Design and Development of a Large USV Series

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Design and Development of a Large USV Series

Thesis

by

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to obtain the degree of Master of Science
at the Delft University of Technology
to be defended publicly on 20 March, 2026 at 16:00

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Project Duration:	November, 2025 - March, 2026
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An electronic version of this thesis is available at `http://repository.tudelft.nl/`.

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AI Statement

For this thesis, Generative AI was used to:

- *Structuring parts of the text of this report after the information that had to be included in the text was provided.*
- *Obtain inspiration for the overall structure and organisation of the report.*
- *Improve grammar, style, layout, and spelling of the text.*
- *Search for relevant academic articles, reports, and reference material.*
- *Enhance front cover image.*

In all cases, the author has reviewed and corrected the work and remains fully responsible for the content of the report.

Abstract

Uncrewed systems are increasingly emerging as a new class of military technology, as demonstrated by their extensive and evolving use in recent conflicts, such as the war in Ukraine. Within the maritime domain, Large Unmanned Surface Vessels form a key element of this broader development. These vessels are viewed as important enablers for future naval operations in which risk reduction, endurance, and persistent presence are dominant drivers. While enabling technologies for uncrewed operation are rapidly maturing, the configuration of naval LUSVs and the associated design decisions are not yet crystallized in the same way as for conventional crewed vessels. As a result, there is a lack of structured approaches to translate naval mission needs into LUSV concept designs.

This research addresses this issue by developing and applying a mission-driven design framework that supports the systematic generation of LUSV concept designs. The main result of this research is a stepwise design method that links mission analysis, capability definition, and modular function deployment to concept-level vessel designs. The application of the method resulted in several LUSV concepts, illustrating different approaches to mission integration and platform configuration.

The results demonstrate how a mission-driven and modular design approach can be used to structure the early-stage design of LUSVs. The derived concepts show how different mission groupings and propulsion requirements lead to distinct platform configurations, providing insight into the trade-offs between flexibility, specialization, and platform commonality.

Beyond the case of LUSVs, the approach presented in this research contributes to the systematic design of complex, mission-driven systems. The framework is transferable to other systems and supports transparent concept exploration in domains characterized by emerging technologies and limited design precedent. In these domains, structured design methods are essential to support informed early-stage decision-making.

Preface

This thesis marks the completion of my Master of Science in Marine Technology at Delft University of Technology. It represents the final stage of my studies and concludes an important and valuable period of my academic development. Looking back, I reflect positively on my time in Delft and on the education I have received throughout the programme.

The research presented in this report was carried out at Damen Naval in Vlissingen. I am grateful to Damen Naval for the opportunity to conduct this thesis within the company and for providing an interesting and highly relevant research topic. The development of Large Uncrewed Surface Vessels is a current and evolving subject within the naval domain, which made this project both challenging and engaging.

I would like to thank everyone who supported me during this research. The guidance, critical feedback, and constructive discussions throughout the process have contributed significantly to the quality and structure of this thesis.

Finally, I would like to thank my family and friends for their continuous support and patience during my studies. Their encouragement has been invaluable throughout this period.

I hope that the work presented in this thesis contributes in a meaningful way to the development of LUSV's.

Contents

Nomenclature

List of Abbreviations

AAW	Anti Air Warfare
AIS	Automatic Identification System
ARAS	Autonomous Refuelling At Sea
ASuW	Anti Surface Warfare
ASW	Anti Submarine Warfare
CUI	Critical Underwater Infrastructure protection
DPM	Design Property Matrix
ESM	Electronic Support Measures
FCS	Fast Crew Supplier
IMMS	Integrated Machinery Monitoring System
ISR	Intelligence, Surveillance and Reconnaissance
LARS	Launch and Recovery System
LUSV	Large Uncrewed Surface Vessel
MCA	Multi-Criteria Analysis
MCM	Mine Countermeasures
MFD	Modular Function Deployment
MIM	Module Indication Matrix
QFD	Quality Function Deployment
SCC	Shore Control Centre
SW	Strike Warfare
UAV	Uncrewed Aerial Vehicle
USV	Uncrewed Surface Vehicle
UUV	Uncrewed Underwater Vehicle
UxV	Uncrewed Vehicle

1

Introduction

1.1. Introduction

Contemporary naval operations are increasingly shaped by rising geopolitical tensions and the growing importance of maritime domains for security and economic stability. Sea lines of communication, critical undersea infrastructure, and access to strategically relevant maritime regions are becoming more contested, while navies are required to operate over larger areas and for longer durations. These developments place increasing demands on naval forces in terms of presence, persistence, and responsiveness.

At the same time, rapid technological developments in autonomy, sensing, and communication are enabling new ways of conducting maritime operations. Uncrewed and remotely operated systems are increasingly being adopted to complement traditional naval platforms, driven by the desire to reduce risks to personnel, extend operational endurance, and increase operational flexibility. Within this broader development of unmanned assets, Large Unmanned Surface Vessels(LUSVs) are receiving growing attention due to their ability to carry substantial payloads, operate over long ranges, and act as hubs for other uncrewed systems.

LUSVs are therefore increasingly viewed as a promising solution to address emerging operational challenges. By removing the requirement for a embarked crew, LUSVs offer opportunities to conduct persistent operations in high-risk or remote environments while potentially reducing life-cycle costs. At the same time, the absence of crew fundamentally affects the design of the platform, its systems, and its operational employment.

Despite the growing interest in LUSVs, their conceptual design remains insufficiently explored. Questions remain regarding which missions are most suitable, which capabilities are required, and how these capabilities should be translated into feasible platform concepts. Addressing these questions is essential to ensure that future LUSV designs are both operationally relevant and technically realistic.

1.2. Thesis Formulation

1.2.1. Thesis Objective

The objective of this research is to develop and apply a structured, mission-driven method for the early-stage conceptual design of a Large Uncrewed Surface Vessel. This method aims to translate naval mission types into required platform capabilities and corresponding concept designs, thereby supporting informed design decisions in the early phases of LUSV development.

1.2.2. Research Question

To achieve this objective, the following research question will be answered:

How can a structured method be developed and applied to translate naval mission types into capabilities and concept designs for a Large Uncrewed Surface Vessel in support of its early-stage development?

1.2.3. Sub-questions

To answer the main research question, the research is divided into the following sub-questions:

1. *Which design approach is suitable for supporting the early-stage conceptual design of a LUSV?*
2. *Which naval missions are most relevant for the employment of a LUSV, and which capabilities do these missions impose on the vessel?*
3. *How can the identified vessel capabilities be translated into system-level solutions for a LUSV?*
4. *How can multiple LUSV concept variants be defined based on the identified systems and capabilities?*
5. *What do the resulting LUSV concepts look like when developed at a conceptual level, and which concepts show the greatest potential?*

1.3. Structure of the Report

The report is structured to follow the logical progression of the research, moving from the establishment of a structured design approach towards the development of concrete concepts. Each chapter builds upon the results of the preceding chapter.

- **Chapter 1 – Introduction:** Introduces the research context, motivation, and objectives. It formulates the research questions and outlines the structure of the report.
- **Chapter 2 – Design Approaches:** Reviews relevant design and systems engineering methodologies. Based on this review, a suitable design approach and tool are selected.
- **Chapter 3 – Mission Analysis:** Identifies and analyses relevant naval mission types for LUSV deployment. The chapter prioritises missions and derives a structured set of platform and mission capabilities.
- **Chapter 4 – Modular Function Deployment:** Applies the Modular Function Deployment (MFD) method to translate capabilities into functions, systems, and a modular architecture using QFD, DPM, MIM, and interface matrices.
- **Chapter 5 – Concept Definition:** Analyses the distribution of systems across mission types and defines a set of LUSV concepts based on the results of all the preceding analyses.
- **Chapter 6 – Concept Development:** Develops the defined concepts at a high level and compares them to identify key differences, implications, and trade-offs between the concepts.
- **References and Appendices:** Provide supporting material, including the roadmap, vignettes, detailed capability, function, and system descriptions.

2

Design Approaches

Since the design of a LUSV is highly complex, suitable design approaches are essential to ensure a structured process and to achieve a feasible and effective design. For this reason, attention must be paid to methods that specifically address the challenges of this project, which is about early-stage or concept-phase ship design.

The concept phase fundamentally differs from later design stages. While detailed design is about refinement and optimization, the concept phase is about shaping the overall system by making high-level decisions that determine the viability of the design. As Ferguson [1] observed, engineering design is made up of "dozens of small decisions and hundreds of tiny ones," but in the concept phase, these decisions are far more consequential: they define the system architecture and are extremely difficult to reverse once subsequent development begins. [2]

A key challenge in this stage is the definition and clarification of requirements. This process, often referred to as requirement elucidation, is necessary because concept design deals with what is known as a wicked problem. Wicked problems are characterized by ambiguity, interdependencies, and shifting priorities; they rarely have a single correct solution. In naval design, this manifests as trade-offs between performance, cost, survivability, and adaptability, where improving one aspect may worsen another. Moreover, the requirements themselves are not always fixed but evolve as stakeholders, technologies, and operational contexts are better understood. [3]

Consequently, the concept phase must be approached using design methods that support decision-making under uncertainty and allow for iteration and adaptation. Within this context, the first research sub-question addressed in this chapter is: *Which design approach is suitable for supporting the early-stage conceptual design of a LUSV?* Addressing this question provides the methodological foundation for the subsequent stages of this research.

2.1. System Engineering

Systems Engineering (SE) provides a structured approach for guiding the design and realization of complex systems. Unlike traditional engineering disciplines that concentrate on specific subsystems or technical specialties, SE focuses on the system as a whole, emphasizing its overall operation and integration.

According to [4], a system is defined as "a set of interrelated components working together toward a common objective." A complex engineered system is characterized by a multiplicity of intricately interrelated and diverse elements.

The distinguishing features of SE compared to conventional engineering practices are:

- System-level perspective: considering the integrated performance of the entire system rather than isolated parts.
- Customer and operational focus: ensuring that the system fulfills user needs within its operational environment.
- Valuable in conceptual design: guiding the early translation of needs into viable system concepts.
- Bridging disciplines: linking specialized engineering domains.

2.1.1. System Life Cycle

SE structures the life cycle of a system into three broad stages, each of which is further subdivided into phases. This framework guides the progression of a system from its initial conception to operational deployment and support. The three stages are: concept development, engineering development, and postdevelopment.
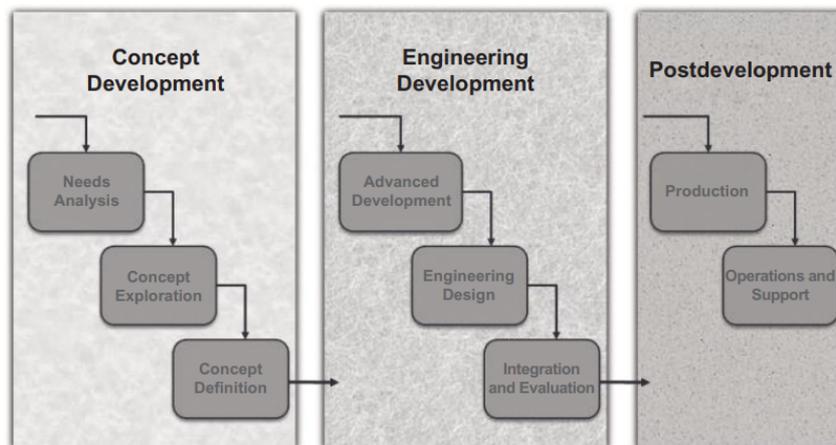

Figure 2.1: SE Life Cycle Model [4]

2.1.2. Concept Development Stage

For this research, the concept development stage is the most relevant, as the focus lies on the creation of a concept design. This stage represents the initial formulation and definition of a system concept that best satisfies a validated need. In this stage the principal objectives are:

1. To verify that there is a valid need (and market) for a new system that is both technically and economically feasible.

2. To explore potential system concepts and formulate and validate a preliminary set of system performance requirements.

3. To select the most attractive concept, define its functional characteristics, and establish a detailed plan for engineering, production, and operational deployment.

4. To develop any new technologies required by the chosen concept and demonstrate their ability to meet performance requirements.

By validating needs, exploring alternatives, defining functional characteristics, and addressing enabling technologies, this phase ensures that the selected concept can progress into detailed development.

The concept development stage consists of three phases: needs analysis, concept exploration, and concept definition. Each phase is guided by a central question and provides specific outputs.

Needs Analysis Phase
Central question: "Is there a valid need for a new system, and can this need be practically addressed?" This phase identifies operational gaps that cannot be solved with existing means and assesses whether technology can support new capabilities. The output is a description of the capabilities and operational effectiveness needed in the new system.

Concept Exploration Phase
Central question: "What performance is required, and is there at least one feasible and affordable approach?" In this phase, alternative system concepts are developed and assessed. The output includes the first set of system performance requirements and a selection of candidate concepts.

Concept Definition Phase
Central question: "Which concept provides the best balance between capability, operational life, and cost?" The alternatives are compared on performance, risk, and cost to select the most promising option. The outputs are functional specifications and a defined system concept that form the basis for further development.[4]

After the concept development stage, SE continues with two additional phases. However, these phases fall outside the scope of this project and will therefore not be addressed.
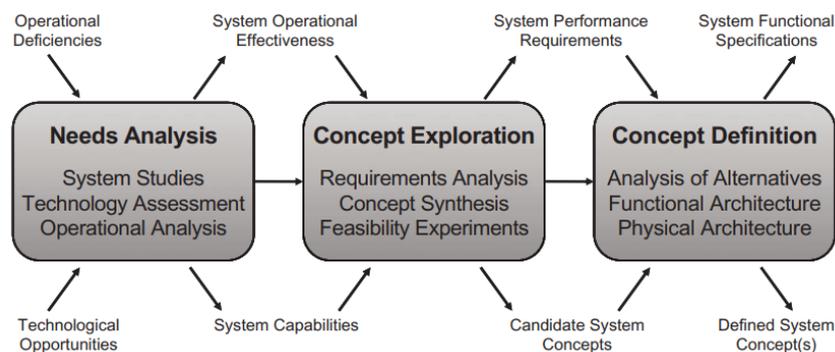

Figure 2.2: Concept development phases within the SE life cycle [4]
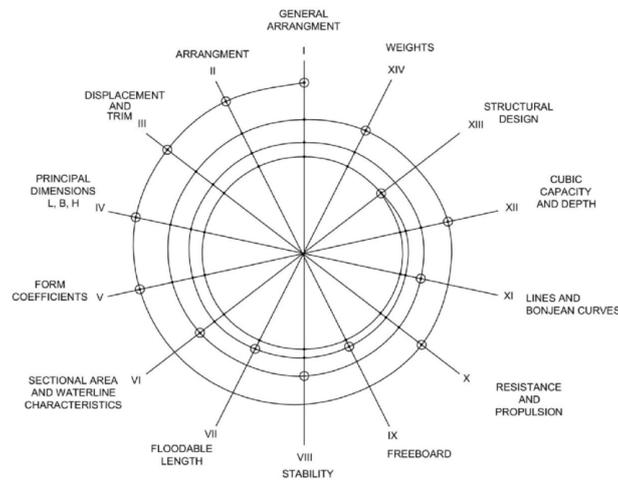
2.2. Design Spiral

Figure 2.3: The Design Spiral of Evans [5]

The concept of the design spiral was first introduced by Evans [5] as a framework for structuring the inherently iterative nature of ship design. Since its introduction, numerous variations of the spiral have been developed, each adapted to specific design contexts or methodological preferences. Despite these differences, the essential lesson of the design spiral remains that ship design is not a linear process, but one of progressive refinement.

The spiral typically begins with high-level requirements and proceeds through successive passes of key design disciplines such as hull form, stability, structures, propulsion, and cost. At each revolution of the spiral, updated calculations are made and trade-offs are revisited, gradually converging towards a balanced and feasible design solution. This cyclical progression ensures that no single discipline dominates and that interdependencies between naval architecture, performance, and cost are continually re-evaluated. As such, the design spiral embodies both the holistic and iterative nature of complex ship design.

At the same time, the design spiral has been criticized for being more of a descriptive paradigm than a prescriptive method. It does not in itself specify how requirements are elicited, how trade-offs should be made, or which decision criteria should guide convergence. Modern adaptations therefore combine the spiral with systems engineering practices, optimization techniques, and digital tools that provide more formal structure to the iteration process.

For the present research, the spiral serves primarily as a conceptual guide to emphasize iteration and progressive refinement. However, before such an iterative process can begin, a clear set of requirements must be established. As this project starts without a well defined requirement set, the initial focus will be on clarifying and formalizing these requirements. Only once this is in place can the iterative design process of the spiral be effectively applied to guide the development of a LUSV. In this way, the design spiral offers a model that aligns well with the nature of concept design.

2.3. Set Based Design

Set-Based Design (SBD) is a design methodology that contrasts with the traditional point-based approach. Rather than selecting a single concept early and refining it step by step, SBD maintains multiple design alternatives in parallel. Feasible regions are defined, and options are gradually eliminated as more knowledge is gained and infeasibilities are identified. This approach delays final decisions until sufficient evidence is available, thereby reducing the risk of rework and allowing greater design freedom. A detailed comparison between point-based and set-based approaches is shown in Figure 2.4, highlighting differences in functions. The table illustrates that whereas point-based design rapidly converges on a single solution, set-based design maintains multiple feasible alternatives for a longer period, allowing uncertainty to be addressed and design decisions to be made at a stage where they can be better informed.

Function	Point-Based Approach	Set-Based Approach
Search: How should solutions be found?	Iterate on existing ideas. Brainstorm new ideas.	Define feasible regions.
Communication: Which ideas are communicated to others?	Communicate the best idea.	Communicate sets of possibilities.
Integration: How should the system be integrated?	Pass the idea among the team for critique.	Look for intersections.
Selection: How is the best idea identified?	Formal schemes for selecting the best alternative. Make prototypes to confirm that the solution works.	Design in parallel on each alternative until it is not worth pursuing. Look for low cost tests to prove infeasibility.
Optimization: How should the design be optimized?	Analyze and test the design. Modify the design as necessary to achieve objectives and improve performance.	Design in parallel on each alternative until it is not worth pursuing. Look for low cost tests to prove infeasibility.
Specification: How should you constrain others with respect to your own subsystem design?	Maximize constraints in specifications to assure functionality and interface fit.	Use minimum control specifications to allow optimization and mutual adjustment.
Decision risk control: How should one minimize the risk of "going down the wrong path?"	Establish feedback channels. Communicate often. Respond quickly to changes.	Establish feasibility before commitment. Pursue high-risk and conservative options in parallel. Seek solutions robust to physical, market, and design variation.
Rework risk control: How should one minimize damage from unreliable communications? *Management:* How should the process be controlled?	Establish feedback channels. Communicate often. Respond quickly to changes. Review designs and manage information at transition points.	Stay within sets once committed. Manage uncertainty at process gates.

Figure 2.4: Comparison of point and set based approaches.[6]

Within this research, Set-Based Design is applied primarily as a way of thinking rather than as a fully formalised process. Instead of developing a single LUSV concept or focusing on one dominant mission, multiple alternatives are considered in parallel throughout the analysis. Missions, capabilities, and platform characteristics are deliberately treated as sets rather than fixed choices, allowing different combinations and interpretations to be explored. This prevents early convergence on a single solution and supports a broader understanding of the design space. While the study ultimately needs to converge to a limited number of concepts, adopting a set-based perspective helps ensure that this convergence is informed by comparison and trade-offs rather than by early assumptions.

2.4. Mission Engineering

Mission engineering treats the mission itself as the system of interest. Its objective is to engineer missions by identifying the right technologies, systems, systems-of-systems, and processes needed to achieve the intended mission outcomes, and to provide mission-based inputs to the systems engineering process so that the department "builds the right things right" [7, 8]. In other words, mission engineering emphasizes the development and integration of technology around mission outcomes rather than focusing on isolated system performance.

The results of mission engineering can inform a wide range of decisions: they may guide technology investments, suggest alternative uses of existing systems, highlight mission gaps and preferred approaches to closing them, and, where necessary, initiate new acquisition efforts to address capability shortfalls [7]. Typical mission engineering activities include

1. Mission Problem Definition,
2. Mission Characterization,
3. Mission Architecture,
4. Mission Engineering Analysis, and
5. Results and Recommendations.

Within this research, mission engineering is applied primarily as a guiding perspective rather than as a complete, formal process. Instead of treating the LUSV as the system of interest, the missions themselves are used as the starting point for the analysis. Mission objectives, operational context, and desired effects are considered first, and capabilities are derived from these considerations. This mission-oriented approach ensures that design choices are evaluated in terms of their contribution to mission outcomes, without requiring a full formal mission engineering implementation.

2.5. Modular Function Deployment

Modular Function Deployment (MFD) is a structured method for translating stakeholder and operational needs into a modular product architecture. Rather than optimising a single baseline configuration, MFD decomposes the problem from requirements to functions, then to technical solutions, and finally to modules, with explicit reasoning for why certain systems should become modules and which interfaces they must share. In a this research context, especially for LUSVs expected to host containerised payloads, this enables mission flexibility and upgradeability. However, MFD inherently assumes the use of modularity and focuses on assessing how systems can benefit from being modular, rather than evaluating whether modularity itself is the most appropriate design choice. Therefore, an trade-off analysis is required to justify the adoption of modularity.

The MFD roadmap in Figure 2.5 consists of four linked steps that also align with three complementary viewpoints. First, clarify stakeholder requirements (voice of the customer) and organise them in a Quality Function Deployment matrix, producing a traceable function structure. Second, select technical solutions for those functions (voice of the engineer) using a Design Property Matrix to ensure coverage and reveal coupling hot spots. Third, generate concepts (voice of the business) by evaluating candidate solutions against modularity drivers in the Module Indication Matrix, which provides

Figure 2.5: MFD Roadmap [9]

the why-modular rationale. Fourth, evaluate concepts and define preliminary interfaces with an the help of the Interface Matrix. Together these steps convert needs into a defendable modular baseline that is ready for subsequent engineering.
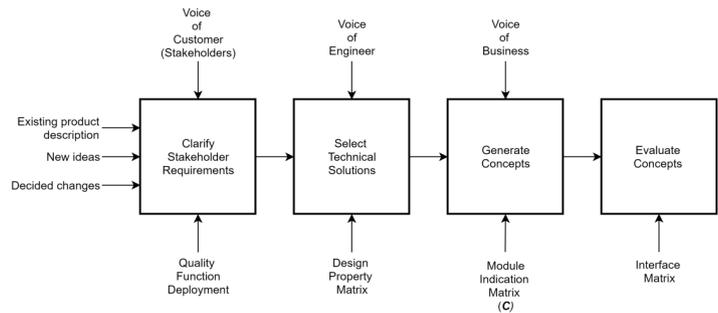
Method   MFD proceeds in four linked steps, each operationalised by a specific matrix and arranged in the Product Management Map (PMM).
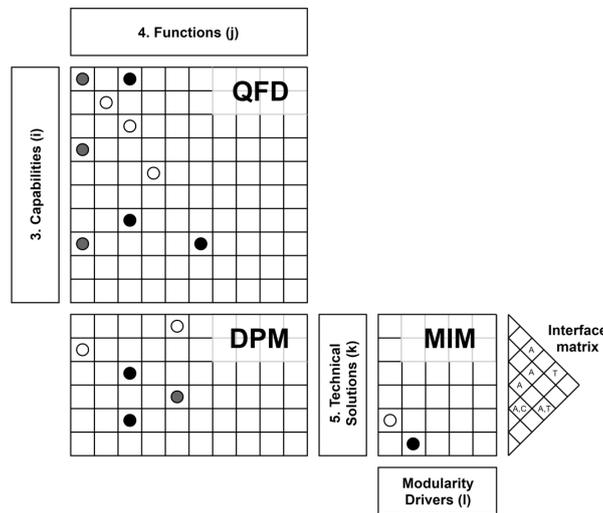

Figure 2.6: Product Management Map [9]

1) Requirements to functions — Quality Function Deployment (QFD). Before applying the QFD, the capabilities are structured in a clear hierarchy (tree or affinity diagram) to remove duplicates and ensure completeness. QFD then maps the set of capabilities against the set of system functions using a simple ordinal scale (9–3–1–0) to indicate strong, moderate, weak, or no relationship. The output is a traceable function structure anchored in user needs.

2) Functions to technical solutions — Design Property Matrix (DPM). The DPM maps functions to candidate systems/technical solutions, ensuring coverage (every function has at least one solution) and revealing coupling hot spots that will later influence module boundaries. A transposed view can be used to check consistency and identify over-designed or under-served functions.

