushbuttons for key functionality and numbered scaling with integrated light. [57]

EVALUATION
The azimuth lever is relatively large compared with other azimuth levers. The speed lever is significantly smaller than the azimuth lever and has a different shape. The shape of the azimuth makes ergonomic sense as the oval shape fits within the operator's hand. It has modern aesthetics, and seems to emphasize the design with use of lights. The design is coherent with the DP system.

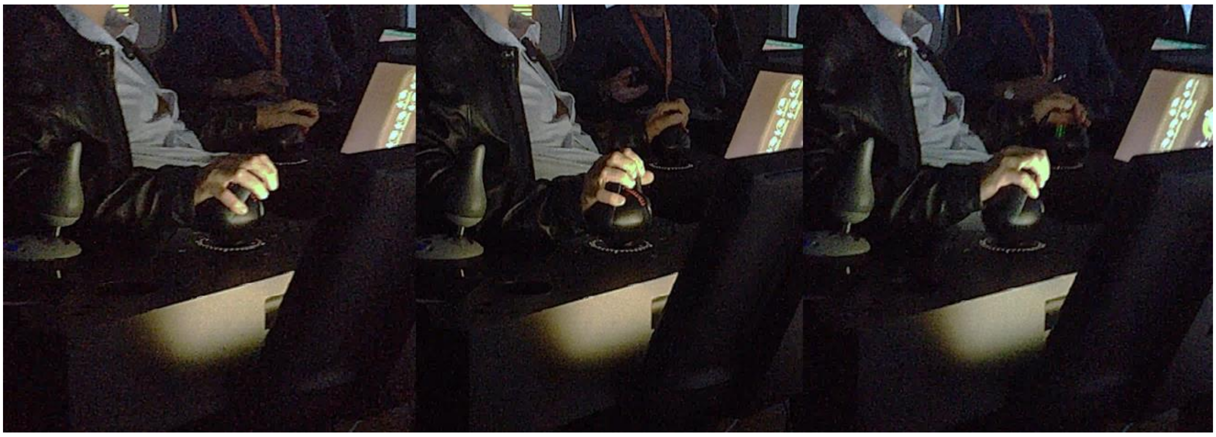

Figure 38: Demonstration at simulator. Sitting at aft bridge in the DP chair. (Own photo)

In the first image of Figure 38 you can see how the operator use a power grip to initiate power astern. He uses the base of his fingers/upper part of palm to push the handle forward initiate power astern. The next slide shows how he cramps his fingers when pulling the handle back, initiating power ahead. In the last slide his left hand has turned the azimuth and his grip has moved to the side of the lever and power is now initiated by the using the thumb and palm/ fingers. Generally, the angle of the operators hand is very steep when operating the levers.

7.2.2 WÄRTSILÄ

Wärtsilä is one of the larger players in the maritime supplier industry and offers wide range of products to the maritime industry. With their propulsion control system, Wärtsilä Protouch they offer one of the newest products on the market. [59]

WÄRTSILÄ PROTOUCH

Figure 39: Wärtsilä Protouch. [25]

Wärtsilä Protouch is a propulsion control system consisting of speed-, and azimuth levers, several small and one larger touch based operator display. The system is designed with focus on being flexible enough for all types of ships, from simple carriers to more complicated offshore supply vessels. The design received a Red Dot Design Award in 2013. [52]

PRODUCT DESCRIPTION

There is a common design language represented throughout the system. All the control units are based on the same cylindrical shape where the cylindrical main component is placed on a platform mounted to the square base plate. On top of the main component, there is either a handle or a grip area for power initiation. The azimuth controller distinguishes by being one-half of the speed lever. This shape also gives a tactile and geometrical reference to what is forward and aft of the azimuth propeller. The azimuth angle is set by rotating the main component.

The baseplate have integrated pushbuttons for emergency stop and backup. The small touch based operator display mounted on the side of each lever accommodates relevant functions and provides relevant information for each individual thruster. The larger touch based operator display works as a common interaction screen where all propulsion units can be controlled from one place. It also utilizes lights for status indication. [52]

EVALUATION

The system has a distinctive design language and there is clear differences between the controllers. There is little scaling and no information feedback on the levers, making the operator dependent on looking at either the accompanying displays for information feedback.

Further, there seem to be an overload of information- screens, making the user experience unnecessary redundancy both in functionality and information display. The screens also contains more information than the operator needs, and it is experienced as an annoyance to flip through all the alternatives.

Even though the screens are mounted separate from the levers to accommodate modularity, this makes the control lever system relative space consuming.

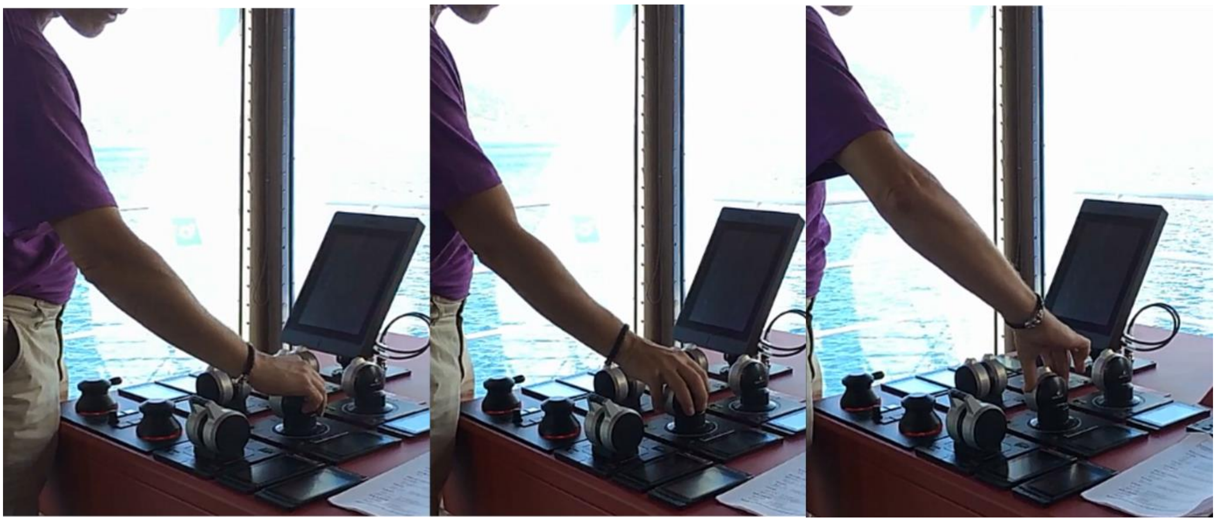

Figure 40: Operator situated on the starboard wing bridge of an OSCV. Demonstrating the use of azimuth lever. [3, 4]

In Figure 40, the operator is demonstrating operation of an azimuth lever from a standing position. The first image illustrates the operator placing the hand “flat” down on the handle. The second shows how he spreads his fingers to control the speed handle between the little finger and thumb. The third shows a pinch grip for power adjustment. To manage this grip his hand and shoulder is twisted outwards. Generally, the user had trouble finding a natural way of placing his hand on the azimuth lever.

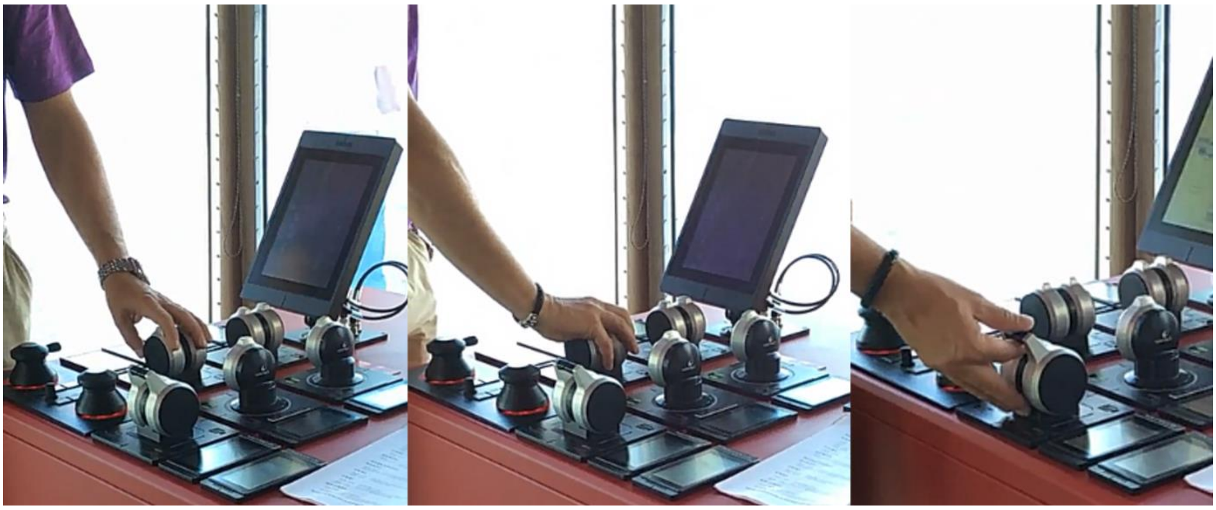

Figure 41: Operator situated on the starboard wing bridge of an OSCV. Demonstrating the use of tunnel thruster and main propulsion lever. [3, 4]

The first two images of Figure 41 demonstrate grips for a split tunnel thruster lever. First, the operator is adjusting power individually by using his fingers. He is here in a typical docking position with his back towards the quay and his left shoulder facing aft. Second, he has turned around and is adjusting both power- handles at once using the back and front part of his palm. The last image demonstrates a pinch grip for power adjusting on the main propeller. Here the operator uses his fingertips while supporting his hand by resting his other fingers underneath the control lever.

7.2.3 LILAAS

Lilaas is an engineering company specializing in manufacturing of joysticks, control levers and precision mechanics mainly for marine and offshore use. In addition to working closely with several companies the maritime industry as technology provider for their control levers, Lilaas also offer their own control lever systems. Their newest control lever system is called Lilaas L01.[54]

LILAAS L01
Lilaas L01 is designed and developed by Lilaas AS. The system consist of speed- and azimuth levers. Lilaas also offer rudder controller and joystick. [54]

PRODUCT DESCRIPTION
The levers are all based on the same cylinder shape, where the main component is placed on a platform, mounted to the base plate. The azimuth angle is set by rotating the main component. Attached to the main component is a handle for initiating power. The base plate contains a display screen accommodating for relevant functions and providing information feedback relevant for the control lever. [54]

EVALUATION
The levers are very similar and have a simple clean design. It is made of aluminum and molded Arnitel. The product offers force- feedback with electronic detents and brake settings. [54]

Figure 42: Lilaas L01 demonstrating the use of azimuth lever. (Own Photo)

Figure 42 shows an operator demonstrating the use of an azimuth lever. In the sitting position combined with the tilting armrest the operator is able to rest his hand on top of the lever making him able to control without stressing his wrist, hand and arm. The second and third image the operator is standing. You can see how the operator uses his index finger to initiate power forward. When he is turning the azimuth lever, he has moved his index finger to the side of the lever and you can see how the lever fits in his grip.

7.2.4 INDIRECT COMPETITORS

Control levers that are not part of a complete control lever system.

BRC 800

Figure 43: BRC 800 control lever panel. [60]

Control levers by Caterpillar/ Berg Propulsion in cooperation with Lilaas. Express modern aesthetics and demonstrates an interesting use of displays. [54]

AUTOCHIEF

Figure 44: Kongsberg AutoChief speed lever.[61]

Speed lever by Kongsberg Maritime. The unit is very large compared to other speed levers. It has traditional EOT scaling and a large display. It has haptic feedback. [62]

AQUAPILOT

Figure 45: Aquapilot azimuth lever from Rolls-Royce. [63]

Aquapilot azimuth lever by Rolls- Royce. It has an interesting form factor different from other azimuth levers.

KWANT

Figure 46: Control levers by Kwant Controls. [23]

Kwant is a technology provider and have worked with many of Vard’s competitors. Illustrated in Figure 46 is some of their own line of control levers. They have traditional aesthetics and a distinct lever for power adjusting. [23]

7.3 COMPETITOR SCREENING

Almost all of the evaluated products are based on the same construction principle. They all consist of a main component attached to a smaller platform, which is again mounted to a base plate. Power is initiated by some sort of handle attached to the main component and the azimuth angle is set by rotating the main component.

The ergonomic analysis shows that for a sitting operator, as long as this lever is placed on a horizontal surface, it does not allow the hand to operate in a natural position. The construction tend to stress the angle of the wrist/ hand and arm when operated from a sitting position. When operating from a standing position the operator is frequently searching for a natural way of placing and supporting, or resting his grip and hand.

It is clear that the operator usually approached the levers with his fingers initiating a precision grip and hereby indicating a desire to perform fine adjustments. A precision grip is initiated independent of the shape of the "power handle" as operators chooses this grip for both the Helicon X3, Wärtsilä Protouch and Lilaas L01. The only alternative illustrating the use of a power grip for adjusting power is the Unified Bridge levers, which is most likely because it is significantly larger than any of the others.

Almost all existing control levers in the offshore vessel market are based on the same type of technology, provided by a small number of suppliers. The base technology for many of the control lever systems is the same, with various customizations to both technology and the "shell design".[3, 4] It is clear that the use of standard components in the production of control levers is very common, and maybe even the most common practice. It is also notable that all the systems evaluated have gone through the process of being approved by the class societies who have demands affecting both technology and design and hereby resulting in certain similarities among the products.

7.4 IDEATION

7.4.1 EXPLORING

Ideation starts by generating ideas, outlining alternatives for power adjustment and rotary movement. The ideation process then continues by combining the findings, identified user needs and specific user suggestions, and learning from the competitor screening. An informal application of SCAMPER is utilized throughout the process.

