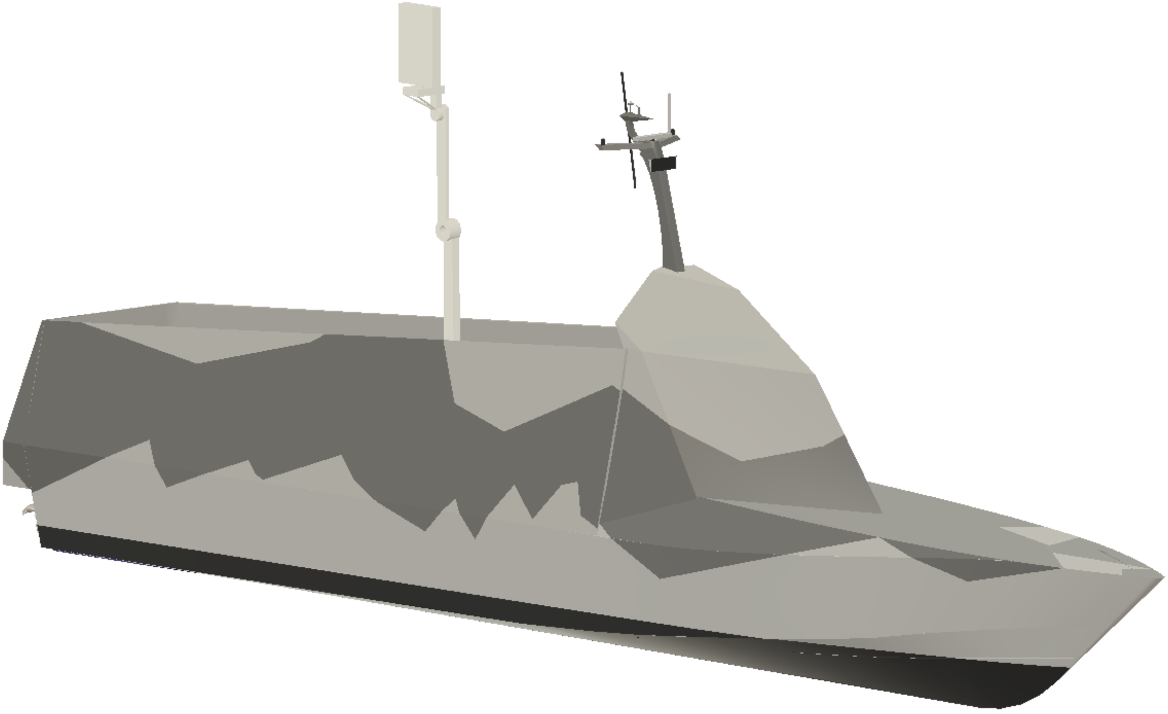

Conceptual design of an autonomous and modular naval vessel

DEPARTMENT OF
MECHANICS AND MARITIME SCIENCES

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Cover: Rendered image of the concept design.

Abstract

The private sector and authorities are both showing increasing interest in autonomous ships, making it necessary to examine and determine the best approach for transitioning toward uncrewed vessels. The maritime legislative landscape regarding autonomous ships remains in a stale mate, as legislators wait for guidance from the International Maritime Organization before formulating national laws to govern these vessels, and private companies wait for the legislators and classing societies before investing large sums into autonomous vessels.

This study investigates the transition from crewed to uncrewed vessels from both a naval architecture and legislative perspective. Based on these findings, an intermediary vessel is proposed through an iterative design process. The transition pathway is examined in depth, considering the technical, operational, and regulatory challenges involved. The resulting vessel concept is designed to operate flexibly in both crewed and uncrewed modes. Emphasis is placed on modularity, with a fully detachable crew compartment that houses crew essential systems such as toiletry and galley. This approach ensures that the vessel remains streamlined and functionally optimized when operating autonomously.

Keywords: autonomous, modular, flexible, concept design, naval, defence, USV.

Preface and Acknowledgments

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- Rebecka Bondesson, Lecturer at Chalmers university of Technology, for her help with navigating maritime rules and regulations.
- Independent Defence analyst H.I. Sutton for invaluable insights into the current landscape of naval warfare and future aspects of USV technologies.
- Mats Hammander from the Swedish Transport Agency for taking us up to date on the current legislative work within IMO regarding unmanned vessels.

Glossary

Autonomous A ship that can navigate and make decisions in order to complete tasks in a safe manner without the need for human input.

Flexibility A vessel that have the capability to change equipment depending on mission profile at a very short notice.

Gross Tonnage Gross Tonnage is a value calculated from total internal volume multiplied with a logarithmic coefficient also calculated from the internal volume.

Large Unmanned Surface Vessel Unmanned surface vessel with an overall length longer than 50 m..

Medium Unmanned Surface Vessel Unmanned surface vessel with an overall length longer than 12 m but less than 50 m..

Modularity A vessel or series of vessels designed to share large parts of its interior, structure and systems in order to facilitate ease of upgrading or class-wide similarities.

Transportstyrelsen Swedish Transport Administration, governmental authority that formulates legislative text regarding all forms of transportation in Sweden.

Acronyms

CONOPS Concept Of Operations.

DARPA Defence Advanced Research Projects Agency.

EW Electronic Warfare.

FMV Swedish Defence Materiel Administration.

GT Gross Tonnage.

IMO International Maritime Organization.

LOA Length Overall.

LUSV Large Unmanned Surface Vessel.

MASS Maritime Autonomous Surface Ships.

MUSV Medium Unmanned Surface Vessel.

NOMARS No Manning Required Ship.

STCW Seafarers' Training, Certification and Watchkeeping.

USV Unmanned Surface Vessel.

Contents

1

Introduction

In the automotive and aerospace industries the technology facilitating autonomous vehicles have in recent years seen great advances, where aerial drones have successfully been deployed in many missions since the turn of the millennia. However within the maritime sector there has been relatively little progress in the field of automation, especially in comparison to the aerospace sector. One reason for this is that while the International Maritime Organization (IMO) is currently developing regulations for autonomous ships, IMO (2025), clear and distinctive legislation regarding unmanned surface vessels (USV) are yet to be implemented. This has lead to some flag states approaching autonomous ships individually instead of relying on the IMO. For example the Norwegian Maritime Authority have developed their own guidelines for domestic testing of autonomous ships (Sjøfartsdirektoratet 2020). Another nation having a similar program is Japan (with the MEGURI2040 (2020) programme) that have developed a multi-stage plan for the introduction of autonomous vessels into commercial traffic. These regulations are based on the existing regulations for conventional ships, the Norwegian government has also created designated testing areas for autonomous ships to be tested in a real environment (Voldsund 2022).

The Russian invasion of Ukraine has shown what strategical potential USVs can provide in a military context. Ukraine has quickly developed a fleet of small USVs that have made a significant impact by attacking several larger Russian warships. H. I. Sutton (2024a) argues that many of these attacks are not possible with crewed vessels, as crewed vessels need extra volume to account for crew compartments and systems related to human needs, thus making them easier to detect and target. With the military implications shown in the war, many other navies have started showing increased interest in the subject of unmanned surface vessels. While much of the recent development is focused on smaller vessels, there is a clear increase in the development of larger vessels such as USA's NOMARS (Parken 2024), China's USV-JARI-A, or Thales and Stellers' TX-Ship programmes, compiled information about those can be found in Appendix B. Saab Kockums AB is likewise interested in exploring the potential of a larger USV and the unique opportunities and challenges that these vessels can provide.

The Swedish Shipowners' Association (SSA) have published their considerations for developing SMART ships (Swedish Shipowners' Association 2021). SMART being the operative word for a collection of advanced assisted or remote controlled vessels. SSA state the overall reason for SMART vessels is:

> The reasons for developing SMART ships should be to attain increased safety, efficiency, and sustainability.

Furthermore SSA provide perspectives from different stakeholders, and state that the IMO must lead the development of the regulations.

> It is not considered that existing rules and regulations are sufficient for highly automated and digitalized vessels with only a minor, or no crew. This means that rules and regulations for SMART Ships needs to be established and this must take place on an international level; IMO needs to lead this.

This creates a regulatory void for shipbuilders that even though some ship builders are willing and capable of manufacturing and implementing autonomous systems, the regulations essentially prevent them from developing and testing new systems. This forces the still willing shipbuilders into a potentially costly IMO1455 process, as RISE (2024) have described it, and this is currently is the only viable way to introduce new technologies, such as unmanned surface vessels, into commercial traffic.

Naval ships have have additional incentives to increase the level of autonomy as this allows allows for fewer crew aboard a ship, thus minimizing the risk for causalities in the case of an attack. Less crew aboard the vessel also means that less space needs to be designated for crew amenities, leading to smaller and lighter ships. This in turn increases the manoeuvrability and reduces the detectability of the vessel.

1.1 Background

Vessels not intended for use in private leisure and exceed 24 meters in length currently needs a trading certificate and subsequently a decision on minimum safe manning and thus the assignment of a crew to ensure safe operation (Regeringen 2003). In Swedish national waters these rules are governed by the Swedish Transport Agency, and by the IMO in international waters. Many nations and thus the aforementioned agencies follow the IMO guidelines for the domestic regulations as well, prompting the need for crew in domestic waters. Current Swedish maritime regulations are derived from the guidelines set out by the IMO. While the IMO have announced the development of a regulatory framework for Maritime Autonomous Surface Ships (MASS), this regulatory framework is not expected to be finalized before 2032 (IMO 2025). The absence of clear international regulation contribute to an uncertainty for shipbuilders and shipowners, where investments in development and research risk being redundant in the near future because of regulatory changes.

Some adaptations and research have been proposed, such as Bolbot et al. (2025) where the authors identified commonly referenced acceptance principles in the maritime regulatory framework related to the new MASS framework. This can be used to aid and support the decision-makers regarding the safety of implementing autonomous ships. Additionally crew wages contribute only a small fraction to the total cost of operating a vessel, Kretschmann et al. (2017), thus reducing the financial incentive to achieve full autonomy. The risk for the crew aboard a surface vessel is also significantly lower than in other sectors such as underwater or aerospace, where unmanned technology has progressed further

(Nakashima et al. 2023). In addition an autonomous vessel will have increased costs in certain areas as costs for remote control centres, large shore based maintenance crews, boarding crews for port calls, etc, (Kretschmann et al. 2017). These factors has lead many shipbuilders to hold off on developing autonomous systems until the IMO releases new guidelines.

The Russian invasion of Ukraine has significantly accelerated the development and operational deployment of small USVs, marking an acceleration from the previously incremental pace of advancement in the field. Previous uses of unmanned systems have been limited to patrolling and surveillance, but now USVs are actively engaging in combat operations, one example being the Ukranian use of USVs to eliminate Russian fighter jets, as reported in the Kyiv Post by Zakharchenko (2025), an image from the instance is included in Fig. 1.1. Ukrainian naval forces have demonstrated notable success in their use of USVs against larger, conventional Russian warships (Rishko 2024). These operations demonstrate that USVs can pose a substantial threat while enabling the operator to remain at a safe distance, thereby reducing the risk to personnel and lowering the operational cost of engagement. The tactical success of the Ukrainians puts into question if the current typical layout and capabilities of modern naval vessels in fact are best suited for modern naval warfare.

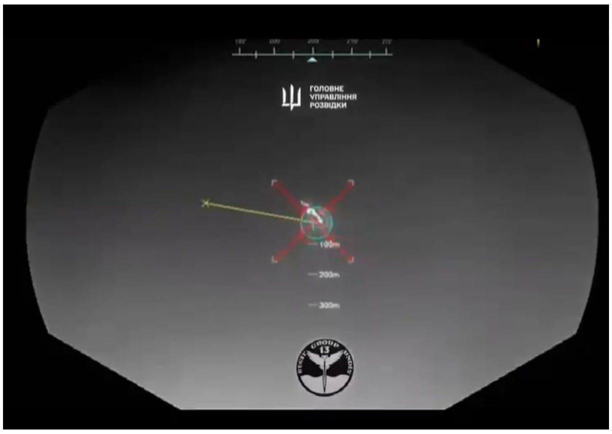

Figure 1.1: Still image from a recording of the moment an Ukranian USV eliminates an Russian Su-30 Fighter jet. Image adopted from English (2025)

How to implement large USVs effectively into a navy is a question that still needs to be explored more with many navies exploring different concepts. The US Navy has developed USVs with the intention for them to provide surveillance and logistical support. The surveillance ship Sea Hunter is intended to locate and track submarines for extended periods of time, Turner (2018), while the vessel Nomad is a former patrol boat that currently serves as a unmanned support ship for the US Navy (Swiftships 2022). The American defence agency Defense Advanced Research Projects Agency (DARPA) has developed a No Manning Required Ship (NOMARS) called Defiant that is intended to be able to extend the range of manned ships by acting as a launch platform, Serco (2022), that can return to port autonomously after expending its payload. This allows for an increased presence in waters far from a ships home port, such as in the Pacific ocean. Another use case for larger USVs is mine countermeasure missions such as mine hunting and mine sweeping, Turner (2018), as these are missions that are time consuming and could pose a potential threat to human life.