3) Technical solutions to modules — Module Indication Matrix (MIM) with modularity drivers. Candidate solutions are evaluated in the MIM against a set of modularity drivers that capture stakeholder and life-cycle concerns. The modularity drivers are: Different specification, styling, carry-over, technology evolution, planned design change, common units, process/organisation, separate testing, supplier availability/purchase, service and maintenance, upgrading, and recycling. Scoring highlights where modularisation adds the most value and provides the explicit "why-modular" justification for each proposed module/system.

4) Define module interfaces — Interface Matrix. Selected modules/systems are characterised through an interface matrix using a clear taxonomy: Attachment, Transfer, Command & Control and Spatial. This converts a set of modules into an integrable architecture with preliminary interface contacts suitable for concept-level integration planning.

In the concept phase, architectural decisions determine much of the downstream cost and flexibility. MFD delivers three concrete outputs that make these decisions explicit and defensible:

1. a traceable link from capabilities to functions and systems (QFD, DPM);
2. a reasoned basis for module selection grounded in modularity drivers (MIM); and
3. preliminary interface definitions (Interface Matrix).

Taken together, these outputs form a clear bridge from capabilities to one or more viable LUSV concepts, while ensuring that modularity remains an explicit design objective rather than an afterthought. [9][10]

2.6. Conclusion

The reviewed design approaches together form the methodological basis for the concept design of a LUSV. Each approach contributes specific strengths that, when combined, create a clear and structured framework for developing a feasible and well-balanced concept design.

Systems Engineering provides the overall structure for managing complexity and keeping a clear link between needs, system functions, and technical solutions. Within SE, the concept development stage(needs analysis, concept exploration, and concept definition) fits well with the steps required in this research and therefore forms the backbone of the proposed design process.

The Design Spiral adds an iterative process that supports gradual improvement of the physical design. It allows the designer to refine elements such as hull form, propulsion, and arrangement while keeping consistency with the operational and functional requirements from earlier stages.

Set-Based Design introduces the mindset of keeping multiple design options open in the early stages and narrowing them down as knowledge increases. This way of thinking will be adopted in this research to manage uncertainty and support balanced decision-making during concept development.

Finally, Modular Function Deployment (MFD) offers a practical method in the concept exploration stage to link require-

Figure 2.7: Roadmap of Design Approach

ments to system functions and modular technical solutions. For a LUSV, which is expected to have modular or containerised payloads, this approach is essential to ensure flexibility, upgradeability, and adaptability over time.

The combination of these methods results in the roadmap for the design and development of a Large USV series (Figure 2.7). This roadmap brings together the structured logic of Systems Engineering, the iterative process of the Design Spiral, and the modular reasoning of MFD. The full-size version of the roadmap is included in the appendix A for reference. It progresses through three main levels of definition:

- Operational definition – identifying customer needs, operational context, and translating these into capabilities.
- Functional definition – translating capabilities into design drivers, system functions, and modular technical solutions.
- Physical definition – developing the concept design using the iterative process of the design spiral, refining dimensions, hull form, propulsion, and arrangement.

Together, these levels create a clear path from operational needs to a feasible physical design. The roadmap therefore forms the main methodological result of this literature study and provides the structure for the next stages of this research.

3

Mission Analysis

This chapter forms part of the needs analysis phase of the research. As illustrated in Figure 3.1, this phase examines the operational problem from a mission oriented perspective in order to determine what the LUSV must be capable of.

The objective of this chapter is to translate relevant naval missions into a structured and traceable set of capabilities for the LUSV. This is achieved by identifying and prioritising mission types based on their operational relevance and technical feasibility for uncrewed execution. The selected missions are subsequently explored through vignettes, which describe representative operational scenarios and clarify how a future LUSV is expected to be employed.

Based on these vignettes, the associated operational needs are translated into capabilities. These capabilities define the functional scope of the design and represent the output of the needs analysis phase. They are used as input for the subsequent phases of the research. In doing so, this chapter addresses the second research sub-question: *Which naval missions are most relevant for the employment of a LUSV, and which capabilities do these missions impose on the vessel?*

Figure 3.1: Roadmap: stage in Chapter 3

3.1. Mission Types

The mission types identified in the preceding literature study are AAW, ASW, ASuW, ISR, CUI, MCM, and SW. These mission types were identified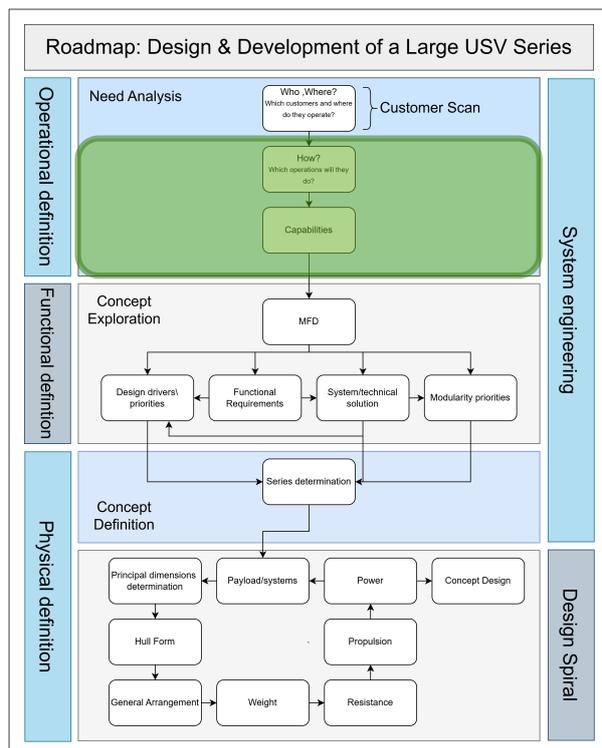 based on the literature study and the customer scan. The abbreviations stand for Anti Air Warfare, Anti Submarine Warfare, Anti Surface Warfare, Intelligence, Surveillance and Reconnaissance, Critical Underwater Infrastructure protection, Mine Countermeasures, and Strike Warfare. Each mission type represents a distinct operational role relevant to naval operations.

- AAW (Anti Air Warfare) focuses on countering aerial and missile threats to protect naval and joint forces.
- ASW (Anti Submarine Warfare) aims to detect, track, and neutralise hostile submarines to maintain control of the undersea domain.
- ASuW (Anti Surface Warfare) concerns the detection and engagement of enemy surface vessels to secure dominance at sea.
- ISR (Intelligence, Surveillance and Reconnaissance) collects and analyses information to build situational awareness for operational decision-making.
- CUI (Critical Underwater Infrastructure protection) ensures the security and continuity of vital seabed systems such as cables and pipelines.
- MCM (Mine Counter Measures) reduce or eliminate the risk posed by naval mines to ensure safe maritime access and freedom of movement.
- SW (Strike Warfare) focuses on conducting precise attacks against land targets from the maritime domain to support broader operational objectives.

Mission Types
AAW
ASW
ASuW
ISR
CUI
MCM
SW

Table 3.1: Mission Types

3.2. Mission Prioritization

To determine which missions should be prioritised during the design phase, a structured prioritisation process is applied. The purpose of this step is not only to assess the operational and technical characteristics of the missions, but also to define a clear and manageable scope for the research. Since the available time and resources are limited, it is essential to focus the analysis on mission areas where LUSVs are expected to provide the highest potential contribution. Prioritisation therefore enables an efficient allocation of research effort, this ensures that subsequent phases of the study remain feasible.

To identify the missions that should serve as the primary focus of the research, a Multi-Criteria Analysis (MCA) is conducted. The MCA provides a systematic framework for comparing missions using a consistent set of evaluation criteria.

The criteria are divided into two categories: operational and technical. The operational criteria examine how each mission contributes to naval tasks and how suitable it is for uncrewed execution. Mission frequency reflects how often a mission occurs within routine operations. Autonomy suitability assesses whether a mission can be performed without continuous human involvement. Risk reduction captures the degree to which operational hazards can be mitigated by assigning the mission to an uncrewed platform. Endurance value indicates how strongly a mission benefits from long-duration deployment, based on the expectation that uncrewed systems can sustain higher endurance than crewed vessels.

The technical criterion focuses on technical dependability, which represents the degree to which a mission relies on stable communication, robust sensor performance, and platform reliability. Missions that require continuous data transmission, detailed sensing, or coordinated multi-asset operations place higher demands on the underlying technology. Including this criterion ensures that mission prioritisation remains grounded in what is technically achievable for uncrewed platforms.

By identifying the missions with the strongest combination of operational relevance and technical feasibility, the prioritisation provides a structured basis for determining the scope of the research. This ensures that the study concentrates on the most promising mission areas and uses the available resources efficiently.

Table 3.2 presents the criteria, scoring scales, and weights used in the analysis, which were defined in collaboration with experts from Damen Naval with extensive operational knowledge.

Category	Criteria	Answer the question:	Scoring			Weight	Reasoning
			1	2	3		
Operational	Mission frequency	How often the mission occurs within maritime operations.	Rarely	Regularly	Often	100	Base
	Autonomy suitability	To what extent the mission is suitable for uncrewed execution.	Low suitability	Medium suitability	High suitability	75	Operational driver
	Risk reduction	How much risk to crewed vessels is avoided by conducting this mission uncrewed.	Low reduction	Medium reduction	High reduction	75	Operational driver
	Endurance value	How much operational value the mission gains from long-duration deployment without human presence.	Low endurance	Medium endurance	High endurance	75	Operational driver
Technical	Technical dependence	How demanding the mission is in terms of dependable technical performance, including reliable communication, secure operation, and overall system integrity.	High dependability	Medium dependability	Low dependability	150	Technical driver

Table 3.2: Criteria with explanation, scoring and weights

3.2.1. Results Mission Prioritization

Category	Mission	Operational				Technical	Total
Criteria		Mission Frequency	Autonomy Suitability	Risk Reduction	Endurance Value	Technical Dependability	
Score	450	100	75	75	75	125	
Weight	1	0.222	0.167	0.167	0.167	0.278	
	MCM	2	3	3	2	3	0.87
	CUI	3	3	1	3	2	0.80
	ISR	3	3	1	3	2	0.80
	ASW	2	2	2	3	2	0.72
	AAW	1	1	3	2	1	0.50
	ASuW	1	1	3	2	1	0.50
	SW	1	1	3	1	1	0.44

Table 3.3: Results Mission Prioritization

The subsequent stages of this research will focus exclusively on four missions: MCM, CUI, ISR, and ASW. Selecting these missions defines the scope of the study and ensures that the analysis remains feasible within the available time and resources. As outlined earlier, scoping is necessary to concentrate the research effort on mission areas where LUSVs are expected to offer the highest potential contribution. This approach allows the study to make effective use of its resources while maintaining depth.

As presented in Table 3.3, these four missions obtain the highest combined scores in operational and technical relevance, which indicates that they offer the strongest potential for meaningful LUSV employment. MCM aligns with current naval practice, where USVs are already used to support mine countermeasure tasks. CUI reflects the growing strategic importance of protecting seabed infrastructure. ISR provides continuous value through enhanced situational awareness, and ASW shows promising potential due to the relevance of distributed undersea sensing. These factors collectively make the four selected missions the most promising for further development within this research.

The missions AAW, ASuW, and SW receive significantly lower prioritisation scores. Their lower operational relevance for LUSVs, combined with the higher technical demands associated with full and independent mission execution, makes them less suitable for inclusion within the limited scope of this study. It is important to emphasise that the assessment assumes complete mission capability, including detection, command and control, and engagement functions. It does not consider partial roles, such as employing the LUSV solely as a missile carrier or as a magazine within a broader networked force structure. Within the context of full mission integration, these missions fall outside the selected scope in order to maintain a clear research focus and to avoid excessive broadening of the study.

Although these missions fall outside the scope of the present study, it remains valuable to consider AAW, ASuW, and SW capabilities in a broader design context. Examining the implications of partially or fully incorporating these missions could provide insight into how the platform design would need to adapt.

A sensitivity check was conducted by varying the individual weighting factors by up to 50%. These variations do not affect the outcome of the analysis, as the same four missions (MCM, CUI, ISR, and ASW) consistently remain the highest-ranked options. This indicates that the mission prioritization is largely insensitive to the applied weighting factors and can be considered robust.

3.3. Capabilities

With the mission prioritisation completed, the focus has been narrowed to four mission types: MCM, ISR, CUI, and ASW. The next step is to identify the underlying operational needs associated with these missions and to translate them into capabilties for the LUSV concept.

This section identifies the capabilities required to support the selected missions and forms the foundation for translating mission demands into functional requirements for the LUSV. By analysing the operational tasks associated with each mission, the section establishes a structured basis for determining what the vessel must be able to do.

3.3.1. Vignettes

To develop the required capabilities, the countries identified in the preceding literature study and the missions defined earlier are now brought together by constructing vignettes for the key missions

A vignette is a narrative description of a mission. In this research, the purpose of the vignettes is to create a clear representation of how each mission is expected to be conducted by a future LUSV. The vignettes describe the operational context, the expected sequence of events, the role of the platform, and the interactions with embarked systems such as USVs, UUVs, and UAVs. In doing so, the assumptions regarding how the LUSV is intended to be operated and employed are explicitly embedded in the mission descriptions. By describing the missions in this way, the vignettes provide a consistent basis for deriving the capabilities that the platform must possess and help ensure that capability requirements are grounded in realistic operational scenarios rather than abstract assumptions.

Based on this approach, vignettes were developed for the following key missions:

Mission	Description	Vignette Summary
Australia		
MCM	Mine Countermeasures in the Bass Strait	LUSV clears a large minefield using multiple USVs and UUVs, supported by a UAV acting as a communication relay.
ISR	ISR in the Timor Sea	LUSV conducts an ISR patrol where a UAV detects AIS gaps and the vessel is monitored over an extended period.
CUI	CUI between Sydney and New Zealand	LUSV surveys cables with USVs and UUVs and tracks a slow suspicious vessel along the cable route.
ASW	ASW in the Timor Sea	LUSV uses TAS and small USVs with UUVs to maintain continuous acoustic tracking of a transiting submarine.
Denmark		
MCM	Mine Countermeasures in the Baltic	LUSV surveys a strategic passage with VDS and UUVs to locate modern naval mines for later neutralisation.
ISR	Patrol near Greenland	LUSV performs a long ISR patrol and detects illegal fishing activity in a remote fjord via UAV.
CUI	CUI in the Baltic	LUSV identifies damage to a pipeline using USVs and UUVs and tracks a suspicious vessel until interception.
ASW	ASW in the Baltic	LUSV detects and tracks a shadowing submarine contact to support a safe route for a NATO task force.
Netherlands		
MCM	Mine Countermeasures in the North Sea	LUSV locates and neutralises a drifting mine with support from a UAV and UUV.
ISR	Patrol in the Caribbean	LUSV detects a semi-submersible drugs vessel using USVs, after which a boarding team intercepts it.
CUI	CUI in the North Sea	LUSV surveys energy infrastructure with USVs, UUVs and UAVs and tracks a suspicious vessel towards UK waters.
ASW	ASW in the GIUK Gap	LUSV uses TAS and sonobuoys to detect a submarine, which then changes course and withdraws.

Table 3.4: Key missions with descriptions and vignette summaries

These key missions were selected based on the strategic interests and operational priorities of each navy.[11][12][13]

Together, these missions represent typical operational challenges that each navy is likely to face in the future. They therefore serve as representative scenarios that guide the formulation of capabilities for the concept design.

The selection of Australia, Denmark, and the Netherlands is not intended to limit the scope of the research to these specific countries. Instead, these nations are used as representative examples due to their advanced plans for the employment of LUSVs and the diversity of their operational environments and strategic ambitions. Together, they illustrate a broad range of potential LUSV applications, ranging from operations in remote and expansive sea areas to missions in confined and strategically waters. As such, the selected countries provide relevant and diverse use cases that support the derivation of generally applicable LUSV capabilities rather than country-specific solutions.

The complete vignettes used for this research are provided in Appendix B. These full versions contain the detailed mission narratives and the operational context from which the capabilities were derived.

3.3.2. Capability Formulation

As described earlier, the capabilities have been derived from the vignettes, supported by input from operational experts. These capabilities are organised into two categories: platform capabilities and mission capabilities. Platform capabilities represent the fundamental capabilities that the platform must always provide, regardless of the mission it is assigned to. Mission capabilities represent the additional capabilities required to enable the platform to conduct a specific mission. An overview of this capability structure is presented in Figure 3.2. All capabilities shown in this figure, and further elaborated in Appendix C, are to be interpreted in the form "*capable of …*", such as "*capable of 1. autonomous navigation*" or "*capable of 2. receiving FAS*".
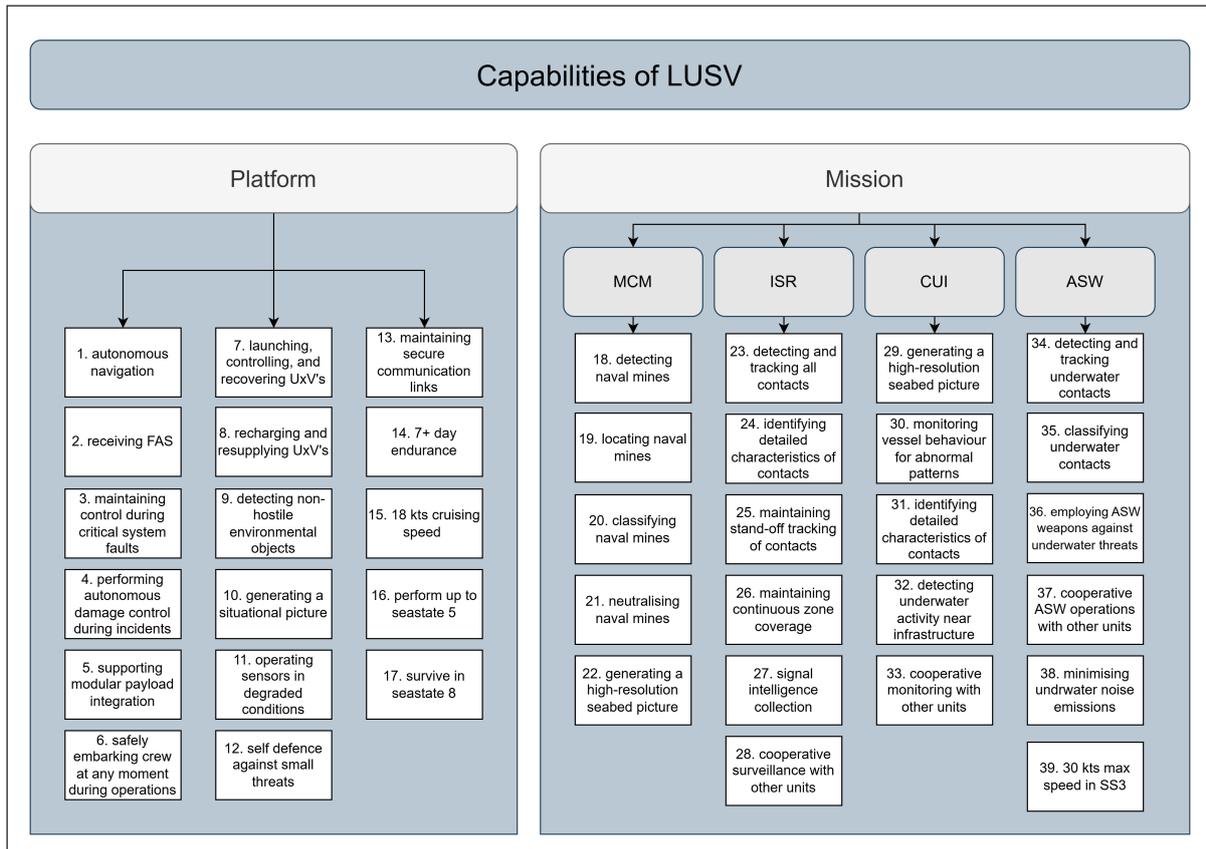
Figure 3.2: Capability breakdown

Depth of Capability Formulation

In line with the V-model, the level of detail used to formulate the capabilities must remain consistent with the level of validation that can be performed at the end of this research. As the final steps of the V-model require verification and validation of the defined requirements, the capabilities presented in this section are intentionally formulated at a high level. Defining them too specifically would imply a level of validation that falls outside the scope of this study. Therefore, only high-level capabilities are included, ensuring that the formulated capability set can be traced, interpreted, and validated within the boundaries of this research.[14]

4

Modular Function Deployment

Now that the operational needs and associated capabilities of the LUSV have been identified in the needs analysis phase, this chapter addresses the translation of these capabilities into a functional architecture. As indicated in Figure 4.1, this chapter covers the Modular Function Deployment (MFD) phase of the research.

The MFD method provides a structured systems engineering approach to translate capabilities into functions, systems, and a modular platform architecture. The overall MFD workflow applied in this research is illustrated in the Product Management Map shown in Figure 4.2. This map clarifies how the individual MFD steps relate to each other and how they support a traceable transition from capabilities to technical solutions.

The MFD method is applied in four sequential steps. First, the Quality Function Deployment (QFD) matrix establishes the relationship between the required capabilities and the functions that the platform must perform. Second, the Design Property Matrix (DPM) links these functions to the systems that enable them. Third, the Module Indication Matrix (MIM) evaluates the identified systems against a set of modularity drivers to determine where modularisation is beneficial. Finally, the Interface Matrix provides an overview of the preliminary interfaces between the selected systems.

Together, these steps provide a structured and traceable pathway from capabilities to a modular system architecture at concept level. In doing so, this chapter addresses the third research sub-question: *How can the identified vessel capabilities be translated into system-level solutions for a LUSV?*

The outcomes of this chapter are used as input for the subsequent concept definition phase.
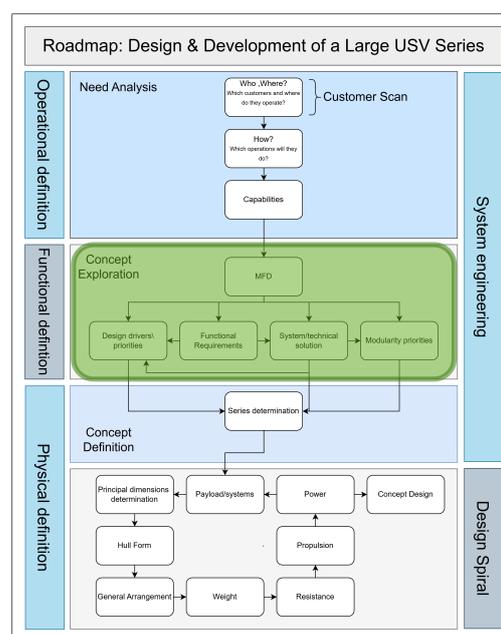
Figure 4.1: Roadmap: stage in Chapter 4
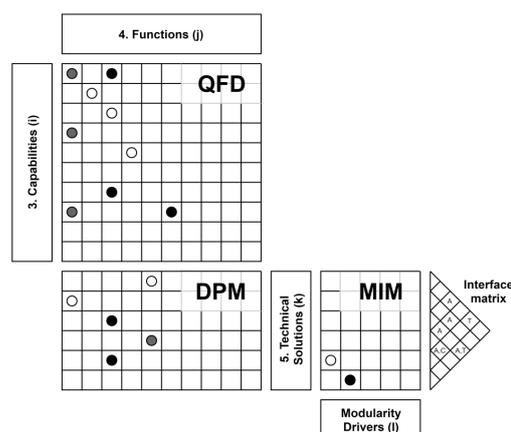
Figure 4.2: MFD: Product Management Map[9]

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4.1. Quality Function Deployment

Figure 4.1: Quality Function Deployment matrix

The Quality Function Deployment (QFD) matrix establishes the relationship between the required capabilities and the functions that must be provided by the design. In this matrix, the capabilities are placed on one axis and the functions on the other, allowing each function to be assessed for its contribution to each capability. The relationship strength is expressed using the standard 9–3–1–0 scale that indicates strong, moderate, weak, or no relationship.

The completed QFD matrix is shown in Figure 4.1. It illustrates which capabilities require extensive functional support and therefore represent complex or demanding capabilities. For example, capabilities such as autonomous navigation, launching and recovering UxVs, and defending against small threats score highly, indicating that multiple functions must act together to realise these capabilities. This analysis provides the input for the subsequent function definition and system allocation steps within the MFD process.