EXPLORING POWER ADJUSTMENT ALTERNATIVES

From the functional analysis it is known that the power adjusting activity is a continuous linear movement. Due to this, I have discarded controls with large activating force, "Two position discrete controls - small activating force" and "*Multiposition discrete controls"* leaving and *"Continuous adjustment controls"* with small activating force to be explored further. The powers initiation should have direction, and be linear with the vessels movements.

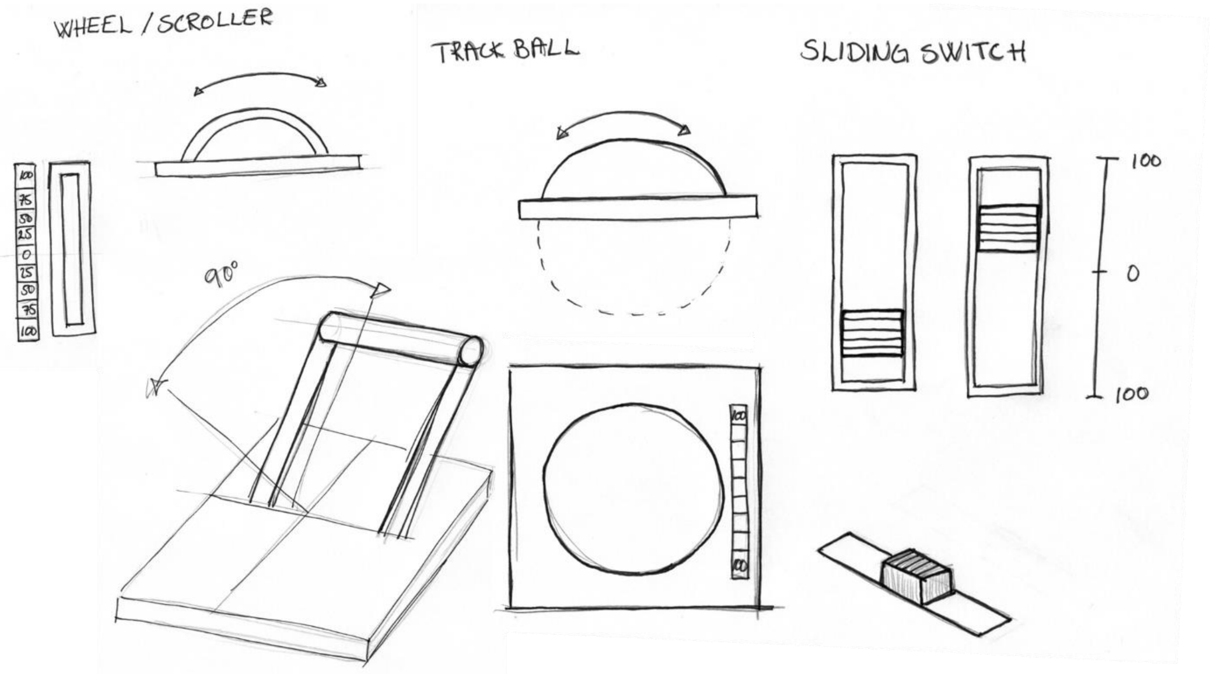

Figure 47: Examples of power adjusting alternatives. Wheel/ scroller, Trackball, Sliding Switches, Lever/ Hand toggle. (Own illustration)

EXPLORING ROTARY MOVEMENTS

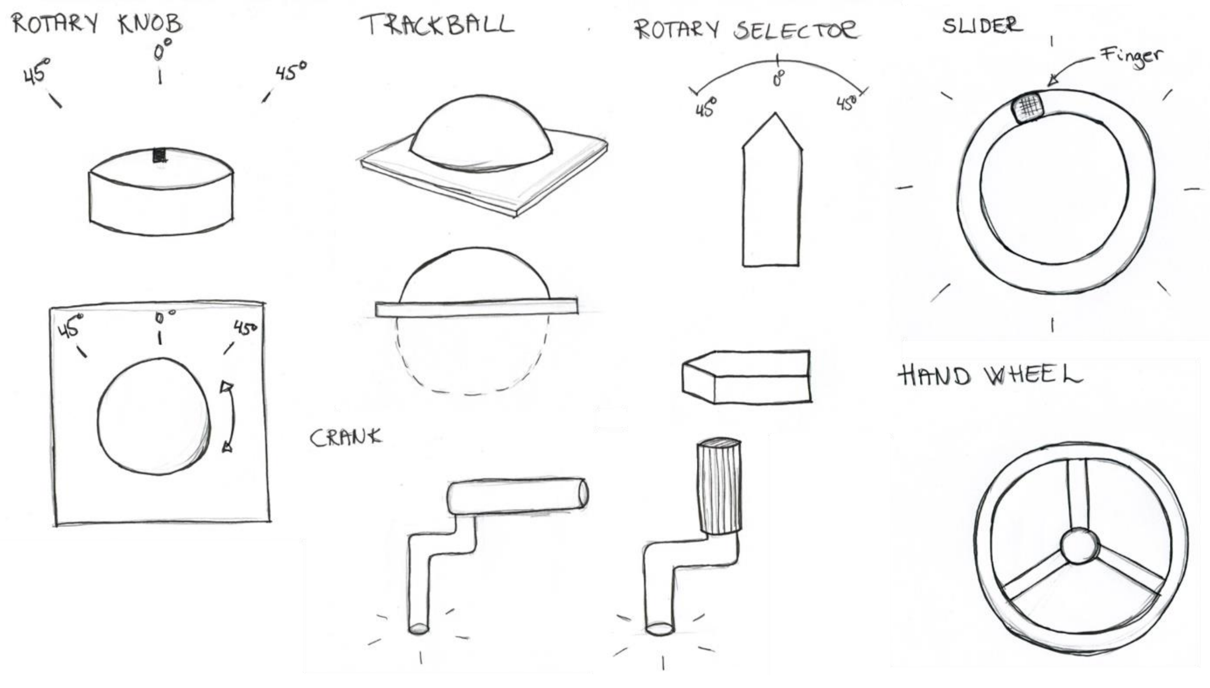

Figure 48: Examples of rotary alternatives. Rotary knob, Trackball, Rotary Selector, Slider, Cranks, Wheel. (Own illustration)

All these functions are similar as they rotate around a fixed point, with different grip/ interfaces. The alternatives that distinguish the most is the “Slider”, and to some extent the “Trackball”. The “Rotary selector” is essentially the same as the “Rotary knob”, only a different grip surface.

7.4.2 CONCEPTS

The identified alternatives are here combined with each other and identified user needs, and modified into concepts. Some of the concepts are purely based on user inputs. Mechanical restrictions and feasibility is ignored in this phase.

Super User Concept

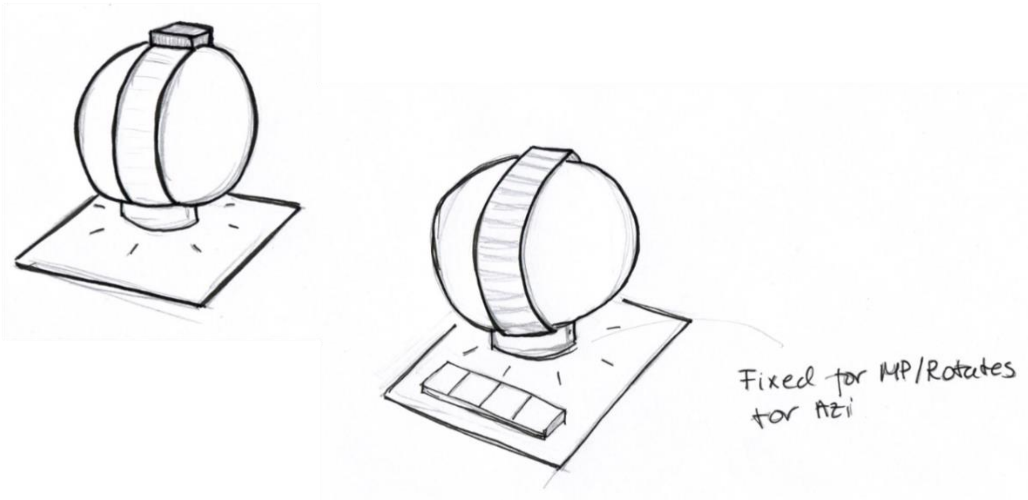

Figure 49: Super User Concept. (Own illustration)

This concept was generated based on specific inputs from the super user. With a basis in known control lever systems, the super user described the parts he liked and put them together to make the ultimate lever. The concept is therefore somewhat similar to existing control levers. Power is adjusted by rotating the band, and azimuth angle is set by rotating the ball.

Touch Screen

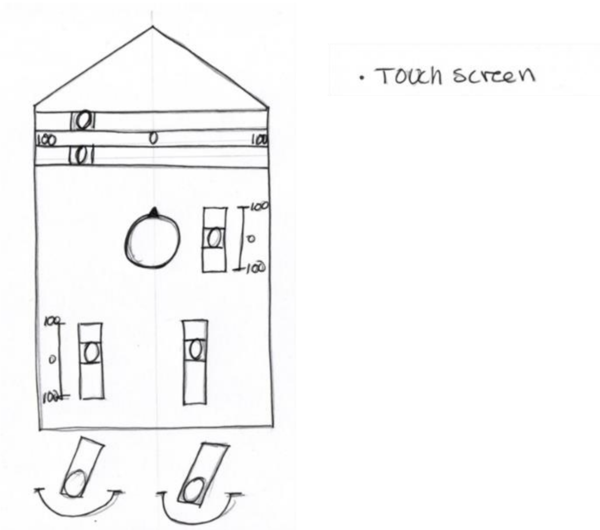

Figure 50: Touch Screen Concept. (Own illustration)

In this concept, all the functionality is transferred to a finger operated touch screen. There is no physical interaction point other than between the operator's fingertip and the screen. The screen shows a setup with two tunnel thrusters in front, an azimuth mid-ship, two main propellers aft accompanied by rudders. Power is initiated as for a sliding switch, and a circular motion rotating the symbol sets the azimuth angle and rudder angles. The screen is portable like a tablet and is partially based on input from users.

Cranks

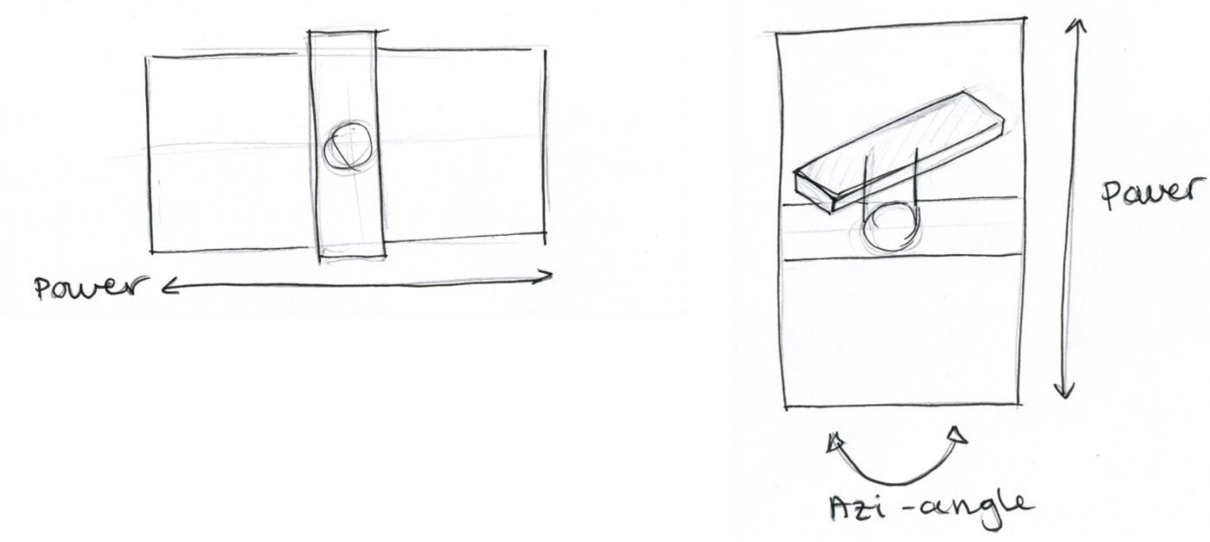

Figure 51: Cranks. (Own illustration)

The levers are operated by hand. Power is set by shoving the handle back and forth along the track. The azimuth angle is set by rotating the handle.

Ball

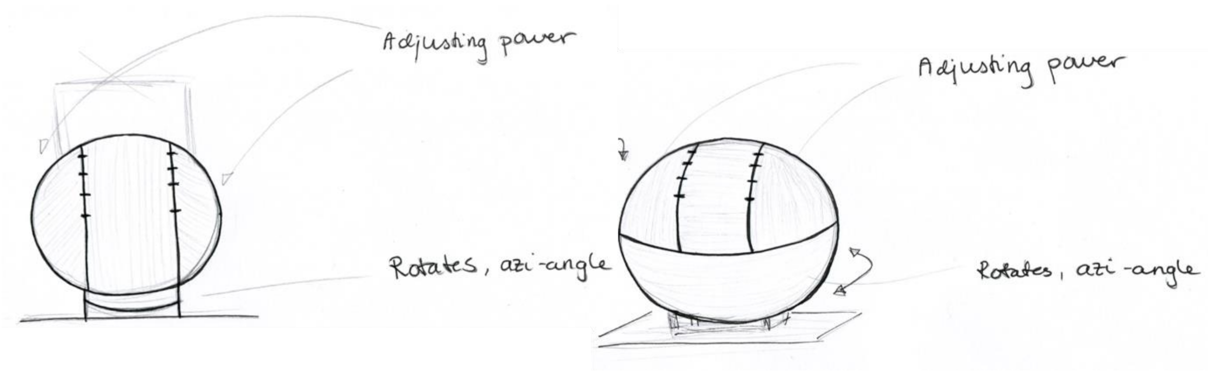

Figure 52: Ball concept. (Own illustration)

The lever to the right represent the finished concept. As illustrated, this concept is a manipulation/ simplification of the typical existing lever. The “Ball” concept was developed based on users expressing how they want the lever to easily fit in the palm of their hand, using their fingers to operate. Removing the typical power handle allows the ball to fit more smoothly within the operators grip. The lever is to be grasped from the side, especially accommodating a sitting operator. The little finger and the ring finger plus the thumb is used to turn the lower half of the ball, setting the azimuth angle. While the thumb and the two left digits are used to adjust the power, back and forth by either touching the left or the right part of the upper half. The lever is symmetrical, so it can easily be operated by a left- handed, as well as a right-handed person.