As naval ships are often designed for a long service life, often more than 30 years, there is often a need for a mid-life modernization where different systems and components are upgraded and replaced with more modern systems better suited for the ever evolving requirements a navy faces (Schank et al. 2016). This has made modular and flexible ship designs popular among navies around the world as it simplifies and lowers the costs of modernizations of systems and allows the ship to easier adapt to evolving requirements Largiadèr (2001). Schank et al. (2016) states that modularity and flexibility are similar but different concepts and describe the main differences between them as:

> *Modularity* entails partitioning a system into modules that consist of self-contained elements. It hinges on a systems engineering process that stresses functional analysis and identification of key interfaces. Typically, the concept calls for using common industry standards for key interfaces.
> *Flexibility* is a broader, less-precisely defined concept, but generally means constructing ships in such a way that they can more readily adapt to changing missions and technologies. Modularity can be a subset of flexibility and together they contribute to adaptable ships.

Schank et al. (2016) further define different types of both modularity and flexibility. This thesis focuses on two of these subtypes of modularity:

- Self-contained modules that provide a plug-and-play capability for the equipment inside the module.
- Modular installations that provide a basic ship structure and services that allow various mission packages to be installed and interchanged as needed.

Self contained modules can be made very versatile where a standard interface secures the module to the ship and provides communication and power. Standard shipping containers are an example of this type of modularity where the containers have a standard interface and the contents of the containers is largely irrelevant for the ship. There are also more specialized examples of this type of modularity in a naval context. Schank et al. (2016) brings up the Vertical Launch System of the Arleigh Burke class destroyers as it can be fitted with several types of missiles using the same boundaries and interface.

Modular installations differ from self contained modules in that they are larger more focused payload packages consisting of several assemblies that are closely associated with each other (Schank et al. 2016). Modular installations also contribute to the structural integrity of the ship and the ship can typically only carry one type of modular installation at once.

1.2 Aim

The aim of this thesis is to generate a concept design for Saab Kockums AB, of an autonomous and flexible ship that is able to take crewed modules and allow for a crew to command the ship in accordance with current regulations. The intention is that once regulations allow for the ship to operate fully autonomously the crew modules can then be removed from the ship to allow for additional cargo and expand the ships capabilities.

This thesis also investigates the challenges and opportunities that face large unmanned surface vessels in a naval context. It investigates the current rules and regulations regarding autonomous vessels and how these can be addressed while still maintaining a high operational efficiency.

Furthermore the thesis studies what other actors are currently exploring in this area. The thesis focuses mainly naval ships of similar size, however civilian ships and ships of other sizes are also considered as well,

The level of modularity is also investigated. This is an important aspect to consider for the ship as a high level of modularity can provide a greater scope of operations, however it can also be associated with decreased effectiveness and increased costs.

The requirements set out by Saab Kockums AB are to generate a concept design of a ship with an approximate length of 50 m that is able to reach speeds of 30 kt and has 14 days endurance.

1.3 Methodology

This thesis conducts a literature study to investigate the current rules and regulations that apply to large unmanned surface vessels. The literature study sources information from scientific databases such as Web of Sience (2025) and Scopus (2025). Laws and judicial texts are collected from sources such as JUNO (2025), Transportstyrelsen (2025) and Regeringen (2025). As the field of autonomous vessels is progressing fast additional information is gathered from journals and news reports from international sources. Information about different conceptual options is also gathered. This includes the hull configuration, the propulsion system and different types of flexibility and modularity. The literature study also studies current USVs and other naval ships of similar design in use and development today.

The literature study establishes the current requirements and constraints facing USVs, utilizing these identified parameters as the foundation for concept development. Operational considerations including manning requirements and command structure are examined, as these factors significantly influence design alternatives. Crew accommodation and habitability standards are also analyzed since the vessel must maintain capability for manned operations. Additionally, various modularity approaches are investigated, given the diverse range of existing market solutions, each presenting distinct advantages and implementation challenges. Some potential use cases for larger USVs are explored in the literature study as the intended mission profile will dictate the design of the vessel.

As only some dimensions are specified from Saab Kockums AB, naval architectural principles according to Lewis (1989) are used to estimate the remaining main particulars to be able to perform estimates for power requirements of the ship as well as range calculations. These calculations are to be used to support the selection and dimensioning of the machinery system as well as the number of crew that are required aboard the ship.

The information gained from the literature study and the initial estimates act as a foundation for the concept generation. The concept generation individually evaluates different aspects of the ship such as hull configuration, machinery and propulsion system, modularity and crew compartments. The concept evaluation follows naval architectural practices and evaluates based on several criteria such as performance, cost, size, weight, serviceability and durability. The selected concept is further explored and preliminary layouts of payload and machinery systems is suggested.

1.4 Scope and limitations

This thesis focuses on the regulatory challenges that face an autonomous ship today, as well as differing design criteria to handle the unique challenges and opportunities that a large modular and autonomous ship faces.

This thesis does not consider on the autonomous control system as there are already several solutions on the market, such as Saab Autonomous Ocean Core, Saab (2024), that are in use today. The thesis only focuses on the conceptual design of the vessel and thus no detailed solutions are considered.

The payload that will be carried by the vessel is only be considered at a high level, such as approximate size, weight, and if the payload needs access to the environment around the ship. As many systems require differing prerequisites, this needs to be studied closer in the detailed design of the ship, which this thesis does not focus on.

No greater in-depth analysis of stealth or low radar/IR signature capabilities are made. For any parts designed all surfaces are instead be designed with flat surfaces and incorporate an angle of approximately 13°. This is due to the limited ability to find openly available information within the field. Furthermore details about radar signatures are outside of the scope of this thesis.

The design process is conducted at a high level where the concept itself is proposed, thus this thesis does not include any in depth studies on the hydrodynamics or the load distribution, structural integrity or any of the structures proposed of the vessel.

1.5 Stakeholders

As this thesis is made in collaboration with Saab Kockums AB to design a vessel for the Swedish Defence Materiel Administration (FMV), there are several different stakeholders interested in this project.

First and foremost Saab Kockums AB as the client for this thesis and main stakeholder when setting performance and operational criteria for the vessel. Saab Kockums AB are also interested in further investigation in developing a similar vessel and could be a potential constructor should the vessel be built.

Chalmers University of Technology is another major stakeholder in the project. Chalmers University of Technology is interested in the regulatory challenges facing autonomous ships as well as how different aspects of the ship design interact with each other.

FMV, is a stakeholder as they are responsible for the materiel and equipment for the Swedish Defence Forces, including the Swedish Navy. Their interest is related to the performance of the vessel as well as the maintenance and cost aspects across the lifetime of the vessel.

The Swedish Transport Administration also have an interest in the project from a regulatory perspective. While not an active stakeholder in the project, the ship is designed to be compliant with the rules set out by the Swedish Transport Administration. Further, as regulations for autonomous ships does not yet exist, there is extra interest from the Swedish regulatory bodies.

2

Literature study

Many different factors need to be considered for the design and operation of a vessel. While naval vessels have the capacity to bypass particular regulations, their design in many cases must remain fundamentally compliant with current regulatory requirements in order to ensure crew safety, asset protection, and environmental preservation, Klesaris et al. (2017). While regulations for USVs are still under development, there are still many regulations about the crewing and watchkeeping of a ship that are of interest. The logistics of the ship are also be studied, especially pertaining to what the crew needs, such as accommodation and provisions.

In addition, a study of other nations similar vessels in development or already implemented is conducted and displayed in Appendix B. This part of the study mainly focuses on naval vessels but civilian counterparts are also of some interest. Similarly modular and flexible solutions in use are also studied.

2.1 Applicable rules and regulations

Unmanned vessels are still considered a novel idea, but regulations regarding operation of unmanned vessels are still not enacted, IMO (2025). This means that in the mean time, before accurate regulation is ready to be implemented, USV's must comply with rules relating to crew and safety that need to be followed by any vessel. As the vessel will mainly be operated in Swedish waters it needs to follow Swedish laws such as Sjösäkerhetslagen 1994:1009. Furthermore, as it will be used by the Swedish defence forces it also needs to be compliant with "Regler för militär sjöfart", the ruleset developed for naval vessels in Sweden (Försvarsmakten 2002). IMO and Seafarers' Training Certification and Watchkeeping (STCW) rules are also considered as Sweden is a member state of the IMO.

The Swedish regulatory system builds upon a constitution, which trickles down into openly formulated laws. These laws are then interpreted into governmental regulations by the Swedish Government. Here after the regulatory administrations, such as the Swedish Transport Administration, take action and formulate the regulatory provisions, or "Föreskrifter", that governs as the actual guiding documents and actions of enforcers. These regulatory provisions are the most practically applicable legislative documents.

In the Swedish legal system, legislative texts are written in an open-ended provision. This means that the practical interpretation is guided primarily by the intent of the law, which may also be documented in preparatory works (förarbeten), which in many cases can be found and used to better interpret the law. One example of an open-ended provision of writing the law is the Fartygssäkerhetslag (Sea Safety Act), which states:

> Fartygssäkerhetslagen (2003:364)(SFS) - 2 kap. 4§ ”Ett fartyg ska vara bemannat på ett betryggande sätt.”

This law translates into: "Any vessel must be crewed in a safe and ensuring manner." which does not explicitly state that there must be any crew onboard the vessel. In many cases certain administrative offices, such as the Swedish transport Administration (Transportstyrelsen)(STA), break down and formulate guidelines of how to interpret the laws regulating their administrative responsibilities. These guidelines are then formulated as a the governing rules, "föreskrift".

In the joint industry and agency symposium "Policylabb smarta fartyg" by Burden et al. (2022), a cooperation between Swedish Transportation Authority (STA), Saab Kockums AB, the Swedish Transportation Authority Ferry Company, ABB and other partners concludes:

> Om vägfärjan däremot inte har någon befälhavare ombord eller enbart har en reducerad bemanning som inte kontinuerlig navigerar och övervakar färden finns krav i både lag, förordning och föreskrifter kopplat till vakthållning och bemanning som i dagslägen är svåra att uppfylla, åtminstone om man utgår från en strikt tolkning av hur kraven är formulerade

Which translates into meaning: A road ferry lacking a captain or has minimal crew not continuously overseeing navigation, current laws and regulations on watchkeeping and manning are difficult to meet under a strict interpretation of current regulations. In Burden et al. (2022) the authors have conducted some thought experiments in the papers appendix, where they explore the needs for different adherence for two smaller USV’s. These thought experiments are continued for medium sized and larger USV’s in this thesis Appendix A, the nomenclature in the appendix is a continuation from Burden et al. (2022), where thought experiment A and B can be found, as such the Appendix A in this thesis are named C and D, as these appendices approximate continued evaluations in the same manner but for increasingly larger unmanned surface vessels.

There are ways to construct and test alternative designs within the current regulatory framework. Questions like these are handled individually within the framework of the IMO1455 "Alternative Design", mentioned in Chapter 1, where the ship builder can test the case of new equipment or concepts via scientifically proving the new concept inherit at least equal safety to already proven designs. Currently there exists several aspects that can be challenged this way. As a few examples, the STCW Manilla Regulation VIII/2.1 state that the bridge must be manned at all times, but they do not specify the location of the bridge. The regulations further require specific outlook criteria, however it does not mention the possibility of using cameras or remote viewing, leaving the possibility of a remote bridge open for interpretation. By implementing an IMO1455 process to vindicate a remote or an autonomous surveillance system could be a good first step.

Swedish maritime law does not explicitly state the manning or crew required, however the IMO rules that the Swedish laws are derived from does mention the capabilities the crew of the ship needs to possess. The IMO Resolution A.1047(27) Principles of minimum safe manning state:

> 3 Principles of minimum safe manning
>
> 3.1 The following principles should be observed in determining the minimum safe manning of a ship:
>
> .1 the capability to:
>
> .1 maintain safe navigational, port, engineering and radio watches in accordance with regulation VIII/2 of the 1978 STCW Convention, as amended, and also maintain general surveillance of the ship;
>
> .2 moor and unmoor the ship safely;
>
> ...
>
> .6 provide for medical care on board ship;
>
> ...
>
> .9 and operate in accordance with the approved Ship's Security Plan;

The regulations does not include a strict number but instead ensures that functional capabilities are reached, which creates the possibility to argue for equivalent safety on many points. While some regulations might prove more difficult to achieve without a crew, such as the regulations regarding mooring, IMO A1047(27) 3.1.1.2. If the rule IMO A1047(27) 3.1.1.6 in the same IMO regulations could be intended to extend to shipwrecked individuals happened upon while the vessel is out at sea, the situation could prove troublesome since no crew member can aid or attend to those in need.

Lastly, the issues of legal responsibility in the event of accidents, and the authority over navigational decisions, remain central challenges that both regulators and stakeholders advocating for unmanned vessel technologies must address before new regulations can be implemented and unmanned vessels fully integrated into operational service.