4.1.1. Functions
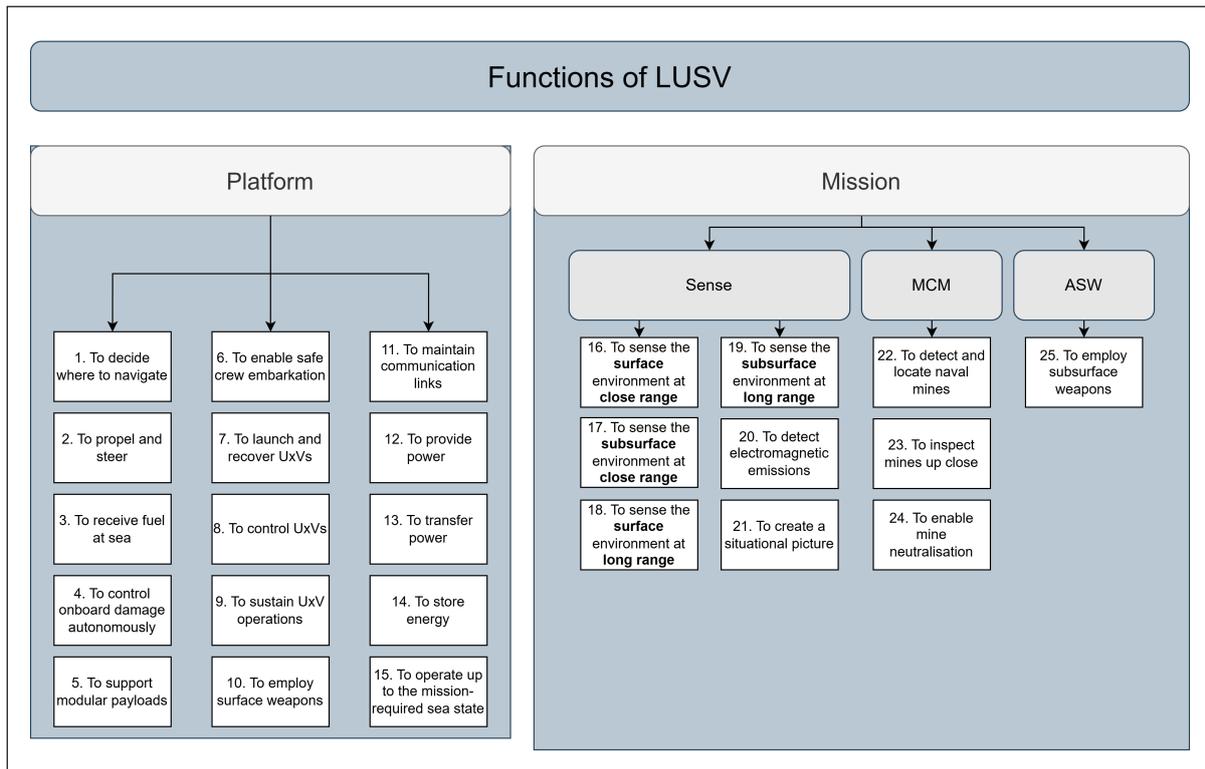
Figure 4.2: Functions breakdown

To ensure that all required capabilities of the LUSV are supported by functions, a structured formulation of platform and mission functions was carried out. These functions were derived through the development of the QFD matrix, In which each capability was systematically linked to one or more functional contributions, and vice versa, ensuring that functions were also traced back to the capabilities they support. This method ensures that every capability introduced in the previous sections is covered by at least one function and that no function is defined without a purpose.

In this research, a function is defined as an action-oriented statement describing what the system must do during operation. It captures the tasks or activities performed by the system as a whole. For this reason, each function is formulated as an action beginning with "*to …*", such as "*to decide where to navigate*".

The resulting function set is divided into two main categories: platform functions and mission functions. Platform functions describe the fundamental activities that the LUSV must always be able to perform, regardless of mission configuration. Mission functions capture additional activities that are required only for specific mission types. Together, these functions form the functional backbone of the LUSV. An overview of this functional structure is presented in Figure 4.2, while a more detailed elaboration of the individual functions is provided in Appendix D.

4.1.2. Functions Analysis

	Functions																								
	Platform															Mission									
																Sense						MCM			ASW
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
	To decide where to navigate	To propel and steer	To receive fuel at sea	To control onboard damage autonomously	To support modular payloads	To enable safe crew embarkation	To launch and recover UxVs	To control UxVs	To sustain UxV operations	To employ surface weapons	To maintain communication links	To provide power	To transfer power	To store energy	To operate in rough seas	To sense the **surface** environment at **close range**	To sense the **subsurface** environment at **close range**	To sense the **surface** environment at **long range**	To sense the **subsurface** environment at **long range**	To detect electromagnetic emissions	To create a situational picture	To detect and locate naval mines	To inspect mines up close	To enable mine neutralisation	To employ subsurface weapons
Platform	12	21	9	12	9	12	9	9	18	9	37	18	18	12	44	30	12	10	1	4	27				
MCM											7						12		11			9	18	9	9
ISR											20					15	15	24	24	15	6				
CUI											15					18	30	18	24		6				
ASW		12									22	3			3		18		18		3				9

Figure 4.3: Function analysis (blue = critical function)

Figure 4.3 shows the cumulative score of each function in relation to the platform capabilities and the capabilities of the respective missions. The values in the table represent, for each function and capability category, the sum of the QFD relationship scores between that function and all capabilities in that category. A higher score therefore indicates that a function has more and/or stronger relationships with the capabilities in that category and thus plays a more significant role in supporting them.

Platform functions

For the platform capabilities, several functions receive noticeably higher scores than the others. These high-scoring functions indicate that they play a central role in supporting core platform capabilities. Based on their relative importance within the capability to function relationships, the key platform functions are:

- **11. To maintain communication links**
- **15. To operate up to the mission required sea state**
- **16. To sense the surface environment at close range**
- **21. To create a situational picture**

11. To maintain communication links, is key because it forms the connection between the LUSV, its operators, and other assets. Continuous communication is required for supervisory control and mission coordination. Without reliable communication, the platform cannot be monitored effectively and cannot contribute to coordinated operations.

15. To operate up to the mission required sea state, ensures that the platform remains functional when conditions become more demanding. If the LUSV cannot maintain its operational functionality under the sea state prescribed by the mission, its operational value decreases, since it would no longer be able to support activities under the required conditions.

16. To sense the surface environment at close range, supports safe navigation by detecting nearby vessels, objects, and hazards. Accurate close range sensing is essential for collision avoidance and contributes to short-range threat awareness, which is important for self-protection against small and fast-approaching threats.

21. To create a situational picture, integrates all available sensor information into a coherent and up-to-date representation of the environment. This function supports safe navigation, awareness of surrounding activity, and informed decision-making by the autonomous control system. Together with close-range sensing, it forms the basis of how the LUSV perceives and interprets its operational environment.

Mission Functions

MCM

For the MCM capabilities, the analysis shows that it is particularly important for the platform to detect underwater objects and support the execution of the dedicated MCM functions. The ability to sense the subsurface environment and identify mines is central to the MCM process.

ISR

For the ISR capabilities, the sense functions dominate the scoring. This is consistent with the core purpose of ISR, which is to collect information about the environment using sensors. The ability to detect and track contacts, observe behaviour, and construct an accurate situational picture forms the basis for producing meaningful intelligence. The analysis therefore highlights that ISR effectiveness primarily depends on the performance of the sensing functions.

CUI

For the CUI capabilities, we observe a pattern similar to ISR, with the sense functions again being the most influential. However, the emphasis shifts towards the subsurface domain. Monitoring underwater infrastructure requires continuous awareness of activity near cables, pipelines, or installations. The ability to sense the subsurface environment therefore becomes more prominent.

ASW

For the ASW capabilities, *"function 2. to propel and steer"* receives a higher score than in the other missions. This is explained by the additional requirement placed on the ASW platform to minimise underwater noise emissions, which is closely linked to propulsion behaviour. The analysis further shows that close range and long range subsurface sensing functions are the most important, which is logical given that ASW relies on detecting, classifying, and tracking underwater contacts. Finally, the *"function 26. to employ subsurface weapons"* also becomes relevant, since ASW requires not only the detection of threats but also the ability to counter them.

Critical Functions

Each function in the functional set contributes to the operational effectiveness of the LUSV. However, several functions can be identified as critical because the loss or degradation of these functions would directly affect platform controllability. These functions must remain operational at all times, including under degraded conditions. This is also observable in the QFD matrix, where these functions support the capability maintaining control during critical system faults. Based on the functional breakdown, the following functions can be classified as critical.

- *1. To decide where to navigate*
- *2. To propel and steer*
- *4. To control onboard damage autonomously*
- *6. To enable safe crew embarkation*
- *11. To maintain communication links*
- *12. To provide power*
- *13. To transfer power*
- *15. To operate up to the mission required sea state*
- *21. To create a situational picture*

Together, these critical functions define the minimum functional set that must remain available for the LUSV to maintain controllability and remain survivable under degraded conditions.

4.2. Design Property Matrix

Functions

Platform: 1–15 · Mission Sense: 16–21 · MCM: 22–24 · ASW: 25

Function numbers:
1. To decide where to navigate
2. To propel and steer
3. To receive fuel at sea
4. To control onboard damage autonomously
5. To support modular payloads
6. To enable safe crew embarkation
7. To launch and recover UxVs
8. To control UxVs
9. To sustain UxV operations
10. To employ surface weapons
11. To maintain communication links
12. To provide power
13. To transfer power
14. To store energy
15. To operate up to the mission-required sea state
16. To sense the **surface** environment at **close range**
17. To sense the **subsurface** environment at **close range**
18. To sense the **surface** environment at **long range**
19. To sense the **subsurface** environment at **long range**
20. To detect electromagnetic emissions
21. To create a situational picture
22. To detect and locate naval mines
23. To inspect mines up close
24. To enable mine neutralisation
25. To employ subsurface weapons

#	System (DPM)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	Total
1	IMMS	9			3	3		3	3	3	3	3					3	3	3	3	3	9				3	57
2	Hull		3													9											12
3	Propulsors		9													3											12
4	Maneuvering systems		9													3											12
5	ARAS system				9							1	3		3												16
6	Damage indication system					9																					9
7	Flexible payload area						9																				9
8	Embarkation systems							9																			9
9	Flightdeck							3	9																		12
10	LARS								9																		9
11	UxV resupply system									9																	9
12	Communication systems	1	1	3	1	1	3	1	9	3	3	9											3	1	1	3	43
13	Gun										9																9
14	Power generation system												9	3	3	3											18
15	Power distribution system												3	9	3												15
16	Energy storage									3			3	1	9	3											19
17	Optical/infrared camera	3															9	1				3					16
18	Navigation radar	3															9		3			3					18
19	Surface search radar	3															3		9			3					18
20	Hull mounted sonar																	9		9		3					21
21	Variable depth sonar																	9				3		3			15
22	Towed array sonar																			9		3					12
23	ESM																				9	3					12
24	MCM USV							3	3	3													9	3	3		24
25	MCM UAV							3	3	3							3		3			9	9				33
26	MCM UUV							3	3	3													3	9	9		30
27	Torpedo launcher																									9	9

Figure 4.4: Design Property Matrix

The Design Property Matrix (DPM) links the functions to the systems that must be implemented within the vessel to realise those functions. Where the QFD identifies what the platform must do, the DPM specifies which systems must be provided in order to enable these functions.

In the DPM, the functions are placed on one axis and the systems on the other. Each system is assessed for its level of contribution to a function using the same 9–3–1–0 scale that expresses a strong, moderate, weak, or no relationship. This structured mapping shows the dependencies between functions and the systems that enable them.

The completed DPM, shown in Figure 4.4, highlights the extent to which functions rely on specific systems. When a system exhibits high relationship values, it indicates that it supports a broad set of functions and therefore plays an important role in enabling the LUSV's overall performance. This applies, for example, to systems such as the Integrated Mission Management System (IMMS) and the communication systems, which show strong contributions across multiple functions.

4.2.1. Systems
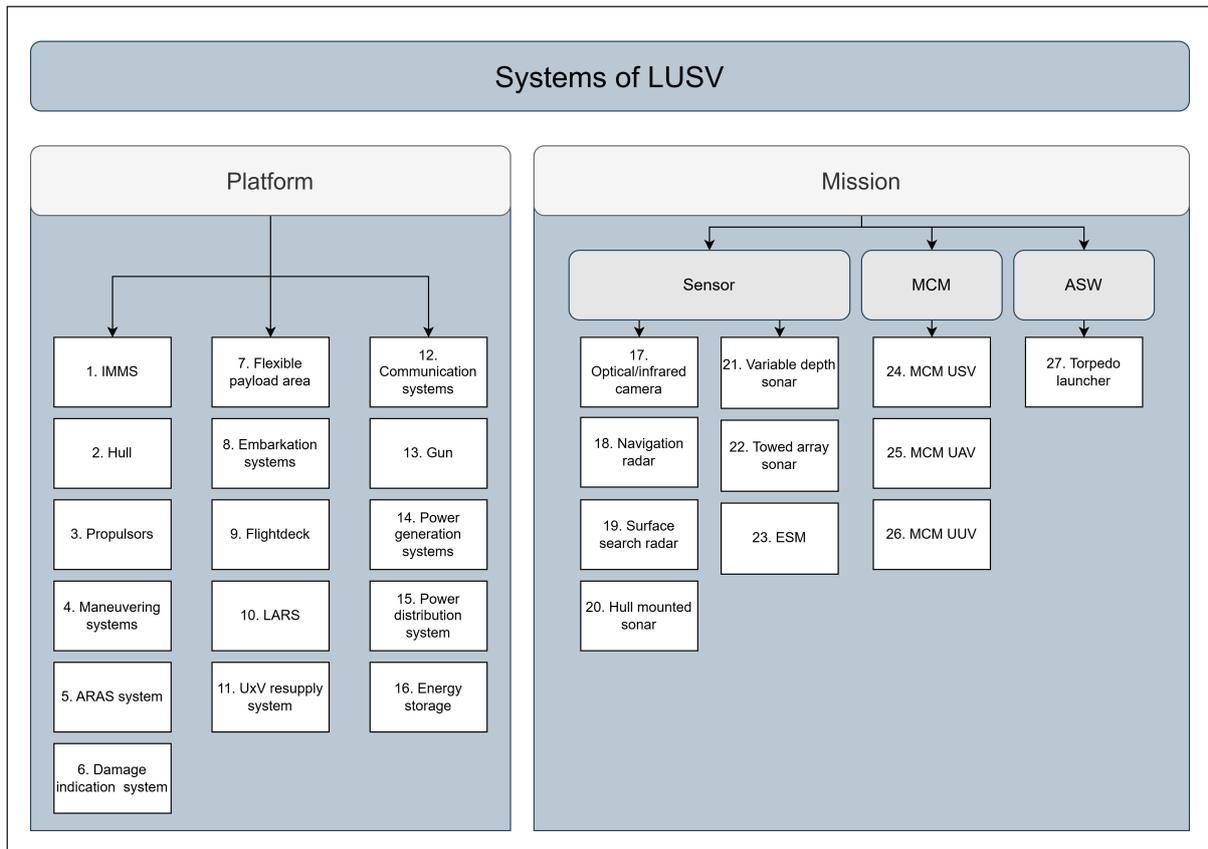
Figure 4.5: Systems breakdown

To realise the defined functions of the LUSV, a structured set of systems is defined. These systems represent the physical and logical building blocks that enable the platform to perform the required functions during operation. The system set was derived through the Design Property Matrix, in which each function was systematically linked to one or more systems. This ensures that every function identified in the previous section is supported by at least one system and that no system is included without a clear functional purpose.

In this research, a system is defined as an arrangement of parts or elements that together exhibit behaviour or meaning that the individual constituents do not, consistent with the system definition used by INCOSE [15]. This implies that each system contributes a specific set of capabilities to the vessel, and that the overall vessel capabilities emerge from the combined interaction of all systems.

The resulting system set is organised into platform systems and mission systems. Platform systems are required for all missions and enable the core operation of the LUSV, such as navigation, control, power generation, and communication. Mission systems represent additional systems that are only required to support specific mission types.

An overview of the system structure is presented in Figure 4.5. A more detailed description of the individual systems and their intended use is provided in Appendix E.

4.2.2. Critical Systems

In the same way that several functions were identified as critical to the operation of the LUSV, a corresponding set of systems can also be classified as critical. These systems are essential because the loss or degradation of any of them would directly affect the platform's ability to carry out its critical functions. As with the functional analysis, this is also reflected in the QFD and DPM matrices, where these systems consistently support the functions of maintaining control during faults.

Based on the linkage between functions and the systems that enable them, the following systems are classified as critical:

- *1. IMMS*
- *2. Hull*
- *3. Propulsors*
- *4. Maneuvering systems*
- *8. Embarkation systems*
- *12. Communication systems*

- *14. Power generation system*
- *15. Power distribution system*
- *17. Optical/infrared camera*
- *18. Navigation radar*
- *20. Hull mounted sonar*

Together, these systems define the minimum system set that must remain available for the LUSV to continue performing its critical functions and to remain controllable and survivable under degraded conditions.

4.3. Module Indication Matrix

4.3.1. Questionnaire

In the Module Indication Matrix, twelve modularity drivers are used to assess the suitability of systems for modular implementation. Together, these drivers provide a comprehensive view of modularity by covering the full product life cycle, including development, integration, operation, maintenance, and future adaptation. In addition, the drivers reflect a broad range of stakeholder perspectives, ensuring that modularisation decisions are not based solely on technical considerations, but also take operational and life-cycle aspects into account.

The questions below correspond to the twelve modularity drivers and provide the scoring options between brackets, following a 9–3–1 scale.[9]

1. **Different specification** – To what extent is this system influenced by specific requirements [strongly, fairly, to some extent, not]?

2. **Styling** – To what extent is this system influenced by trends and fashion such that its form and/or colour must be altered or tied to a trademark [strongly, fairly, to some extent, not]?

3. **Carry over** – To what extent are there reasons that this system should be a separate module because the design can be carried over to future product generations [strong, medium, any, no]?

4. **Technology push** – To what extent is there a risk that this system will undergo a technology shift during the product lifecycle [great, medium, some, no]?

5. **Product planning** – To what extent are there reasons that this system should be a separate module because it carries attributes that will change according to the product plan [strong, medium, some, no]?

6. **Common unit** – To what extent can this system have the same physical form across product variants [all, most, some, none]?

7. **Process and organisation** – To what extent are there reasons that this system should be a separate module because of

    (a) a specialised process is needed?

    (b) it has suitable work content for a group?

    (c) a pedagogical assembly can be formed?

    (d) the lead time will differ extraordinary?

    [strong, medium, some, no]?

8. **Separate testing** – To what extent are there reasons that this system should be a separate module because its function can be tested independently [strong, medium, some, no]?

9. **Purchase** – To what extent are there reasons that this system should be a separate module because

    (a) there are specialists can deliver it as a black box?

    (b) logistics cost can be reduced?

    (c) manufacturing and development capacity can be balanced ?

    [strong, medium, some, no]?

10. **Service and maintenance** – To what extent would service and maintenance activities be easier if this system were easy to detach [all, most, some, none]?

11. **Upgrading** – To what extent could future upgrades be simplified if this system were easy to replace or change [all, most, some, none]?

12. **Recycling** – To what extent can highly polluting or easily recyclable materials be recycled within this system [all, most, some, none]?

4.3.2. MIM Matrix

| | | | Modularity drivers | | | | | | | | | | | | | | |
| | | | Different specification | Styling | Carry over | Technology push | Product planning | Common unit | Process and/or organisation | Separate testing | Purchase | Service and maintenance | Upgrading | Recycling | | Modular implementation |
Number		MIM	1	2	3	4	5	6	7	8	9	10	11	12		
Systems	Platform	1 IMMS			1	1	3	9	1	1	9	1	3	1	30	
		2 Hull											3		3	
		3 Propulsors			1	1	1		3	3	3	3	1	1	17	
		4 Maneuvering systems			1	1	1		3	3	3	3	1	1	17	
		5 ARAS system	3		9	9	3	9	9	9	9	9	9	1	79	x
		6 Damage indication system	1		1	3	1	9	1	3	9	1	1	1	31	
		7 Flexible payload area				3								3	6	
		8 Embarkation systems	1		3	1	1	9	3	3	3	9	9	3	45	x
		9 Flightdeck	3					3						3	9	
		10 LARS	9		9	3	3	3	3	9	9	9	9	3	69	x
		11 UxV resupply system	9		9	9	9	3	9	9	9	9	9	1	85	x
		12 Communication systems			3	3	3	9	3	9	9	3	9	1	52	x
		13 Gun	1		3	3	3	9	9	9	9	9	9	1	61	x
		14 Power generation system			3	3	3	3	3	9	9	9	9	1	52	x
		15 Power distribution system			1	1	1	3	1	1	3	1	1	1	14	
		16 Energy storage	3		1	3	3	3	1	3	3	3	3	3	29	
	Mission / Sensors	17 Optical/infrared camera	3		9	3	9	9	9	9	9	9	9	1	79	x
		18 Navigation radar	3		9	3	9	9	9	9	9	9	9	1	79	x
		19 Surface search radar	9		9	3	9	9	9	9	9	9	9	1	85	x
		20 Hull mounted sonar	9		9	3	9	9	9	9	9	9	9	1	85	x
		21 Variable depth sonar	9		9	3	9	9	9	9	9	9	9	1	85	x
		22 Towed array sonar	9		9	3	9	9	9	9	9	9	9	1	85	x
		23 Electronic support measures	9		9	3	9	9	9	9	9	9	9	1	85	x
	MCM	24 MCM USV	9		9	9	9	9	9	9	9	9	9	1	91	x
		25 MCM UAV	9		9	9	9	9	9	9	9	9	9	1	91	x
		26 MCM UUV	9		9	9	9	9	9	9	9	9	9	1	91	x
	ASW	27 Torpedo launcher	9		9	3	3	9	9	9	9	3	9	3	75	x
			117	0	144	95	128	165	148	170	186	162	172	43		

Figure 4.6: Module Indication Matrix

The Module Indication Matrix (MIM) was initially populated by the author. The resulting scores were subsequently reviewed with experienced engineers from Damen Naval, providing a practical validation of the modularity assessments.

The second column from the right of the MIM shows the cumulative scores of each system across the modularity drivers. These values provide an initial point of reference for assessing whether a system may be suitable for modular implementation. The rightmost column indicates whether a system is ultimately considered to be implemented as a module. The rationale behind these decisions is discussed in the following paragraphs.

Integrated Platform Systems

The systems that are not selected for modular implementation include the IMMS, hull, propulsors, manoeuvring systems, damage indication systems, flexible payload area, power distribution system, and energy storage. All of these systems achieve relatively low modularity scores, with values below 31, which provides limited indication that modularisation would be beneficial.

A common characteristic of these systems is their high degree of structural or functional integration within the platform. The hull forms the permanent structural backbone of the vessel, on which all other systems are arranged, making modularisation illogical and impractical. Similarly, the propulsors and manoeuvring systems are closely coupled to the hull, which limits the feasibility of treating them as separate modules. The IMMS, damage indication system, and the power distribution system are all functionally and spatially integrated within the platform, and therefore it is not logical to implement these systems in a modular manner. Finally, the case for energy storage system is more nuanced. Certain energy storage technologies lend themselves better to modular implementation than others. Conventional solutions such as diesel fuel tanks are typically highly integrated into the platform, whereas alternative technologies, such as battery systems, can be more easily implemented in a modular manner. However, within this concept, energy storage is treated as an integrated system.

Modular Platform Systems

Several platform systems are selected for modular implementation based on their relatively high modularity scores and the logical suitability of these systems for a modular approach. These systems include the Autonomous Refuelling at Sea (ARAS) system, embarkation systems, Launch and Recovery Systems (LARS), the UxV resupply system, communication systems, the gun system, and the power generation system.

The ARAS system can logically be implemented as a module, as it supports a distinct and largely self-contained function with limited interaction with other systems. Embarkation systems show similar characteristics, as they also provide a standalone operational function.

LARS and the UxV resupply system are closely related, as both are directly linked to the operation and sustainment of unmanned assets. These systems are strongly dependent on the type, size, and number of unmanned vehicles employed. Modular implementation allows these systems to be adapted when different unmanned assets are used, without requiring changes to the core platform.

Communication systems and the gun system each support a largely self contained function. Their interfaces with other systems are primarily limited to power and command and control, which makes them suitable candidates for modular implementation. Finally, the power generation system is selected for modularisation to allow flexibility in installed capacity, support mission dependent power demands, and facilitate maintenance or future technology upgrades. Taken together, these reasons indicate that modular implementation of these platform systems is logical within this concept.

Modular Mission Systems

All mission systems are selected for modular implementation. These systems consistently achieve high modularity scores in the MIM, which provides a strong initial indication that a modular approach is appropriate. A defining characteristic of mission systems is their strong dependency on the specific mission being executed. Mission systems are therefore expected to vary between mission types, configurations, and future capability updates. Implementing these systems as modules allows mission specific capabilities to be added, removed, or replaced without affecting the integrated core of the platform.

In addition, many mission systems exhibit limited structural and functional coupling with other platform systems. This makes them well suited for modular implementation. Modular mission systems also support flexibility in fleet configuration, facilitate upgrades and technology insertion, and reduce the impact of mission specific changes on the platform. Taken together, the MIM results and the mission dependent nature of these systems indicate that modular implementation of all mission systems is logical within this concept.