Joystick

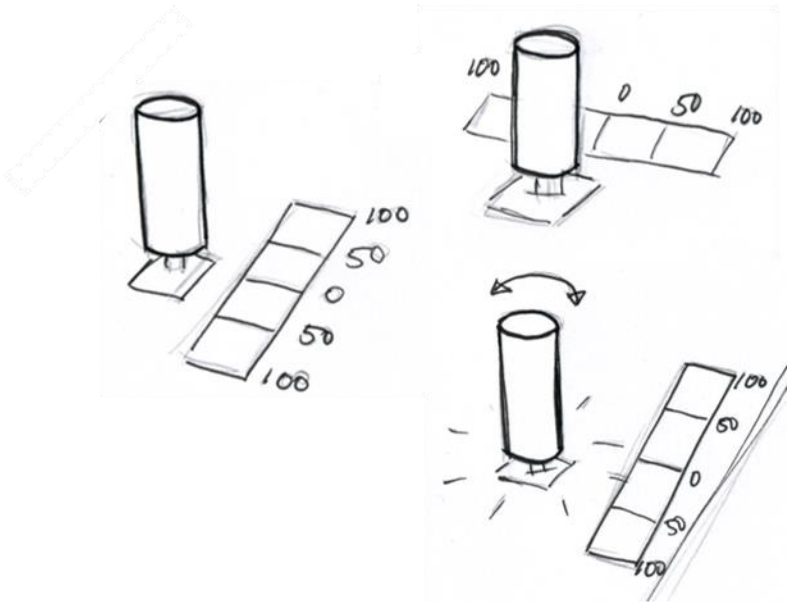

Figure 53: Joystick Concept. (Own illustration)

The concept is based on static joysticks with a bending angle of 90 degrees, much like a traditional toggle/lever. The joysticks moves back and forth to initiate power and it rotates for the azimuth.

Basic

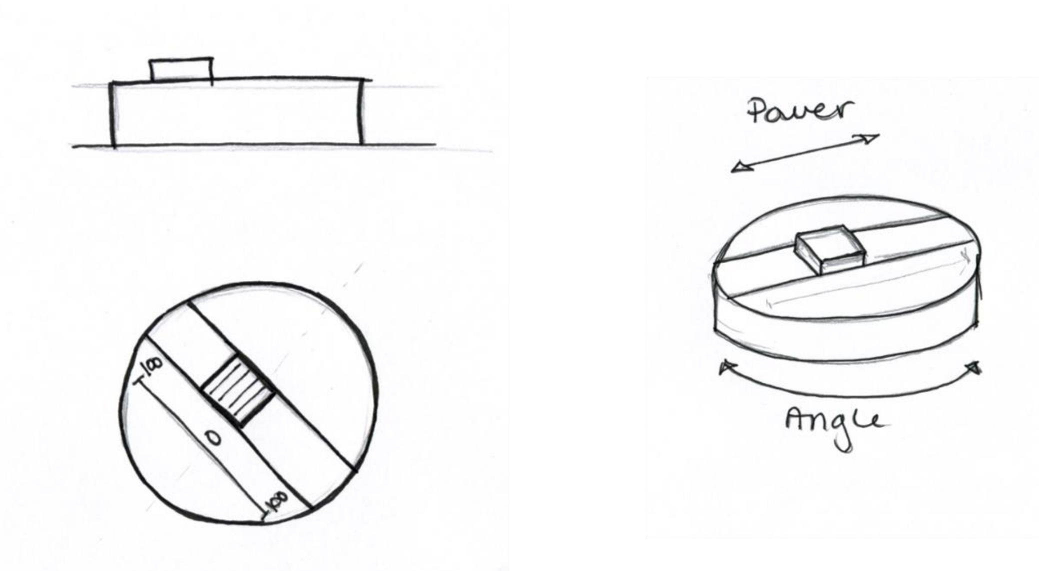

Figure 54: Basic Concept. (Own illustration)

This concept is simply based on combining the basic functions of a sliding switch adjusting power and a knob for the rotating azimuth movement. It is as basic as you can get an azimuth lever. Power is set by showing the “sliding switch along the lever” and azimuth angle is set by rotating it. The concept accommodates the use of fingers both for rotating and linear movement.

Trackball

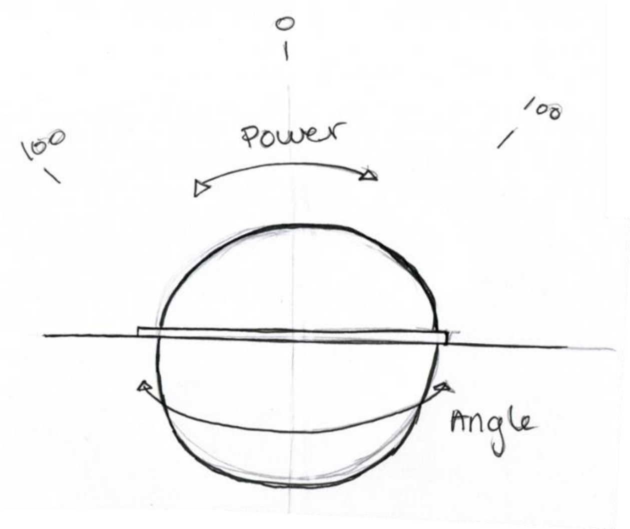

Figure 55: Trackball Concept. (Own illustration)

This concept is based on the trackball that appeared both as an alternative for power adjusting, and for rotary movement. The track ball is movable both back and forth and it rotates. The idea is that the operator puts his hand on it and operates it with his palm and/ or fingers providing a more tactile and interactive sensation to the ship operator interactions.

Rotary Knob - Spring

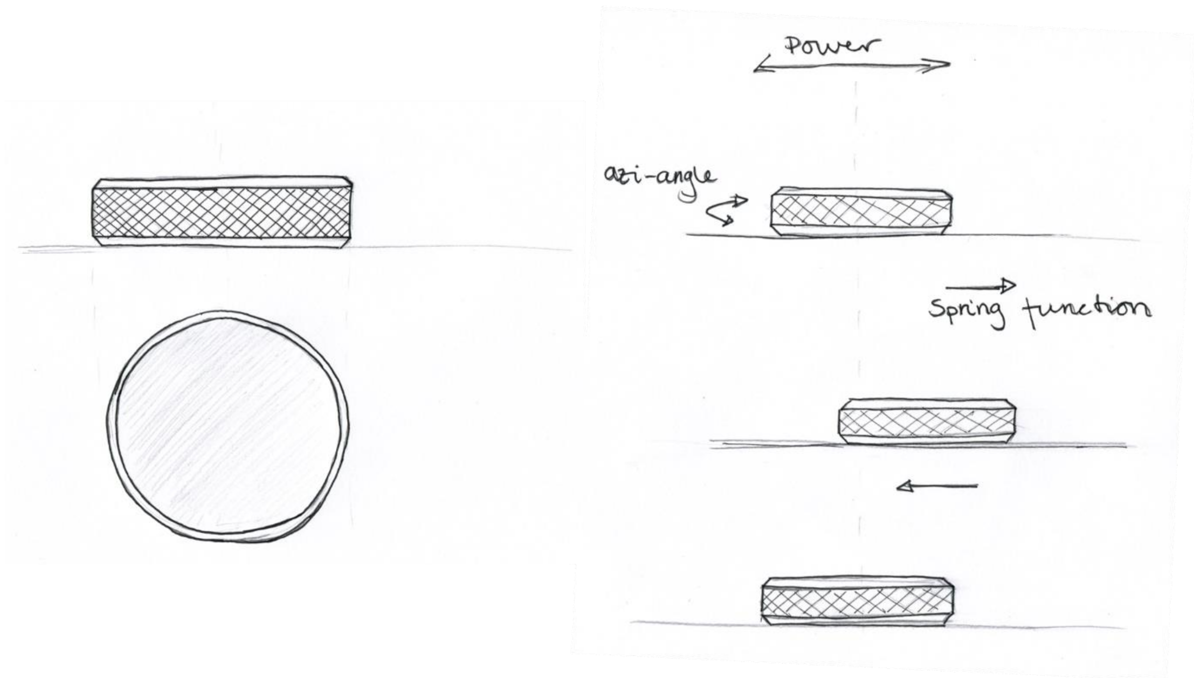

Figure 56: Rotary Knob- Spring Concept. (Own illustration)

The knob rotates and moves back and forth along a track for power initiation. The spring functionality is put in to correspond with the expressed aspect of fine maneuvering where the operator initiates power in one direction before setting it back to zero, observe the ships movement, initiate again before putting back to zero and observing again.

8. CONCEPT SELECTION

The concept selection is performed through a two stage process using Pugh's method. First a concept screening is performed, and then a concept scoring. The screening criteria are the same for both stages.

The screening criteria are mainly based on the specified product goals, but in order to emphasize important aspects some user needs have been added to the list. The last screening criteria relates to the findings in the customer screening and the product goal of bringing something new to the market. The needs categorized as "Technology" and "Placing" are set aside as these aspects more closely relate to the overall system functionality and on- bridge installation then to the development of the physical levers. These will be brought back at during the specification of the final concept.

Screening criteria:

1. Sound ergonomics.
2. Accommodates both sitting and standing operating positions.
3. User friendly.
4. Modularity.
5. Clear indications.
6. Different from existing systems/ innovative.

The chosen reference concept for the screening process is the "best- in- class" benchmark Helicon X3 from competitor Rolls- Royce Marine. This product is well established in the marked, and has on several occasions, by several stakeholders been identified as the market leader in terms of both ergonomics and functionality. [3, 4]

8.1 CONCEPT SCREENING

In this section the concepts are in relation to the benchmark product rated by;

+ = Better than.

0 = Same as.

- = Worse than.

Table 17: Screening Matrix. "Trackball" and "Basic" are ranked first, followed by "Super User", "Touch Screen", "Ball" and "Rotary Knob- Spring" on second. "Joystick" ranks third and "Cranks" is ranked last.

	Concepts							
Selection criteria	**Super User**	**Touch Screen**	**Cranks**	**Ball**	**Joysticks**	**Basic**	**Trackball**	**Rotary Knob - Spring**
Sound Ergonomics	0	-	-	+	0	0	+	0
Accommodates sitting and standing operating positions	0	0	0	-	0	0	0	0
User Friendly	0	0	0	0	0	+	+	+
Modularity	0	+	-	0	+	0	0	-
Clear indications	0	-	+	-	-	0	-	-
Different from existing systems/ innovative	0	+	-	+	-	+	+	+
Sum +'s	0	2	1	2	1	2	3	2
Sum 0's	7	2	2	2	3	4	2	2
Sum -'s	0	2	3	2	2	0	1	2
Net Score	0	0	-2	0	-1	2	2	0
Rank	2	2	4	2	3	1	1	2
Continue?	Yes, develop/ modify	No	No	Yes	No	Combine	Yes	Combine

SUMMARY OF SCREENING PROCESS
"Super User" is developed by inputs referencing the benchmark concept, so not surprisingly the net score comes out to zero. Still it is ranked second, and because its greatest fault is its similarity to the benchmark product the concept is to be developed further.

"Touch Screen" is rejected because it does not correspond with many of the user needs clearly indicating a need for physical control levers. It is also most likely premature technology wise.

"Cranks" comes out last, and is therefore rejected. The concept is rather space consuming and not very ergonomically sound.

"Ball" comes out second. The way its rotation function differs from existing solutions is probably the concepts most important feature. On the other hand, this particular feature does not particularly accommodate standing operations. This concept is developed mostly for a sitting operator. It fits smoothly in the operators hand without any "pointing" handles in the way.

"Joystick" comes out third and is rejected. The largest drawbacks is that it does not clearly indicate azimuth angle and power, and it is considered too similar to other control systems on the bridge. Joysticks are usually used for the DP- systems. One positive quality is its modularity, as it is not very space consuming.

"Basic" comes out first. The concept is considered different from existing systems due to its rotary function. Because of its simplicity it is also considered user friendly. Indications might not be very clear from far away, but close up power and azimuth angle is clearly indicated.

"Trackball" comes out first. Its greatest benefit is that it really accommodates a sitting operators hand to be in the neutral position. It is also very different from existing systems. Its drawback is that the indications are not necessarily very clear, especially from far away. Indications should be made clear during the detailed design phase.

"Rotary Knob- Spring" comes out second. It is clear that there is a great similarity between this concept and the "Basic" concept. The drawback of this concept is the spring functionality which is suitable for some operational modes, but does not really comply with all the potential operation modes.