2.1.1 Specific regulatory limitations

Swedish maritime legislation does not prescribe explicit minimum levels of manning for vessels. Instead the governing laws and regulations are again written in a vague form, stating that there must be a plan of safe manning for each vessel. This plan is submitted to the Swedish Transport Agency and then an individual evaluation is done for, at least, each class of vessels. Mention of explicit physical presence on board the vessels is appear in the STCW Manilla regulations, where concrete regulations requiring crew members to be physically present on the bridge as well as stand by to physically enter the machine room. Specifically the VIII/2.1 and VIII/2.3 regulations.

> STCW Manilla Reg. VIII/2.1 - officers in charge of the navigational watch

> are responsible for navigating the ship safely during their periods of duty, when they shall be physically present on the navigating bridge or in a directly associated location such as the chartroom or bridge control room at all times;
>
> STCW Manilla Reg. VIII/2.3 - officers in charge of an engineering watch, as defined in the STCW Code, under the direction of the chief engineer officer, shall be immediately available and on call to attend the machinery spaces and, when required, shall be physically present in the machinery space during their periods of responsibility;

As stated in the STCW Manilla regulations, an appropriately skilled operator must physically be located on the bridge or prepared to enter the machine room. With an USV, the position of the bridge could be argued that if the USV is in fact remotely controlled the actual bridge is not located on board the vessel itself, but rather on another vessel or even on land. This would possibly fulfil the direct need of manning on the bridge. However the possibility to physically enter the machine room is impossible to achieve remotely. This also holds true for unmanned machinery spaces or partially unmanned machinery spaces, however in these cases a high level of automation in the onboard machinery systems is a prerogative, allowing alarms to be sounded in the cabins of the crew responsible for the machinery instead of requiring constant supervision. This means that the crew is still needed to be physically onboard the vessel.

2.1.2 Specific regulatory exemptions

The regulations set out by the IMO and other agencies could inherently reduce specific systems effectiveness or in some cases add complexity to systems in need of simplicity. This is specially true for naval vessels, where regulations about crew and environment could effectively render the design of small and nimble warships or submarines mute. In Sweden this is solved by the possibility for state owned and operated vessels exempt from certain regulations, one example being "Fartygssäkerhetslag" (SFS) (2003:364) Ch 3, 12 §, where it states that the agency that operates the ship shall decide the minimum safe manning needs of the vessel, in collaboration with the Swedish Transport Agency. It also leaves the possibility for direct governmental intervention into the matter in special cases.

Fartygssäkerhetslag Kapitel 3, 12 §.

> För fartyg som ägs eller brukas av svenska staten och som används uteslutande för statsändamål och inte för affärsdrift skall säkerhetsbesättning fastställas av den myndighet som förvaltar fartyget, om inte regeringen föreskriver eller för särskilda fall beslutar annat. Myndigheten skall samråda med Transportstyrelsen före beslutet. Lag (2008:1378).

Similar exemptions are found in several other legislative texts, where the government have secured a regulatory freedom in how the state owned vessels can be operated. Yet another example can be found in "Transportstyrelsens föreskrifter och allmänna råd om fartyg i nationell sjöfart" (TSFS) (2017:26 Ch 1, 3.7 §) where it states that the regulations stipulated in does not pertain to naval vessels.

> "Transportstyrelsens föreskrifter och allmänna råd om fartyg i nationell sjöfart" (TSFS) (2017:26 Ch 1, 3.7 §)
>
> 2 Föreskrifterna gäller inte
>
> [] ...
>
> [.7] Örlogsfartyg.

This opens up for a cooperation with the different Swedish agencies, such as the FMV, the Coast Guard or the Swedish states road ferry company under the transportation agency, to successfully implement USVs and develop the technology.

The Swedish defence force has an internal process to setup rules of manning and staffing marine vessels called "Försvarsmaktens Interna Bestämmelser", which translates to Swedish Armed Forces (SAF) Internal Directives. In FIB (2018) the manning requirements state:

> 1 §En besättning på ett örlogsfartyg ska vara sammansatt så att den kan:
>
> .1 hålla säker vakt på brygga, maskin och radio,
> .2 klara förtöjnings- och losskastningsarbeten,
> ...
> .6 hantera livräddningstjänsten och sjukvården ombord,
> ...
> .9 bistå eventuella passagerare ombord,
> 1. efterleva viloregler för att inte uppnå kritiska nivåer av sömnbrist, samt
> 2. med hänsyn till örlogsfartygets avsedda användningsområde och i enlighet med CONOPS, kunna genomföra resa i aktuellt fartområde.
>
> 2 §Ett örlogsfartyg ska alltid bemannas enligt relevant bemanningsplan så att kraven enligt
>
> .1 krav på behörigheter enligt 4-5 kap.
> .2 utbildningskrav enligt 7 kap.
> .3 det lägsta antalet tjänstgörande i besättningen som krävs för att örlogsfartyget ska få framföras.
>
> För örlogsfartyg med tekniska system som, utöver skeppstekniska system, kräver särskild kompetens ska kompetenskrav framgå av aktuell bemanningsplan.

Comparing the SAF's internal rules with the IMO A.1047(27) it is clear that SAF have interpreted the IMO in order to safely man their vessels. However the SAF directives deviate in certain areas where it deems it necessary to maintain effectiveness without compromising safety. Further more the SAF have the mandate to accept their own estimation of safe manning of their vessels, creating the possibility to implement an unmanned naval surface vessel.

2.2 Crew Logistics

All vessels requiring a crew have logistical challenges related to human necessities. This includes living quarters and storage, food and water facilities, and waste. As the ship is relatively small compared to many civilian cargo ships, there are several requirements that are exempt such as the need for several toilets or showers, since the crew is small and distances within the living quarters relatively short.

2.2.1 Living quarters and personal space

Since many of the regulations are built on each other, and all humans require the same basic needs, many of the rules regarding the living spaces onboard a ship is quite similar in many different regulations. According to the ILO MLC 2006 Reg, all crew must have access to a personal locker, there must be a toilet per every 12 passenger, the indoor height must be at least 2m, and many other specific requirements are listed in Chapter 3. In addition to the ILO MLC 2006 Regulations more logistical needs have been gathered from Naval Sea Systems Command (2016).

2.2.2 Crew estimates

Given the vessel is intended to operate at sea for at least 14 days, there needs to be a watch rotation on board. This means that there needs to be a commanding officer, a chief and at least four other crew members, depending on power production of main engines. This means that each watch needs to contain

- Commanding officer
- Coxswain
- Engineer

Providing there is two separate watches, this yields a minimum crew of 6. Given the number of crew members on board and awake at all times is three, two crew are always be available for docking or mooring operations which is one of the big issues for the safe handling of the vessel, until autonomous docking is implemented. During these operations it will be all hands on deck and seeing as the crew will either muster on or off at the same time to possibly switch the crew or perform checks and maintenance of the vessel, this will be a negligible problem.

In order to reduce the watch on board, there is an possibility to incorporate the onboard sensors instead of having sailors standing around. Sensors such as cameras can be fitted with night vision technology or even IR and heat sensors, giving them much better visual observation in many conditions. Only in clear daytime conditions the human eye could rival the modern sensors given the resolution of said systems might be lower than the humans eyes perception, this is however something that might have to go through a IMO1455 Alternative Design process.

Regler för militär sjöfart (RMS) allows for multiple berths in the same cabin, and lists different requirements for free floor area depending on the number of berths, Försvarsmakten (2002). The floor area requirements are listed as follows

- Cabins with one or two berths: 2 m^2
- Cabins with three to five berths: 2 m^2 + 0.7 m^2 for each berth above two
- Cabins with more than five berths: 4 m^2 + 0.5 m^2 for each berth above five

They further list requirements for the berth itself as

- The dimensions of the bed shall be at least 80 x 200 cm
- All crew shall have their own bed
- There shall be at least 65 cm of free space above the top of the berth
- Berths placed longitudinally shall be placed with the foot end forward
- Berths separated by less than 60 cm shall be separated by a divider
- The cabins should be located so that they can be used even during MCR-operations in unfavourable weather conditions

MCR stands for Maximum Continuos Rating and refers to the maximum sustained power the ship can operate at for extended periods of time, as stated in MAN Energy Solutions (2023).

One way to save space is the use of bunk beds, meaning that the berths are stacked vertically on each other. This way the footprint of the berths is reduced as well as using otherwise dead space for something useful. Assuming that the headroom is kept at 203cm as required by ILO MLC 2006 Reg 3.1.6a, and assuming that each berth itself is 10 cm tall, to comply with the requirement of 65 cm of free space above each berth, it is possible to fit two berths atop each other.

This creates several different possible cabin configurations to consider

Configuration	Floor area per cabin	Total floor area for all cabins	Total room area including beds
Three cabins with two berths each	2 m^2	6 m^2	10.8 m^2
One cabin with two berths and one cabin with four berths	2 m^2 + 3.4 m^2	5.4 m^2	10.2 m^2
One cabin with six berths	4.5 m^2	4.5 m^2	9.3 m^2

Table 2.1: Free floor area required for different cabin configurations

As the floor area of a standard 20 foot container is 13.86 m^2, it would be possible to have all configurations listed in Table 2.1 above, however for simplicity the solution with one cabin with six berths is chosen as this allows for more open floor space for the crew, as well as eliminating the need for interior walls that would otherwise take up space. This is then coupled with another 20 foot container housing the galley, food storage, as well as bathrooms and showers.

2.3 Current USVs in development and use

Currently there are very few autonomous ships in civilian operation. This is in large part due to regulations not accommodating the unique challenges that autonomous vessels face. Some countries, such as the UK and Norway, have however granted exceptions from certain rules to aid with the development and testing of new technologies, though most of this has been most prominent in military applications. Many military projects are however kept secret, meaning that reliable information about said developments can be difficult to find.

An overview of autonomous ship concepts, operational and conceptual are presented below. More information about these as well as other ships of interest in the current study can be found in Appendix B.

2.3.1 Yara Birkeland

One of the leading countries when it comes to civilian USV technology is Norway, where several ships are currently being tested and developed. The worlds first electric and autonomous container ship, the Yara Birkeland, as can be seen in Fig. 2.1, has been in commercial operation for over 2 years along the Norwegian coast (Yara 2024). While the ship was initially planned to have a crew supervising operations for the first two years before transitioning to fully autonomous operations, this transition has been delayed by technical as well as regulatory issues. Knut Midtsian, Interface Manager for Yara Birkeland says that the regulatory aspects of autonomous ships are challenging as no regulations yet exist.

Figure 2.1: Yara Birkeland in 2020. Adopted from Yara (2020)

Mr. Midtsian further comments that for innovative projects such as autonomous vessels, the technical solutions must come first, and the robustness and reliability need to be presented to the authorities for approval of the regulatory requirements.

While Yara Birkeland has a completely different mission profile to a naval vessel it still showcases many of the challenges any USV faces. Extensive trial periods with crew aboard the vessel will most likely be required as there are many situations that could potentially lead to disaster without a crew on board to remedy it.

2.3.2 Sea Hunter

The US Navy is also far along in the development of autonomous vessels. The 40 m long prototype Sea Hunter, as seen in Fig. 2.2 has a range of 10.000 km and can reach speeds of 27 kt. It is currently being tested with a crewed module onboard for a crew member to monitor the ship in case of any issues. The ship is intended to carry out submarine surveillance missions and currently is no plan for the ship to carry any weapons.

Figure 2.2: Sea hunter during RIMPAC 2022. Adopted from Freutel (2022)

2.3.3 NOMARS Defiant

The Defence Advanced Research Projects Agency (DARPA) have also developed the the No Manning Required Ships (NOMARS), a modular autonomous ship platform that has been designed from the ground up with the purpose of not considering the human element to further push the development in the field. A 55m prototype ship, Defiant, was launched in February 2025 (Parken 2024). A computer rendering of the Defiant can be seen in Fig. 2.3. The ship is intended to be highly flexible with the ability to quickly swap between different cargo types or seemingly even weapon system modules.

Figure 2.3: Computer rendering of NOMARS Defiant. Adopted from DARPA (2022)

2.3.4 JARI USV-A

China has constructed a 58m USV with a small bridge for crewed operations, called the JARI-USV-A, see Fig. 2.4. Interestingly both the American Sea Hunter and the Chinese JARI-USV-A are both trimarans, allegedly to improve stability in rough seas. The mission profile of the ship is not made public, however defence analyst H. Sutton (2024), speculates that it might carry both advanced sensors as well as sophisticated weapons.

Figure 2.4: Image of JARI-USV-A docked in harbour. Adopted from H. Sutton (2024)

2.4 Use cases for naval USVs

There are certain areas of operation and tasks that larger USVs are well suited for that cannot be completed effectively by smaller vessels. High risk or mundane operations can benefit from being handled by autonomous vessels so that personnel can be utilized effectively in other areas instead. In this section some proposed use cases for large naval USVs are discussed. This section is an inventory of identified areas where an autonomous or unmanned vessel can operate.