4.3.3. Types Of Modularity

The MIM analysis indicates which systems are more likely to benefit from modularity and which systems are selected to be implemented in a modular manner. But it does not yet specify which type of modularity is applicable. Figure 4.7 illustrates the different types of modularity. A first distinction is made between modularity with a main body and modularity without a main body. Since a LUSV requires a permanent hull that forms the structural and functional backbone of the platform, only modularity with a main body is considered relevant for this design.

Figure 4.7: Types of modularity[16]

Within modularity with a main body, two types are applicable: component swapping modularity and bus modularity. Component swapping modularity is characterized by diverse interfaces and allows individual components to be replaced or upgraded independently. This type of modularity is particularly suitable for equipment where rapid replacement or upgrade is beneficial. Bus modularity, on the other hand, is based on standardized and identical interfaces. This allows multiple systems to connect to a common interface, making it especially suitable for mission systems. An example of bus modularity is the integration of mission systems using standardized container interfaces. Both types of modularity are therefore considered applicable within the LUSV design.[16]
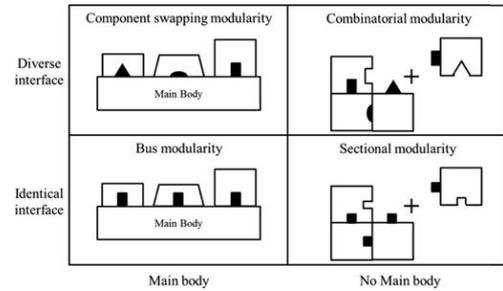
4.4. Interface Matrix

The following matrix (Figure 4.8) lists the systems numbered 1–27:

1 IMMS, 2 Hull, 3 Propulsors, 4 Maneuvering systems, 5 ARAS system, 6 Damage indication system, 7 Flexible payload area, 8 Embarkation systems, 9 Flightdeck, 10 LARS, 11 UxV resupply system, 12 Communication systems, 13 Gun, 14 Power generation system, 15 Power distribution system, 16 Energy storage, 17 Optical/infrared camera, 18 Navigation radar, 19 Surface search radar, 20 Hull mounted sonar, 21 Variable depth sonar, 22 Towed array sonar, 23 Electronic support measures, 24 MCM USV, 25 MCM UAV, 26 MCM UUV, 27 Torpedo launcher.

#	Interface	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
1	IMMS	C	C	C	C	C	C		C	C	C	C	C	C,T	C	C	C	C	C	C	C	C	C	C	C	C
2	Hull	A	A	A	A	A	A	A	A	A									A							
3	Propulsors		S										T					S								
4	Maneuvering systems												T													
5	ARAS system												T	T												
6	Damage indication system												T													
7	Flexible payload area						S	S	S				T							S	S	S	S	S	S	
8	Embarkation systems												T													
9	Flightdeck									S														A		
10	LARS									S			T										A		A	
11	UxV resupply system												T										A,T	A,T	A,T	
12	Communication systems												T										C	C	C	
13	Gun												T			A		C								
14	Power generation system													A,T	T											
15	Power distribution system														A,T	T	T	T	T	T	T	T				T
16	Energy storage																									
17	Optical/infrared camera																									
18	Navigation radar																									
19	Surface search radar																									
20	Hull mounted sonar																									
21	Variable depth sonar																									
22	Towed array sonar																									
23	Electronic support measures																									
24	MCM USV																							C	A,C	
25	MCM UAV																									
26	MCM UUV																									
27	Torpedo launcher																									

Figure 4.8: Interface matrix

The interface matrix provides an overview of the preliminary interfaces between the selected systems. Systems are characterized using a consistent interface taxonomy consisting of attachment, transfer, command and control, and spatial interfaces.

The matrix shows that most systems have a command and control interface with the Integrated Machinery Management System (IMMS), as this system is responsible for monitoring and controlling a large part of the platform and mission systems. Many platform systems are physically attached to the hull, reflecting the hull's role as the main structural element of the vessel. The hull mounted sonar is also directly attached to the hull, as indicated by its name.

The matrix shows that all systems, with the exception of the hull and the UxVs, are connected to the power distribution system. This reflects the fact that power is required for the operation of nearly all onboard systems. The UxVs are indirectly connected to the power distribution system through the UxV resupply system, which provides power for charging and support functions. Variable depth sonar, towed array sonar, electronic support measures (ESM), and the UxVs show a spatial interface with the payload area, as these systems require space for deployment, storage, or operation.

Finally, the UxVs show attachment interfaces with the Launch and Recovery System (LARS) and the UxV resupply system. These interfaces reflect the physical and functional dependencies required to deploy, recover, and sustain UxVs.

The interface matrix can be used during the design process to verify that systems are placed logically within the platform.

5

Concept Definition

Following the needs analysis and the MFD presented in the previous chapters, this chapter addresses the concept definition stage of the research. As indicated in Figure 5.1, this phase focuses on translating the derived functional and system level insights into coherent platform and fleet concepts for the LUSV.

The objective of this chapter is to explore how the identified missions, functions, systems, and modularity considerations can be combined into alternative platform concepts. Rather than converging directly on a single solution, multiple concepts are defined to represent different design philosophies with respect to mission flexibility, platform optimisation, and fleet composition.

To support this process, the chapter first analyses the distribution of systems across mission types. The outcomes of this analysis, together with the results of the preceding chapters, form the basis for the formulation of four LUSV concepts: a Universal LUSV concept, a Mission-Based concept, a Propulsion-Based concept, and a Specialised Fleet concept. In doing so, this chapter addresses the fourth research sub-question: *How can multiple LUSV concept variants be defined based on the identified systems and capabilities?*
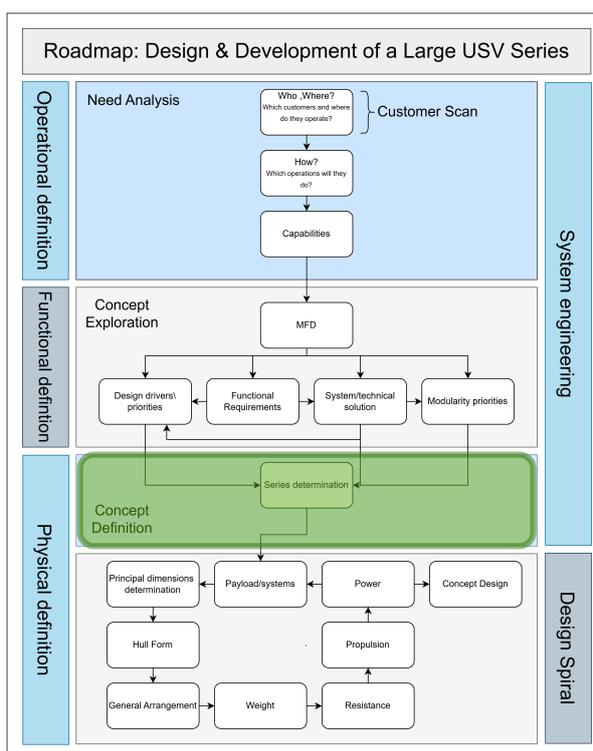

Figure 5.1: Roadmap: stage in Chapter 5

5.1. System Analysis

First, an analysis is performed to determine which systems are required for each mission type. The results of this analysis are subsequently used as input for the development of the concepts.

All platform systems are required for every mission, as the platform forms the basis of the vessel and is therefore always in use regardless of mission type.

For sensor systems, not every sensor is required for every mission. The systems *'17. Optical/infrared camera'* and *'18. Navigation radar'* are both essential for navigation and are therefore required for all mission profiles. In addition *'19. Surface search radar'* is required for all missions, as it supports self defence functions and contributes to building a long range situational picture. The *'20. Hull mounted sonar'* is also required for all missions in order to obtain a subsurface picture. From a navigation perspective, this system is necessary to detect underwater obstacles and prevent collisions. However, for all the missions additional requirements apply. In these missions, the hull mounted sonar must not only detect obstacles but also be capable of detecting and tracking underwater contacts and providing a reliable seabed picture. As a result, the hull mounted sonar must meet two different sets of performance requirements depending on the use.

The *'21. Variable depth sonar'* is important for several missions because it improves underwater detection performance compared to relying solely on a hull mounted sonar. A variable depth sonar can operate at different depths, allowing it to mitigate the effects of the thermocline, which can reflect or refract sound and limit sonar performance. By operating below or within this layer, underwater objects at greater depths can be detected that might otherwise remain undetected. The variable depth sonar is an active sonar system, while its passive counterpart is *'22. Towed array sonar'*. Towed array sonar provides the capability to detect and track underwater contacts based on emitted noise rather than active transmissions. These systems are required for the ISR, CUI, and ASW missions. For MCM missions, passive sonar does not provide a significant advantage over active detection methods and is therefore not required. [17, 18]

System *'23. Electronic support measures'* is required only for the CUI and ISR missions, as these missions benefit from the ability to detect, classify, and analyse electromagnetic emissions to improve situational awareness. [19]

Systems *'24. MCM USV'*, *'25. MCM UAV'*, and *'26. MCM UUV'* are exclusively required for MCM missions. These unmanned systems are essential for the execution of MCM operations and form the core of the mission capability. While unmanned systems could also provide added value in other missions, they are not core systems in those cases.

Finally, system *'27. Torpedo launcher'* is required only for ASW missions, as it provides an effector capable of neutralising underwater threats during ASW operations.

The results of the reasoning presented above are included in the Table 5.1 .

Systems		Number	Name	Mission (which systems are needed for the mission)			
				MCM	ISR	CUI	ASW
Platform		1	IMMS	x	x	x	x
		2	Hull	x	x	x	x
		3	Propulsors	x	x	x	x
		4	Maneuvering systems	x	x	x	x
		5	ARAS system	x	x	x	x
		6	Damage indication system	x	x	x	x
		7	Flexible payload area	x	x	x	x
		8	Embarkation systems	x	x	x	x
		9	Flightdeck	x	x	x	x
		10	LARS	x	x	x	x
		11	UxV resupply system	x	x	x	x
		12	Communication systems	x	x	x	x
		13	Gun	x	x	x	x
		14	Power generation system	x	x	x	x
		15	Power distribution system	x	x	x	x
		16	Energy storage	x	x	x	x
Mission	Sensors	17	Optical/infrared camera	x	x	x	x
		18	Navigation radar	x	x	x	x
		19	Surface search radar	x	x	x	x
		20	Hull mounted sonar	x	x	x	x
		21	Variable depth sonar	x	x	x	x
		22	Towed array sonar		x	x	x
		23	ESM		x	x	
	MCM	24	MCM USV	x			
		25	MCM UAV	x			
		26	MCM UUV	x			
	ASW	27	Torpedo launcher				x

Table 5.1: System analysis

5.2. Defining The Concepts

The objective of this section is to define and structure a set of LUSV platform concepts based on the results of the preceding work. The earlier analyses have established a clear understanding of the operational needs, functional demands, and system-level implications associated with future LUSV employment. Building on this basis, multiple platform concepts are formulated to explore how these requirements can be translated into alternative fleet and platform configurations.

Rather than converging directly on a single solution, several alternative concepts are defined. Each concept represents a different design philosophy with respect to mission flexibility, platform optimisation, and fleet composition. Defining multiple concepts enables a structured comparison and allows trade-offs to be assessed at a later stage of this research.

Four concepts are defined in this section: a Universal LUSV concept, a Mission Based concept, a Propulsion Based concept, and a Specialized Fleet concept. Together, these concepts span a range of approaches from maximum platform commonality to maximum mission specific optimisation. An overview of the concepts is provided in Figure 5.2. The following subsections describe the assumptions, fleet composition, and intended role of each concept in more detail.
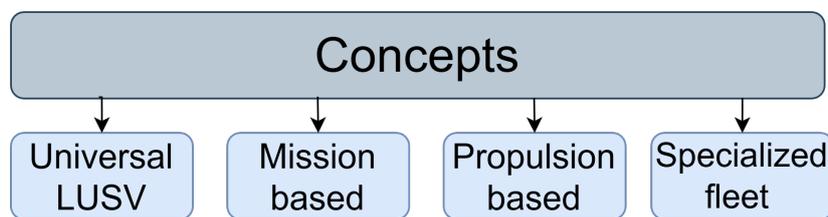

Figure 5.2: Concept overview

5.2.1. Universal LUSV

The Universal LUSV concept is based on a single platform type that is capable of executing all selected mission types. Within this concept, all platform and mission systems are integrated into one vessel design. The Universal LUSV therefore represents a maximally flexible solution, capable of supporting MCM, ISR, CUI, and ASW operations using a common platform architecture. A key assumption within this concept is that not all mission capabilities need to be employed simultaneously. Instead, the vessel must be capable of executing at least one mission at any given time. Mission systems may therefore be reconfigured between deployments, allowing the platform to adapt its role without requiring structural modifications. This approach limits system complexity while retaining a broad mission portfolio.

The Universal LUSV relies heavily on modular mission systems and flexible payload integration to support its wide range of tasks. By exchanging mission-specific modules and unmanned assets, the vessel can transition between mission roles while maintaining a stable core platform. This concept prioritises fleet simplicity and commonality, as only one vessel type is required to cover all missions.

However, the integration of all systems into a single platform introduces design trade-offs. Requirements for low acoustic signatures, high endurance, sensor performance, and payload flexibility must all be balanced within one design. As a result, the Universal LUSV is expected to be a compromise solution rather than an optimised platform for any single mission type.

5.2.2. Mission Based Concept

Mission Grouping

In the previous phases, several missions with high potential for execution by a LUSV were identified and analysed. Rather than selecting a single mission, the focus of this concept is on grouping missions in a logical manner based on their system requirements.

When comparing the required systems for each mission, as shown in Figure 5.1, a clear distinction can be observed between MCM missions and the other mission types: ISR, CUI, and ASW. MCM missions rely less on onboard sensor systems and instead depend primarily on unmanned assets such as USVs, UAVs, and UUVs to execute their core tasks.

Figure 5.3: Mission grouping

In contrast, ISR/CUI/ASW missions require a comprehensive set of onboard sensors. These missions show significant overlap in sensor types and system capabilities, indicating a high degree of commonality. Based on these similarities and differences in system requirements, the missions can be logically grouped into two categories: MCM and ISR/CUI/ASW

Fleet Composition

Based on this distinction, it is a logical design choice to separate these mission groups into different vessel types. The LUSV fleet within this concept therefore consists of two distinct vessel types.

The first vessel type is dedicated to MCM missions. This vessel is equipped with the full set of platform systems, supplemented with the mission specific systems required to support MCM operations.

Figure 5.4: Mission based fleet decomposition

The second vessel type is designed to perform ISR, CUI, and ASW missions. This vessel also incorporates the complete set of platform systems, combined with the sensor systems and mission-specific systems required to conduct ISR, CUI, and ASW operations. It is not assumed that all three missions must be executed simultaneously. Instead, the vessel must be capable of performing at least one of these missions at any given time, while allowing efficient switching between ISR, CUI, and ASW roles through reconfiguration.

This fleet decomposition allows each vessel type to be optimised for its respective mission set.
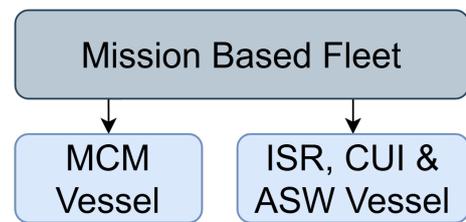
5.2.3. Propulsion Based Concept

In this concept, the LUSV design is approached from a propulsion driven perspective. The objective of this concept is to assess whether differences in propulsion requirements across mission types lead to a logical division within the LUSV fleet. Propulsion is considered a primary design driver, as it directly affects platform performance and acoustic signature.

When analysing the propulsion requirements of the different mission types, a clear distinction emerges between ASW missions and the remaining missions. For MCM, ISR, and CUI missions, the propulsion demands are relatively moderate. These missions operate at cruising speeds of 18 knots and emphasise endurance. In MCM operations, the LUSV mainly serves as a host and support platform for UxVs, while ISR and CUI missions focus on persistent presence and area coverage. As a result, propulsion requirements for these missions are driven by efficiency and reliability, rather than by high speed or stringent acoustic constraints.

Figure 5.5: Propulsion requirements distribution

In contrast, ASW missions impose different propulsion requirements. Effective ASW operations depend on the performance of sonar systems, which are highly sensitive to noise generated by the propulsion system. Minimising underwater radiated noise therefore becomes a key requirement, placing strong constraints on drivetrain configuration and operating modes. In addition, ASW missions require a significantly higher maximum speed, specified as 30 knots in sea state 3, to enable rapid repositioning and effective cooperation with other ASW units.

This propulsion based analysis suggests a potential fleet level distinction, where a subset of LUSVs is optimised for low acoustic signature and high speed performance to support ASW missions, while another subset is optimised for MCM, ISR, and CUI missions. This concept provides an alternative basis for defining LUSV variants and is evaluated further in the subsequent design phases.

Fleet Composition

Within the propulsion based concept, the LUSV fleet is composed of two distinct vessel types. This division follows directly from the fundamentally different propulsion requirements associated with ASW missions compared to MCM, ISR, and CUI missions.

The first vessel type is dedicated to ASW missions. This vessel is equipped with a propulsion system designed to minimise underwater radiated noise while still providing sufficient installed power to enable a maximum speed of 30 knots. Noise reduction is assumed to be achieved through the application of dedicated measures, such as vibration isolation and low-noise propulsion components. At the same time, a relatively high installed power is

Figure 5.6: Propulsion based fleet decomposition

required to meet the high speed requirement. As a result of the combination of additional noise mitigation measures and increased installed power, this propulsion system is assumed to be more complex and costly than the propulsion system applied to the other vessel types. In addition to the standard platform systems, this vessel integrates the mission-specific systems required for ASW operations.

The second vessel type is intended to perform MCM, ISR, and CUI missions. This vessel employs a other propulsion system than the ASW variant. The ship incorporates the full set of platform systems, supplemented with the mission specific systems required to support MCM, ISR, and CUI operations.

This fleet composition allows each vessel type to be optimised for its propulsion-driven mission profile, while grouping mission types that share similar propulsion requirements within the same vessel class
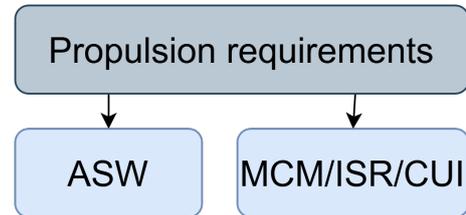
5.2.4. Specialized Fleet Concept

The Specialized Fleet Concept represents the most differentiated approach among the defined concepts. Whereas the mission based and propulsion based concepts each apply a single primary division criterion, this concept combines both mission specific and propulsion driven distinctions. As a result, the fleet is divided into multiple vessel types, each optimised for a narrowly defined mission set.

Within this concept, ASW operations are separated into a dedicated vessel type based on their distinct propulsion requirements, particularly the need for low acoustic signature and higher maximum speed. MCM operations are assigned to a dedicated vessel type based on their fundamentally different mission system requirements and reliance on unmanned assets. ISR and CUI missions are combined into a single vessel type, as both missions require largely overlapping mission systems and sensor capabilities.
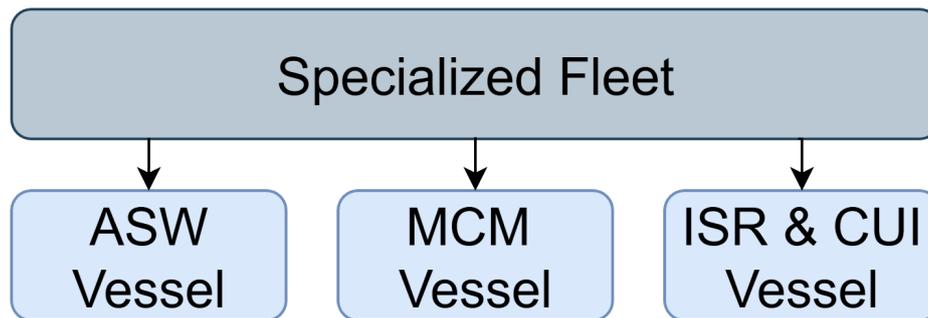
Fleet Composition

Figure 5.7: Specialized fleet decomposition

The Specialized Fleet Concept consists of three distinct vessel types, defined by applying both mission driven and propulsion driven distinctions simultaneously.

The first vessel type is dedicated exclusively to ASW missions. This vessel is designed to meet the same propulsion and acoustic requirements as defined in the propulsion based concept, including minimised underwater radiated noise and high speed capability. As the operational and technical requirements for ASW remain unchanged, this vessel type is identical to the ASW vessel defined in the propulsion based concept.

The second vessel type is dedicated to MCM missions. This vessel fulfils the same role and is subject to the same mission system requirements as the MCM vessel defined in the mission based concept. It primarily functions as a host, control, and support platform for unmanned MCM systems. As the underlying requirements are identical, this vessel type is the same as the MCM vessel defined in the mission based concept.

The third vessel type is designed to perform ISR and CUI missions. These missions are combined into a single vessel type because they require largely identical mission systems. While ISR and CUI differ in operational focus, with ISR primarily oriented towards the surface domains and CUI focused on the subsurface domain, these differences do not necessitate separate platform designs. This ISR/CUI vessel therefore represents the only additional vessel type introduced by the Specialized Fleet Concept.

In this way, the Specialized Fleet Concept reuses the vessel types already defined in the mission based and propulsion based concepts where the requirements are identical, while introducing a dedicated ISR/CUI vessel to fill the gap between the specialised ASW and MCM vessels.

6

Concept Development

Following the concept definition stage presented in the previous chapter, this chapter addresses the concept development phase of the research. As indicated in Figure 6.1, this phase focuses on further elaborating the defined LUSV concepts in order to assess their feasibility and relative potential.

The objective of this chapter is to develop the previously defined LUSV concepts to a level of detail that allows a meaningful comparison between them. This is achieved by estimating key system characteristics, power demand and configuration, and weight for each concept. These analyses are conducted at a conceptual level and are intended to provide realistic order-of-magnitude estimates rather than detailed design solutions.

By applying a consistent set of assumptions and reference data across all concepts, the chapter enables a structured comparison of the different concept variants. This supports the identification of key trade-offs and provides insight into how the concepts take shape when developed further.

In doing so, this chapter addresses the fifth research sub-question: *What do the resulting LUSV concepts look like when developed at a conceptual level, and which concepts show the greatest potential?*
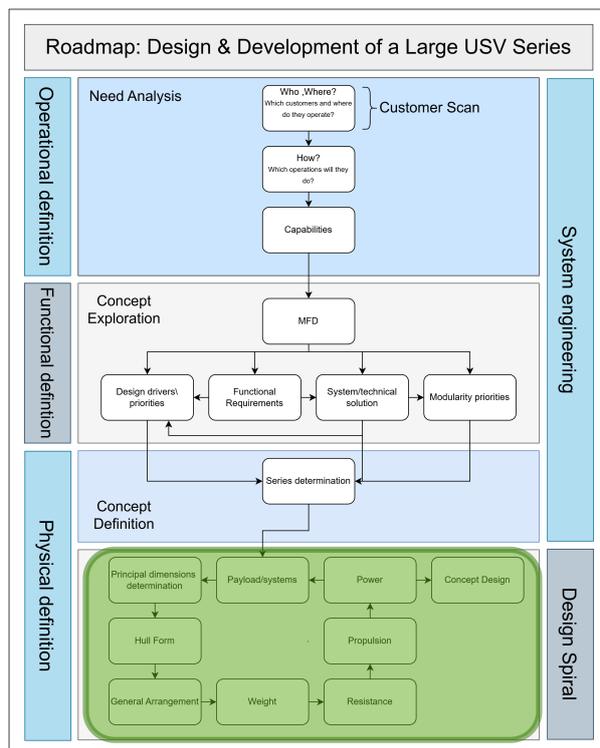

Figure 6.1: Roadmap: stage in Chapter 6

6.1. System Characteristics

In order to further develop the previously defined concepts and to enable a meaningful comparison between them, an estimation of the main system characteristics is required. The objective of this analysis is not to describe every system in full technical detail, but rather to obtain a realistic order of magnitude estimate of the dimensions and mass of the subsystems. This level of fidelity is sufficient to assess the overall feasibility of the concepts and to support a consistent comparison between the concepts.

Not all identified subsystems are considered design driving. Several subsystems are assumed to have a relatively small size and mass and are therefore considered to have a negligible influence on the overall feasibility and principal dimensions of the platform. These subsystems are excluded from the sizing analysis. The following subsystems are considered non–size-driving and are not further considered in the development of the concepts:

- *1. IMMS*
- *6. Damage indication system*
- *12. Communications system*
- *16. Power distribution system*
- *17. Optical/infrared camera*
- *20. Hull mounted sonar(partly)*

The hull mounted sonar is only partly considered non size driving, as its size strongly depends on the required performance. A small sonar is sufficient for navigation support and obstacle avoidance, whereas a mission-oriented hull mounted sonar requires a substantially larger sensor and installation volume.