NEW CONCEPTS
"Rotating Bands"

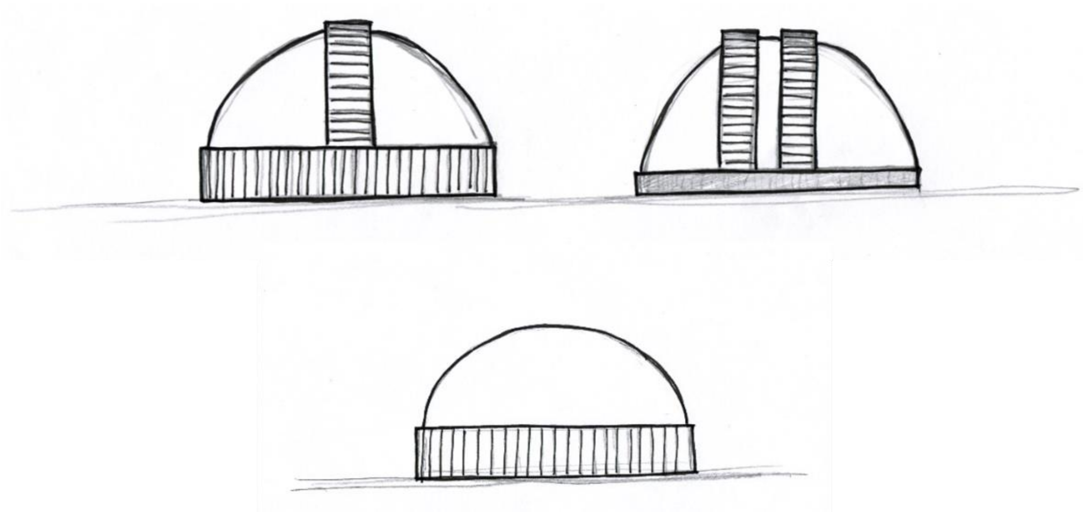

Figure 57: Rotating Bands Concept illustrating an azimuth lever, tunnel thruster/ main propulsion lever and a rudder controller. (Own illustration)

As the Super User concepts greatest fault is its similarity to existing products, this concept was developed as an experiment to see how it could be made different from existing products. The competitor screening shows that the greatest similarity between the products currently on the market is that they are all based upon the same construction principle where the main component is attached to a platform mounted to a base plate where the azimuth angle is set by rotating the main component. The ergonomically sound oval base shape and the band adjusting power is kept, but the rotary function is changed. Power is adjusted back and forth somehow along the band and the azimuth angle is set by rotating the band horizontal with the console.

“Basic Knob”

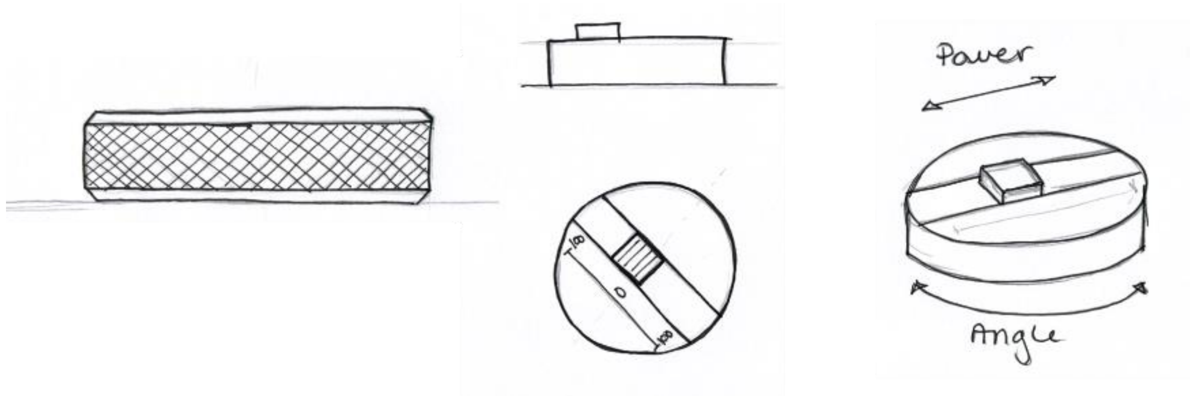

Figure 58: Basic Knob. (Own illustration)

Combining “Rotary Knob- Spring” with “Basic” results in “Basic Knob”. The new concept combines the aesthetics of “Rotary Knob- Spring” and the functionality of basic knob, eliminating the power adjusting issue of “Rotary Knob-Spring”.

The two new concepts are together with “Super User”, “Ball” and “Trackball” taken to the scoring stage.

8.2 CONCEPT SCORING

The concepts scoring stage follow the same procedure as the concept screening, but weights are now added to the scoring criteria. The concept are then rated by the following scale:

1 = Much worse than reference.
2 = Worse than reference.
3 = Same as reference.
4 = Better than reference.
5 = Much better than reference.

The weights for the scoring is set based on the importance of the criteria. To correspond with the overall product goal of functionality, “sound ergonomics” and “accommodates sitting and standing operating positions” are given the highest weights. These criteria are directly tied to the physical shape and functionality of the control levers and are harder to change at a later stage in the product development process. Then follows “user friendly” and “modularity”, also representing the product goals, but as these criteria are also dependent on factors implemented in a later phase, such as overall system design and integration they are given smaller weights. This is also the case for “clear indication” and “different from existing system/ innovative” as these are more easily altered by detailed design at a later in the process.

The concepts are scored according to the same reference product as for the screening process, the Helicon X3.

Table 18: Scoring Matrix. Ref. Formula 3.1.

		Concept									
		Super User		Super User		Ball		Basic Knob		Trackball	
Selection Criteria	**Weight**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**
Good Ergonomics	**30 %**	3	0.90	4	1.20	4	1.20	3	0.90	4	1.20
Accomodates both sitting and standing operating positions	**20 %**	3	0.60	3	0.60	1	0.20	3	0.60	3	0.60
User Friendly	**15 %**	3	0.45	3	0.45	3	0.45	4	0.60	4	0.60
Modularity	**15 %**	3	0.45	3	0.45	3	0.45	3	0.45	3	0.45
Readability	**10 %**	2	0.20	3	0.30	2	0.20	3	0.30	3	0.30
Different from existing systems/ innovative	**10 %**	3	0.30	4	0.40	4	0.40	4	0.40	4	0.40
	Total Score	2.90		3.40		2.90		3.25		3.55	
	Rank	4		2		4		3		1	
	Continue	NO		YES		NO		YES		YES	

“Super User” and “Ball” is ranked last. Due to its similarity to other products, the “Super User” segment is rejected. The same is “Ball” who’s biggest drawback is not accommodating standing operations. The three standing concepts are “Rotating Band”, “Basic Knob” and “Trackball”.

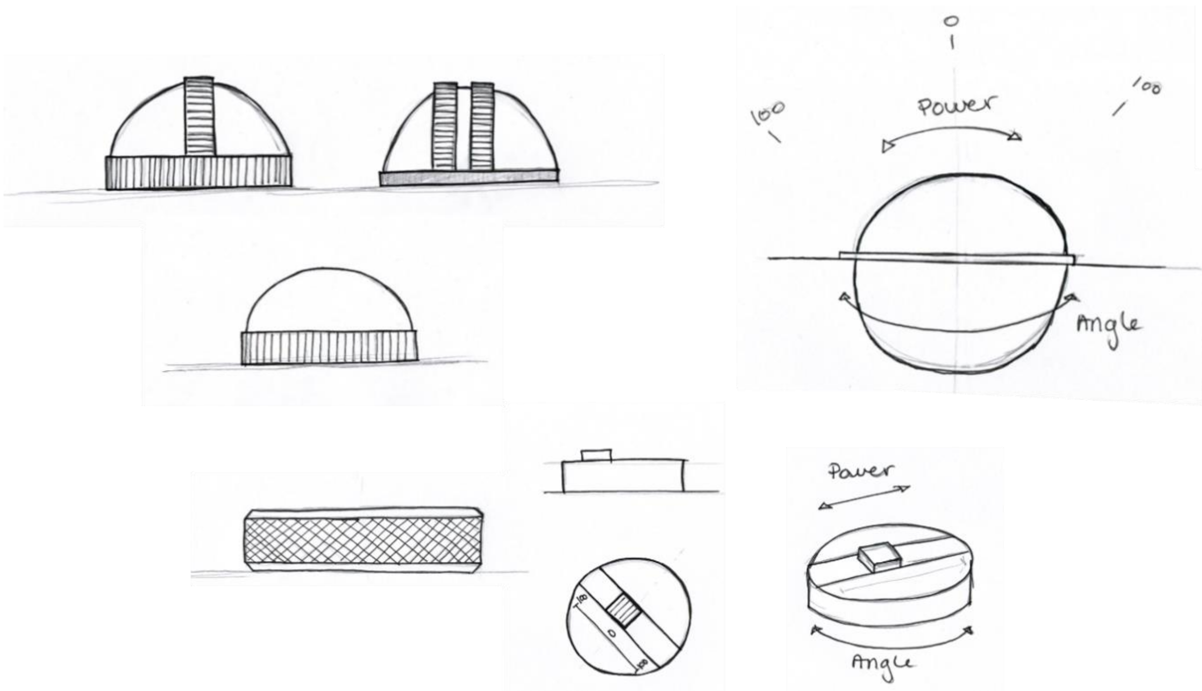

Figure 59: Winning Concepts. (Own illustration)

There are several similarities among the winning concepts, where it becomes clear that the "Rotating Band" in many ways is a hybrid of the other two. It has the rotating function of the basic knob and its rather mechanically undefined power adjustment alternative and shape is more similar to the "Trackball".

The "Basic Knob" concept has a very simple functionality and is easy to comprehend as it clearly indicates how it is operated. Its largest weakness is its simple form, not typically demonstrating a sound ergonomic shape. The "Trackball's" best quality on the other hand, is how it accommodates the operator's hand to fit in the controller while in the neutral position. The biggest challenge of the "Trackball" is how to accommodate a split lever functionality and it does not essentially indicate the azimuth direction or the amount of power applied at any given time.

The final concept is developed based on the similarities and challenges of the remaining concepts. Using the oval shape of the "Trackball" and "Rotating Band" the ergonomic qualities of these concepts are preserved. As the rotary function of the "Basic Knob" and "Rotating Band" is essentially the same, this is also utilized in the finale concept giving a clear indication of the rotary function. By implementing the sliding switch from the "Basic Knob" concept a clear and functional power adjusting alternative is implemented in the control lever. This also more easily accommodate for a split function of the speed lever.

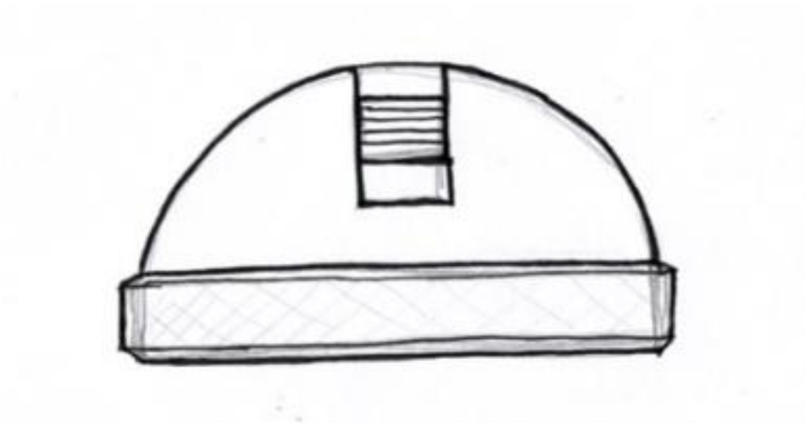

Figure 60: Final Concept, azimuth lever. (Own illustration)

The finished concept preserves the “Trackball’s” strength of the lever fitting within the hand of the operator as the power adjusting knob is kept as low as possible. A sitting operator is able to rest his hand horizontally on the console or armrest operating the control lever with the arm and hand placed in a neutral, relaxed position making adjustments with his fingers.

The final concept is to consist of an azimuth lever, a speed lever, a rudder controller and a display/ combined operator screen.

9. FINAL CONCEPT SPECIFICATION

In this chapter, the details of the final concept is established. First the control levers dimensions are developed. Second comes the establishment of scaling and a suggestion for display design. Finally, specific recommendations to design of operator screen and overall system functionality is presented.

The identified human framework is used as basis when establishing the dimensions of the control levers and scaling. The measures not directly identified in chapter 4 are calculated here. The overall system design recommendations are based on the expressed user needs and the findings of operator and marine framework.

9.1 CONTROL LEVERS

9.1.1 AZIMUTH LEVER

To ensure that the controller fits the grip of the operator, optimal height and grip area for rotation function and power adjustment need to be established. The final dimensions of the azimuth lever results from the ergonomic recommendations identified, and uses the recommended diameter for a rotary knob as starting point.

DIMENSIONS FOR ROTARY FUNCTION.
The rotary function is in many ways recognized as a rotary knob and the recommended measures for this is utilized.

The outer diameter of the ring is set to the maximal recommended diameter of 75 mm and the depth is set to 15 mm, which is between the recommended depth of 13 mm and 25 mm. The measure is kept to the lower side to ensure that the controller does not become too tall.

The thickness of the ring is set to 2 mm resulting in an inner diameter of 71 mm.

DIMENSIONS OF SPHERE
In order not to strain the hand and wrist especially for a sitting operator, a suitable height is calculated based on the comfort range of wrist extension. An operator with his harm resting on the console, as it would in a DP chair, is together with the maximum comfort angle of extension used to establish the total height for the azimuth lever.