2.4.1 Logistical

The US Navy have an ongoing project that aim to solve autonomous logistical solutions, foremost intended to be used within the Pacific Ocean, where the logistical chain is longer and replenishment can take weeks. This can be solved with autonomous supply ships. Similarly the same missions could be adopted within the Baltic region, where either logistical support can be offered to allied nations or units out at sea without the need to induce a break in their own operations.

2.4.2 Anti-Surface Warfare (ASuW)

The Armed Forces of Ukraine (AFU) have proven the case for using USVs in modern warfare. What started as One Way Attack (OWA) USV's have quickly evolved into carriers of different UXV's, anti-air platform, torpedoes, mine layers and other capabilities that have allready been mounted upon them. While much of this success is attributed to the size of the vessels, making them hard to detect by both radar or visuals, the development of these Ukranian USVs have steadily increased in ambition and the latest iterations now boast of using torpedoes, anti-air missiles and launching drones from them. All these added systems might make an increase of vessel size imminent as all systems increase the mass and require energy, and increased energy demand require increased power production and more fuel.

2.4.3 ISTAR

Intelligence, surveillance, target acquisition, and reconnaissance could potentially be distributed to unmanned systems, especially in combination with crewed stealth warships. Warships or aircraft built for stealth often utilize passive radar receivers to reduce their chances of detection as an active radar emits electromagnetic waves. This prompts the stealth vessel to instead rely on other radar detection systems to gain awareness of their surrounding. Airborne early warning and control (AEW&C), such as the SAAB GlobalEye (2025) can provide naval vessels with over the horizon detection of adversary units at longer ranges, but many navies still mount large radar units on their warships to enable stand-alone operations and increase detail resolution.

An unmanned system could potentially relieve the stealth warship of some of the risk of detection by instead acting as a distributed forward ISTAR unit that sends the data back to the warship.

2.4.4 Anti-Submarine Warfare (ASW)

There already exist USVs intended for ASW, such as the American Sea Hunter and Chinese JARI-USV-A. These vessels are designed to have extensive endurance, allowing them to operate far from home for extended periods of time. This type of mission is well suited for USVs as the main operational mode consist of loitering in an area and collecting data. Larger vessels are well suited for this type of missions as they are able to carry more sophisticated sensors, as well as carry more fuel for increased endurance.

2.4.5 Minelaying

For mine laying operations the size comes into play since larger vessels can carry more mines and also since mines can be placed defensively as well as offensively. Where larger USVs could facilitate an form of loitering mine field, for defensive purposes, the operation of laying mines is in many cases quite easy for an adversary to monitor and thus avoid. USVs could aswell instead offer an solution for an offensive mine strategy, where mines are used to deny an adversary from leaving their ports or naval bases. Partaking an offensive mining mission is an very risk filled and dangerous operation, therefore it is better suited for an unmanned vessel.

2.4.6 Mine Counter Measure (MCM)

There are two main strategies for MCM, the first being mine hunting, where mines in singular form are carefully disposed of. The second is mine sweeping missions where vessels clear paths of mines en masse. Mine sweeping have previously been troublesome to carry out in a modern context due to the incredibly high risk these types of missions pose for the crew. The emergence of USVs, and especially larger ones that can either sweep with nets or sustain little to no damage when triggering a mine open up new avenues for these tactics.

2.4.7 Carrier or communications relay

Within areas with heavy electronic warfare (EW), often called EW bubbles, the use of direct radio communication is impaired, thus by posting an relay vessel outside the bubble and utilize optical fibres to an advanced units within the EW bubble, the effect of the EW bubble could be negated. In the Russo-Ukrainian war advanced electronic warfare have increasingly been implemented due to the increased presence of unmanned remote controlled drones (Joseph Trevithick 2024). USV's that carry UAV drones have already been implemented in the AFU and used in the Russo-Ukrainian war (H. I. Sutton 2024b), with examples of successful operations within the black sea, where USVs have acted as an remote launch platform for UAVs that can either inspect areas out of sight of the drones, or perform precision strikes on enemy forces and installations.

2.5 Modularity and flexibility

Large naval vessels are typically very costly and time-consuming to build, and they are usually designed for a prolonged service life, often designed with the intention to be upgraded in the future (Klesaris et al. 2017). Due to the significant initial investment, it is common practice to perform a mid-life upgrade, where systems and capabilities are modernized to ensure the vessel remains operationally effective over an extended period. These mid-life upgrades are themselves expensive and often time-consuming, and because much of the work is performed while the ship is in dry dock, the vessel is rendered inoperable for an extended period. For example, the mid-life upgrade of the USS John

Paul Jones, an Arleigh Burke-class destroyer in the U.S. Navy took approximately 10 months to complete according to Schank et al. (2016).

Another approach to the ship design process is to instead design the ship with the intention of being easy to modify during its lifetime from the initial design phase. This is the pretence of designing naval vessels with modularity in mind (Largiadèr 2001). Since the implementation of modular design reached the naval sector the approach have spread and today each navy, or naval ship builder, have different definitions of exactly what it means, but the overall intention is still to mitigate both the time spent and cost of modernizing a vessel. Some examples of this can be seen both in Europe, such as the Danish Absalon class and the German MEKO class vessels, and the US with the Littoral Combat Ships and several classes of aircraft carriers.

In Schank et al. (2016) the differences between modularity and flexibility is specified that modularity is the possibility to construct ships in the same series with different purposes, and that a ship can be repurposed into the different variants in short notice. This operation would include reconstruction and moving of parts such as bulkheads, walls or decks that might interfere with the new components and layouts. Flexibility on the other hand is that the ship can be set up on a mission basis, with the best load out for that specific mission, with minor to no actual changes to the ship structure itself, but maybe adjusting of an movable internal wall or floor in order to house different equipment within each void. These movable walls and floors are often called flexible decks and walls, and are implemented in vessels such as aircraft carriers, logistical vessels or amphibious assault vessels in order to provide the best internal spaces for the planes, armoured personnel carriers, boats or other equipment based in the internal hangars and storage spaces.

Schank et al. (2016) defines modularity as:

> Modularity involves creating fixed boundaries, defined interfaces and defined ship services (such as power and cooling) to standard portions of a ship, which are termed modules.

Modularity is then divided into three different types of modularity.

- Common modules used across multiple ships
- Self-contained modules that provide plug-and-play capabilities
- Installations that provide basic ship structure and services that allow various mission packages to be installed and interchanged

Schank et al. (2016) also define flexibility as

> Flexibility involves the ability to change boundaries, whether they are physical or related to ship services.

Which also is divided into three distinct types of flexibility

- Flexible infrastructures that allow changes to the boundaries of ship spaces to be made quickly

- Additional space within a ship
- Additional ship services within a space

Designing a modular and mission-flexible vessel has the potential to introduce additional logistical complexities, particularly concerning the storage, maintenance, and deployment of interchangeable mission-specific equipment. To fully take advantage of a modular/flexible system, these modules must be readily available ashore between deployments, which necessitates dedicated infrastructure and inventory management. At a certain point, the operational and logistical costs associated with maintaining flexibility may outweigh the benefits. An alternative approach could involve deploying multiple vessels, each configured for a specific mission profile, thereby reducing the need for duplicate equipment stockpiles. This shift in strategy reflects a broader cost trade-off—where savings are achieved by minimizing hull production, yet significant resources are still allocated to maintain multiple high-value equipment sets that cannot be simultaneously utilized.

2.5.1 Modular and flexible ships in use today

There are several examples of modular and flexible ships in use today. The STANFLEX system was developed by the Danish navy in the 1980s as a way to reduce the costs of replacing an ageing fleet according to Rear Admiral Søren Torp Petersen in Harboe-Hansen (1992). The system consists of non-permanent equipment such as guns, torpedoes or sonars that are mounted to standardized containers with a standard interface that is able to be swapped out quickly with the help of a crane. According to Rear admiral Knud Brock this flexibility allows the Danish navy to perform a much broader scope of tasks with fewer ships than a traditional navy as the ships can change their capabilities depending on the current need (Harboe-Hansen 1992).

Another example of a modular ship design is the SIGMA-class of corvettes and frigates designed by the Dutch company DAMEN that is designed to allow for different sections to be added or subtracted to the ship, as well as the locations of the different sections (Naval Technology 2014). This allows the ship to easily be customized to a specific need and also makes potential future upgrades simpler as the ship is already sectionalized.

2.6 Conclusions of literature study

The initial literature study indicates that, in Sweden, a larger civilian unmanned surface vessel is not likely to be adopted or allowed into service other than under governmental agencies. The legislation within the field is simply not mature enough to allow for unmanned vessels. For unmanned air vessels the situation looks different, since the governing rules have had longer time to mature. As the IMOs process to formulate new regulations is inherently slow to ensure safety and clarity, it is clear that this is causing shipowners to be cautious about developing large USVs ahead of regulatory decisions. This is even though there is an obvious interest from the merchant fleets, as cutting crew costs and reducing the risk of personnel on board ships. Different companies do however try to position themselves into this new technology. As an example there are already companies that are starting to offer solutions to remotely controlling larger merchant vessels such as SeaQ Remote from Vard (2025). This could be the first step into creating large uncrewed vessels that can navigate themselves from shore to shore, but as one can see from the Norwegian autonomous vessel Yara Birkeland, the de-crewing takes time.

In the PolicyLabb initiative Burden et al. (2022), conducted by the Swedish Transport Administration in collaboration with its partners, two analyses were carried out regarding test operations for autonomous surface vessels (ASVs). These analyses, referred to as Alternative A and Alternative B, see Appendix A, explore the current legislative frameworks applicable to the implementation of small USVs. Through a series of thought experiments, the study illustrates both the regulatory opportunities and the legal challenges associated with different USV configurations, providing a concise overview of potential operational constraints and enablers.

The results of these adapted analyses are presented in Appendix B. It is important to note, however, that the PolicyLabb report considers only the most restrictive interpretations of current legislation and jurisdictional authority, not taking into account the possibility for governmental agencies to own and operate the vessels.

In this report, these thought experiments, as can be seen in Appendix A, have been extended to assess larger autonomous vessels. The thought experiments from the PolicyLabb does not extend beyond vessels larger than 12 m, thus the replicated though experiments in this thesis follows the nomenclature from the PolicyLabb but instead focus on a Medium Unmanned Surface Vessel (MUSV) example with a length from $<$ 12 m to $\leq$ 50 m, and a Large Unmanned Surface Vessel (LUSV) with a length $<$ 50 m. Since this also is a question about the strict legislation, there are different answers for each question, where the question are answered in the manner of strict adherence to the law, a questioning stance to the law, and a completely naval perspective, as written into the Swedish SjöLag, vessels owned and operated by governmental agencies, such as FMV or Swedish Armed Forces, does not have to comply strictly with all regulations for civilian vessels. Some certificates gets valid depending on gross tonnage, as gross tonnage gets calculated from a logarithmic coefficient based on the internal volume of the ship, multiplied with the internal volume of the ship. However for the cause of these thought experiments the MUSV are considered below all gross tonnage requirements, meaning below 400 GT, while the LUSV might fit within those ranges.

2.6.1 Alternative approaches

When researching the subject of how to best incorporate an unmanned surface vessel some different feasible approaches have been found. The different approaches are either to strictly follow the current rules and regulations, or challenging the current equivalent safety measures in an IMO1455 process, or disregarding the regulations for civilian use and instead incorporating the vessels into governmental use as research or naval vessels.

Strict interpretation of current regulations

The vessel can be designed in full compliance with current rules and regulations, this however necessitates significant compromises with respect to its autonomous configuration, as the design must accommodate crew presence. All systems required to support human habitability must be included, thereby diminishing the advantages associated with an unmanned or automated solution. This solution could either be implemented into an new vessel or into an midlife upgrade of a vessel in service by upgrading the automated systems to be able to control the vessel while under human supervision. This way the vessel could conduct tests, data collection and system improvements while still in service.

IMO 1455

The second approach is to design the vessel and satisfy the regulations by getting approved as an alternative or equivalent design. This allows for novel approaches to the design as long as it can be proven that it is safe. So while following the regulations is not necessary, the approval process can in this case be lengthy. Especially if there are many or large deviations from the current accepted systems, and large deviations can demand intermediate solutions like actually placing a crew on the vessel during testing. The process of proving equal safety follow a scientific model, where tests and documentation is performed and gathered in order to provide for a statistical equivalent safety. This means that a IMO1455 process quickly becomes a costly and time consuming venture where detailed data of every system must be gathered. This approach would mimic a project that is close to what the MS Yara Birkeland is achieving in the Norwegian tests.

Naval vessel

The regulations set out by the IMO and other agencies can inherently reduce specific systems effectiveness or in some cases add complexity to systems in need of simplicity. This is specially true for naval vessels, where regulations about crew and environment could effectively render the design of small and nimble warships or submarines mute. In Sweden this is solved by the possibility for state owned and operated vessels to neglect the regulations, one example of this is the TSFS 2017:26 §3.7. If the vessel were to be incorporated into a cooperation between a shipbuilder and governmental agency, either within SAF or one of the sub-agencies as FMV or FOI, or even within the Swedish Coast Guard, the vessel could be designed to follow all the current rules and regulations, with the exceptions that being a governmental owned and operated vessel allows.