For the remaining systems that are considered size driving, mass, dimensional, and power estimates were derived based on existing systems and publicly available manufacturer data. The objective of this analysis is not to determine precise specifications, but to establish orders of magnitude that reflect the relative scale of the various subsystems. Where publicly available manufacturer data or reference designs were available, these were used to inform the estimates. In cases where such data was incomplete, inconsistent, or unavailable, coarse engineering estimates were applied. Dimensions were assessed on a metre-scale, mass was estimated in tonnes, and power requirements were selected from a limited set of representative values rather than treated as continuous variables. This approach ensures that the resulting values are realistic and suitable for the scope of this study. The resulting system characteristics are summarised in Table 6.1. These values form the basis for the further development of these concepts.

		Number	Name	Size driving	L (m)	B (m)	H (m)	Weight (t)	Power (kW)	Notes
Platform		1	IMMS	No					5	
		2	Hull	Yes	TBD					
		3	Propulsors	Yes	TBD					
		4	Maneuvering systems	Yes	TBD					
		5	ARAS system	Yes	2	2	1.5	4	25	
		6	Damage indication system	No					5	
		7	Flexible payload area	Yes	20+	8+	x	TBD		
		8	Embarkation systems	Yes	2	2	2	2		
		9	Flightdeck	Yes	10+	10+	x	TBD		
		10	LARS	Yes	Included in UxV's					
		11	UxV resupply system	Yes	6	3	3	8	50	New technology / 1 TEU
		12	Communication systems	No					10	
		13	Gun	Yes	4	2.5	2.5	3		Above deck
					2	2	2	2	20	Below deck
		14	Power generation system	Yes	TBD					
		15	Power distribution system	No					50	
		16	Energy storage	Yes	TBD					
Mission	**Sensors**	17	Optical/infrared camera	No					5	
		18	Navigation radar	Yes	3	1	1	2	20	1 solution for both systems
		19	Surface search radar	Yes						
		20	Hull mounted sonar	No					2	Navigation HMS
				Yes	1	1	3	8	50	Mission HMS
		21	Variable depth sonar	Yes	9	3	3	9	100	1 TEU + 1 TEU Support
		22	Towed array sonar	Yes						
		23	Electronic support measures	Yes	6	3	3	5	50	1 TEU
	MCM	24	MCM USV	Yes	13	5	5	19	20	Only USV
					14	6	6	10		LARS
		25	MCM UAV	Yes	4	2	2	0.25	20	Only UAV
					10	10	x	1		LARS
		26	MCM UUV	Yes	5	1	1	0.5	20	Only UUV
					6	3	3	4		LARS
	ASW	27	Torpedo launcher	Yes	6	3	3	3	10	1 TEU

Table 6.1: System characteristics [20, 21, 22, 23, 24, 25, 26, 27, 28, 29]

6.2. Power Estimation

In order to obtain a first-order estimate of the required onboard power generation capacity, a conceptual power estimation is performed. This estimation is intended to determine the order of magnitude of the required power and does not represent a detailed resistance or propulsion analysis.

The total power demand of the platform can be divided into two main categories:

- **Propulsion power**: power required for ship propulsion.
- **Mission & Auxiliary power**: electrical power required for all non-propulsion systems supporting vessel operation and mission execution, including navigation and communication equipment, control and monitoring systems, pumps, sensors, and mission-specific system.

6.2.1. Propulsion power

In order to obtain a first-order estimate of the required propulsion power, a conceptual resistance and propulsion analysis is performed using NavCad. NavCad is naval architecture software that allows the estimation of resistance and propulsion performance based on different methods.[30]

For this analysis, the Hard Chine method developed by De Groot is applied. This method was selected because it is the most suitable for the present case. The principal parameters of the proposed platforms fall within the recommended ranges of this method. These parameters include the Froude number, the length-to-beam ratio (L/B), the beam-to-draft ratio (B/T), and the maximum section coefficient (C_x). The vessels are expected to operate at relatively high Froude numbers, with a maximum value of 0.78. Methods such as Holtrop and Mennen are less suitable for this case, as they are primarily intended for vessels operating within a Froude number of approximately 0.5 or lower.

Two platform sizes are considered in the concept design: a small platform with a length of 40 m and a large platform with a length of 53 m. For both platforms, two speed requirements are defined, namely 18 knots and 30 knots. The rationale behind these platform sizes and speed requirements will be further explained in the concept description presented later in this report.

Small Platform

For the small platform, the required propulsion power obtained from the NavCad analysis amounts to 1652 kW for a speed of 18 knots. For a speed of 30 knots, the required propulsion power increases to 5577 kW.

Speed (kts)	Calculated Power (kW)	Assumed Power (kW)
18	1652	1825
30	5577	6150

Table 6.2: Propulsion power levels small platform

Big Platform

For the large platform, the required propulsion power is estimated at 2034 kW for a speed of 18 knots. At a speed of 30 knots, the required propulsion power increases to 8929 kW.

Speed (kts)	Calculated Power (kW)	Assumed Power (kW)
18	2034	2250
30	8929	9850

Table 6.3: Propulsion power levels big platform

These values are used as representative propulsion power levels. To account for the uncertainties associated with the estimation method and to ensure sufficient installed propulsion power, a margin of approximately 10% has been added to the calculated power levels. The resulting increased values are adopted as the assumed propulsion power levels and are used as the basis for all subsequent work. This conservative approach is considered appropriate given the early design phase and the objective of obtaining order-of-magnitude estimates.

These power levels are consistent with the installed propulsion power of comparable reference vessels such as the *Damen FCS 4208* and the *Damen FCS 5209* when scaled to the corresponding design speeds. The obtained values therefore provide a realistic order-of-magnitude estimate of the propulsion power requirements for the proposed platforms [31][32].

6.2.2. Mission & Auxiliary power

Based on Table 6.1, the combined electrical power demand of the mission and auxiliary systems is estimated at 462 kW. To account for uncertainties inherent to this early design stage, an uncertainty margin of 25% is applied to the estimated mission and auxiliary power demand. This margin is assumed and reflects common practice for vessels in the concept and early preliminary design phases. This results in an initial design power demand of 578 kW.

However, Table 6.1 does not include several regular vessel systems that are expected to be present on any vessel, such as fire-fighting systems, fuel handling systems, and associated pumps and auxiliaries. To include these standard vessel systems, reference vessels are used as a baseline. The small reference vessel is equipped with two 99 kW generators dedicated to regular vessel systems, while the large reference vessel is equipped with two 150 kW generators for the same purpose. These power levels are assumed to be representative of the reference vessels and comparable to the requirements of the proposed designs.

Adding the power demand of the regular vessel systems to the mission and auxiliary power estimate yields a total power demand of 776 kW for the small platform and 878 kW for the large platform.

Finally, this estimate does not yet account for future growth in electrical loads over the vessel life cycle. A future growth margin of 10% is applied, which is commonly used in naval ship design to accommodate additional systems and increasing power demands.[33] Consequently, the required installed power generation capacity for mission and auxiliary systems is estimated at 853 kW for the small platform and 965 kW for the large platform.

It is noted that the applied future growth margin of 10% reflects common practice in naval ship design, but is not intended to cover the potential integration of high-energy weapon systems, such as directed-energy or laser-based systems, which may impose substantially higher electrical power demands. The inclusion of such systems would require a dedicated reassessment of the onboard power generation architecture. However, this limitation is not considered critical for the present study. The LUSV concepts developed in this research are expected to have a relatively short operational life compared to conventional naval platforms, driven by the rapid pace of technological development in uncrewed systems, sensors, and autonomy. As a result, it is considered unlikely that high-energy weapon systems would be integrated within the anticipated service life of the proposed designs.

(kW)	Mission & Aux Power	Mission & Aux Power + 25%	Total power	Total Power + Growth
Small Platform	462	578	776	853
Big Platform			878	965

Table 6.4: Mission & Auxiliary power

6.2.3. Power levels and configuration

Table 6.5 presents the resulting propulsion and electrical power levels for each vessel type, as well as indicative configurations showing how these power levels can be achieve. To assess the feasibility of the required power levels, the size and dimensions of representative engines and generator sets were estimated based on existing commercially available systems. These estimates are derived from manufacturer data of engines and generator sets [34, 35, 36, 37, 38].

In the power estimates presented in Table 6.5, as well as in the subsequently developed general arrangements, a diesel direct propulsion configuration is assumed, with electrical power for mission and auxiliary systems generated by dedicated generator sets. This configuration represents one feasible and conventional solution for achieving the required power levels. However, several alternative power generation and propulsion configurations are conceivable. These include, for example, the use of alternative energy sources such as fuel cells or hybrid arrangements, although the suitability of such technologies for providing the required power levels on board a naval vessel would require careful assessment.

A more realistic alternative for the proposed LUSVs is a diesel-electric propulsion configuration. Compared to diesel direct propulsion, diesel-electric systems offer increased flexibility, as the combustion engines are mechanically decoupled from the propeller shaft. This allows generator sets to be replaced more easily and rapidly, without the extensive alignment procedures required for direct-drive propulsion systems. Such rapid replacement could be particularly beneficial for LUSVs, as it enables quick turnaround during port visits for maintenance and resupply, thereby reducing downtime.

The main disadvantage of diesel-electric propulsion is the increased system weight and complexity compared to diesel direct propulsion. As a result, further investigation is required to determine which power generation and propulsion configuration offers the most suitable balance between flexibility, complexity, and operational effectiveness for the proposed LUSV concepts.

Vessel Type	Propulsion Power (kW)	Engines	Engine type	Dimensions (l x b x h)(m)	Electrical Power (kW)	Gen set	Gen set type	Dimensions (l x b x h)(m)
Universal Vessel	9850	4x 2463 kW	CAT 3516	3.1 x1.8 x 2.3	965	4x 241 kW		
ASW Vessel	6150	4x 1538 kW	CAT C32	2.2 x 1.5 x 1.5	853	4x 213 kW		
MCM Vessel	2250	4x 563 kW	CAT C32	2.2 x 1.5 x 1.5	965	4x 241 kW		
ISR/CUI Vessel	1825	2x 913 kW	CAT C32	2.2 x 1.5 x 1.5	853	4x 213 kW	Cat 9.3	1.5 x 1 x 1
ISR/CUI/ASW Vessel	6150	4x 1538 kW	CAT C32	2.2 x 1.5 x 1.5	853	4x 213 kW		
MCM/ISR/CUI Vessel	2250	4x 563 kW	CAT C32	2.2 x 1.5 x 1.5	965	4x 241 kW		

Table 6.5: Power levels and engines/gensets

6.3. Weight Estimation

To assess the feasibility of the developed concepts, a first-order weight estimation is performed. Similar to the power estimation, the objective of this analysis is not to determine an exact weight breakdown, but to obtain an order-of-magnitude estimate that allows verification of whether the proposed concepts remain within realistic limits.

The weight estimation is based on the system characteristics presented in Table 6.1. For each platform size, the total payload weight was determined by summing the masses of all systems associated with the most demanding mission configuration. This approach results in a conservative estimate, as it assumes that the heaviest plausible payload combination is embarked simultaneously. Based on this method, the total payload weight for the small platform amounts to approximately 56t for the heaviest payload configuration. For the large platform, the corresponding payload weight is approximately 121t.

Similar to the power estimation, uncertainty and future growth margins are applied to the estimated payload weights. An uncertainty margin of 25% is included to account for uncertainty at this early design stage. In addition, a future growth margin of 10% is applied to account for potential payload increases during the vessel life cycle. Applying both margins results in design payloads of 77 t for the small platform and 166 t for the large platform, as summarised in Table 6.8.

(t)	Payload	Payload + 25%	Payload + 25% & Growth
Small Platform	56	70	77
Big Platform	121	151	166

Table 6.6: Payload

To assess the feasibility of the estimated payload weights, the available deadweight and deck cargo capacity of the proposed platforms are estimated using the same Damen FCS vessels as reference as applied in the preceding analyses. A first-order scaling approach is used to obtain an order-of-magnitude estimate. This method has limitations, as it simplifies the relationship between vessel geometry and carrying capacity by assuming proportional scaling, which may not fully capture the influence of other factors. However, given the limited differences between the reference vessels and the proposed designs, the associated inaccuracies are assumed to be acceptable for the current design stage.

For the small platform, again the *Damen FCS 4208 Patrol Vessel* is used as reference. The primary difference is a reduction in length from 43.2 m to 40.0 m, while the beam remains unchanged at 8.3 m. It is assumed that deadweight and deck cargo capacity scale linearly with vessel length. Under this assumption, the capacities of the small platform are estimated by applying a ratio of 40.0/43.2 to the reference values.

For the large platform, the *Damen FCS 5209 Vessel* is again adopted as reference. In this case, the vessel length remains constant at 53.2 m, while the beam is increased from 9.8 m to 11.0 m. It is assumed that the increase in beam results in a proportional increase in displacement and available carrying capacity. The deadweight and deck cargo capacities are therefore scaled using a beam ratio of 11.0/9.8.

The resulting deadweight and deck cargo capacities are presented in Table 6.7. Comparison with the design payloads shows that both platform concepts can accommodate their maximum payload, including margins, within the available deadweight. For the small platform, the design payload exceeds the available deck cargo capacity. However, this is not considered limiting as a substantial portion of the payload, such as the radar, hull-mounted sonar, and gun are integrated into the vessel rather than carried on deck.

	Length (m)	Beam (m)	Deadweight (t)	Deck Cargo (t)	Payload (t)
Small Platform	40.0	8.3	139	74	77
Damen FCS 4208	43.2	8.3	150	80	x
Big Platform	53.2	11.0	365	281	166
Damen FCS 5209	53.2	9.8	325	250	x

Table 6.7: Deadweight and Deck Cargo

6.4. Stability Estimation

To provide a first-order indication of stability, the deck cargo capacity of the reference vessels is used. The allowable deck cargo is defined based on the stability limits of the vessel. According to information obtained from the designer of the reference vessel, it is assumed that the centre of gravity of the deck cargo is located 1.0 m above deck level [39]. Based on this reference condition, the maximum allowable deck cargo moment can be determined. The deck cargo of the proposed concepts is then evaluated by calculating its weight and vertical centre of gravity, after which the resulting moment is compared to this reference value.

Based on the data presented in Table 6.7, the small platform can carry a maximum deck cargo of 74 t with a centre of gravity at 1.0 m above deck. This corresponds to a limiting deck cargo moment of 74 t·m. For the large platform, the corresponding value is 281 t at 1.0 m, resulting in a limiting moment of 281 t·m.

For the small platform, the most demanding deck payload configuration consists of 40 t located at a vertical centre of gravity of 1.3 m above deck level. Similar to the payload estimation, an uncertainty margin of 25% and a future growth margin of 10% are applied. This results in a design deck payload of 55 t. The corresponding deck cargo moment becomes

$$55 \times 1.3 = 71.5 \text{ t·m} < 74 \text{ t·m}$$

This value remains below the limiting moment of 74 t·m. It can therefore be concluded that the maximum deck payload configuration of the small platform remains within the stability boundary derived from the reference vessel.

For the large platform, the most demanding deck configuration consists of 100 t at a height of 1.7 m above deck level. Applying the same uncertainty margin of 25% and a future growth margin of 10% results in a design deck payload of 138 t. The resulting deck cargo moment equals

$$138 \times 1.7 = 234.6 \text{ t·m} < 281 \text{ t·m}$$

This value remains below the limiting moment of 281 t·m. Hence, the large platform configuration also remains within the assumed stability limit.

It must be emphasised that this method provides only a preliminary stability check. Vessel stability depends on multiple factors that are not explicitly evaluated in the present assessment. The analysis is limited to a comparison of deck cargo moments with a reference boundary condition derived from the reference vessel. Although simplified, this approach provides sufficient confidence at the conceptual design stage that the proposed payload configurations remain realistic and do not indicate an stability limitation.

6.5. High-Level Concept Description

6.5.1. Universal LUSV

The resulting Universal LUSV concept is a 53 m uncrewed surface vessel designed to provide a common platform for all selected mission types while meeting a maximum speed requirement of 30 kn. The overall vessel layout is illustrated in the general arrangement shown in Figure 6.3.

Key features of the Universal LUSV include an aft-located flight deck, a USV garage, and a flexible payload area. The flight deck supports the operation of UAVs with a wingspan of up to approximately 4.5 m, with adjacent modules provided for UAV stor-

Figure 6.2: Universal vessel

age and resupply. The USV garage enables the storage, launch, and recovery of USVs with lengths of up to 13 m, such as an Exial Inspector 125 [24]. Located beneath the flight deck, the flexible payload area accommodates modular mission systems. While the vessel can carry the mission modules required for all four selected mission types, simultaneous deployment of all capabilities is not required.

For self protection, the vessel is equipped with a gun mounted on the foredeck. Directly aft of the gun, the mast is positioned to provide sufficient height for sensors such as cameras and radar systems, thereby increasing sensor coverage and detection range. On both sides of the mast, an autonomous refuelling at sea system is installed, enabling the vessel to be refuelled while underway.

On the lower deck, a bow thruster room is located in the fore part of the vessel. Additionally, a hull-mounted sonar is installed on the bottom of the hull. A large volume of the lower deck is reserved for fuel tanks. The propulsion system is arranged in two separate machinery rooms, providing redundancy and improving survivability in the event that one machinery space is damaged. Each machinery room houses two main engines, resulting in a total of four engines, which together provide the installed power required to achieve a maximum speed of 30 kn. In addition to the power requirement, the propulsion system is designed with a focus on reduced acoustic signature, as low noise levels are desirable for ASW operations.

The overall vessel length of 53 m results from the sequential development of the general arrangement. The layout was first defined by allocating space in the aft part of the vessel for the flight deck, followed by the UAV modules and the USV garage. Together, these elements define the required length of the mission section. Subsequently, a mast was positioned forward of this section, followed by the allocation of deck space for a gun. When these elements were arranged consecutively along the vessel length, the resulting configuration led to a minimum required vessel length of 53 m.
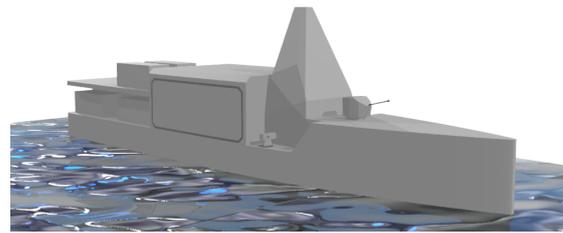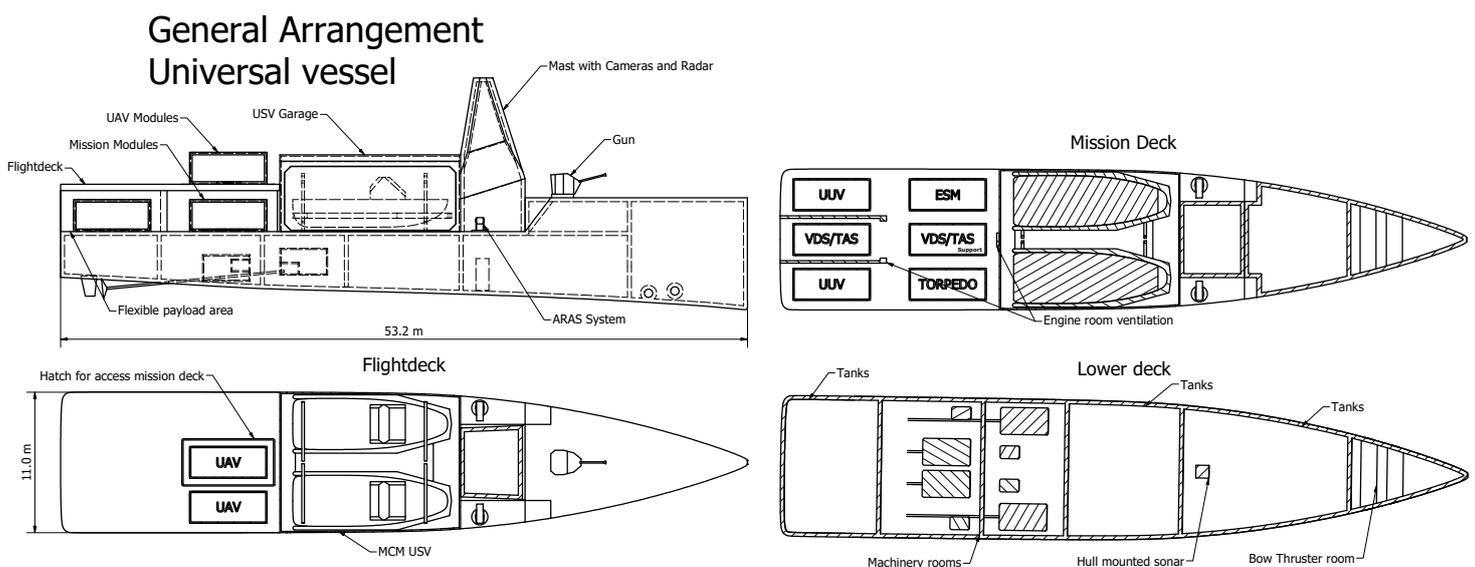

Figure 6.3: General arrangement Universal vessel

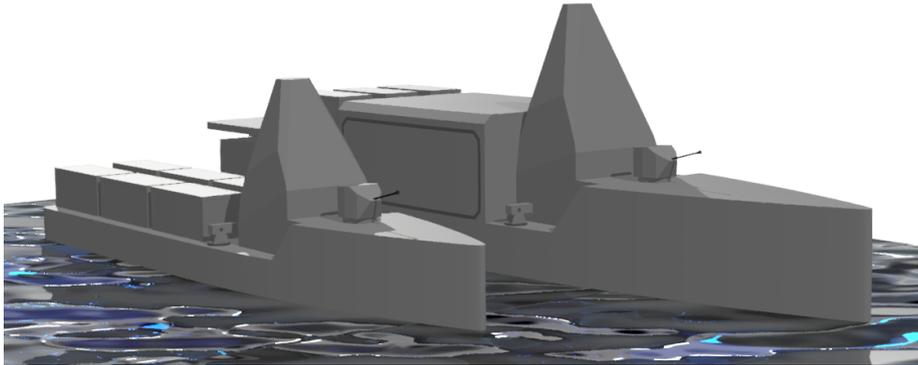## 6.5.2. Mission Based Concept

Figure 6.4: Mission based concept

The mission based concept divides the required mission set over two dedicated vessel types rather than relying on a single universal platform. As illustrated in Figure 6.4, this concept consists of a larger MCM vessel and a smaller vessel dedicated to ISR, CUI, and ASW missions. By separating the mission roles, each vessel can be tailored more closely to the specific operational requirements of its assigned missions.

MCM Vessel

The MCM vessel concept is largely similar to the Universal LUSV design. However, as ISR, CUI, and ASW missions are no longer required, additional internal volume and payload capacity become available for MCM systems. This allows the vessel to carry a larger number of MCM specific tools and unmanned assets, enabling it to perform MCM operations more effectively than the Universal LUSV, which must accommodate a broader mission set.