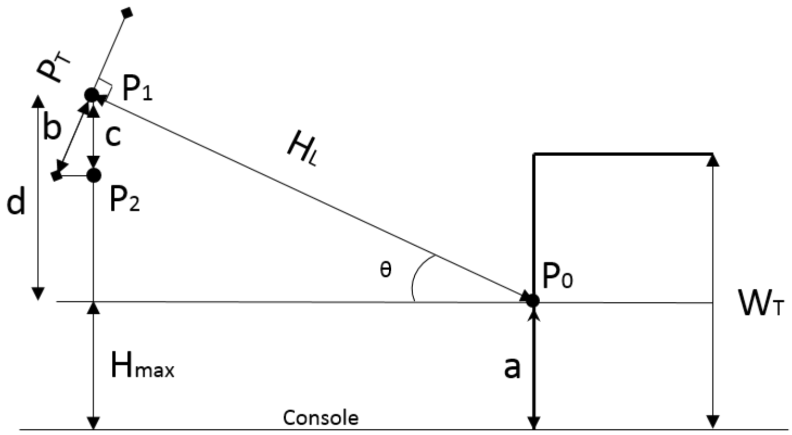

Figure 61: Calculation of maximum recommended height of control lever. (Own illustration)

The selected anthropometric data gives:

Length from hand joint to grip line of H_L = 76 mm.

Wrist thickness, W_T = 43 mm

Extension angle, θ = 25°

Palm thickness, P_T = 23 mm

Distance from horizontal surface/ console to hand joint:

$$a = \frac{W_T}{2} = \frac{43\ mm}{2} = 21.5\ mm$$

P_1 is located 76 mm from hand joint at an angle of θ = 25° horizontal with the console.

Distance from hand centerline point of interaction, c:

$$c = b\ \cdot \cos(25)$$

$$b = \frac{P_T}{2} = \frac{23\ mm}{2} = 11.5\ mm$$

$$c = \ 11.5\ mm\ \cdot \cos(25) = 10.4\ mm$$

The maximum height, H_{max} is given as the distance from console to P_2, which is the point of interaction between hand and sphere:

$$H_{max} = a + d - c$$

d is given by:

$$d = \ 76\ mm\ \cdot \sin(25) = 32\ mm$$

The distance from the console to P_2 is:

$$H_{max} = 21.5\ mm + 32\ mm - 10.4\ mm = 43\ mm$$

As 25 degrees is the maximum recommended extension angle, 43 mm express the max height. The max height at the top of the lever is therefore set to 42 mm. It is further assumed that the point of interaction P_2 between the sphere and the grip line will be located a lite of the top as the front part of the palm will curve towards the top of the sphere making room for finger operations.

The sphere height is set to 42 mm – 15 mm = 27 mm.

The width of the sphere is set equal to the inner diameter of the rotary ring of 71 mm.

DIMENSIONS OF POWER ADJUSTMENT
The power adjusting alternative is recognized as a sliding switch and based on recommended dimensions the length and the width is set to 15 mm. As the intention of the concept is to keep the power adjusting as close to the sphere as possible, the height is kept to a minimum and set to 3 mm.

The button is marked in the center to indicate power and the overall touch surface is covered with ridges creating friction preventing the finger to slip of the switch. The bottom surface is adjusted to suit the radius of the sphere.

The travel of the power adjusting is based on recommendations set to 45 degrees to each side, resulting in a travel of 90 degrees calculated from the bottom of the lever.

Every 22.5 degree is marked, giving the lever a power indication at 0, 50% and 100% in each direction.

Positive azimuth indication is given by an arrow on top of the sliding switch.

DIMENSIONS OF BASEPLATE
The azimuth lever is mounted to a square baseplate of 120 mm x 120 mm.

9.1.2 SPEED LEVER

The main propulsion lever and the tunnel thruster lever consist of the exact same functionality, only with different directions of orientation. A speed lever is therefore applied both for main propulsion control and for tunnel thruster control where the lever for main propulsion control has the power initiation situated forward- aft, and the lever for tunnel thruster control has it situated starboard- port. As main propellers and tunnel thrusters often appear in pairs, it is common to accommodate for double power adjusting reducing the number of levers.

DIMENSIONS OF SPHERE
As there is no rotary function for the speed lever the total diameter is increased to more easily accommodate for the double power adjusting. As the operator in certain instances puts his hand around the tunnel thruster the same way as an azimuth, the total height of the lever is set to the same as for the azimuth of 42mm. This gives a height of the sphere of 37 mm and the height of the ring of 5 mm.

The ring around the sphere has no functionality and is reduced in height to illustrate that it is not a functional gripping surface and thereby distinguish it from the azimuth lever.

The total diameter of the lever is set to 100 mm with a thickness of 2 mm resulting in a sphere diameter of 96 mm.

DIMENSIONS OF POWER BUTTON
As the power adjusting function is the same as for the azimuth a slide switch is also utilized here, but the switches are made narrower to accommodate space for double power adjustment function. The length of the switch is set to 15 mm, the width is 12 mm and the depth is 3 mm.

The button is marked in the center to indicate power and the overall touch surface is covered with ridges creating friction preventing the finger to slip of the switch. The bottom surface is adjusted to suit the radius of the sphere.

The travel of the power adjusting is based on recommendations set to 45 degrees to each side, resulting in a travel of 90 degrees calculated from the bottom of the lever.

Every 22.5 degree is marked, giving the lever a power indication at 0, 50% and 100% in each direction.

DIMENSIONS OF BASEPLATE
The speed lever is mounted to a square baseplate of 120 mm x 120 mm.

9.1.3 RUDDER CONTROLLER

The diameter of the rudder controller is set to 65 mm remaining within the recommended diameter for rotary knobs. Rudder controllers usually appear in pairs, as an OSV often has two main propellers, and to reduce footprint it is an advantage to reduce the size of it. The depth is kept the same as for the azimuth lever at 15 mm. The touch surface is covered with ridges creating friction preventing the finger to slip of the switch.

DIMENSIONS OF BASEPLATE
The rudder controller is mounted to a square baseplate of 100 mm x 100 mm.

9.2 DISPLAY AND SCALING

While operating the levers, the operator mostly have his line of sight directed outside and rarely look directly at the levers. It is however recognized that some indications needs to be implemented on the actual control units to quickly inform the operator of what position the control levers are in. For more detailed information feedback, the operator normally references screens and displays located in his line of sight. To accommodate both these aspects, rough scaling is to be implemented on the levers referencing the input parameters, and a display screen presenting detailed information is to be developed.

SCALE GRADUATION AND READABILITY
The optimal scale graduation for information display is defined by the length of the sight line, a. A standing operator situated in front of the control levers looking down at the console sets the expected maximum sightline.

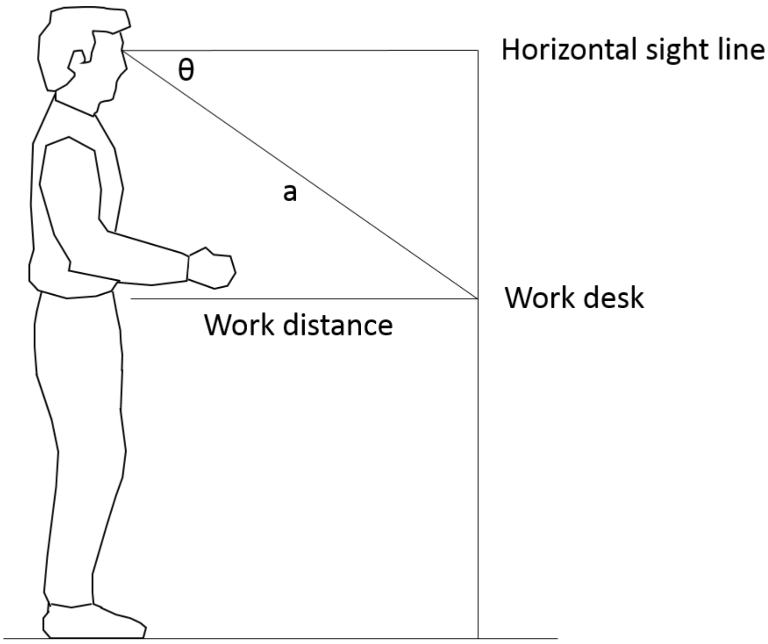

Figure 62: Optimal sight line. (Own illustration)

Assumed that an optimal work height is provided, as established in the human framework, where the operation of the control levers are defined as “Light work”. For “Light work” the recommended work desk height is specified between 100 mm and 150 mm below elbow height.

Elbow height is given as the distance between shoulder height and shoulder- elbow distance of 1440 mm – 366 mm = 1074 mm.

The recommended light work height is then 1074 mm – 100 mm = 974 mm and 1074 - 150 = 924 mm. The height of 924 mm is chosen.

The operator height is given at 1755 mm and the distance from top of head to eyes is 112 mm. This gives a height between horizontal eyesight line and the work desk of 1755-112-924 = 719 mm.

Based on the measures of optimal work area the assumed maximum distance between the operator and the controls are set to 450 mm.

The angle, θ is given by Formula 4.1:

$$\theta = tan^{-1}\left(\frac{719mm}{450mm}\right) = 58$$

The sightline is then given by

$$a = \left(\frac{719mm}{\sin(58)}\right) = 847\ mm$$

58 degrees lies within the range of maximum eye rotation and with the possible additional head tilt, the angle will be further reduced.

The straight sightline is than set to a = 847 mm which gives the following recommended scale graduations and size of characters.

Table 19: Minimum scale graduations.

Height of biggest graduations	847 mm/ 90	9.4 mm
Height of middle graduations	847 mm/ 125	6.8 mm
Thickness of graduations	847 mm/ 5000	0.17 mm
Distance between two small graduations	847 mm/ 600	1.4 mm
Distance between two big graduations	847 mm/ 50	16.9 mm

The following recommended proportions are to be applied for letters and numerals, based on the Height = a/ 200 = 847 /200 = 4.2 mm.

Table 20: Minimum proportions of letters and numerals.

Large numbers height		4.2 mm
Large numbers breadth	4.2 mm * (2/3)	2.8 mm
Small number height	4.2 mm * (2/3)	2.8 mm
Small number breadth	2.8 mm * (2/3)	1.9 mm
Thickness of line	4.2 mm * (1/6)	0.7 mm
Distance between letters/numerals	4.2 mm* (1/5)	0.84 mm

READABILITY
To ensure readability it is recommended to have a clear contrast between the letters and the background. General black letters on white background provides best readability, but because of the varying light conditions onboard the bridge this might become problematic. The concept therefore illustrates the use of white indicators on black backgrounds.

However, as lights are to be integrated in the control lever scale graduations, light settings discriminating between day and nighttime operations is to be designed. A more detailed graphic design of the display should in the same way also discriminate according to the light conditions, always ensuring good readability.

9.2.1 SCALING ON LEVERS

The main intention for scaling on the levers is to provide an approximate indication to what position the levers are in if the operator suddenly have to take command of the control levers. An operator in command over time is mostly looking outside and at the monitor screens where detailed information regarding lever positions are presented.

A rough power scaling of 0, 50 and 100 is therefore implemented on top of the azimuth and speed lever. Representing respectively 50% and 100% power. The scaling stretches about 11 mm to each side of the power button and are 1.5 mm wide.

For the rotary movement a larger scale of 90 degree and a smaller for every 45 degree is implemented in the azimuth lever baseplate.

As rudders are delivered to different specifications, the rudder angle varies. To illustrate the scaling of a potential rudder controller, this rudder controller is designed based on a 45 degree rotation of the rudder. A scale ranging a total of 180 degrees is implemented in the baseplate. Indicating a 45 degree rotation to respectively port and starboard at 90 degrees. A larger scale for every 10 degree and smaller scale for every 5 degree is incorporated.

The scale graduation is the same for both the azimuth controller and the rudder controller. The large scale has a height of 10 mm and a width of 1.5 mm. The small scale has a height of 7 mm and a width of 0.7 mm for both the azimuth lever and the rudder controller.

These indication have integrated lights and are light at night time.

9.2.2 DISPLAY DESIGN

The control screen illustrated in the presentation is based on a screen size close to that of a tablet. The overall dimensions are 250 mm x 170 mm with a screen surface of 223 mm x 150 mm.

The intention of the display is to present the detailed information required by the operator. Rough indications are presented by a physical scale on the control levers, but the detailed information of power and angle is presented on the display. The display illustrates the complete propulsion control system and the most relevant information parameters, i.e. angle and power for the respected components. The display is designed to demonstrate the physical movements of the control levers and their exact values. Pictograms are used to illustrate the different propulsion units and establish the vessel and propulsion relationship. The setup of the display is to correspond with the same setup as the control levers. In keeping with expressed user needs, the information displayed is kept to a minimum.

As identified in the function analysis the power adjustment is a linear movement, also indicating direction. To accommodate this a column bar display with level indications is applied. The scale will range from – 100 to 100 with smaller indications at the 50 % mark to correspond with the control lever. A digital display is placed to the right of the scale, presenting values from -100 to 100 referring to the positive and negative direction of the propeller.

As the azimuth lever and the rudder controller themselves works as pointers, the display type “moving pointer with fixed scale” is chosen for these characteristics. The azimuth lever is presented as a pictogram with an arrow indicating the positive orientation of the thruster. The power scale is here implemented behind the arrow, following it as it turns. This is done to keep with the same logic as the lever. Due to the lack of space there is no scaling on this power display, but the direction is indicated by a mark at the zero position and the exact power is presented in a digital display to the right, indicating + or – referencing the direction according to the zero position. The rotary scaling have larger graduations at every 45 degree and smaller grading for every 22.5 degree going 360 degrees around the azimuth lever, corresponding with the scaling on the control lever.

The rudder controller is presented with the same scaling as on the baseplate, ranging 180 degrees from starboard to port, with a large scaling at 0 and a smaller scaling for every 10 degrees.

The scale graduations corresponds with the calculated values above. All numbering of exact values are scaled according to “large number” with height minimum of 4.2 mm and breadth of minimum 2.8 mm. Numbering used on the scale is graded after “smaller numbers” with minimum height of 2.8 and minimum breadth of 1.9 mm. The scale grading is divided in “largest” with minimum height of 1.5 mm and “smaller” with minimum height of 6.8 mm, both wider than 0.17 mm.