3

Requirements

In this chapter the requirements for the ship are discussed. These requirements include the requirements set out by Saab Kockums AB, as well as regulatory requirements with regards to manning and crew necessities. Different example missions are discussed in this chapter.

3.1 Mission profile

Here the mission profile of the ship are discussed. The mission profile depends on the requirements set by Saab Kockums AB, as well as what the rules require in terms of equipment and safety. Furthermore, the fact that the ship must accommodate some crew aboard the ship dictates certain aspects as well. Saab Kockums AB have defined the operational profile of the vessel is to be able to stay out at sea for at least 14 days with varying speeds and operational modes. Following are two different missions with descriptions of the modes of operation.

3.1.1 Example mission 1

The first example mission derived for the vessel mimics an intelligence or surveillance mission. The mission starts with a high speed transit to the area of operations (AOE), then operating within the AOE at lower speeds for a prolonged period of time, ending in a burst of speed to transit back to home base. This mission description excludes what kind of operations the vessel carries out in the AOE, but could resemble patrolling in a designated area. For this mission the time spent in the area of operation is key, therefore the distance is denoted as x as it is of less importance. The ship operates at 5 kt within the AOE.

Activity	Insertion	OP	RTB
Speed [kt]	30 kt	5	30
Distance [km]	277	x	277
Distance [NA]	180	x	180
Time [h]	5 h	326 h	5 h

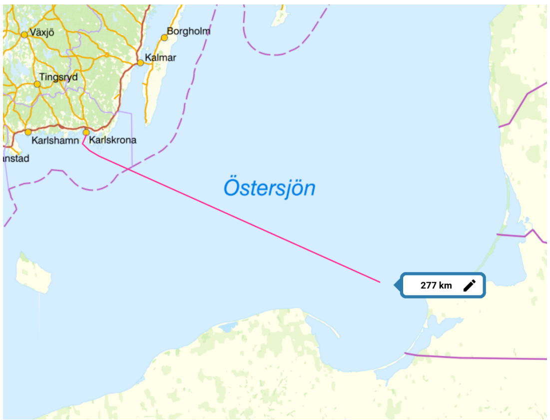

Figure 3.1: Example mission 1, transporting from Karlskrona naval base to area of operation in high speed, conducting operations within AOE in low speeds but prolonged time, then and returning base in Karlskrona in high speed.

3.1.2 Example mission 2

The second example mission derived for the vessel mimics interception and escort of another vessel. The idea is to mimic a counter to the merchant vessels dragging the chains on the bottom of the Baltic Sea, destroying sea floor data or energy cables in the process. With a mission profile like this, the suspected vessel could be intercepted before it reaches the Swedish economical zone east of Copenhagen and escorted to Finnish waters, where upon it leaves the vessel and returns to base. The mission starts from port and makes it's way towards the target vessel in high speed, then follows along the target vessel in it's speed. Here assumed to match the typical merchant tanker vessel of 12kt, then upon reaching the another country jurisdiction abort the escort and return to base. The return trip is assumed to also be done in high speed. This mission could also be reversed, as to intercept at the longer distance and return to base (RTB) at a shorter distance.

Activity	Intercept	Escort	RTB
Speed [kt]	30	12	30
Distance [km]	200	736	530
Distance [NM]	108	397	286
Time [h]	3.4	34	10

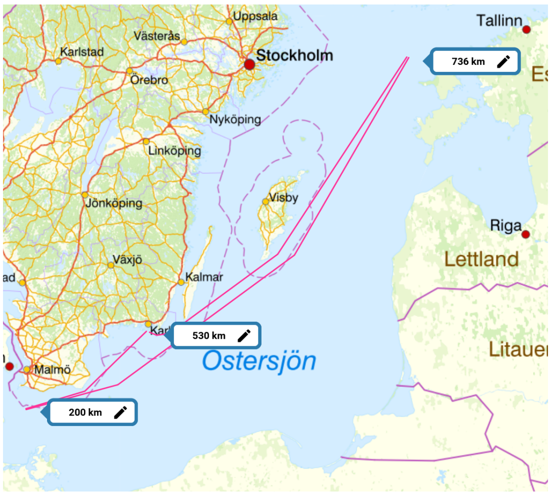

Figure 3.2: Example mission 2, starting Karlskrona naval base, intercepting a vessel south of Malmö, escorting the vessel to Finnish waters to then return to Karlskrona.

3.2 Requirements from stakeholders

In this section the requirements from different stakeholders are presented. As the different stakeholders are concerned with different perspectives

3.2.1 Saab requirements

Saab Kockums AB have stated a set of requirements that the ship needs to fulfil. These requirements only concern very high level aspects of the ship, and more detailed requirements are up to the authors to decide.

- Length $\geq$ 50 m
- Service speed $\geq$ 30 kt
- Endurance of up to 14 days at sea
- Vessel should be capable of both autonomous and remote controlled operation

3.2.2 Regulatory requirements

There are many rules dictating the design of ships. While certain issues with the current rules with regards to autonomous operations have already been discussed in Chapter 2, there are other rules that have implications for the overall design of the vessel.

- ILO MLC more often regulate ships above 3000 gross ton, with less restrictions for smaller vessels.
- Keeping the ship below 500 gross ton provides the opportunity for a single person to keep watch from the bridge. (TSFS 2012:67:3.1.2)
- Keeping the power below 3 MW avoids the need for 2 machinists aboard. Keeping the power below 1.5MW there is no need for a machinist aboard. (ILO MLC 2006 Reg A3.2.5)
- DNV High Speed and Light Craft and Naval Surface Craft, part 2 and 3 are to be applied

3.2.3 Requirements for crew modules

As the ship needs to accommodate a crew the requirements of the each crew member in terms of supplies and space is found in texts such as Naval Sea Systems Command (2016) and the regulatory text from the International Labour Organization. Below is listed hard requirements for safely housing the crew mentioned in those sources.

- 152 L fresh water per person per day
- 10 L cold food storage per person per day
- 0.5 L freezer food storage per person per day
- 10-60 L black water capacity per person per day. Possibility to pump black water directly overboard outside of 12 nautical miles from shore.
- Minimum 203 cm headroom (ILO MLC 2006 Reg 3.1.6a)
- Minimum berth size 198x80 cm (ILO MLC 2006 Reg 3.1.9e)

- On ships with less than 10 crew a cook is not required, but anyone handling food in the galley must be trained in areas of food and personal hygiene as well as handling and storage of food (ILO MLC 2006 Reg A3.2.5)
- Ventilated personal locker of >500 L per crew
- 1 Toilet per 12 crew. If crew >8, 2 toilets are recommended.
- 1 Shower per 7 crew.
- 1 sink per 6 crew, not including toilet sinks.
- Washing machine and dryer is a must for longer missions.
- Cabinets for cleaning appliances must be well ventilated and close to accommodations.
- Indoor temperature must be between 18 and 24°C.

4

Main particulars

The main particulars are dependent on what type of mission the ship should be optimized for, as different hull shapes are optimized for different tasks. In the following chapter the main particulars of the ship are discussed, and initial estimates that give the required performance are shown.

4.1 Ship particulars

The requirements given from Saab Kockums is that the ship should be around 50 m long, achieve a speed of 30 kt, and have an endurance of around 14 days at sea. This would put a category of ships generally called Fast Patrol Boats, and they are popular with many navies around the world for tasks such as coastal defence and border security. They are generally smaller than corvettes but usually fulfil similar roles by focusing on coastal operations rather than ocean-going journeys.

Table 4.1 shows a list of similar ships together with their main dimensions as well as their length-to-beam and beam-to-draught ratios. According do Lamb (2004) the length-to-beam ratio is an important metric when it comes to the resistance of the hull. A higher ratio means a more slender ship which is advantageous from a resistance perspective, however a lower ratio tends to yield a more manoeuvrable ship. In Table 4.1 it can be seen that similar ships usually have a length-to-beam ratio of around 6.5 to 7.2, which would mean a beam of around 7 m for a 50 m long vessel.

Another important metric is the beam-to-draught ratio. This has an effect on the transverse stability of the vessel, as well as the residuary resistance. According to Lamb (2004) most ships have a B/T between 2.25 and 3.75, however they note that draft limited vessels can have a ratio of up to 5. This can also be seen in Table 4.1 that all monohull designs have a B/T between 3 and 5, and as these are ships meant to operate close to shore, a shallower draught is preferable. For a ship with a beam of 7 m, a 1.8 m draught corresponds to $B/T = 3.9$ which is in line with other similar ships.

Ship Class	**Nationality**	**Length**	**Beam**	**Draught**	Δ	L/B	B/T
Visby	Sweden	72.8	10.4	2.4	650	7	4.33
Stockholm	Sweden	50	7.5	2.6	320	6.67	2.88
Flyvefisken	Denmark	54	9	2.5	320	6	3.6
Buyan	Russia	62	9.6	2	420	6.46	4.8
Hamina	Finland	51	8.5	1.7	250	6	5
Kılıç	Turkey	62.4	8.6	2.82	552	7.26	3.05
Roussen	Greece	62	9.5	2.6	580	6.53	3.65
FC50	Qatar	43	9.2	2	-	4.67	4.6
FS56	France	56	8.2	2.6	-	6.83	3.15
Skjold	Norway	47.5	13.5	2.2	274	3.52	6.14
Tuo Chiang	Taiwan	60.4	14	2.3	567	4.31	6.09

Table 4.1: Ships of similar size and operational roles. Note that the Skjold and Tuo Chiang classes are catamaran designs and therefore significantly wider than their monohull counterparts

The displacement is largely a factor of the size of the ship, and the amount of equipment it carries. As the approximate size of the ship is known, but not the amount or types of equipment, given that naval vessels of similar size, such as Stockholm-class corvettes[1], the since out of service Swedish missile boats[2] or the recently laid down Dearsan 50 Meters Fast Attack Craft[3], the estimated of displacement of the vessel is assumed to be close to 300 t. This assumption is also based on a scaled down version of the Visby-class corvette FMV (2025), as this ship is already operated by the Swedish navy with a similar operational profile, the biggest difference is that the Visby-class is considerably larger at 72 m in length and weighing 650 t. The Visby-class is designed to be operated by a crew of 43, meaning that a lot of interior space must be designated to crew accommodation, workstations, and mess. As can be seen in Fig. 4.1 the crew accommodation (yellow), mess (green), and workstations (pink) take up a considerable amount of space. Approximately 20 m of the midship section is used solely for crew facilities, meaning that the remaining 50 m are used for payload, machinery, and auxiliary systems. As a ship with the same proportions as the Visby-class would also be scaled down in beam and height, the weight would also need to be scaled down. The scale factor can be computed as

$$SF = \frac{L_{New\,Ship}}{L_{Visby}} = \frac{50}{72.8} = 0.69 \tag{4.1}$$

Linear scaling of all three dimensions gives displacement as

$$\Delta_{New\,Ship} = \Delta_{Visby} * SF^3 = 210.6t \tag{4.2}$$

By applying a linear scaling factor in all three dimensions the displacement for the 50 m vessel is calculated as 210 t, however as the crew facilities that are being removed are

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[1] https://sv.wikipedia.org/wiki/HMS_Stockholm_(K11)

[2] https://sv.wikipedia.org/wiki/HMS_Norrk%C3%B6ping_(T131/R131)

[3] https://www.navalnews.com/event-news/dimdex-2024/2024/03/dearsan-signs-contract-with-qatar-for-2-fast-attack-craft/

comparatively light in comparison to many other systems it is assumed that the new ship weighs around 300t in loaded condition. This assumption is further supported by looking at similar ships that can be seen in Table 4.1, where it can be seen that ships such as the Flyvefisken and Skjold classes have similar main particulars and similar displacements as well. The construction material of the hull also has a large effect on the total system weight. Many modern naval vessels are constructed from composite materials due to the superior strength to weight ratio such materials provide compared to traditional steel structures (FMV 2025). Composite structures are however more expensive to construct, but they also offer other advantages such as a lower magnetic signature.