As the requirement for high transit speeds is removed due to the absence of ASW missions, the propulsion system can be adapted accordingly. Smaller main engines can be installed, reducing installed power while still meeting the speed requirements for MCM missions. In addition, requirements on acoustic signature are less stringent for this concept, allowing the propulsion system to be designed without extensive noise reduction measures. This change contributes to a more efficient vessel design by avoiding unnecessary propulsion capacity and system overdimensioning, while remaining well suited for its dedicated mission role.
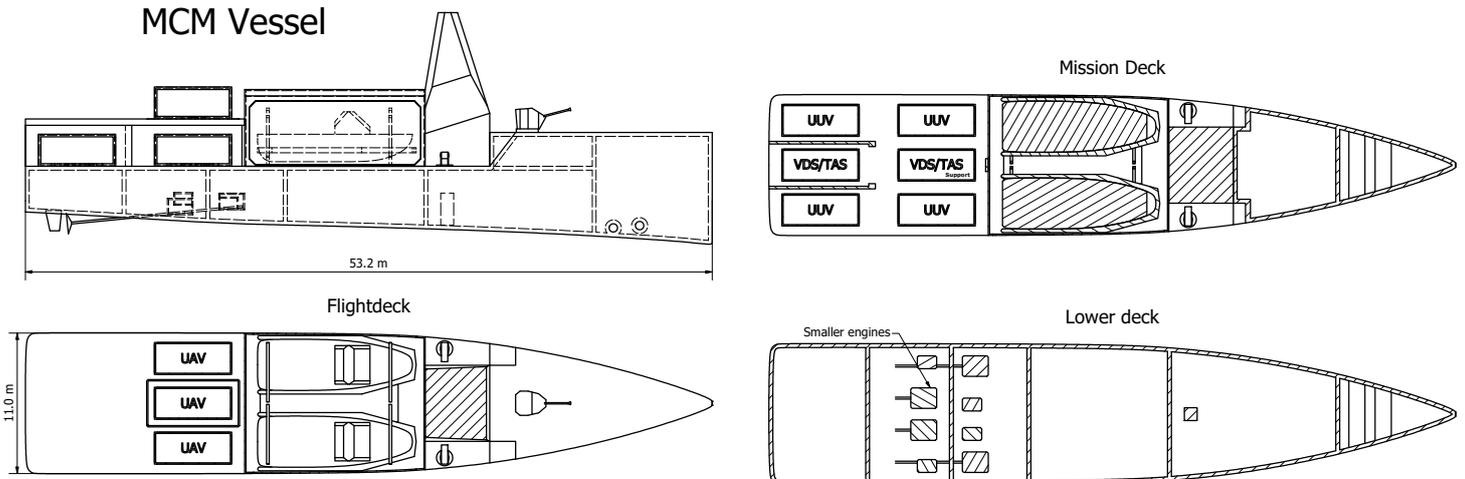
General Arrangement MCM Vessel

Figure 6.5: General arrangement MCM vessel

ISR/CUI/ASW Vessel

The ISR/CUI/ASW vessel is a 40 m long uncrewed surface vessel with a beam of 8.3 m, making it significantly smaller than the previously described designs. The reduced size is possible as this vessel does not support MCM operations and therefore does not need to accommodate large MCM systems or associated handling equipment.

The overall vessel length of 40 m results from the application of the same layout driven design approach as used for the Universal LUSV, adapted to the reduced mission scope of this vessel. Starting from the aft, a mission deck is provided on which the mission modules for ISR, CUI, and ASW and the ARAS are installed. Forward of the mission deck, the mast is positioned, followed by sufficient deck space on the foredeck to accommodate a gun. When these elements are arranged consecutively along the vessel length, the resulting configuration leads to a required vessel length of 40 m. The same design logic and arrangement methodology has been applied to all other vessel concepts developed in this research.

The general layout of the vessel follows a similar arrangement philosophy to the other concepts. At the aft part of the vessel, a flexible payload area is provided, on which modular mission systems for ISR, CUI, and ASW missions can be installed. In principle, the vessel can carry the mission modules required to support all three mission types simultaneously; however, this is not a strict requirement. Mission systems can be exchanged or duplicated depending on the specific operational focus of a deployment.

Forward of the flexible payload area, an ARAS is installed to enable refuelling at sea. The mast is positioned forward of the ARAS and provides the required height for sensors such as cameras and radar systems. A gun is mounted on the foredeck to provide basic self defence capabilities.

On the lower deck, a bow thruster room is located in the fore part of the vessel, followed by fuel storage tanks to support endurance requirements. The propulsion system is arranged in two separate machinery rooms to provide redundancy. Each machinery room houses two main engines, resulting in a total of four engines, which provide the installed power required to achieve a maximum speed of 30 kn. As the vessel is intended to perform ASW missions, the propulsion system is designed with a focus on reducing acoustic signature.
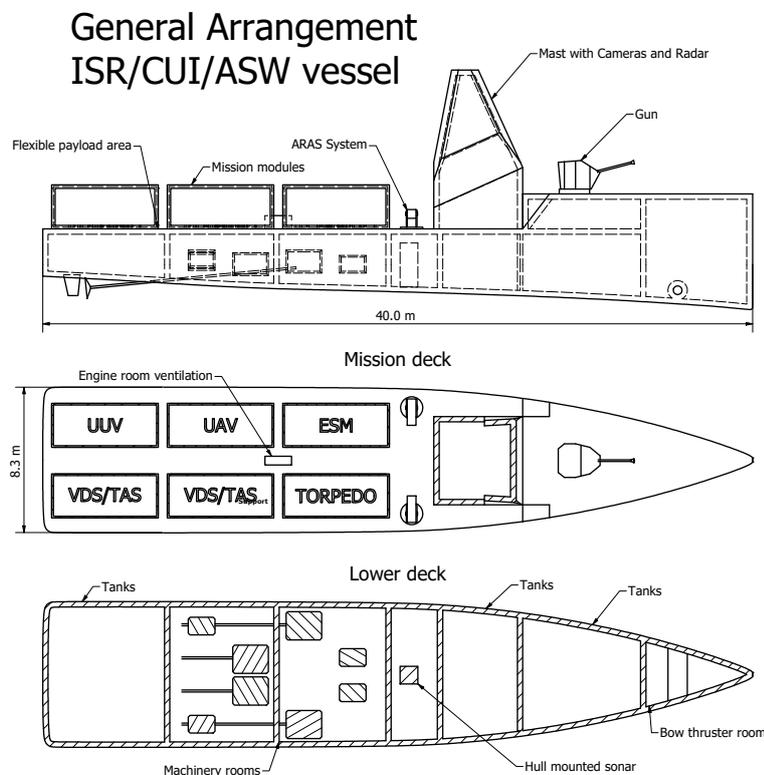

Figure 6.6: General arrangement ISR/CUI/ASW vessel
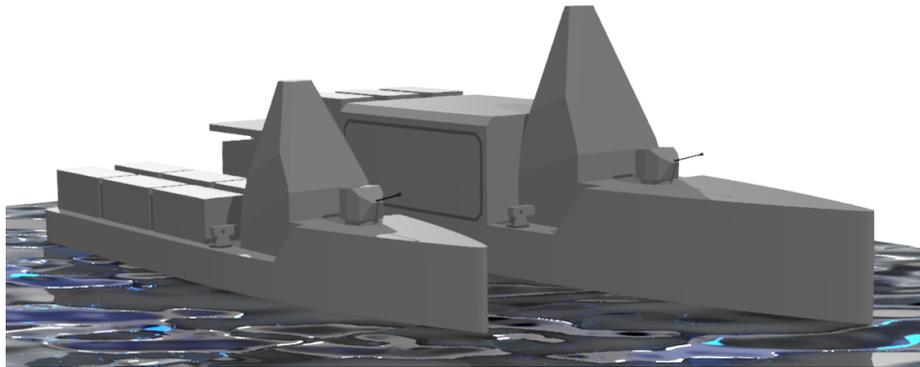
6.5.3. Propulsion Based Concept

Figure 6.7: Propulsion based concept

The propulsion based concept divides the fleet based on propulsion and speed requirements rather than mission type. Within this concept, a smaller high-speed vessel is designed to support ASW operations, where both high speed and low acoustic signature are critical, while a larger vessel is dedicated to MCM, ISR, and CUI missions, for which speed and acoustic requirements are less stringent. By separating platforms based on speed and acoustic requirements, each vessel can be sized and equipped according to its propulsion demands without introducing unnecessary machinery capacity.

ASW Vessel

The ASW vessel is largely identical to the previously described ISR/CUI/ASW vessel. The primary difference is the absence of an electronic support measures system, which is not required for dedicated ASW operations. Apart from this change, the vessel layout and system configuration remain unchanged.

The removal of the ESM system frees up space within the flexible payload area, allowing alternative mission systems to be embarked. One possible application is the deployment of additional unmanned aerial vehicles, which could be used to support ASW operations, for example by distributing sonobuoys. The propulsion system of the ASW vessel is sized specifically to meet the operational requirements of this mission profile, including a maximum speed of 30 kts and the requirement for low underwater radiated noise. This results in a propulsion configuration that provides the necessary performance while avoiding excess installed power or unnecessary system overdimensioning.
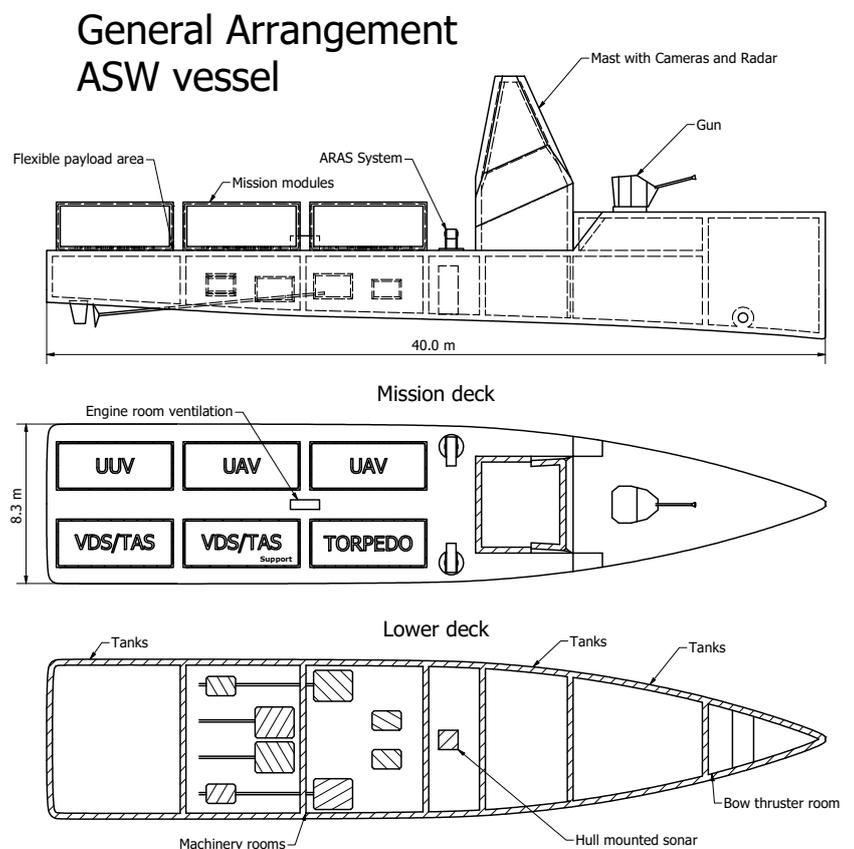

Figure 6.8: General arrangement ASW vessel

MCM/ISR/CUI Vessel

The MCM/ISR/CUI vessel is largely identical to the previously described MCM vessel. The key difference is the inclusion of an ESM module to support the ISR and CUI mission set. As a result, part of the flexible payload area is allocated to this additional mission module, which slightly reduces the available space for MCM-specific tools and unmanned assets. However, the impact on the overall MCM capacity is limited, and the vessel remains primarily optimised for MCM operations while providing the additional capabilities required for ISR and CUI missions.

In contrast to the ASW vessel, this vessel is not subject to stringent requirements on underwater radiated noise and is only required to achieve a maximum speed of approximately 18 kts. As a result, a simpler propulsion system can be adopted, without the need for extensive noise-reduction measures or high installed power. This allows the propulsion arrangement to be optimised for efficiency and simplicity, in line with the operational profile of the MCM/ISR/CUI mission set.
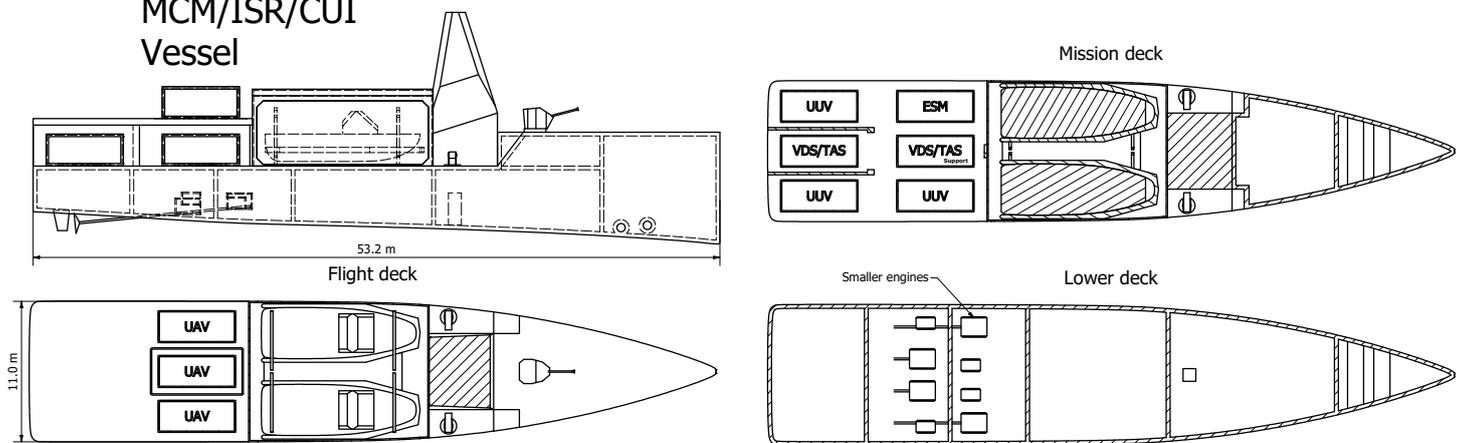

Figure 6.9: General arrangement MCM/ISR/CUI
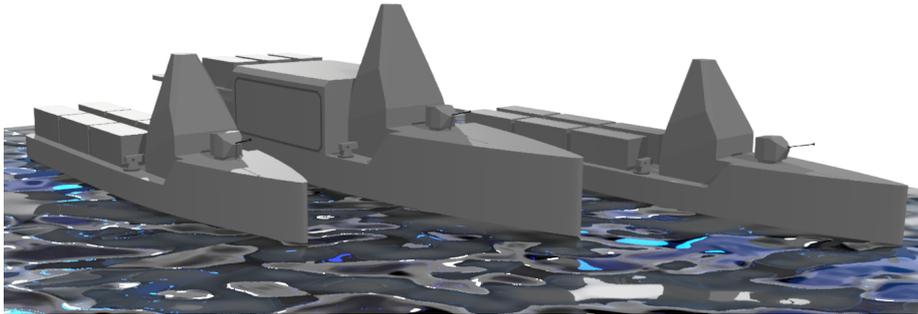
6.5.4. Specialized Fleet Concept

Figure 6.10: Specialized concept

ASW Vessel

The ASW vessel in this concept is identical to the ASW vessel defined in the Propulsion Based Concept and is therefore not described again in this subsection.

MCM Vessel

The MCM vessel is this concept is identical to the MCM vessel defined in the Mission Based Concept and is therefore not described again in this subsection.

ISR/CUI Vessel

The ISR/CUI vessel is mostly similar to the ISR/CUI/ASW vessel but is dedicated solely to ISR and CUI missions. As ASW is not required for this vessel, the high speed and low noise propulsion requirements associated with ASW operations are removed. This allows the propulsion system to be simplified, using two main engines driving two shafts, while still meeting the operational requirements of the ISR and CUI mission set.

Apart from the adapted propulsion system, the vessel retains a similar deck arrangement. Space is provided for essential ISR and CUI mission systems, as well as for additional unmanned assets that can enhance mission effectiveness. Examples include UAVs to extend surveillance coverage or UUVs to support close range underwater inspection and cable monitoring tasks.
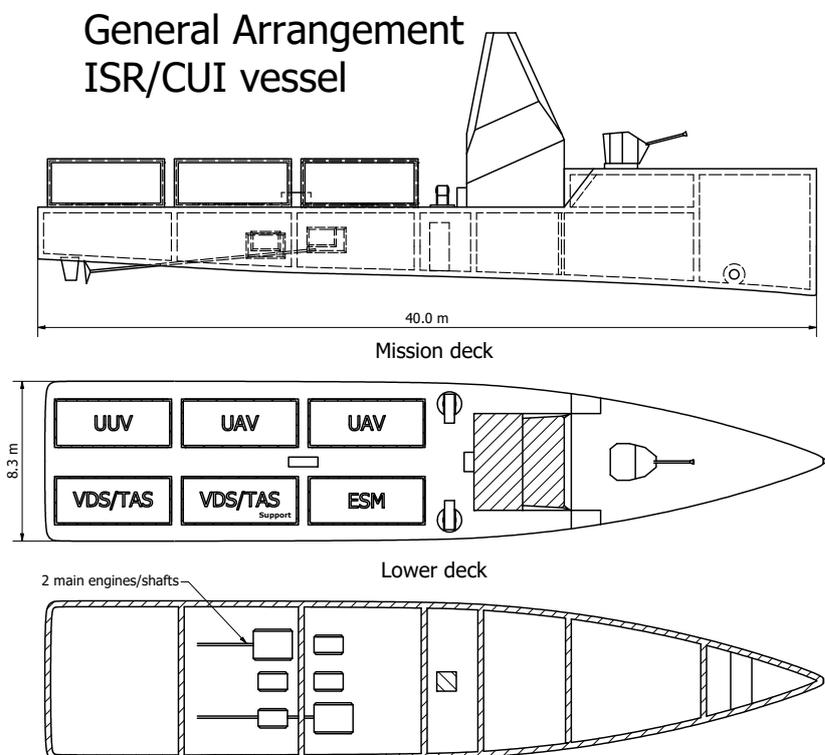

Figure 6.11: General arrangement ISR/CUI vessel

6.6. Remarks to the concepts

6.6.1. Hull Forms

Within the concept definition, no optimisation of hull form has been performed. Instead, the hull form of an FCS-type Damen vessel has been adopted as a reference. This hull form is known to provide favourable seakeeping characteristics and has demonstrated the ability to operate at relatively high speeds in comparable vessel designs.

At this stage, the hull form is represented schematically and primarily serves as a geometric and functional reference for the concept development. The detailed underwater hull geometry has not been defined, and important FCS-specific features, such as course stabilisation fins, have not yet been modelled or assessed.

While the adopted hull form is considered reasonable for concepts with a maximum speed requirement of approximately 30 kts, it may be less suitable for vessels that only require lower speeds, such as 18 kts. For these concepts, alternative hull forms could potentially offer improved efficiency or performance. Consequently, detailed definition and optimisation of the hull form are identified as important next steps in the further development of the presented concepts.

6.6.2. Seakeeping

Seakeeping performance has not been explicitly assessed within the scope of this research. FCS hull forms are generally designed to remain operational across a wide range of sea states and to maintain survivability in high wave conditions. As a result, seakeeping is not considered a limiting factor in terms of vessel operation and survival for the presented concepts.

However, while the vessels are expected to remain operational, the effectiveness of specific missions may be affected by vessel motions in higher sea states. Certain operations may impose limits on allowable motions, accelerations, or relative movements, beyond which mission execution becomes impractical or ineffective. Consequently, although the vessels themselves are not expected to be restricted by sea conditions, mission performance may be.

Further analysis is therefore required to determine mission-specific seakeeping limits and to assess how vessel motions in various sea states influence overall operational effectiveness. Such analysis falls outside the scope of the present study but is essential for refining the concepts and establishing realistic operational envelopes.

6.6.3. Technological Maturity

The presented concepts differ in their level of technological ambition when evaluated against the current maturity of relevant systems and enabling technologies. Some concepts rely primarily on technologies that are already available or are currently being integrated into naval platforms, whereas others depend on higher levels of autonomy, system integration, and coordination between unmanned assets.

In particular, concepts that require the deployment, recovery, sustainment, and coordinated operation of unmanned systems place significantly higher demands on technology maturity. Even when operated from manned platforms, these functions remain technically challenging, and performing them from an uncrewed surface vessel further increases the required level of system robustness, autonomy, and reliability.

Consequently, while all presented concepts are considered plausible within a future operational context, their near-term feasibility differs. Concepts with lower system complexity are more likely to be realised in the short to medium term, whereas more complex concepts are expected to depend on further technological development and operational experience

6.6.4. People on Board

All LUSV concepts presented in this research are designed to operate without personnel on board. This remains a fundamental design principle, as the presence of a permanent crew would fundamentally change the vessel classification and move it away from the definition of an uncrewed platform.

Nevertheless, although routine operation without personnel is assumed, it is not inconceivable that humans may occasionally need to board the vessel. Examples include emergency repairs, fault diagnosis, or inspection tasks. For such situations, the designs assume that a small number of personnel, for example two technicians, may need to embark the vessel for an extended period.

To support these exceptional cases, limited provisions are required to allow personnel to remain on board safely and effectively. This includes basic facilities such as sleeping arrangements, sanitary facilities, and a simple space for food preparation and consumption. These accommodations are not intended to support regular habitation and therefore do not need to meet the standards of a fully manned vessel. Instead, they can be implemented in a minimal and functional manner, comparable to a temporary or expedition-style arrangement, which is considered acceptable given the military context in which these vessels are expected to operate.

6.6.5. Other Mission Types

Three mission types have not been considered in this research: Anti Air Warfare, Anti Surface Warfare, and Strike Warfare. These missions are potentially suitable for uncrewed platforms. However, they were assessed to be less relevant for the present study, as discussed and motivated in Chapter 3.

Despite this, it is conceivable that LUSVs could be employed in a supporting role for such missions. For example, a LUSV could function as a magazine platform, carrying additional missiles to extend the fire capacity of other naval units. While this approach could offer operational advantages, the autonomous employment of weapon systems, including independent targeting and engagement decisions, would introduce significant technical, operational, and ethical challenges.

Existing naval initiatives already explore concepts in which uncrewed or minimally crewed platforms contribute to missile-based warfare in a supporting role. An example is the Multifunctional Support Ship (MSS) concept of the Royal Netherlands Navy [40]. The MSS is intended to perform tasks such as missile launching, deployment of loitering munitions, and monitoring of maritime traffic.

In line with these developments, the employment of LUSVs in Anti Air, Anti Surface, or Strike Warfare is more likely to be realised through cooperative concepts, in which the uncrewed platform supports manned vessels or higher-level command systems. These mission types may therefore be considered in future extensions of the presented concepts, but fall outside the scope of the current research.

6.7. Concept Evaluation

Concepts		Vessel types
	Universal LUSV	Universal Vessel
	Mission Based Concept	MCM Vessel
		ISR/CUI/ASW Vessel
	Propulsion Based Concept	ASW Vessel
		MCM/ISR/CUI Vessel
	Specialized Fleet Concept	ASW Vessel
		MCM Vessel
		ISR/CUI Vessel

	Universal Vessel	ASW Vessel	MCM Vessel	ISR/CUI Vessel	ISR/CUI/ASW Vessel	MCM/ISR/CUI Vessel
Length (m)	53,2	40	53,2	40	40	53,2
Beam (m)	11	8,3	11	8,3	8,3	11
Speed (kts)	30	30	30	18	30	18
Nr of mission modules	9	6	9	6	6	9

Table 6.8: Overview of the concepts

When evaluating the four developed concepts, it becomes apparent that they can be grouped into two fundamental categories. On the one hand, a universal concept is proposed, in which a single vessel type is intended to support all selected mission types. On the other hand, a set of focused concepts is developed, in which vessels are tailored to specific missions, specific propulsion requirements, or a combination of both.

The differences between the mission based, propulsion based, and specialised fleet concepts are relatively limited in terms of overall design. Instead, these concepts primarily differ in the degree to which individual vessels are optimised for particular operational roles. For example, within the mission based concept, the MCM vessel is tailored to MCM operations and is therefore optimised for that specific mission profile. Similarly, within the propulsion based concept, the ASW vessel is optimised to meet the propulsion driven requirements associated with ASW operations, such as high maximum speed and low underwater radiated noise.
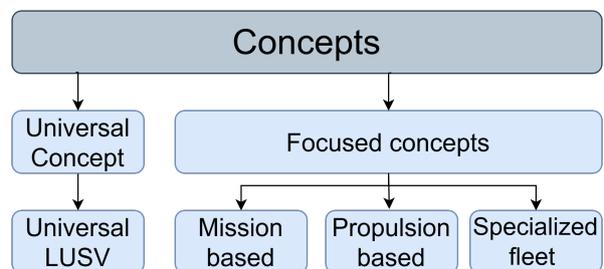
Figure 6.12: Concept categories

From this perspective, the distinction between mission based and propulsion based concepts becomes less rigid. In practice, propulsion requirements are a direct consequence of mission requirements. As a result, the propulsion based concept can be interpreted as a mission driven concept in which propulsion characteristics act as the primary differentiator between vessel types. The various focused fleet concepts therefore represent different ways of grouping and prioritising mission requirements within the fleet design.

Consequently, the key question in evaluating the developed concepts is not which of the four individual concepts performs best in isolation, but whether a universal fleet or a more specialised and focused fleet is preferred. Within the latter category, multiple variants are possible, each offering a different balance between specialisation, flexibility, and fleet complexity.

The interpretation of concept performance is inherently context-dependent and strongly influenced by how vessels are employed, the size and composition of the fleet, and the applied operational doctrine. A concept that performs well in one operational context may therefore be less suitable in another.