To satisfy general recommendations for controller – display relationship the power scale is to move in correspondence with the slider knob increasing when the slide knob is pushed forward. The scale is further to travel faster than the scale during precision adjustments.

9.3 OPERATOR SCREEN AND SYSTEM FUNCTIONALITY

User needs connected to the technology functionality of the system has been identified. Based on this the general recommendation is that functions that are of specific importance or are frequently used should be implemented on the respective control lever. The final concept illustrates the possibility to implement such functions in the baseplate. Functionality that are not ranged as such is to be implemented in the operator control screen. When not utilized as a display the screen is to work as an operator screen providing access to different system functionality. The user needs generally express that the operator screen should be easy to navigate, it should to some degree display more detailed information, but not unnecessary and redundant information.

The user needs further expresses a desire to have control levers, at all times, synchronized between workstations. It is therefore recommended that an electric shaft system is implemented in the final product.

In addition, haptic feedback is to be implemented in the control units, respectively producing force feedback at 0 and 50 % power for the power initiation of both the speed- and azimuth levers. The rotary function is to produce a force feedback for every 90 degree of the azimuth lever and at 0 for the rudder controller.

10. FINAL CONCEPT

Below follows a CAD presentation of the developed concept illustrating the individual components.

Figure 63: Final concept illustrating Speed lever, Azimuth lever and Rudder controller.

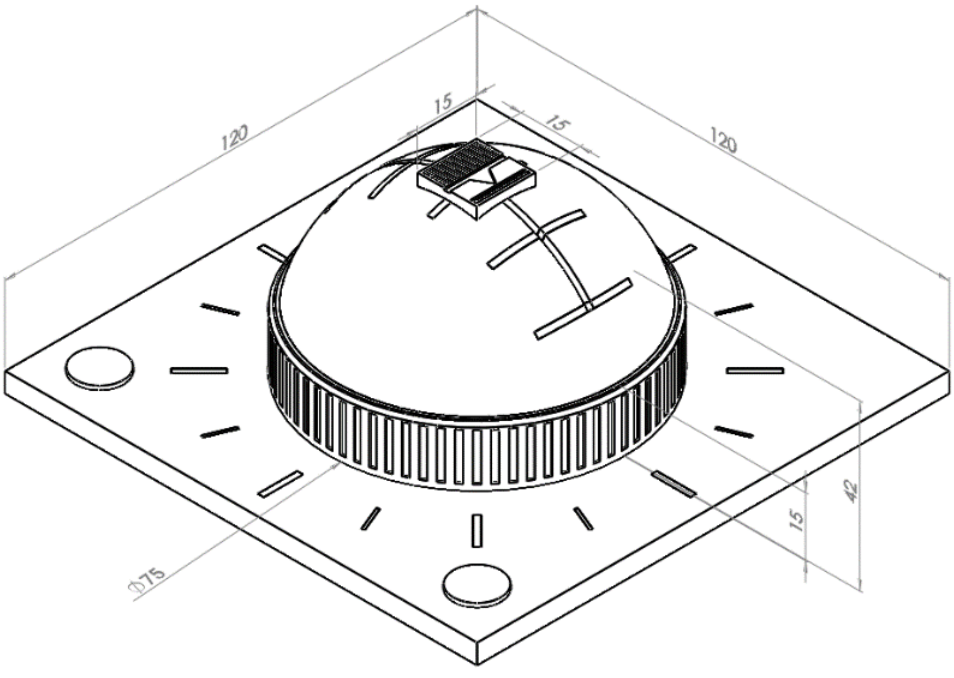

Figure 64: Azimuth lever, all measures in mm.

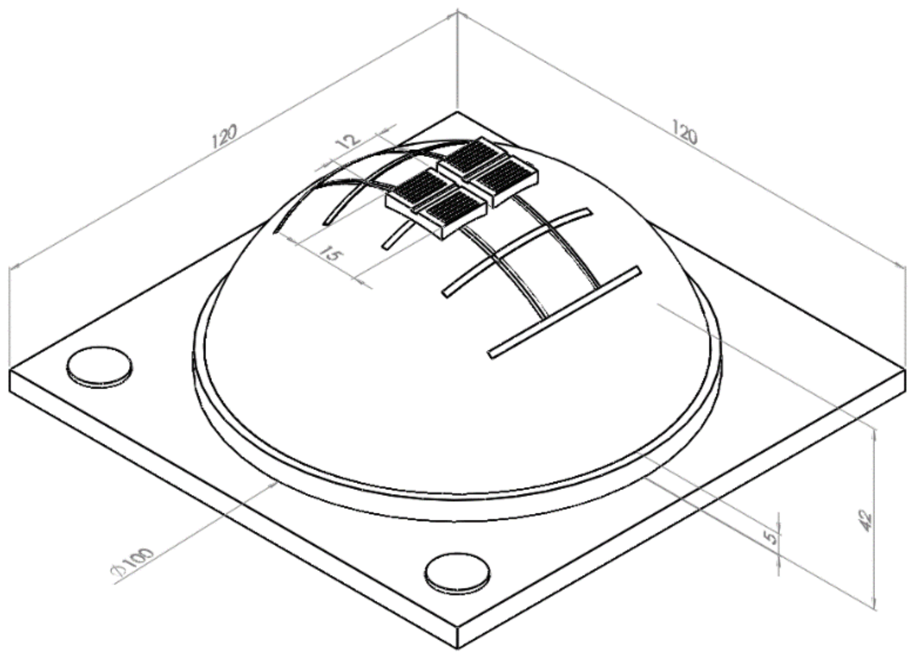

Figure 65: Speed lever, all measures in mm.

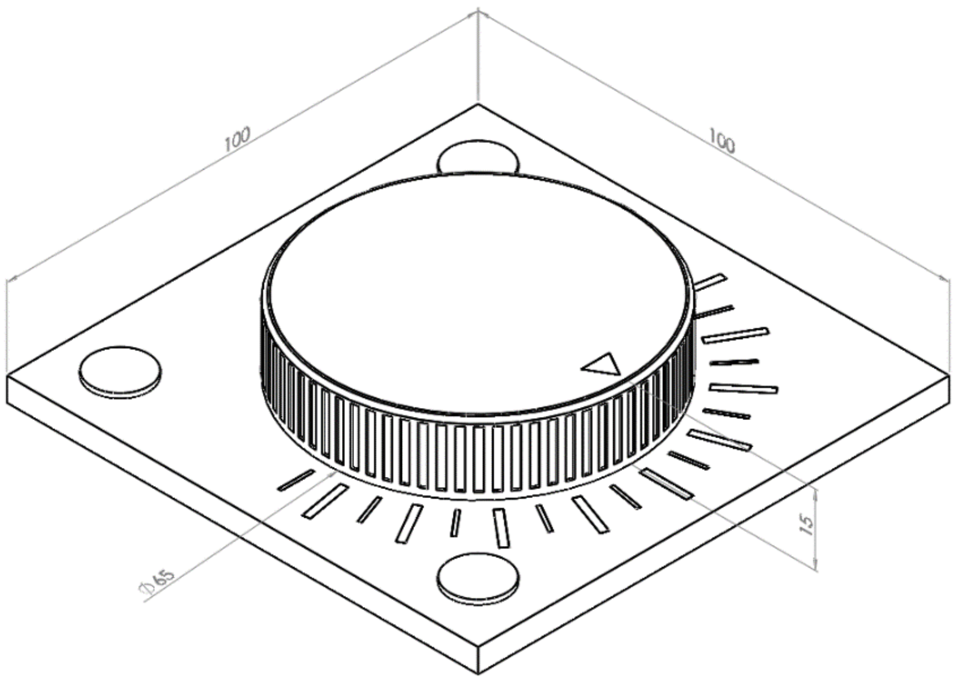

Figure 66: Rudder controller, all measures in mm.

10.1 AZIMUTH LEVER

Azimuth lever mounted to baseplate with incorporated scaling and two buttons for necessary functionality. Power adjusting with sliding switch on top of a total of 90 degrees. Grip area for rotary function setting rotation of the control lever of 360 degrees.

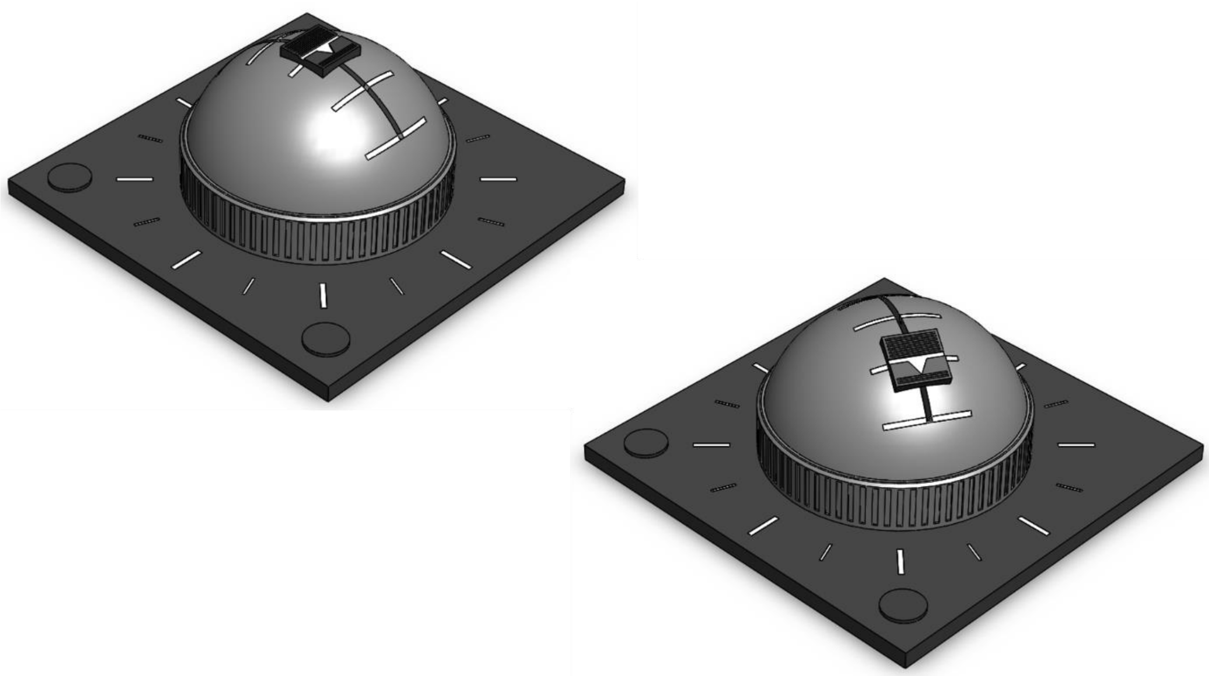

Figure 67: Left: Azimuth lever in neutral, forward- aft position. Right: Azimuth lever with 50 % power and approximately 30 degree rotation.

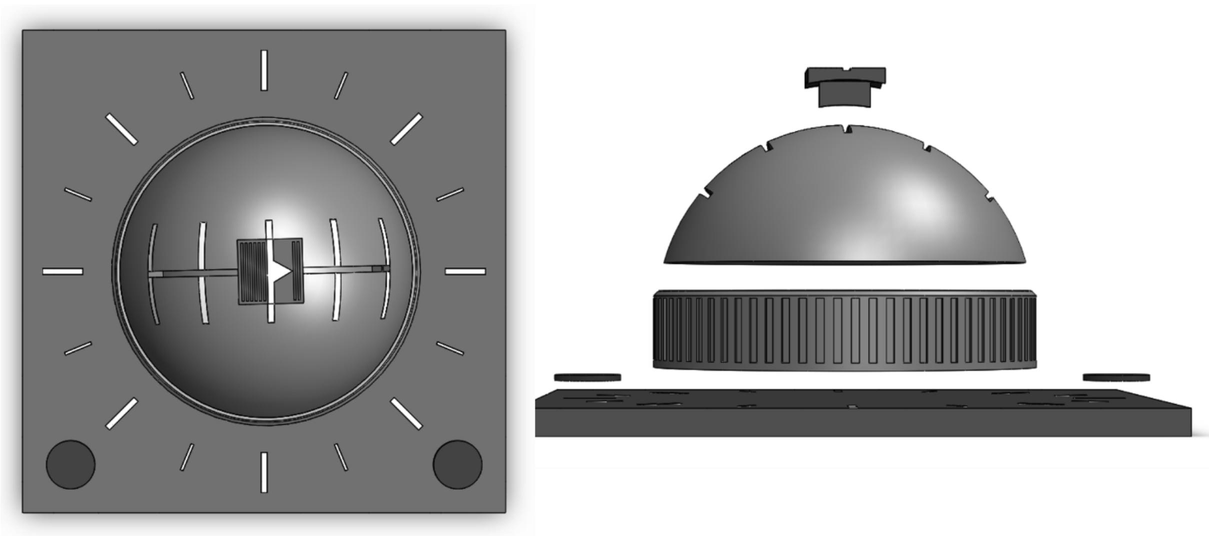

Figure 68: Left: Azimuth lever top- view, displays two buttons. Right: Azimuth lever exploded view, displaying main components. Sphere and rotary band are fastened together and rotated as one component.

10.2 SPEED LEVER

Speed lever mounted to a baseplate with incorporated buttons. Double power adjusting possibility on top and incorporated scaling. Power adjusting by sliding switches with a total of 90 degrees travel.

Figure 69: Left: Speed lever in neural, forward- aft position. Right: Speed lever with approximate power on actuators of 65 % port and 30 % starboard.