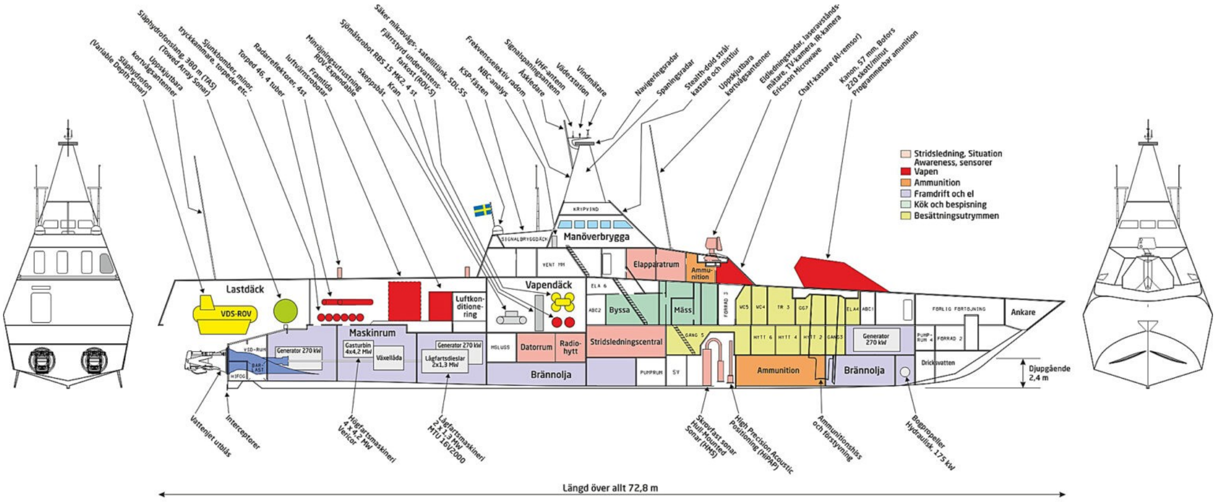


Figure 4.1: Visby-class corvette general arrangement. Adapted from Städje (2024). Note the large internal volumes designated for the crew.

4.2 Payload

The point of any vessel is the payload, and by removing the crew from a vessel can be seen as an exercise in optimization, where all the space used for crew facilities are repurposed directly into capability enhancing volumes. Since the ship is designed to be flexible it is reasonable to expect it to be able to carry different types of payloads dependent on what mission profile the vessel needs to operate. Having a flexible configuration where specific capabilities are connected to certain modules allows the possibility to quickly swap out modules containing weapons or sensors in case of changing operational profile or different mission parameters. Initially, until regulations are in place, this could mean crew modules and modules for search and rescue, mine sweeping, surveillance or regular logistical support. When the regulations for unmanned vessels are in place the crew modules can be switched out to instead incorporate modules that further increase the effectiveness of the vessels. To fully utilize such a system the estimated time required to swap modules needs to be kept at a minimum. This also creates an unfavourable situation where several unused modules with different systems could be forced to be stored ashore, rendering the investment in those capabilities unused. It is also important to consider whether to use an existing system for the modules, or if it is better to design a new system. There already exist several systems that promise to be able to quickly swap payloads in port, such as the Cube system from SH Defence, or the STANFLEX system, both of which are currently in use by the Danish navy.

For the purpose of this design study, the time required to swap a module for another is allowed to take several hours, excluding docking and manoeuvring actions. This time constraint is derived from collaborative discussions with experts at Saab Kockums AB. It is however desirable to be able to be able to swap out modules as quickly as possible to allow the ship to spend less time in port and more time conducting mission specific tasks.

4.3 Energy estimates

In this sections initial estimates are presented. These estimates serve to provide an idea of what the ship needs to perform its duties to a satisfactory level, both from performance and regulatory standpoints.

To ease the calculations the onboard systems that handle the operations of the vessel, the sensor suite and computers, have been given a set value at 4kW. This number is given from SAAB Kockums AB and represent the whole suite of internal systems, meaning if an external larger radar module is mounted on the vessel this is not considered. The total energy requirement for a 4kW system adds little in the context of the ship at large, so this is neglected in future calculations.

4.3.1 Power estimate

An initial power estimate is calculated to get an idea of the approximate power needed for the ship.

The initial power estimate is calculated using the following parameters:

- L = 50 m
- B = 7 m
- T = 1.8 m
- Δ = 300 t
- V_{kt} = 30 kt

The Froude number is calculated as

$$Fn = \frac{V_{m/s}}{\sqrt{L \cdot g}} = \frac{30 \cdot 0.5144}{\sqrt{50 \cdot 9.81}} = 0.70 \tag{4.3}$$

This puts the vessel in the semi-displacement speed range.

The Reynolds number is calculated as

$$Rn = \frac{V_{m/s} \cdot L}{\nu} = \frac{30 \cdot 0.5144 \cdot 50}{1.19 \cdot 10^{-6}} \approx 648 \cdot 10^{6} \tag{4.4}$$

The block coefficient is calculated as

$$C_B = \frac{\Delta}{L \cdot B \cdot T} = \frac{300}{50 \cdot 7 \cdot 1.8} = 0.46 \tag{4.5}$$

A low block coefficient like this is consistent with similar high speed vessels as it reduces resistance at higher speeds.

From Papanikolaou (2014) the wetted surface area is estimated as:

$$S \approx (3.4 \cdot \nabla^{1/3} + 0.5 \cdot L) \cdot \nabla^{1/3} = 316m^2 \tag{4.6}$$

With this the two biggest resistance factors can be calculated, the frictional resistance R_F and the wave-making resistance R_W

The frictional resistance coefficient is calculated as follows according to Papanikolaou (2014):

$$C_F = \frac{0.075}{(\log Rn - 2)^2} = 0.0016 \tag{4.7}$$

And the frictional resistance as:

$$R_F = 0.5 \cdot \rho \cdot V_{m/s}^2 \cdot S \cdot C_F \approx 63kN \tag{4.8}$$

For the wave-making resistance a coefficient of 0.004 is assumed as this is on the higher end of values for semi displacement hulls according to Yeung (2005). The wave making resistance is then calculated as:

$$R_W = C_W \cdot \rho \cdot g \cdot B^2 \cdot L \approx 99kN \tag{4.9}$$

The total resistance can then be calculated with a form factor value of $k = 0.2$ which is typical for semi displacement hulls.

$$R_T = (1 + k) \cdot R_F + R_W = 173kN \tag{4.10}$$

From this the required power at the design speed is calculated. Molland et al. (2017) states that a system propulsive efficiency of $\eta = 0.6$ can be assumed.

$$P_{req} = \frac{R_T \cdot V_{m/s}}{\eta} \approx 5350kW \tag{4.11}$$

A collection of different estimated power requirements can be seen in Table 4.2. With the current legislations mentioned in Chapter 2, this power requirement indicates the vessel indeed needs an engineer in addition to the chief engineer in order to pass the current regulations in the STCW code, also shown in Chapter 2.

Speed	Estimated Power requirement
6 kt	520 kW
8 kt	860 kW
12 kt	1380 kW
18 kt	2360 kW
24 kt	3650 kW
30 kt	5350 kW

Table 4.2: Power estimates for different speeds in calm water conditions.

The values presented in Table 4.2 represent the calm water resistance, however the installed power needs to be slightly higher to account for sea margin as well as to avoid having to run the engines at full power when sailing at the ships service speed. Commonly a sea margin of 10-20% is used according to ITTC (2008), meaning that the installed power needs to be at least 6400 kW.

4.3.2 Fuel estimate

One of the requirements from Saab Kockums AB is that the ship should have enough endurance to be able to stay at sea for at least 14 days, meaning that the sizing of the fuel tanks must be considered. To do this the example mission 1, described in Fig. 3.1, is considered where the ship patrols for 14 days at 5 knots, and also spends 10 hours at 30 knots. The choice of running the ship at 30 kt for 10 hours is made to simulate the ship crossing the Baltic Sea, as the Baltic sea is on average just over 100 nautical miles wide. Designing the vessel for 30 kt and a 150 nautical mile to and return ranges would allow for the ship to cross the Baltic Sea in around 5 hours.

From Eq. 4.11 the calm water power is calculated for 30 kt, the same approach can be used to calculated to get an idea of the power required for patrolling at 5 kt as well.

It can be assumed that for longer missions most, if not all, operations consist low speed patrolling and surveillance. On the other hand missions such as when relocating to another port or crossing the Baltic sea, a significant portion of the operation is conducted at high speeds

Some extra power is also needed to account for sea margin and auxiliary systems, so the calculations are performed assuming the power required is increased with 15%. This gives 6,152.5 kW when operating at 30 kt, 1587 kW for 12 kt and 598 kW when operating at 6 kt.

Given that a high speed marine diesel engine typically has a Specific Fuel Consumption (SFC) of around 200 g/kWh, (Zamiatina 2016), the fuel consumption can be calculated as:

$$m_{fuel} = \sum \frac{P \cdot t \cdot SFC}{1000} \tag{4.12}$$

Where P is the required power in kilowatts at a given speed and t is the amount of hours spent at that speed, SFC is the specific fuel consumption in g/kWh. For a gas turbine the SFC is slightly higher at around 280 g/kWh according to Vericor (2025).

For the 14 day operation in example mission 1 the necessary fuel capacity is calculated to 51,295 kg, calculated using Eq. 4.12. It can also be seen that even though the time spent at 30 kt only accounts for 3% of the total mission time, it consumes over 20% of the total fuel, meaning that the time spent at high speed is a major driving factor for the sizing of the fuel tanks. For the example mission 2 the same fuel estimation for the propulsion system can be calculated to 27,280 kg if the same addition of 15% increased resistance to account for weather, making the fuel estimate for Example Mission 1 the determining factor for the fuel capacity requirement.

With the fuel requirement for Example Mission 1 the total range of the vessel would yield a total range of over 3500km, which would be more than enough to patrol the entire length of the Swedish coastline. Alternatively it would be enough fuel to drive at 30 kt for 42 hours uninterrupted.

To be noted is that this estimated fuel consumption is without considering neither the internal autonomous systems or sensors. With values given from Saab Kockums AB the complete sensor suite and autonomous systems on board can be assumed to demand around 4 kW of power at anytime the vessel is powered on. This is quite the small power drain, only adding another 1.344 MWh to the 14 day mission, or if the vessel is equipped with additional equipment that increases the passive power consumption significantly. Active radars can require power in the tens to hundreds of kilowatt range, and power consumption numbers on other weapon systems are undisclosed. Estimating the power consumption of these additional systems to 100 kW the total power requirement increases to approximately 35 MWh. Using the same equation for fuel estimation as before, Eq. 4.12, this additional power consumption yields another 6,988 kg, resulting in the final total estimated fuel requirement of 58,283 kg for example mission 1, and 28,266 kg for Example Mission 2.

$$\text{Required Fuel Capacity: } 58,283\text{kg}$$

5

Concept Design

In this chapter different concepts are explored and advantages and disadvantages are discussed. The chapter starts of with discussions regarding the different evaluating aspect of the concept generation, starting with hull forms and shapes, to then continue on with other aspects of the major design alternatives. In total the concept generation phase potentially can generate just above one thousand unique concepts, due to the study including three different hull forms. Four different hydrodynamic features, being simple displacing hull, foil assisted hull, foiling hulls, and surface effect. Five different machinery layouts with the main differences being the electric motor propulsion with different gensets or direct shaft on combustion engines. Six different propulsions alternatives, ranging from straight shaft with CPP or FPP, waterjets, pods and azimuths. Lastly three levels of modularity or flexibility was recognized as major categories that could be separated and used as a base line for the concepts. The first being a fully ISO container based system, where all future modules and equipment. The vast majority of these concepts are simply not feasible, or fall outside of the strict parameters set upon the design. Two of the main design criteria that yield high significance is the structural simplicity and low maintenance requirement. As the Froude number for the specified length and top speed is approximately 0.7 the vessel does not reach planing, thus the distinction of displacing hulls have been made to separate from planing hulls.

5.1 Hull Configurations

Different hull forms provide different characteristics and most of them have strengths and weaknesses that can be used to optimize a vessel designated for a specific task (Molland et al. 2017). Traditionally the monohull is the most common shape for all but a few merchant vessels, where certain passenger or RoPax ships use configurations with several hulls such as catamarans or trimarans. In addition to the hull form, certain hull features can be implemented to further optimize the hydrodynamics of the vessel, such as the hydro planes or stabilizers. In this section the different aspects are discussed.

5.1.1 Monohull

With monohull design the idea is to have a traditional hull that operates in displacement and planing conditions. There are many advantages to this design, it is a well proven design that is efficient in a wide range of conditions, as described in Molland et al. (2017). This is a very common design that is found all over the world, from small pleasure craft displacing in the hundreds of kilograms, to large merchant vessels of several hundreds of thousands of tonnes. The Swedish navy currently operates several types of ships of this design, such as the Visby-class corvette. The Visby-class is designed to be able to perform several different tasks such as submarine hunting, surface combat, minehunting, and assisting civilian ships in crisis (FMV 2025). The monohull design of the Visby-class as seen in Fig. 5.1 is able to reach a speed of 35 kt, while also being able to operate undetected at slow speeds.