For this reason, the concept evaluation presented in this section is conducted using two generic reference contexts. The first represents a navy with the capacity to operate and sustain a relatively large fleet and to conduct multiple mission types in parallel. The second represents a navy with a more limited fleet size and support capacity. These reference contexts are used solely to structure the evaluation and to illustrate how different conditions influence the assessment of the developed concepts.

To enable a structured comparison of the developed concepts, a set of key performance indicators (KPIs) is defined. These KPIs reflect aspects that are considered relevant at concept level and allow the concepts to be assessed. Separate KPI sets are defined for two representative reference contexts: a large navy and a small navy.

6.7.1. Large Navy

In this evaluation, a large navy is assumed to operate a relatively large and diverse fleet, with sufficient resources to sustain multiple vessel classes and specialised platforms. It is further assumed that such a navy conducts multiple mission types in parallel and accepts a higher degree of fleet complexity in exchange for improved fleet-level effectiveness. Under these assumptions, flexibility is primarily achieved at fleet level rather than at platform level, and individual vessels are therefore not required to be multi-role by design.

From a large navy perspective, the distribution of capabilities across the fleet is an important consideration. It is assumed to be preferable to lose a simpler vessel, whether temporarily due to maintenance or permanently due to damage or destruction, than to lose a highly complex platform that concentrates multiple mission capabilities. Consequently, the degree to which capabilities are distributed across vessel types is treated as a relevant aspect in the assessment of fleet concepts.

The key performance indicators defined below are not intended to capture all aspects that may be relevant when assessing naval vessel concepts. Instead, they represent a simplified evaluation framework that focuses on those aspects that provide clear contrast between the developed concepts and allow their differences to be assessed in a transparent manner.

Based on these assumptions, the following key performance indicators are used to evaluate the developed concepts from a large navy perspective:

- *Mission effectiveness*: the extent to which vessel capabilities are appropriately matched to mission requirements, avoiding significant overdimensioning.
- *Parallel mission capacity*: the ability of the fleet to conduct multiple different mission types simultaneously without mutual interference.
- *Capability distribution*: the degree to which multiple mission capabilities are distributed across the fleet rather than concentrated within individual vessels.

6.7.2. Small Navy

In this evaluation, a small navy is assumed to operate a limited number of vessels. As a result, it is assumed to be important that individual platforms are capable of performing a wide range of missions, as the available fleet must collectively cover the full set of required capabilities. Multi-role employment of individual vessels is therefore considered a key consideration from a small navy perspective.

In addition, operating and maintaining a limited number of vessel types is assumed to be advantageous. A fleet composed of a small number of identical or closely related platforms is therefore assumed to reduce organisational complexity and simplify fleet management compared to a fleet consisting of multiple highly specialised vessel types.

Finally, efficient use of available assets is assumed to be of particular importance for a small navy. Given the limited fleet size, vessels are expected to be employed frequently across different mission types, and concepts that result in low utilisation of individual platforms are therefore considered less favourable within this evaluation.

Similar to the large navy case, the following KPIs represent a simplified evaluation framework intended to highlight the key differences between the developed concepts, rather than to provide a complete assessment.

Based on these assumptions, the following key performance indicators are used to evaluate the developed concepts from a small navy perspective:

- *Mission flexibility*: the ability of a single vessel to perform multiple mission types with limited reconfiguration.
- *Fleet simplicity*: the degree to which the fleet consists of a limited number of vessel types, reducing training, logistics, and maintenance complexity.
- *Vessel utilisation*: the extent to which a vessel can be employed frequently and consistently across the available mission set, with the aim of maximising the operational use of each platform.

6.7.3. KPI Assessment

Large Navy

From a large navy perspective, the assessment is based on mission effectiveness, parallel mission capacity, and capability distribution.

KPI	Universal	Mission Based	Propulsion Based	Specialised Fleet
Mission effectiveness	Low	Medium	Medium	High
Parallel mission capacity	Low	Medium	Medium	High
Capability distribution	Low	Medium	Medium	High

Table 6.9: KPI assessment – Large Navy

The results show a clear differentiation between the universal and specialised concepts. The Universal LUSV scores low across all three KPIs, as the concentration of multiple capabilities within a single platform limits mission effectiveness, constrains parallel mission capacity, and reduces capability distribution at fleet level. In contrast, the Specialised Fleet concept achieves high scores in all categories. By allocating dedicated vessel types to specific operational roles, it enhances mission effectiveness, enables simultaneous execution of different mission types, and distributes capabilities across the fleet structure. The Mission Based and Propulsion Based concepts occupy an intermediate position, achieving medium scores across the KPIs. Both introduce differentiation within the fleet and partially improve mission effectiveness and capability distribution, while maintaining a more limited number of vessel types than a fully specialised structure.

Small Navy

From a small navy perspective, the assessment is based on mission flexibility, fleet simplicity, and vessel utilisation.

KPI	Universal	Mission Based	Propulsion Based	Specialised Fleet
Mission flexibility	High	Medium	Medium	Low
Fleet simplicity	High	Medium	Medium	Low
Vessel utilisation	High	Medium	Medium	Low

Table 6.10: KPI assessment – Small Navy

In this context, the relative performance is effectively reversed. The Universal LUSV achieves high scores across all KPIs, as a single vessel type supports mission flexibility, maintains fleet simplicity, and promotes high vessel utilisation. The Specialised Fleet concept performs least favourably, as reduced mission flexibility, increased fleet diversity, and lower utilisation of individual platforms limit its suitability for a small fleet structure. The Mission Based and Propulsion Based concepts again represent intermediate solutions, offering partial optimisation while maintaining moderate levels of flexibility and complexity.

The combined assessment demonstrates that concept suitability is dependent on fleet structure and operational context. A large navy benefits from high mission effectiveness, parallel mission capacity, and capability distribution, which favours the Specialised Fleet concept. A small navy benefits from high mission flexibility, fleet simplicity, and vessel utilisation, which favours the Universal LUSV concept. The Mission Based and Propulsion Based concepts occupy a balanced position between these two extremes, indicating that hybrid approaches may provide compromise solutions but do not fully maximise the advantages associated with either universality or specialisation.

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Conclusions, Discussion, and Recommendations

7.1. Conclusions

This research addressed the following main research question: *How can a structured method be developed and applied to translate naval mission types into capabilities and concept designs for a Large Uncrewed Surface Vessel in support of its early-stage development?*

To answer this question, the research was structured around a sequence of sub-questions, each addressed in a dedicated chapter. In Chapter 2, suitable approaches for early-stage LUSV development were examined. As discussed in that chapter, early design decisions are characterised by uncertainty, evolving requirements, and strong interdependencies. To address these challenges, a structured design method was adopted and captured in a dedicated roadmap. This roadmap organises the design process into successive levels of definition, progressing from operational context and mission needs to capabilities, functional requirements, and ultimately physical concept designs. In doing so, it provides traceability between operational intent and technical solutions while allowing iteration and informed trade-offs during concept development.

Chapter 3 focused on the identification and analysis of relevant naval missions for LUSV employment. Based on a literature study and mission prioritisation, a set of missions was selected that is both operationally relevant and technically feasible for uncrewed execution. These missions were elaborated through representative vignettes, which provided a consistent operational context from which mission-driven capabilities were derived.

In Chapter 4, the derived capabilities were translated into system-level solutions using Modular Function Deployment. By systematically linking capabilities to functions and systems, and by explicitly considering modularity, a structured and traceable connection was established between operational needs and the technical system architecture at concept level.

Chapter 5 synthesised the identified systems and modularity choices into multiple LUSV concept variants. Four distinct concepts were defined, each representing a different approach to mission integration, platform optimisation, and fleet composition. Defining multiple concepts preserved design freedom and enabled meaningful comparison between different fleet-level solutions.

Finally, Chapter 6 evaluated the developed concepts using a set of fleet-level Key Performance Indicators. This evaluation demonstrated that no single concept performs best across all criteria. Instead, each concept exhibits specific strengths and limitations, making its suitability dependent on the intended operational use. The results confirm that the assessment of LUSV concepts is context-dependent.

Taken together, the results presented across Chapters 2 through 6 demonstrate that a structured, mission-driven design method can be effectively developed and applied to support the early-stage conceptual design of Large Uncrewed Surface Vessels. The proposed roadmap enables the systematic generation of LUSV concepts by explicitly linking missions, capabilities, systems, and concept design. Rather than producing a single optimal design, the method provides insight into the trade-offs between efficiency and flexibility, thereby supporting concept selection in the early design phase.

7.2. Discussion

7.2.1. Concept-Level Limitations

A key limitation of this research is that the developed LUSV concepts remain at a conceptual design level. For the early design phase targeted in this study, this level of detail is appropriate, as the objective is to explore fleet-level trade-offs rather than to converge on a final design. The assessments are therefore based on order-of-magnitude estimates and qualitative comparisons, and should be interpreted as indicative rather than precise. Further design stages would require more detailed analyses to validate feasibility and quantify performance with greater confidence.

7.2.2. Design Maturity

Several design aspects identified in Section 6.6 require further clarification. While a representative hull form was adopted, no hull form optimisation was performed, and its suitability across different operational profiles remains to be confirmed.

Seakeeping performance was not assessed within the scope of this research. Although the adopted hull form is designed for operation and survivability in high sea states, seakeeping is therefore not considered a limiting factor with respect to vessel survival. However, the influence of seakeeping on both operational performance and mission execution in more demanding environmental conditions remains uncertain and requires further analysis.

The presented concepts also differ in their technological maturity. Concepts relying on higher levels of autonomy, system integration, and the launch, recovery, and coordinated operation of unmanned assets from the LUSV place increased demands on system robustness and reliability. While all concepts are plausible in a future operational context, their near-term feasibility differs, with lower-complexity concepts being more likely to be realised in the short to medium term.

7.2.3. Mission Scope

The mission set considered in this research represents a bounded selection of relevant and feasible LUSV missions. While this scope enabled focused concept development, the inclusion of additional mission types may introduce new capability requirements and lead to alternative concept configurations. The four concepts presented serve as representative examples within a broader design space, while the proposed method can be reapplied if additional missions are introduced.

7.2.4. Reflection on the Modular Function Deployment Approach

Modular Function Deployment supported a structured translation from mission-driven capabilities to system architectures and enabled explicit consideration of modularity at concept level. However, the outcome of the MFD process depends on the chosen functional decomposition and system boundaries. In addition, the method implicitly assumes that increased modularity is desirable, while in practice modular solutions may also introduce drawbacks. As such, MFD should be regarded as a decision-support tool rather than a deterministic design method.

7.2.5. Use of Mission Vignettes

Mission vignettes were developed to reflect how LUSVs are expected to be employed in future naval operations. They were used to translate anticipated operational use into a consistent context from which capability requirements could be derived. However, the exact future employment of LUSVs remains uncertain. While the vignette-based approach provides a transparent basis for early-stage concept development, alternative future use cases may lead to different requirements and different design outcomes.

7.3. Recommendations

Based on the findings and limitations identified in this research, several recommendations are formulated for future work and further development of LUSV concepts.

First, the developed concepts should be advanced beyond the conceptual design level through more detailed analyses. This includes refined weight and power estimations, resistance and propulsion analyses, and preliminary cost assessments. Such analyses are required to validate the feasibility of the concepts and to quantify fleet-level trade-offs with greater confidence.

Second, hull form selection and optimisation should be addressed explicitly in subsequent design stages. While a representative reference hull was adopted in this research to support concept development, alternative hull forms may be more suitable for specific operational profiles. Dedicated resistance analyses are recommended to assess the impact of hull form selection on efficiency and propulsion performance.

Third, seakeeping performance should be evaluated in direct relation to mission execution rather than survivability alone. Future work should assess how vessel motions and environmental conditions affect operational effectiveness, including sensor performance and the launch, recovery, and sustained operation of unmanned systems from the LUSV.

Fourth, technological maturity should be considered more explicitly in future concept development. Concepts that rely on high levels of autonomy and the coordinated launch, recovery, and operation of unmanned systems would benefit from a staged development approach, in which near-term feasible concepts are distinguished from longer-term ambitions that depend on further technological and operational maturation.

Fifth, the mission-driven design method presented in this research should be reapplied with expanded mission sets. The inclusion of additional missions may lead to new capability requirements and alternative concept configurations, further exploring the available fleet-level design space.

Finally, the use of mission vignettes is recommended to remain an integral part of early-stage LUSV design. However, vignettes should be iteratively updated as operational concepts evolve, ensuring that derived requirements remain aligned with anticipated future employment.

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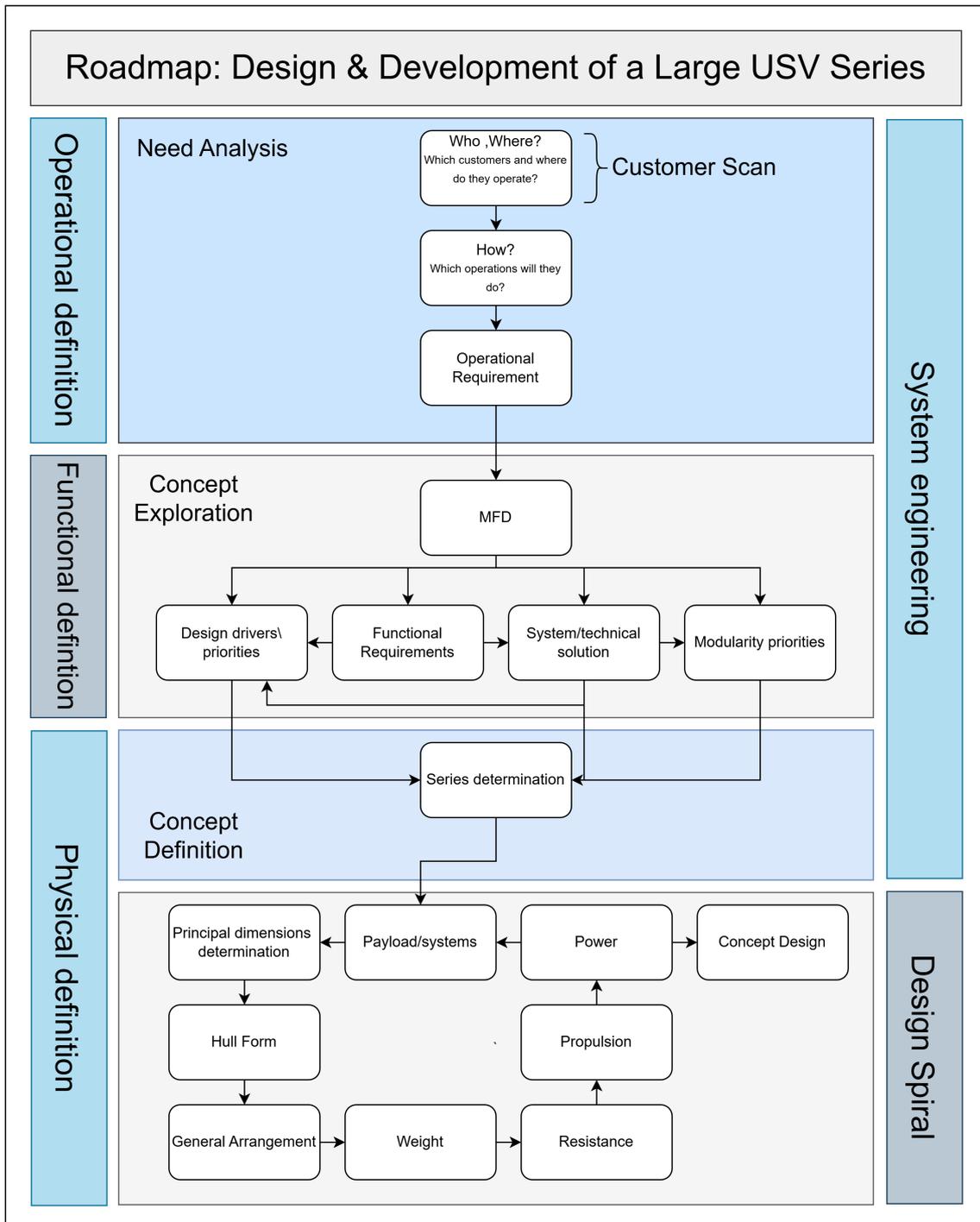
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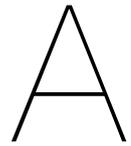
Roadmap

Figure A.1: Roadmap of Design Approach

B

Vignettes

B.1. Australia

B.1.1. MCM in the Bass Strait

Goal: To clear the Bass Strait after an adversary has laid mines in this strategic chokepoint, so that national and regional shipping routes remain safe.

Scenario: Maritime intelligence reports indicate that an adversary has laid naval mines in the Bass Strait. Instead of a limited area, it concerns an extensive zone that blocks a significant part of the shipping corridor. To keep access open for national and regional shipping routes, a wide and safe corridor must therefore be cleared within a short period of time. A LUSV departs from HMAS Waterhen in Sydney and conducts a 600 nautical mile transit towards the extended minefield. Due to the scale of the operation, a long mission duration and continuous deployment of multiple systems are anticipated from the outset.

On board the LUSV are several smaller UAVs and USVs. Each clearance USV is equipped with UUVs that are deployed for detailed detection, classification, and marking of mines. Because the area to be cleared covers a large number of square nautical miles, the simultaneous deployment of multiple USVs is necessary to create a safe corridor within the required time frame. The USVs are launched as soon as the LUSV reaches the edge of the minefield.

After launch, the USVs enter the minefield and conduct systematic search patterns. As they move deeper into the area, they operate beyond the direct line of sight of the LUSV. At that point, a UAV is launched to act as a continuous communication relay, ensuring a stable data link between the LUSV, the USVs, and the UUVs throughout the operation. Because of the large size of the area, this relay remains necessary for an extended period.

Once the minefield has been fully surveyed and the corridor has been declared safe for navigation, the USVs return to the LUSV for recovery and are taken back on board. During the mission, the USVs have returned to the LUSV several times to refuel or change batteries. The LUSV served as an autonomous forward base at sea from which the USVs could be relaunched. Throughout the entire operation, continuous communication was maintained between the LUSV and the Shore Control Centre (SCC). This allowed remote operators to provide mission updates, adapt search patterns, and redirect the USVs when required by the tactical situation. After completion of all tasks, the LUSV sets course back to its home port.

B.1.2. ISR in the Timor Sea

Goal: To continuously collect maritime information in the Timor Sea in order to detect unwanted activities, such as unauthorised fishing vessels or suspicious routes, at an early stage.

Scenario: In the Timor Sea, several commercial vessels are observed that switch off their AIS signal at irregular intervals and display abnormal course patterns. This behaviour deviates from regular commercial traffic and may indicate preparatory reconnaissance, intelligence gathering, or attempts to avoid detection. To improve understanding of this activity, a LUSV is deployed for a focused ISR mission.

The LUSV departs from Darwin and follows a pre-planned route along areas where AIS gaps have been recorded in recent weeks. When the LUSV reaches the operational area, a UAV is launched to conduct initial observations at greater range. The UAV detects a commercial vessel that is not transmitting

an AIS signal and is executing a series of illogical course changes. From the air, hull contours and cargo configurations are observed that do not match the declared vessel class, but these data are insufficient to fully explain the behaviour.

Because additional information is required, the LUSV is directed towards the contact area. The LUSV is equipped with higher-resolution sensors than the UAV and can combine passive and active observations with greater accuracy. At a safe distance, the LUSV conducts a series of scans, supported by surface search radar and passive signal analysis. The collected data show that the vessel follows course patterns resembling predefined grid routes, which are often associated with reconnaissance or survey-like operations.

The LUSV continues to monitor the vessel over an extended period in order to determine whether the behaviour repeats itself or forms part of a broader pattern of suspicious activities in the region. All collected ISR data are transmitted in real time to the Shore Control Centre (SCC), where analysts compare the behaviour with previous incidents in the Timor Sea. After completing the observations, the LUSV resumes its patrol and continues the mission along other AIS silence zones.

B.1.3. CUI between Sydney and New Zealand

Goal: To monitor critical data cables and energy interconnections between Australia and New Zealand in order to detect possible sabotage, manipulation, or disruption at an early stage.

Scenario: A LUSV departs from Sydney to conduct a routine inspection along the route where several data cables and energy connections between Australia and New Zealand are located. These connections lie in a busy shipping area where unknown survey vessels and fishing activities are regularly present, making early detection of possible interference essential. During the mission, the LUSV deploys several uncrewed systems, including a small USV for surface inspections and multiple UUVs that conduct close-up surveys of cable segments where minor anomalies were previously identified by monitoring.

Halfway through the patrol, the LUSV detects a vessel operating outside normal shipping routes and moving at low speed along the cable corridor. To assess the situation, a USV is dispatched ahead to observe the vessel and collect additional data. The collected information indicates unauthorised activity requiring further investigation. While the LUSV maintains position and continues to track the vessel, the information is transmitted to the Shore Control Centre so that the competent authorities can organise follow-on action. After the suspicious vessel leaves the area, the LUSV completes its survey, and UUV imagery confirms that no damage has occurred to the cables.

B.1.4. ASW in the Timor Sea

Goal: To locate and track hostile submarines operating in the access routes north of Australia, in order to safeguard the security of national maritime corridors.

Scenario: There are indications that a hostile submarine is conducting a transit through the Timor Sea towards deeper waters in the Indian Ocean. Because this route runs close to the approaches to Darwin and is frequently used by submarines seeking to operate undetected, the Royal Australian Navy wants to closely monitor how this transit develops. A LUSV is deployed ahead of other units to conduct a prolonged listening pattern in a sector where the submarine is expected to pass.

During the mission, the towed array sonar (TAS) detects subtle acoustic anomalies consistent with a submarine moving through the area at low speed. To refine the information, the LUSV launches two small USVs, each carrying a UUV. The UUVs are deployed close to the suspected track to obtain additional measurements, with the USVs acting as communication platforms. The combined data confirm a clear direction of transit, after which the LUSV, supported by the small USVs, continues to track the contact at stand-off distance. The submarine maintains a steady pattern towards the open ocean, while the LUSV continuously collects acoustic updates to ensure that no course changes or abnormal behaviour occur.

B.2. Denmark

B.2.1. MCM in the Baltic

Goal: To detect and neutralise both old and modern mines in the Baltic Sea, in order to guarantee safe passages for national and NATO vessels.

Scenario: There are indications that an adversary has deployed advanced naval mines in a strategic passage in the western Baltic Sea. These mines pose a direct threat to access routes to important shipping lanes. Because the passage is of vital importance, the minefield must be charted as quickly as possible. To limit the risk to crewed platforms, a LUSV is deployed to carry out the initial detection and reconnaissance phase.

The LUSV departs from a Danish naval base and conducts a transit towards the suspected minefield. On board are several UUVs and a variable depth sonar (VDS). During the transit, the LUSV remains in contact with the SCC, which provides situation reports and updates on the expected extent of the minefield.

As the LUSV approaches the operational area, the VDS is deployed to determine, from a safe distance, where the edge of the potential minefield lies. This creates an initial picture of the area in which mines may have been laid. Once the outer boundary has been established, it becomes clear that the passage is likely to contain modern mines that may be highly sensitive to disturbance.

Because it is too risky for the LUSV to enter the minefield itself, UUVs are launched to investigate the inner zone of the mine area. The UUVs follow pre-planned search patterns and collect data on objects that match the characteristics of modern naval mines. This information is continuously transmitted to the LUSV, which acts as a coordination point and relay platform towards the SCC.

After the scan has been completed, a clear overview is available of the locations and extent of the minefield in the passage. The UUVs return to the LUSV and are recovered on board. The collected data are used to deploy a crewed MCM unit that is responsible for the actual neutralisation of the mines.

B.2.2. Patrol near Greenland

Goal: To monitor the northern waters around Greenland in order to detect unauthorised presence, illegal economic activity, and strategic reconnaissance by other states at an early stage, given the limited regional surveillance capacity.

Scenario: The mission focuses on monitoring the northern waters around Greenland, an area with limited regional surveillance capacity and growing international interest. The Royal Danish Navy deploys a LUSV to conduct a long-endurance ISR patrol. The goal is to detect unauthorised presence, illegal economic activities, and potential strategic reconnaissance movements at an early stage.

The LUSV departs from the naval facility in Nuuk and proceeds north along a pre-planned patrol route. Due to the vast and sparsely populated nature of the region, air and surface surveillance are limited, which makes the LUSV an important asset for increasing maritime situational awareness.

During the routine patrol, the sensors of the LUSV detect a group of slow-moving vessels operating in a remote fjord. The LUSV launches a UAV to conduct an initial assessment from altitude. The UAV imagery shows several vessels deploying fishing nets in an area outside the designated fishing zones. Small tenders are also observed moving rapidly between the ships, indicating an organised illegal fishing activity.