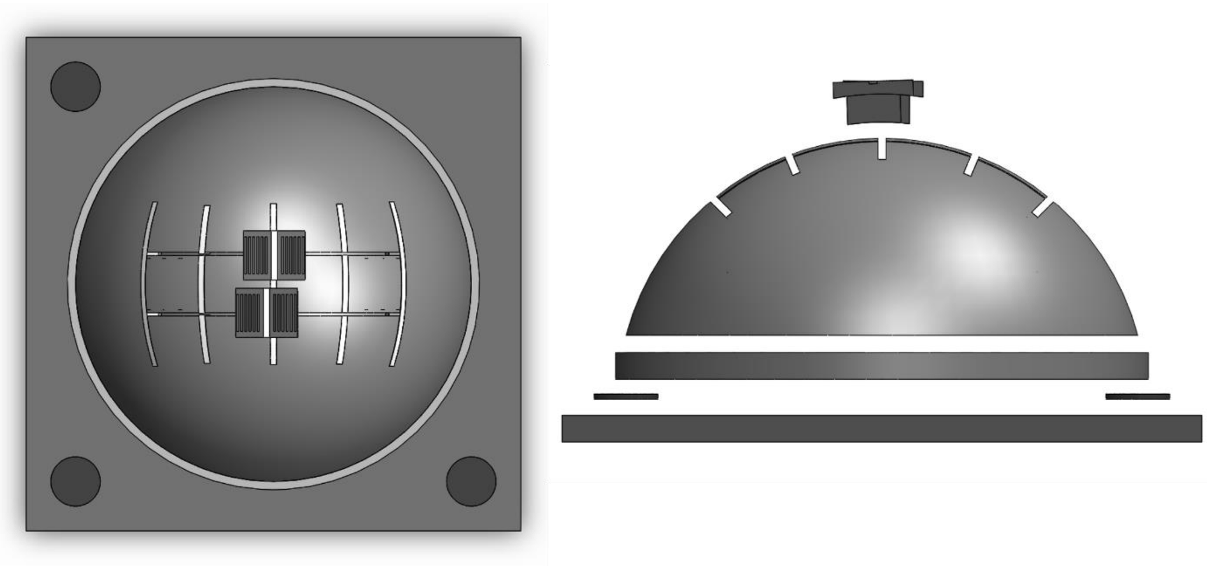

Figure 70: Left: Speed lever top view, displays three buttons. 2. Right: Speed lever exploded view displaying main components.

10.3 RUDDER CONTROLLER

Rudder controller mounted to baseplate with incorporated scaling and three buttons for necessary functionality. Grip area for rotary function of 180 degrees.

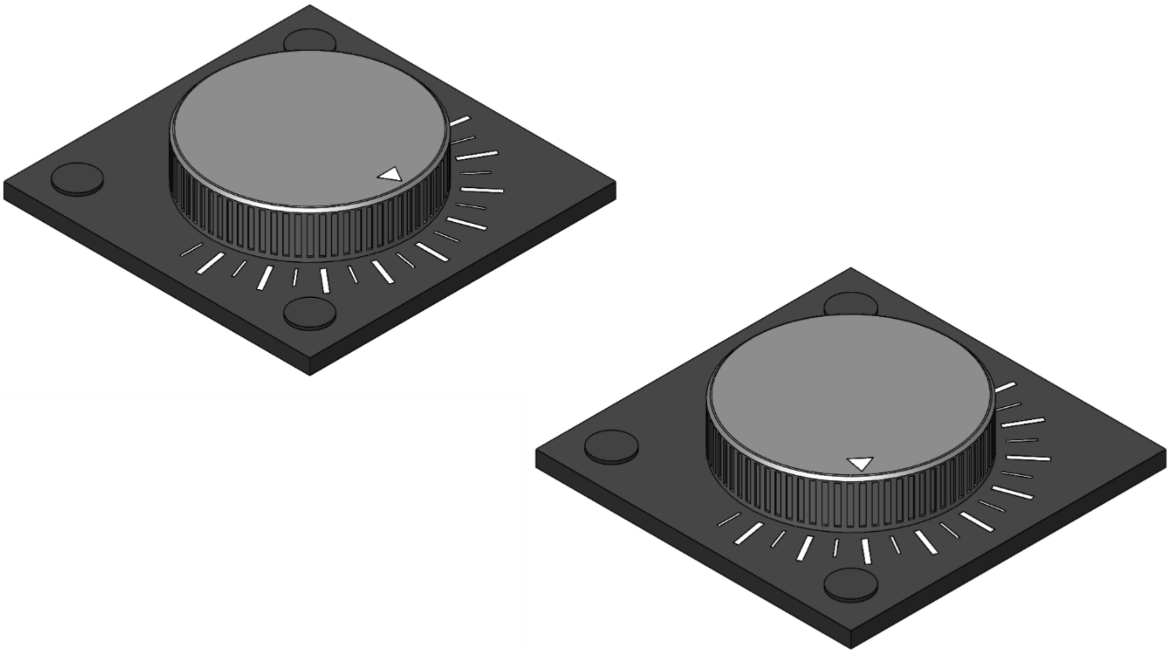

Figure 71: Left: Rudder controller in neutral, forward- aft position. Right: Rudder controller with approximate 20 degrees of rotation.

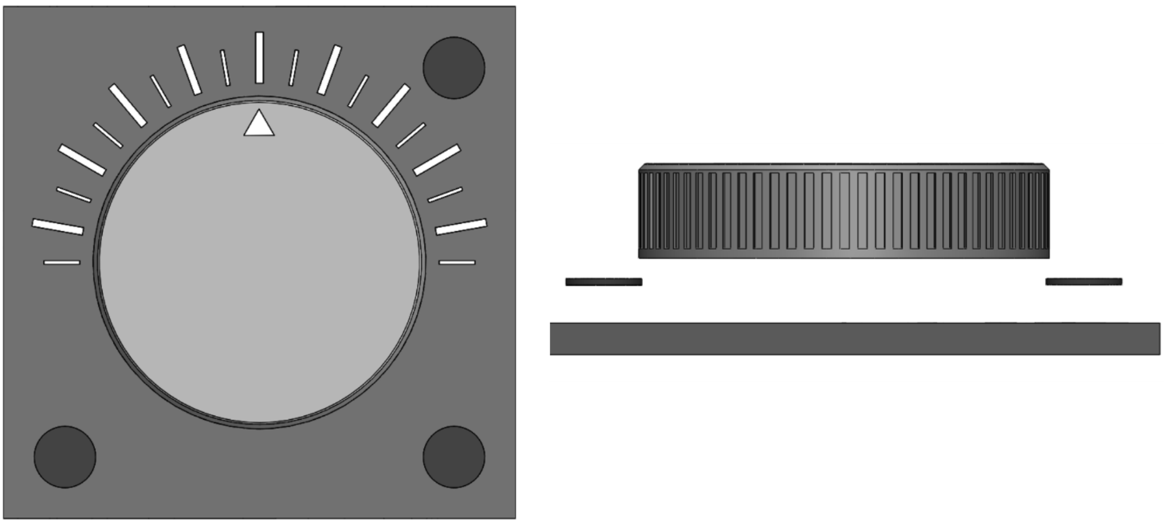

Figure 72: Left: Rudder controller top view, displays three buttons. Right: Speed lever exploded view displaying main components.

10.4 DISPLAY

Below follows suggested displays for the control units. The displays are designed according to a forward bridge position. All the displays corresponds with the scaling of the control levers. To accommodate for more precise adjustments, exact values of the control parameters are indicated respectively.

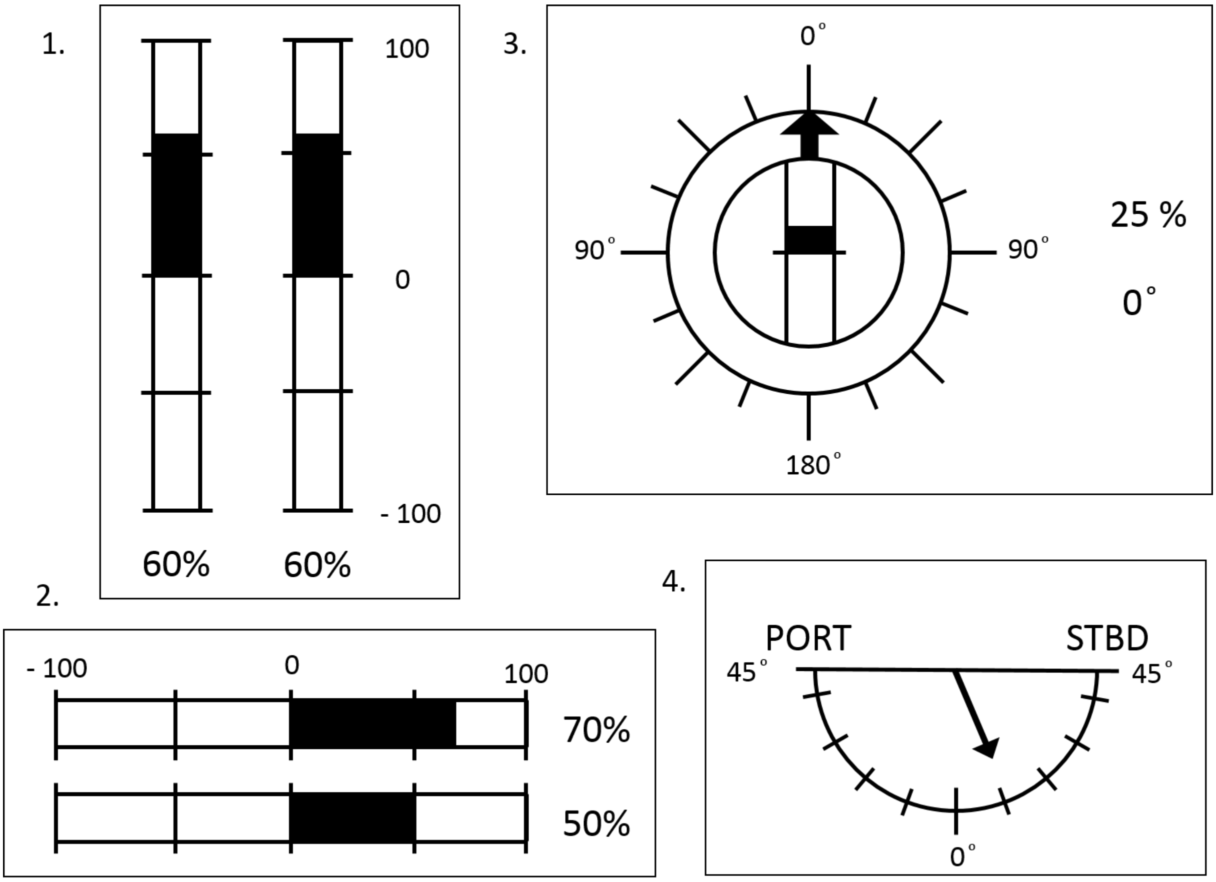

Figure 73: 1. Speed lever display. 2. Speed lever display for a tunnel thruster. 3. Azimuth lever display. 4. Rudder controller display.

Figure 73 illustrates a Speed lever display (1.) for two main propulsion units with respective powers forward of 60%. It also illustrates a speed lever display for a two tunnel thrusters (2.) with respective powers of 70% and 50 %. The Azimuth lever displays (3.) has a level indicator for power in the middle and an arrow representing positive thruster orientation. As the azimuth lever rotates, the arrow followed by the level indicator turns. Current position is straight forward with 25% power. The rudder control display (4.) indicates an angle of 10 degrees.

10. 5 CONTROL LEVER WORKSTATION

Below, the concept is presented as a complete workstation setup. It illustrates a potential setup for an OSV, with a double tunnel thruster in front, an azimuth thrusters amidships, and two main propellers accompanied by two rudders aft.

Figure 74: Setup consisting of two rudders, two speed levers, an azimuth lever and a corresponding display.

Figure 75: Close- up of azimuth lever, tunnel thruster lever and display.

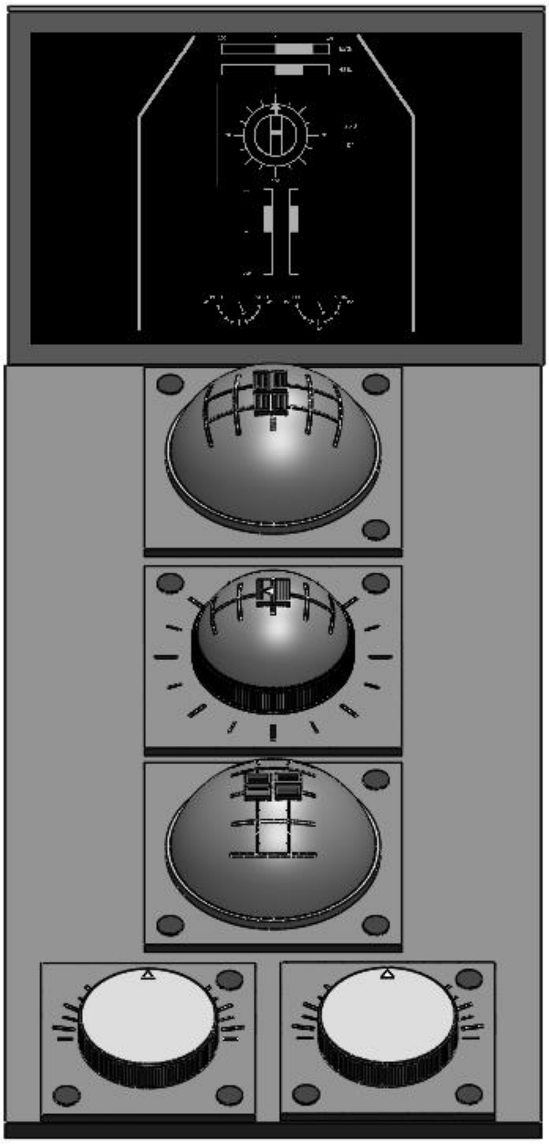

Figure 76: Operator view of control lever workstation.