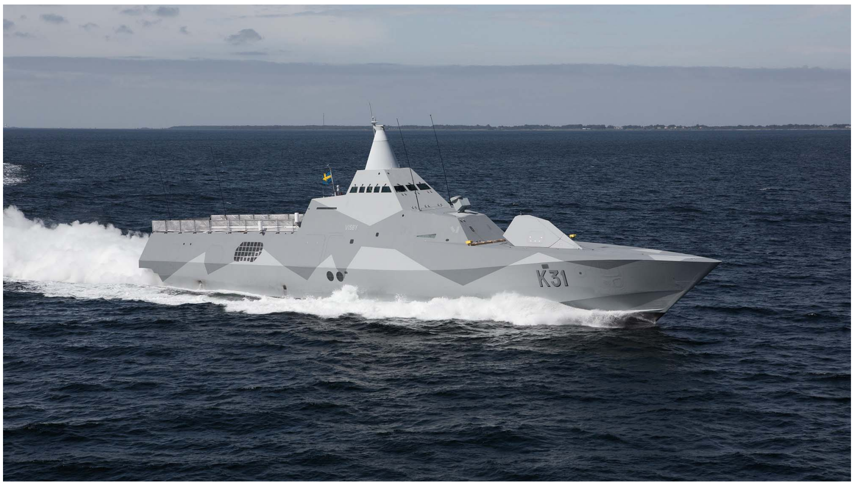


Figure 5.1: The Swedish Visby-class corvette is an example of a monohull design. Adopted from FMV (2025)

One of the main advantages of the monohull is the strength and simplicity of the structure, while at the same time offering large internal volumes, thus reducing the centre of mass. A simple design is also cheaper to construct, potentially making it easier to find a wharf that can construct the vessel.

Some disadvantages of a monohull is the wave induced rolling motion, since the initial transverse stability is lower than in multihull configurations. This has effects both for crewed missions, where the comfort of the crew is affected, as well as for autonomous operations where sensors might be negatively affected by excessive rolling of the ship. Further, the increased hydrodynamic pressure the monohull creates, since all mass is distributed within one hull also increases the hydrodynamic wave-making resistance, which reduces the hull efficiency in higher speeds.

5.1.2 Catamaran

A catamaran design has the potential to provide several valuable advantages. Catamarans have lower resistance than monohulls and due to their increased beam they are transversally stable and allows a large deck area (Molland et al. 2017). However the structure needs to be heavier and more complex to support the span between the hulls, leading to increased construction costs. Catamarans are also generally less comfortable in beam and quartering seas. For an unmanned vessel the comfort on board is of lesser importance, and a valid advantage for catamarans is the lower tendency to roll by having a steep initial GZ-curve, since the platform becomes more stable and thus induce less noise into the sensor data. Another aspect of the catamaran is the area in between the catamaran hulls that creates a very protected environment. Between the hulls equipment can be housed and lowered into the sea, or located to reduce risk of exposure. As an example, the Swedish Transport Agency's fairway maintenance vessels MS Fyrbjörn operate within shallow coastal areas, and are designed so that the propulsion system are mounted on the inside of the both hulls, thus protecting propellers from striking underwater obstacles.

Figure 5.2: The South Korean Tuo Chiang-class corvettes is an example of a catamaran design. Adopted from Teh (2019)

5.1.3 Trimaran

This concept consists of a central hull, with two outriggers off the side to provide roll stability. The advantages of such a system is that the central hull, which carries most of the buoyancy, can be made narrower and thus reducing the resistance according to Yun and Bliault (2012), while the transverse stability is aided by the outriggers that can provide a large righting moment as they are situated far from the centreline.

Trimaran designs are currently in use by both the US Navy autonomous test ship Sea Hunter, as well as the Chinese autonomous vessels JARI USV-A, see Fig. 2.4, and Thales TX Ship, see Appendix B. Potential negative features with this design is that it could potentially restrict payloads that need to be launched from the side of the ship, such as torpedoes or rescue craft. Deck space is also restricted as the hull is narrower, and the outriggers might need support structures on deck, further limiting cargo space. The structure of a trimaran is more complex and generally heavier than the same size monohull, as well as the coherent inter-hull volumes are reduced. The JARI-USV-A is an example of a trimaran design as seen in Fig. 2.4.

5.1.4 Foiling monohull

Another way to reduce resistance at high speed is to fit the vessel with hydrofoils that instead of hydrostatic lift from buoyancy relies on hydrodynamic lift when the vessel makes speed through the water. Once the ship reaches a certain speed the hydrofoils generate enough dynamic lift to heave the hull up and out of the water. This greatly reduces the hydrodynamic resistance due to the reduction of wetted surface area and exposed water-displacing elements. Tests with hydrofoils were conducted as early as 1861 and has since been used on many different types of ships through the years (Yun and Bliault 2012). The concept requires higher levels of maintenance and either significantly increases the draught of the vessel if not mounted with retracting foils, which in turn significantly increases the weight and complexity of the vessel. Foils also require an increased level of maintenance to remove fouling in order to maintain the required lift. This might be hard to achieve on an otherwise autonomous or unmanned vessel, but can be solved by shorter missions and increased maintenance intervals when in or close to port.

Figure 5.3: The American Pegasus-class was a class of fast patrol craft fitted with hydrofoils. Adopted from Hurst

5.1.5 Foil assisted multihull

A foil assisted catamarans or trimarans have the potentials to lower the hydrodynamic resistance forces even further than the regular respective hull shapes due to a foil that can be designed to span between the hulls. This foil only assists the vessel, not lifting the entirety of the hulls out of the water, but aids in increasing the ride height of the vessel in the water. This in turn reduces the wetted surface area, thus reducing drag. The point of not raising the entire catamaran out of the water is to reduce the complexity of the system, by just incorporating a passive foil optimised for a designated cruising speed.

Figure 5.4: The Superfoil40 passenger ferry is a foil assisted catamaran. Adopted from Yun and Bliault (2012)

5.1.6 Surface effect ship

Surface effect ships (SES), also called sidewall hovercrafts, are essentially catamaran hulls with the bow and stern gaps sealed by flexible skirts to create an air cushion between the hulls. This air cushion helps lift the ship out of the water, thus reducing drag. Yun and Bliault (2012) notes that development of SES started in China in 1957 and was initially based on pure marine versions of regular hovercraft, the main difference being that the sidewalls of a SES are submerged in the water at all times. Since then several countries such as China, USA, Japan, UK, and Norway have all developed SES vessels for both civilian and military use. The Norwegian navy currently operates several classes of SES, most notably the Skjold-class corvette as seen in Fig. 5.5, which is able to reach speeds of 60kt, making it the fastest combat ship in the world (Umoe Mandal 2025). However the design and construction of a SES is complex and expensive as the structure needs to be both light and strong to be able to benefit from the air cushion. The ship also needs a lot of power installed as the fan for the air cushion needs to be able to pressurize the void between the hulls (Yun and Bliault 2012). Performance in seaway can also be an issue due to air leakage.

Figure 5.5: The Norwegian Skjold-class is a Surface Effect Ship. Adopted from Forsvaret (2023)

5.1.7 Chosen hull concept

The hull shape that is determined as the most suitable for the vessel is a monohull as described in Section 5.1.1. A monohull is a simple structure that is cost effective and easy to maintain. A monohull design also provides large amounts of usable volume low down in the ship to mount machinery and other heavy components, aiding with the stability of the vessel. A conceptual sketch of the chosen monohull design can be seen in Fig. 5.6. The hull form is a semi displacement hull that incorporates design aspects from both displacement and planing hull forms.

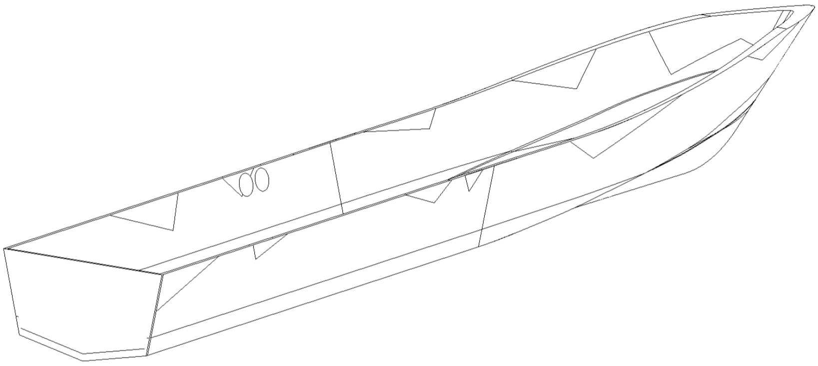


Figure 5.6: Conceptual sketch of the chosen monohull design

The downsides of a monohull design include worse roll stability in beam seas compared to multihull designs, and higher resistance at high speeds compared to other designs such as SES or hydrofoil concepts. However these downsides are considered minor in comparison to the advantages the monohull design brings.

5.2 Propulsion system

There are many different solutions for main propulsion systems for any vessel, where each offers different advantages and limitations. This section describes the propulsion systems considered within the design process in broader terms, some specific solutions depending on hull configuration, are not considered here and is a subject left to future work. There exists many different types of propulsion systems and by combining different base systems the options multiply. This thesis focuses on simplicity and reducing costs of operation, as the vessel is not serviceable during autonomous missions.

It is assumed that all propulsion systems consist of a dual setup, with one propulsion unit on either side of the ship. This provides redundancy should one propulsion unit fail, as well as allowing each propulsion unit to be smaller in size to reduce draught. A dual propulsion setup also increases the manoeuvrability of the vessel as the vessel can then utilize asymmetric thrust or thrust vectoring to manoeuvrer.

5.2.1 Straight shaft propellers

Straight shaft with either fixed pitched (FPP) or controllable pitch propellers (CPP) are a well developed technology and have many inherent positive characteristics. Some of the positive aspects of a straight shaft alternative are the low maintenance demand and high efficiency in a broad range of speeds, but risk cavitation at higher speeds (Molland et al. 2017). Compared to other propulsion systems such as waterjets or pods the straight shaft generally offer a lower level of manoeuvrability, however accompanied with bow thrusters a FPP fixed to an electrical motor, or a CPP in cases of engines that cannot change rotational direction, offer high efficiency while still maintaining quite the high level of manoeuvrability. A schematic layout can be seen in Fig. 5.7.

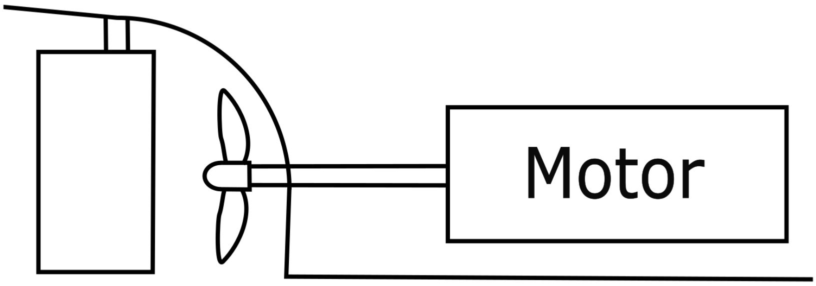


Figure 5.7: Straight shaft propeller schematic.

5.2.2 Water jets

A pair of waterjets provides excellent manoeuvrability, as well as having good efficiency at higher speeds, but can suffer slightly higher losses in efficiency at lower speeds (Eslamdoost et al. 2018). In addition the internal structure of the water jet unit lessens the acoustic noise generated by the propulsion, partially because of the reduction in tip vortices and having no exposed blades to the free stream surrounding the vessel. These characteristics reduce noise from a water jet and have the additional benefit of fading into the background noises of the sea faster, and improvements into the field is continuously improving the technology (Gong et al. 2025). A schematic layout of a waterjet can be seen in Fig. 5.8.

Another major benefit of water jets is the reduced draught of the vessel, reducing the potential of damaging propulsion units when operating in shallow or unknown waters. This factor together with the agility of the scoops of the water jets offer is favourable, as it reduces the need for bow thrusters or any other equipment needed for adjusting trim. There exist readily available water jet propulsors with adequate power, as an example this vessel could be fitted with two Kongsberg STEEL SERIES S-4 size 71 water jets as they fit dimensionally and yields an adequate power rating.

Some negative traits is the prominence of getting debris like rocks or fishing nets stuck in either the inlet of the channels or in the impellers. Obviously, if an unmanned vessel were to suffer a malfunction with fishing nets getting stuck in the impellers, or malfunctions of similar magnitude, human assistance would be required.