The collected imagery is transmitted in real time to the SCC in Denmark, where analysts confirm that the vessels are not listed in Danish or Greenlandic fishing registries. Based on this, it is decided to direct the LUSV closer to the fjord in order to collect additional sensor information. Using its sensors, the LUSV can accurately record which vessels are actively fishing, which equipment they employ, and which routes they follow.

Because the area is difficult to access for crewed naval vessels and air support is limited, the LUSV remains in the fjord for an extended period to monitor patterns of behaviour. The collected data show that the group has remained in the same area for several days and is likely part of a wider illegal fishing operation.

All ISR information is transferred to the authorities, who subsequently deploy a crewed unit when weather conditions permit. Until then, the LUSV continues surveillance and functions as a persistent sensor

post in an area where regular monitoring is hardly feasible. After completing the patrol in the fjord, the LUSV resumes its route along the Greenlandic coast.

B.2.3. CUI in the Baltic

Goal: To surveil pipelines and data cables in the Baltic Sea, given the increased threat of sabotage, in order to detect suspicious activities at an early stage.

Scenario: A LUSV is deployed by the Royal Danish Navy to surveil pipelines and data cables in the western Baltic Sea, due to the increased threat of sabotage in the area. During this patrol, the Shore Control Centre receives a report of a vessel moving at an unusual distance along a pipeline. The vessel's AIS data show several anomalies, including irregular course changes and periods without signal. In addition, sensors indicate that the vessel is operating with only one anchor deployed, which may indicate earlier contact with the seabed.

The LUSV dispatches a small USV ahead for observation, while UUVs conduct underwater inspections along the section where the vessel previously proceeded at low speed. UUV imagery reveals clear damage to the pipeline, indicating physical interference. On this basis, the LUSV continues to closely track the suspicious vessel in order to prevent it from evading control. The Shore Control Centre deploys a crewed unit to the area, which intercepts and seizes the vessel for further investigation upon arrival. After the vessel has been brought under control, the LUSV resumes its surveillance route to verify that no additional disruptions are taking place.

B.2.4. ASW in the Baltic

Goal: To detect submarine movements in the shallow and busy Baltic Sea, where in particular Russian strategic submarine activities can affect both regional and wider NATO security interests. Scenario: A NATO task force is transiting through a narrow and strategically vulnerable area in the central Baltic Sea, a region in which Russian submarine movements are regularly observed. To increase the safety of the task force, a Danish LUSV is deployed ahead to survey the planned route. The LUSV uses its TAS to conduct continuous passive acoustic measurements and thereby create an early warning capability.

As the task force proceeds towards the sector, the LUSV records an acoustic anomaly that does not match the normal background noise of the area. Based on this initial detection, a UUV is launched to conduct additional observations closer to the contact. Analysis indicates a submarine moving at low speed, likely attempting to shadow the approaching NATO units.

The collected information is transmitted to the fleet command centre that coordinates the combined ASW operation. In coordination with the task force, it is decided to subtly adjust the course so that the ships remain outside the detection and interception pattern of the submarine. Meanwhile, the LUSV maintains position at a safe distance and continues to track the submarine, providing continuous updates on course, speed, and manoeuvring behaviour.

Due to the persistent pressure from multiple NATO sensors, it becomes clear to the submarine that it has been detected and cannot approach unnoticed. Ultimately, the submarine diverts to another sector, after which the task force resumes its original route and the LUSV is again employed to ensure a safe corridor.

B.3. The Netherlands

B.3.1. MCM in the North Sea

Goal: To clear mines in the North Sea, both in national waters and within NATO operations, in order to support free navigation and access to ports.

Scenario: A merchant vessel reports a suspected drifting mine on a busy traffic route towards Rotterdam. The Royal Netherlands Navy deploys a LUSV to the area to locate the object as quickly as possible. Upon arrival, the LUSV launches a UAV that searches the area from the air and visually confirms the drifting mine. Based on the UAV imagery, the LUSV manoeuvres to a safe position and deploys a UUV to inspect and neutralise the mine from close range. After the UUV has successfully neutralised the mine, the area is re-checked, after which the route can again be declared safe for shipping.

B.3.2. Patrol in the Caribbean

Goal: To conduct maritime patrols in the Caribbean in order to detect smuggling activities, illegal fishing, and other destabilising activities.

Scenario: In the Caribbean, the volume of suspicious maritime activity is increasing. There are reports of drug smuggling, illegal fishing, and vessels deliberately operating outside regular shipping routes. To closely monitor the situation and enable early intervention, a LUSV is deployed to conduct an extended patrol mission within the Dutch Caribbean area of responsibility.

The LUSV departs from Curaçao and follows a pre-planned patrol route along zones where suspicious activity has been observed previously. At several points during the mission, two smaller USVs are launched to create additional observation points. These USVs operate at some distance from the LUSV and use their sensors to monitor low-profile vessels and surface routes, particularly in areas where smugglers often try to remain below the detection threshold.

During the operation, one of the USVs detects an unusual acoustic signature consistent with a semi-submersible vessel, a type frequently used for drug smuggling. The contact information is automatically transmitted to the Shore Control Centre (SCC), after which the LUSV changes course towards the reported contact to collect additional identification data. The sensors of the LUSV confirm that it is indeed a semi-submersible smuggling vessel moving slowly through the area.

Because rapid action is required, a helicopter from a nearby ship detachment is directed to the LUSV. After landing on the LUSV, a small team transfers to a RHIB launched from the deck. The RHIB proceeds towards the smuggling vessel, approaches it, and brings it under control. The vessel is then seized and escorted to a secure location for further processing.

After completion of the operation, the USVs return to the LUSV, where they are recovered and recharged. The LUSV then resumes its patrol to continue contributing to maritime stability in the Caribbean.

B.3.3. CUI in the North Sea

Goal: To safeguard energy infrastructure such as wind farms, pipelines, and cables in the North Sea in order to detect sabotage or interference at an early stage.

Scenario: During a routine patrol of the Royal Netherlands Navy in the North Sea, a LUSV departs from Den Helder to relieve another LUSV that has been operating in the area for an extended period. On board are multiple uncrewed systems, including USVs, UUVs, and UAVs, which are jointly employed to survey energy infrastructure and subsea connections. During the patrol, a suspicious situation is detected near a cable route, prompting the launch of a UAV to conduct an initial inspection. The imagery obtained suggests possible unauthorised activity, making additional human inspection desirable.

The suspicious vessel then proceeds towards UK waters, after which all collected information is immediately shared with the authorities of the United Kingdom. Until British units can arrive on scene, the vessel is remotely monitored by a USV launched from the LUSV.

B.3.4. ASW in the GIUK Gap

Goal: To track submarine movements through the GIUK Gap, as this is a crucial access route for Russian submarines towards North Atlantic operating areas.

Scenario: The GIUK Gap is continuously monitored within NATO, because it constitutes a critical gateway for Russian submarines seeking to deploy into North Atlantic operating areas. The Dutch LUSV forms part of a larger multinational ASW task group led by a frigate that coordinates all participating units. The LUSV operates in an assigned sector and uses its TAS to passively detect submarine activity. In addition, a UAV is used to deploy sonobuoys to obtain further information on course, depth, and acoustic characteristics.

During the mission, a suspicious submarine is detected by the LUSV, after which all data are immediately transmitted to the frigate responsible for building the tactical picture. Based on this information, it is decided to continue tracking the submarine and to increase pressure by positioning multiple units, thereby making clear that its presence has been established and that the mission cannot be carried out unnoticed. The submarine then changes course and withdraws from the area, after which the LUSV resumes its assigned patrol within the NATO ASW operation.

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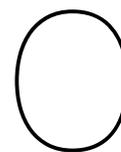
Capabilities of LUSV

C.1. Platform Capabilities

The platform capabilities describe the baseline capabilities that the LUSV must provide at all times, regardless of the mission it supports, as described above. These capabilities define what the platform must inherently be able to deliver as an asset, ensuring that it can perform its core tasks without depending on external support. Together, they establish the minimum level of capability that the platform must continuously maintain throughout its deployment.

1. Autonomous navigation The LUSV must be able to determine its own navigation decisions. This requires the capability to plan and adjust its route without human intervention.

2. Receiving fuel at sea The LUSV is expected to operate for extended periods without returning to port. Since it does not require provisions, the only form of resupply needed is fuel. The platform must therefore be capable of receiving fuel at sea.

3. Maintaining control during critical system faults When system failures occur, the platform must remain controllable. This means it must preserve essential control during critical faults.

4. Autonomous damage control during incidents If the platform suffers damage, such as fire, flooding, or weapon impact, it must be able to limit the effects of the incident autonomously. This includes detecting damage and taking automated measures to contain it.

5. Supporting modular payload integration It is expected that modular payloads will be used for mission configurations. The platform must therefore support the integration of such payloads, ensuring that different mission packages can be installed without big changes.

6. Safety embarking at any moment during operations In situations where crew must board the platform, safe embarking must always be possible. The platform must therefore provide a boarding arrangement that remains accessible under varying operational conditions.

7. Launching, controlling, and recovering UxVs It is expected that UxVs will be employed during various missions. The LUSV must therefore be able to launch, control, and recover these unmanned vehicles, enabling the platform to support a range of unmanned systems across different tasks.

8. Recharging and resupplying UxVs Because embarked UxVs often have shorter endurance than the LUSV, the platform must be able to recharge and resupply them. This allows for repeated deployment cycles without external support.

9. Detecting non-hostile environmental objects To ensure safe navigation, the LUSV must detect non-hostile objects such as civilian vessels, coastlines, islands, and navigation buoys.

10. Generating a situational picture The LUSV must independently generate a representation of its surroundings. This capability supports safe navigation and contributes to the overall tactical picture.

11. Operating sensors in degraded conditions The platform must collect sensor information under degraded conditions, such as poor visibility or environmental interference.

12. Self defence against small threats The LUSV must protect itself against small threats to ensure mission continuity. Such threats may include small USVs, small UAVs, or other low-signature platforms

that can approach at short range. The LUSV must therefore be able to detect, track, and counter these threats to prevent disruption of its mission or loss of the platform.

13. Maintaining secure communication links The LUSV must maintain secure and continuous communication links. Reliable communication is essential because it forms the primary connection between the platform and external command structures, enables coordination with other units, and ensures that mission data can be exchanged without interruption.

14. 7+ day endurance The platform must be able to operate autonomously for at least seven days. This represents the bare minimum for its intended use, ensuring that the LUSV can remain in the operational area without immediate support. From an operational perspective, longer endurance would be much more advantageous, because it increases persistence, allows more efficient use of time and therefore money, and removes the need for frequent resupply activities. Extended endurance therefore improves operational flexibility and reduces logistical demands. The concept design will examine what level of endurance is technically feasible.

15. 18 kts cruising speed The platform must maintain a cruising speed of 18 knots. This speed is required to ensure that the LUSV can sail in formation with a task force, for example during transit or coordinated fleet movements. Maintaining this speed allows the platform to remain aligned with the operational tempo of the group and to support collective maritime operations.

16. Perform up to sea state 5 The platform must be able to perform basic operations in sea state 5. This requirement is considered a normal and reasonable operational standard by subject matter experts, as vessels are generally expected to remain functional and effective under these conditions.

17. Survive in sea state 8 The platform must remain structurally survivable in extreme sea state conditions. On the open ocean, a vessel must be able to withstand such conditions to ensure its survival, as severe weather events cannot be avoided. In regions such as the North Atlantic during winter, sea states in the range of 6 to 8 occur regularly.

C.2. Mission Capabilities

C.2.1. MCM

The Mine Countermeasures (MCM) mission capabilities describe the capabilities required for the LUSV to detect, classify, and neutralise naval mines. These capabilities enable the platform to contribute effectively to mine clearance operations and to support the deployment of specialised tools and sensors needed for MCM operations.

18. Detecting naval mines The platform must have the capability to detect naval mines, as this is the first essential step in any mine countermeasure operation.

19. Locating naval mines After detection, the platform must be able to determine the precise location of naval mines to support follow-on actions.

20. Classifying naval mines The platform must have the capability to classify naval mines to distinguish between different mine types and to determine the appropriate response.

21. Neutralising naval mines The LUSV must have the capability to neutralise naval mines to ensure that identified threats are rendered safe.

22. Generating a high-resolution seabed picture The platform must be able to generate a high-resolution representation of the seabed, as accurate environmental information is essential for reliable mine detection.

C.2.2. ISR

The Intelligence, Surveillance, and Reconnaissance (ISR) mission capabilities describe the capabilities required for the LUSV to detect, analyse, and monitor activities within the maritime environment. These capabilities ensure that the platform can contribute to building an accurate and continuous situational picture and support information sharing with other units.

23. Detecting and tracking all contacts The platform must have the capability to detect all relevant surface, air, and subsurface contacts and track them accurately to support the development of a complete situational picture.

24. Identifying detailed characteristics of contacts The platform must be able to identify the characteristics and behaviour of relevant contacts to support assessment and classification.

25. Maintaining stand-off tracking of targets To reduce risks to the platform, the LUSV must be able to track suspicious vessels from stand-off distance without being detected itself.

26. Maintaining continuous area coverage The platform must have the capability to maintain continuous surveillance of the assigned area to ensure that the situational picture remains complete and up to date.

27. Signal intelligence collection The platform must be able to collect and analyse electronic emissions to enhance understanding of activities at sea.

28. Cooperative surveillance with other units The platform must be able to do surveillance tasks with other manned and unmanned units to improve the completeness and accuracy of the shared situational picture.

C.2.3. CUI

The Critical Underwater Infrastructure (CUI) mission capabilities describe the capabilities required for the LUSV to monitor, assess, and protect underwater infrastructure such as cables and pipelines. These capabilities ensure that the platform can detect abnormal activity, identify potential risks, and contribute to coordinated monitoring efforts with other units.

29. Generating a high-resolution seabed picture The platform must have the capability to generate a detailed representation of the seabed and its surroundings, as this is essential for assessing the condition of underwater infrastructure.

30. Monitoring vessel behaviour for abnormal patterns The platform must be able to monitor and analyse vessel behaviour near underwater infrastructure to identify abnormal or potentially harmful patterns.

31. Identifying detailed characteristics of contacts The platform must have the capability to determine the characteristics of relevant vessels to support the assessment of suspicious or irregular activity.

32. Detecting underwater activity near infrastructure The platform must be able to detect underwater activity in the vicinity of cables, pipelines, or other infrastructure to identify actions that may pose a risk.

33. Cooperative monitoring with other units The platform must have the capability to do monitoring tasks with other manned and unmanned units to enhance the overall understanding of activity around underwater infrastructure.

C.2.4. ASW

The Anti-Submarine Warfare (ASW) mission capabilities describe the capabilities required for the LUSV to detect, classify, and engage underwater contacts. These capabilities ensure that the platform can contribute effectively to ASW operations and coordinate its activities with other units involved in building the underwater tactical picture.

34. Detecting and tracking underwater contacts The platform must have the capability to detect underwater contacts and track them accurately to support the development of an underwater tactical picture.

35. Classifying underwater contacts The platform must be able to classify underwater contacts to distinguish between submarines and non-threatening underwater objects.

36. Employing ASW weapons against underwater threats The platform must have the capability to employ ASW weapons to neutralise underwater contacts when required.

37. Cooperative ASW operations with other units The platform must have the capability to coordinate ASW activities with other manned and unmanned units to improve the accuracy and completeness of the underwater tactical picture.

38. Minimising underwater noise emissions The platform must minimise its underwater noise emissions, as self-generated acoustic noise reduces the effectiveness of ASW sensors. Low noise levels are required to prevent interference with the detection and tracking of underwater contacts.

52. 30 kts max speed For ASW missions, a maximum speed of 30 kts is required to enable the effective use of the sprint-and-drift tactic, which allows the platform to reposition rapidly when underwater contacts are detected

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Functions of LUSV

D.1. Platform Functions

1. To decide where to navigate This function is required to generate a safe and efficient route that meets mission objectives while avoiding hazards and collisions.

2. To propel and steer The platform must produce thrust and directional control to follow the selected route and execute manoeuvres under all operational conditions.

3. To receive fuel at sea This function enables the platform to extend its operational endurance by taking fuel from a other unit at sea, reducing the need for port returns during missions.

4. To control onboard damage autonomously This function is required to detect and contain damage such as fire or flooding so that its effects remain limited and platform survivability is preserved as much as possible.

5. To support modular payloads This function enables the vessel to host mission-specific modules without big changes, ensuring flexibility across different mission roles.

6. To enable safe crew embarkation This includes providing a safe and stable access arrangement that allows personnel to board the platform for maintenance, inspection, or recovery operations, even under degraded conditions.

7. To launch and recover UxVs This function is required to deploy and retrieve unmanned vehicles that enable these assets to contribute effectively to mission execution

8. To control UxVs UxVs must receive commands and return mission data, without this function, the platform cannot coordinate unmanned assets.

9. To sustain UxV operations This function is required to recharge or resupply unmanned vehicles so they can continue operating for extended periods and maintain their contribution to mission execution.

10. To employ surface weapons This function enables the platform to defend itself against small surface or air threats that could disrupt operations or compromise safety.

11. To maintain communication links This function is required to sustain continuous information exchange with command structures, other units, and deployed unmanned systems, ensuring coordinated and safe operation.

12. To provide power This function generates power for propulsion, sensors, payloads, and support systems, enabling operations.

13. To transfer power This function distributes power across all onboard systems and ensures that each subsystem receives the amount of power it requires.

14. To store energy This function ensures that sufficient energy storage is available onboard so that operations can be sustained whenever energy is required.

15. To operate up to the mission required sea state This function ensures that the platform can continue performing its operational tasks up to the sea state prescribed by the mission. The vessel must be able to sustain navigation, sensor use, and other mission activities within the conditions associated with that sea state.

D.2. Mission Functions

D.2.1. Sense

16. To sense the surface environment at close range This function detects nearby surface objects or hazards to support safe navigation and short-range situational awareness.

17. To sense the subsurface environment at close range This function enables the platform to obtain a detailed view of the nearby seabed and to detect underwater obstacles that affect safe navigation. It also supports mission tasks that require accurate assessment of subsurface features in the vessel's vicinity.

18. To sense the surface environment at long range This function detects surface contacts at extended distances to support early threat assessment and defensive awareness. It also enables the platform to identify relevant surface activity at range for mission related tasks.

19. To sense the subsurface environment at long range This function enables the platform to detect underwater contacts at extended distances so that it can support mission tasks that require wide-area subsurface awareness.

20. To detect electromagnetic emissions This function collects and analyses electromagnetic signals in the surrounding area to identify sources of electromagnetic activity.

21. To create a situational picture This function integrates all sensor information into a coherent and up-to-date representation of the environment. It supports safe navigation, threat evaluation, and mission decision-making by ensuring that the platform maintains a comprehensive understanding of its surroundings.

D.2.2. MCM

22. To detect and locate naval mines This function is required because naval mines must first be detected and their position determined before any mine countermeasures can be applied. It enables the platform to identify mine threats and to support the subsequent steps of the mine-clearance process.

23. To inspect mines up close This function is required to obtain detailed information about identified mines so that appropriate mine countermeasures can be selected. Close inspection supports the assessment of mine type.

24. To enable mine neutralisation This function ensures that the platform can support the application of mine countermeasures aimed at neutralising or removing identified mines.

D.2.3. ASW

25. To employ subsurface weapons This function ensures that the platform can support the use of subsurface weapons to counter underwater threats.

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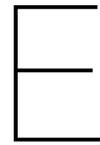
Systems of LUSV

E.1. Platform Systems

1. IMMS The Integrated Mission Management System functions as the central decision-making system of the vessel. It processes sensor inputs, monitors system status, and coordinates all mission and navigation functions. By overseeing platform behaviour and executing decisions autonomously, it effectively acts as the vessel's operational brain and maintains control and oversight during the missions.

2. Hull The hull forms the structural foundation of the vessel and supports all other installed systems. Its shape and construction strongly influence the vessel's seakeeping performance, stability, and resistance through the water, enabling operation and performance across a range of sea states.

3. Propulsors Propulsors provide the thrust required to drive the vessel. They ensure the platform can progress through the water and maintain the speed necessary to conduct its missions effectively.

4. Maneuvering systems Maneuvering systems provide the vessel with control over its movement and heading. They are essential for maintaining accurate vessel control under all operating conditions, ensuring the platform can safely navigate, reposition, and respond effectively during mission tasks.

5. ARAS system An autonomous replenishment at sea system enables the vessel to receive fuel or other supplies without human intervention. It is essential for restoring the platform's endurance during extended missions, allowing the LUSV to continue operating independently even when no crew is onboard to conduct or supervise the replenishment process.

6. Damage indication system The damage indication system monitors the vessel for signs of flooding, fire, or structural damage and reports these conditions automatically. It is essential on an unmanned platform, as no crew are present to detect such hazards, ensuring the vessel can respond to and manage damage conditions that would otherwise go unnoticed.

7. Flexible payload area The flexible payload area provides a configurable space for carrying mission-specific equipment or modules. It is effective for supporting different operational roles by allowing the vessel to adapt its payload without major structural changes, enhancing mission versatility.

8. Embarkation systems Embarkation systems provide safe access to and from the vessel for personnel during maintenance, inspection, or recovery activities. They enable controlled transfer operations in varying sea states and are essential for ensuring that crew can board or leave the platform safely when required.

9. Flightdeck The flightdeck provides a dedicated area for operating airborne assets, primarily unmanned aerial vehicles. It enables safe launch and recovery of UAVs, and it can also support operations involving manned units, such as helicopter hoisting or personnel transfer when required.

10. LARS The Launch and Recovery System enables the safe deployment and retrieval of unmanned assets. It is essential for ensuring that UxVs can be launched and recovered efficiently and reliably, allowing the vessel to employ these systems effectively during operations.

11. UxV resupply system The UxV resupply system provides replenishment services for unmanned vehicles, such as refuelling, recharging, or rearming. It is effective for restoring the endurance of smaller UxVs, enabling them to continue operating and contributing to mission tasks over extended periods.

12. Communication systems Communication systems provide the links needed to exchange information with command structures, other units, and deployed systems. They are critical for coordinating operations, maintaining situational awareness, and ensuring that the vessel remains under effective control and oversight. Their reliable performance is essential for mission execution and for managing the LUSV from remote or supervisory control modes.

13. Gun A gun provides the vessel with a close-range defensive capability against small surface or aerial threats. It is effective for deterring or neutralising hostile units that approach the vessel, supporting self-protection during operations.

14. Power generation system A power generation system converts the vessel's stored energy, such as fuel, into usable power. It provides the energy supply required for all onboard operations.

15. Power distribution system A power distribution system transfers power from the vessel's generators and storage units to all onboard systems. It ensures that each subsystem receives the power it needs to operate effectively.

16. Energy storage An energy storage system holds the vessel's energy reserves, for example fuel and electrical capacity. It ensures that sufficient energy is available to generate power and to support all operations.

E.2. Mission Systems

E.2.1. Sensors

17. Optical/infrared camera This camera system provides visual and thermal imagery to support navigation and identification. It is effective for detecting and identifying objects when visual conditions are limited, providing reliable imagery across day and night operations.

18. Navigation radar This radar system detects nearby surface contacts and hazards to support safe navigation. It is effective for collision avoidance and close range situational awareness, ensuring the vessel can operate safely.

19. Surface search radar This radar system detects and tracks surface targets at longer ranges. It is effective for threat assessment and maintaining maritime domain awareness, ensuring the vessel can identify and monitor relevant activity at extended distances.

20. Hull mounted sonar A hull mounted sonar is an active sonar system integrated into the vessel. It provides acoustic coverage ahead and beneath the ship. The system supports safe navigation by detecting underwater obstacles, mines, and shallow features. It also contributes to other operations by identifying nearby submarines and other underwater threats.

21. Variable depth sonar A variable depth sonar is an active sonar system deployed on a cable so it can operate at different depths. By placing the sonar body in the optimal acoustic layer, it improves the detection and tracking of underwater contacts, especially in challenging or layered water conditions.

22. Towed array sonar A towed array sonar is a long passive sensor streamed behind the vessel to avoid self-noise. It is highly effective at detecting and tracking quiet submarines at long ranges and provides accurate bearing information. Because it does not transmit, it offers covert and highly sensitive underwater surveillance.

23. ESM An Electronic Support Measures system passively detects and analyses electromagnetic emissions from other units. It excels at providing early warning, identifying radar and communication sources, and improving situational awareness without revealing the vessel's presence.

E.2.2. MCM Systems

24. MCM USV An unmanned surface vehicle capable of supporting MCM operations

25. MCM UAV An unmanned aerial vehicle capable of supporting MCM operations

26. MCM UUV An unmanned underwater vehicle capable of supporting MCM operations

E.2.3. ASW Systems

27. Torpedo launcher This system enables the deployment of torpedoes to counter underwater threats, supporting the platform's anti-submarine warfare capability.