10.6 FINAL CONCEPT SUMMARY

The final concept is a result of the complete process. It inhabits much of the identified customer needs, and it is developed to fulfill the established product goals. According to the product goals, the product is to represent the Vard brand, have excellent ergonomic qualities, consist of modern technology and be modular. The goals states two main categories of needs, where one is tied to the physical control units and the other is more related to the overall technical system functionality. The focus throughout the development process has been on the physical aspects of the control levers, which is reflected in the presented concept.

As the ergonomic framework has directly affected the dimensioning of the control levers and the concept is clearly based on the findings of the functional analysis, the final concept has preserved the ergonomic and functional aspects of the product goals. However, in order to ensure the ergonomic qualities the product must be tested by a user.

The concept further preserves the aspect of modularity in that it can be set up to fit any propulsion setup, and it reduces the number of levers needed by accommodating for double power adjusting of the speed lever.

To complete the product, industrial design is required both to finalize the physical design, and to ensure the integration of the branding aspects of the product.

Much of the possible technological advancement of the control levers is identified to be in the system based technology and the user experience of the system. Different preferences in type of information displayed in different operational modes, indicates a potential benefit in having systems adapt for the individual users and it is recommended that this is explored further. Typically, this has been solved by standardizing, as it has in this thesis.

The final concept represents a new type of construction, different from most of the control levers found on the market. The construction in many ways more resembles that of a trackball then a traditional lever, and hereby relates to a more modern type of control. Still, the concept inherits some tradition as it consists of the same functionality and logic as traditional control levers. Potentially the control levers are something midway between tradition and the future as they still provide something physical for the operator to relate to, and potentially through implementation of more advanced systems technology can bring “some of the future” into it.

11. COSTS

Estimated costs of initial project.

Table 21: Project costs.

Project Phases	Hours	Rate/ Hour	Sum NOK
Research	300	550	165000
Concept development	100	550	55000
3D modeling	75	550	41250
Project Report	55	550	30250
Presentation	30	550	16500
Sum	**560 ***		**308000**

*) Efficient time estimated at 60- 65 % of total 900 hours.

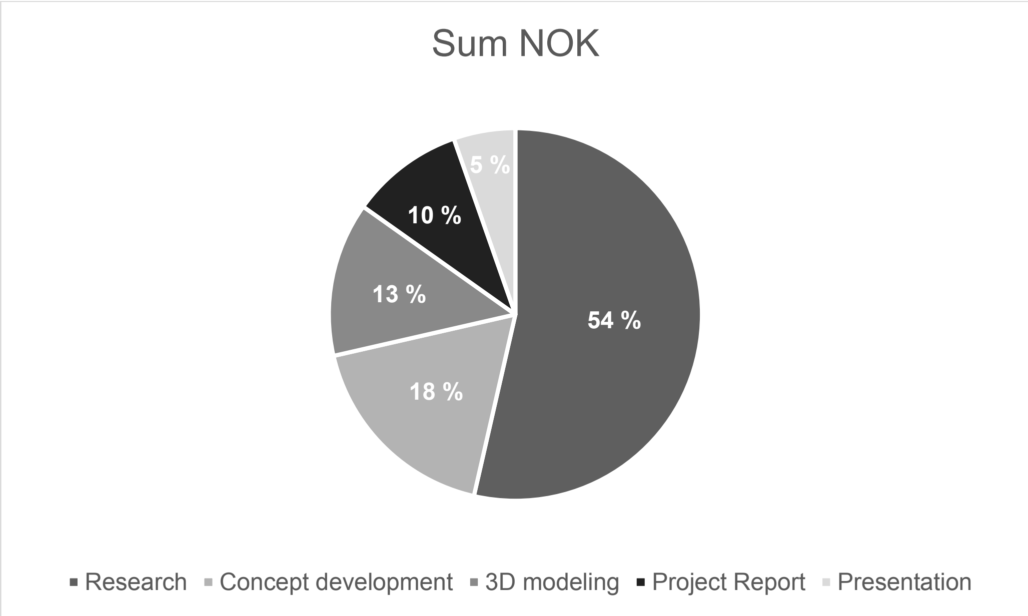

Figure 77: Pie chart demonstrating split of the total cost between project phases.

There will be no detailed cost analysis for the development of a prototype. The development of a prototype can be done in several ways, one common way of testing complex products is through the use of a simulator.

12. PROCESS DISCUSSION

The most time consuming activity of this project has undoubtedly been the establishing of human-, and marine and operator framework, which in many ways lasted throughout the process until the very end of the thesis.

Familiarizing myself with the operator and marine characteristics has also been one of the most challenging aspects of the thesis. The time set aside was probably correct considering the frame of the paper, but far too underrated to ensure a complete comprehension of thruster and propulsion control systems. The product itself and its respective environment makes for a very complex user situation, and I have realized the importance of understanding as much as possible of the use situation, and ideally being able to think as a mariner, in order to develop a good product. As there is still much to be learnt, further studies of the operator and marine framework is recommended. A greater understanding of the cognitive aspects of the ship operator would benefit the development of the feedback and input parameters of the product.

Part of the reason the establishment of the framework was so time consuming resulted from the difficulty to identify relevant literature concerning the bridge- environment and human framework in connection to this. The lack of identified literature dealing with problem under investigation resulted in the use of standard human framework for reference. A direct result of this is that the establishing of the marine and operator framework is much based on own experiences and on data gathered from user interviews, which leaves a potential risk of error. In order to validate my findings DNV Rules for Classification of Ships has been consulted.

PRODUCT DEVELOPMENT PROCESS

The product goals and final concept is based on the identified stakeholder needs, in other words the result is very dependent on the data gathered. A potential source for error is that the population of the interviews were rather narrow and there is therefore a chance of misrepresentation. It is assumed that the data would be more reliable if the population represented a wider background.

The process of interpreting the raw data in terms of stakeholder needs leaves a chance for misinterpretation where potentially important aspects has been lost or misunderstood. This further extends to involve the ranging of the relative importance of the needs, which were both based on my educated guess established from the context and expression of the person interviewed. The final concept is further influenced by the concept screening process where Pugh’s method was applied. Here the concepts were rated against the chosen selection criteria, again a result of the data interpreted, and most critically, the assigned weights which again was established based on my educated guess.

It is clear that the result is dependent on my judgement. Ideally, the concept should have been subject to testing already in the concept selection process to ensure user feedback on the established product goals. As this was not done, it is important that the final concept is verified through testing before the product development process continues.

RESULTS

The dimensions of the final concept is a direct result of the ergonomic framework and hereunder the anthropometric data. Anthropometric data specific for the target group has not successfully been identified, ideally this would be data from i.e. captains unions. In lack of this and other data generalizing the target segment, the 50- percentile man was used to calculate the relevant measures when standard recommendations were not available. The consequence of this is that the chosen dimensions are potentially not optimal to the target segment, risking the very important and key product goal of optimal ergonomic functionality. Anthropometric data for the target segment should be mapped in the further development process.

The focus through the paper has been on the physical controls of the human- machine system, making the displays and feedback parameters the weakest part of the final result. There are clearly weaknesses in the suggested display design as this is based on simple user inputs, standard practices and assumptions. An optimal and user friendly display is ideally built on data from a user study focusing on cognitive ergonomics, clarifying all the systems control parameters and the users reference to them. Due to the complexity and the apparent differences in systems there has not been time for a detailed analysis of the information feedback. The process has however clarified that there is need for a further study of the feedback parameters.

Because of the extensive use of ergonomic data in the specification of the final concept, it very much depends on theoretical characteristics and little “human touch” which products often benefit greatly from. Especially a product like the control levers, with such a high degree of user interactions.

13. CONCLUSION

This thesis presents a review of human framework concentrating on aspects relevant for the operation of thruster and propulsion control units. It maps out the operator environment and explains relevant marine framework for the operation of offshore service vessels (OSV). The thesis is structured as an IPD- initial project, mapping out historic as well as potential future trends, stakeholder needs and product competitors, resulting in a specific product design suggestion for Vard’s control levers.

RESULTS AND RECOMMENDATIONS

Three propulsion and thruster control units has been developed through this thesis. The final concept consists of one oval azimuth lever, one oval speed lever, a circular rudder controller and a feedback display presenting scaling for the control parameters of each individual control unit.

- The azimuth lever consist of a power adjusting and a rotary function. It has a total height of 42 mm and a diameter of 75 mm.
- The speed lever consist of a double power adjusting functionality and has a total height of 42 mm and a diameter of 100 mm.
- The rudder controller contains a rotary function and has a height of 15 mm and a diameter of 65 mm.
- The feedback display presents scaling for the control parameters of each individual control unit.

In addition to these physical attributes, the final concept is also specified to contain an operator control screen and a set of overall system functionality. The operator control screen is to contain less frequently used / non- critical control functionality for the control levers system. It is recommended that the feedback display is also used as an operator control screen. Functionality that identifies as frequently used/ critical is to be placed on the control levers. The final concept presents potential implementation of buttons for such functionality. The overall system is also recommended to contain haptic feedback and an electronic- shaft system.

The presented concept has been developed with focus on the physical aspects of the control levers. The geometrical dimensions are strictly based on generalized ergonomic re-commendations and the 50-percentil man where the optimal height for the oval shaped control units was identified as 42 mm, and maximum diameter of rotary function as 75 mm.

In order to complete the product a complete operator screen must be developed. To ensure best operating conditions it is recommended that the user interface corresponds with the overall bridge UI/UX. The same applies for potentially further development of the displays where it is also recommended that the display is consistent with the control levers.

It is further recommended that a complete list of overall system functionality is established as these systems will affect the overall user experience of the product. These features are important for the product as a whole and has to be implemented in the finished product

FURTHER WORK

The following is considered further work:

- Perform user testing.
- Perform detailed analysis of the feedback parameters of the human- machine system, and their correspondence to input values.
- Develop operator control screen, including GUI and UI/UX.
- Build prototype of control levers.
- Provide complete list of control lever technical system functionality and implement in final product, such as electric- shaft, haptics and backup systems.
- Perform industrial design and produce detailed production drawings.
- Further study of marine and operator framework.
- Develop electronics and mechanical specifications.
- Identify relevant rules and regulations and get product approved by relevant classification societies.

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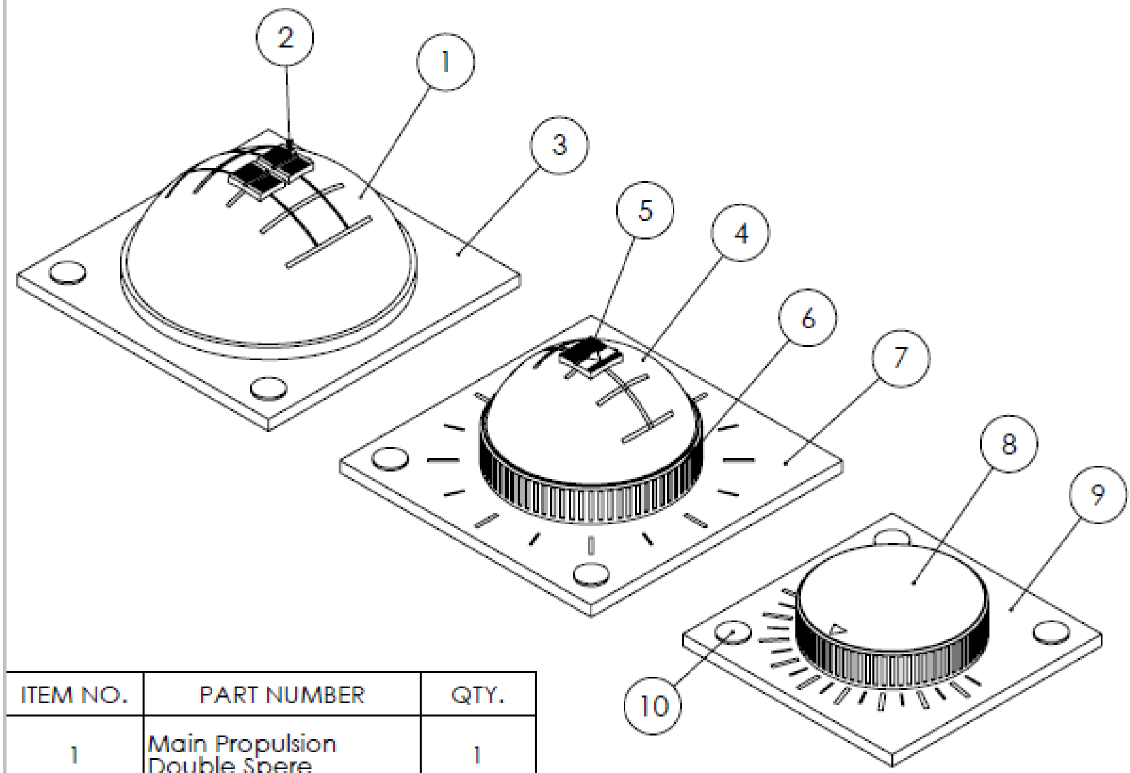
15. APPENDIX

Table of content **Page:**

Appendix 1: Component overview.



ITEM NO.	PART NUMBER	QTY.
1	Main Propulsion Double Spere	1
2	Main Propulsion Powerbutton	2
3	Main Propulsion Baseplate	1
4	Azimuth Sphere	1
5	Azimuth Powerbutton	1
6	Azimuth Ring	1
7	Azimuth Baseplate	1
8	Rudder	1
9	Rudder Baseplate	1
10	Button	8

TITLE: Assembly

A4

SCALE:1:5

SHEET 1 OF 1

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