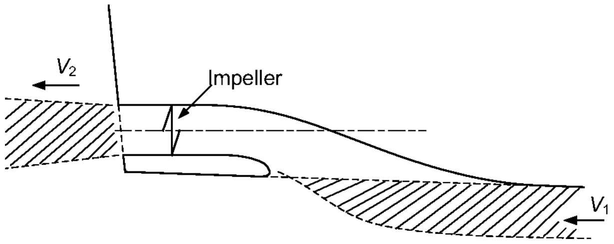


Figure 5.8: Waterjet schematic. Adopted from Molland et al. (2017)

5.2.3 Pods or Azimuth propulsion

Both azimuth thrusters and podded propellers have intriguing manoeuvring characteristics, with potential of reducing the vessels need for bow thrusters. However given the estimated draught of the designed vessel is approximately 1.8 m, the size of the pods might be too large to not increase the draught or risk damaging the pods in shallow or unknown waters. In order to mount pods to the vessel, the hull must either be designed with a upswept aft section in order to allow for flow of water to reach the pods, or mount the pods directly to the hull in the free stream. This however significantly exposes the pods and is not a feasible approach for a vessel that might need to operate in shallow waters as in the Swedish archipelago or Baltic Sea, rendering the upswept aft section a better alternative. Still the thrust requirement of this vessel the smallest pair of thrusters capable of delivering the full 6 MW of thrust was found to be approximately 3m in diameter, such as the Kongsberg Elegance pods or the Schottel STP, rendering a pair of pods unfeasible for this design because of the shallow draught. Another configuration would be to incorporate multiple pods, or even a combination of different propulsion systems such as shaft propeller and pods, see Section 5.2.5. By using a multiple configuration, such as triplets or quadruplet, pods would reduce the diameter of each pod. By downsizing from 3MW per pod to 2MW per pod, and instead mounting 3 pods, the propeller diameters are reduced to 2m for the Kongsberg Elegance pods. Mounting three of these pods to the aft part of the vessel could probably cause interference, since the estimated width is of the vessel is just 7m, thus requiring a reduction in possible turning radius of each pod in order to not collide with its neighbouring pod. This also increases the vessels complexity and induces more parts that could fail into the design. A schematic layout of a podded propeller can be seen in Fig. 5.9

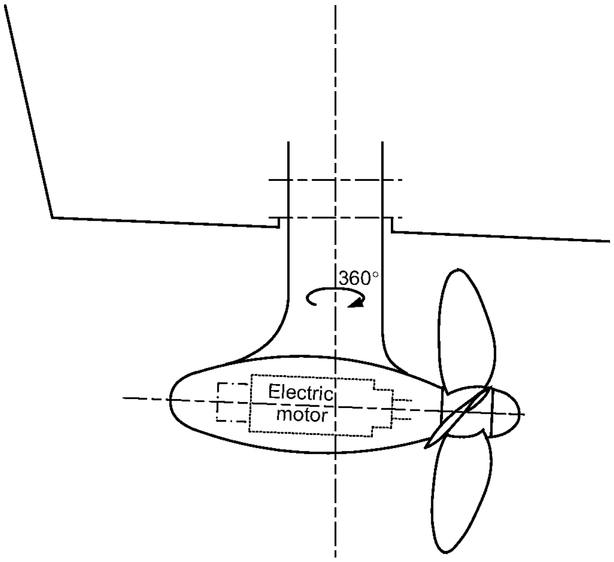


Figure 5.9: Schematic layout of a podded propeller. Adopted from Molland et al. (2017)

5.2.4 Surface piercing propellers

Surface piercing propellers (SPP) offer good efficiency at higher speeds, making them the prominent for racing boats and some smaller high-speed marine vessels, such as the Iranian Peykaap-Class Fast Attack Craft, but suffer significantly lower efficiencies at lower speeds (Seyyedi and Shafaghat 2020). Unlike conventional fully submerged propellers, SPPs operate with part of the blade disc emerging from the water during each rotation. This partial submergence ventilates the propeller blades and thus lowers the drag forces of the propeller and lowers the risk of cavitation, making them ideal for fast boats. Although since this vessels need of some level of stealth, the continuous breaking of the water surface by the propellers blades induce much noise in the water, increasing the potential for acoustic sensors to spot and identify the vessel. This combined with the low efficiency at lower speeds argue strongly against the SPP alternative.

5.2.5 Combining different propulsion systems

A combination of different propulsion systems is possible, the main disadvantage is increased maintenance, logistical need and complexity to the vessel, but seeing as the breadth constrains the possible propeller sizes, a combination of systems could still be beneficial for the design. Using one straight shaft propeller and two smaller pods could create manoeuvrability comparable with water jets or pods and still maintain high and low speed performance. However this alternative is not deemed feasible due to the increased complexity of the vessel. It is considered better to focus on one propulsion system alternative in order to keep the maintenance and logistical demand low.

5.2.6 Chosen propulsion system

The propulsion system selected as the most suitable for the vessel is a waterjet setup as described in Section 5.2.2. A pair of waterjets provides great manoeuvrability, a low acoustic profile, and good efficiency at high speeds. A waterjet is also beneficial as it allows for a shallower draught, however the inlet of the waterjet is susceptible to debris getting stuck, especially when operating in shallow waters.

5.3 Machinery

In the current project, simplicity and low maintenance requirement are seen as key features, as the machinery is not serviceable while at sea when the regulations are ready to remove the crew from the ships are implemented. The engine system also has to fulfil the power and versatility requirements given by the operations, see Section 3.1.

5.3.1 Combined diesel or gas turbine

Combined Diesel or Gas (CODOG), this is similar to the propulsion system of the Visby-class and many other naval corvettes in the Swedish Navy. However in this project the power requirement is not as large, so a similar but scaled down version of the system would fit this smaller vessel. This is beneficial from a crew training perspective as machinists that are already trained on the propulsion system of the Swedish coastal corvettes is already familiar with the propulsion system and could therefore easily assist in case the ship suffered any failure at sea. Another advantage of using gas turbines is the fact that they are very compact compared to ICE engines of similar output. The TF50A gas turbines, Vericor (2025), on the Visby-class are approximately 1 cubic meter in volume while producing up to 4000 kW, excluding the exhaust cooling systems and gearbox. However one downside with gas turbines is that they require more maintenance and service, although Latarche (2021) states that this is also dependent on the mission length, with longer missions requiring relatively maintenance. The increased need for maintenance is undesirable as the ship first is intended to operate with a small crew, and eventually without any crew at all, therefore maintenance needs should be kept to a minimum. The increased maintenance and service requirement of a CODOG, or a Combined Diesel and Gas (CODAG) system is also more costly than the similar system of diesel motors of equivalent power capabilities. The implementation of a gas turbine also has further implications, as the high temperatures of the exhaust system needs to be cooled down significantly in order to reduce the IR signature of the vessel.

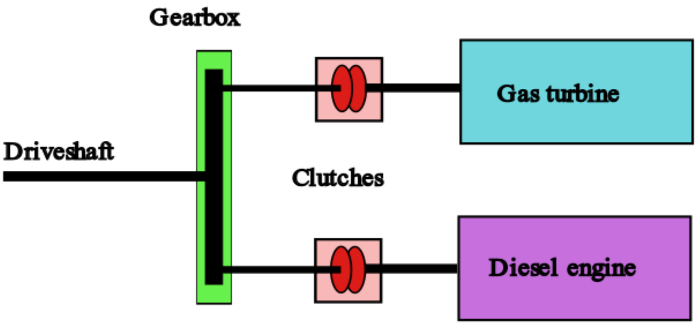


Figure 5.10: Schematic layout of a combined diesel and gas propulsion system.

5.3.2 Diesel Engine

Diesel engines connected to the driveshaft via a reduction gearbox have the advantage that it is a mechanically simple solution based on well established technology. Another positive factor is that a purely mechanical system offer high efficiency. Compared to a diesel electric alternative (integrated electric propulsion, IEP) some sources of efficiency losses in the generation, conversion are eliminated. Having fewer but larger motors is also beneficial from an efficiency standpoint, as larger displacement diesel engines typically achieve higher efficiency than multiple smaller displacement engines generating the same effect (Takaishi et al. 2008). For the power range of this vessel a combination of several medium sized diesel engines in a combined diesel and diesel (CODAD) configuration would be possible.

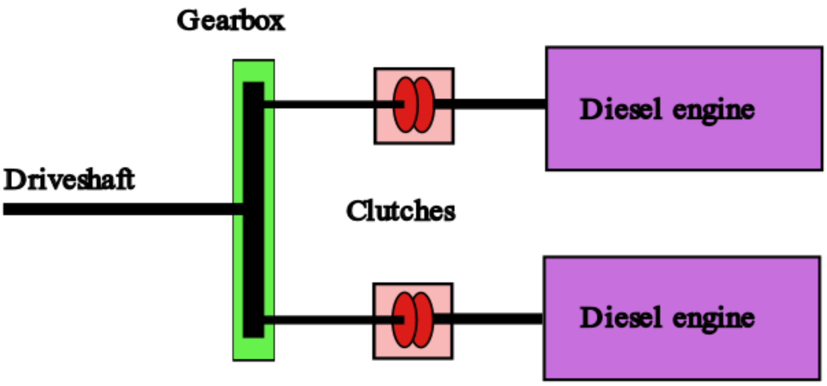


Figure 5.11: Schematic layout of a combined diesel and diesel propulsion system.

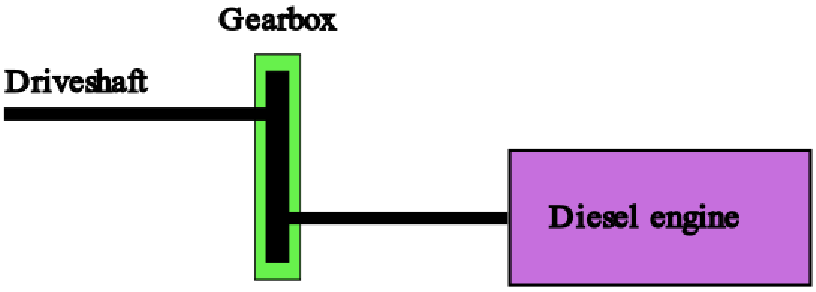


Figure 5.12: Schematic layout of a diesel engine propulsion system.

5.3.3 Combined gas or diesel electric

With a hybrid propulsion setup the low speed machinery consists of an electrical motor that is powered by diesel generators, while the high speed machinery consists of a gas turbine, much like it is described in Section 5.3.1. The advantages of this type of setup is that the generators for the electrical motor also serve as auxiliary generators for other systems on the ship, such as navigation and sensor systems.

The usage of gas turbines for the high speed machinery is beneficial from a packaging perspective as gas turbines provide a lot of power in a small volume. As desctibed in

Section 5.3.1, the TF50A gas turbines installed on the Visby-class corvett is approximately 1 m^3 and produces 4000 kW of power. Comparatively the Wärtsila 34DF, Wärtsila (2023), that also produces 4000 kW is around 55 m^3 in volume.

The low speed machinery in this concept consists of an electrical motor that is powered either by stored battery power, or from the auxiliary engines. Allowing for battery powered operations means that the vessel can significantly reduce its acoustic signature at low speeds which can be beneficial in a range of operations. Molland et al. (2017) also states that one advantage of using diesel engines as generators instead of as prime movers is that they can then be placed on floating mounts to further reduce the acoustic signature.

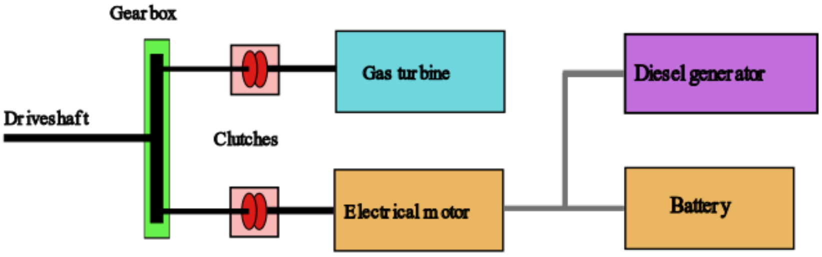


Figure 5.13: Schematic layout of a combined gas or diesel electric propulsion system.

5.3.4 Batteries

For the battery system of the vessel a few different approaches are investigated in order to conclude the size of the electric energy storage (EES). Since the total energy required for propulsion alone of the entire extent of the example mission is approximately 266 MWh, an all battery electric vessel would require an total volume of batteries much larger than the vessel itself, illustrated in 5.15, thus full battery electric was ruled out as a non-feasible solution.

Only focusing on part off the energy requirement needed to propel the vessel to the area of operation (AOE) is thus an intermediate solution that could have beneficial implications for the system as a whole. The total energy needed for the transit from port to AOE is approximately $6MW \cdot 5h = 30\ MWh$, and focusing on parts of this energy requirement as using the batteries in a reversed range extension scenario, where instead of the gensets are used to extend the range of a vessel otherwise powered by stored electrical energy, the batteries are used to engage the full power of the electrical motors, and the gensets are intentionally under-dimensioned in order to reduce cost and complexity. This mode of operation slowly drains the stored electrical energy during the transit, but would unlock the full range of power of the electrical motors. This method can however potentially have some operational implications, the foremost being that the vessel is not be able to enter strict low acoustic signature mode when the stored electrical energy is depleted. Since a genset also generate noise and vibrations, different solutions such as rubber mounts and silencing boxes exist but the lowest acoustic signature will of course be obtained when the gensets are powered down and the vessel instead relies solely stored electrical energy. After transit and before the batteries have been charged up there will be some delay before the ship regain the capability to engage a lower signature mode.

5.3.5 Diesel electric

A diesel electric propulsion system consists of a electric motor powering the driveshaft with the electricity for the motor coming from a battery or from electrical generator units. This has several advantages such as the need for additional auxiliary engines is eliminated as the generators can handle this function as well (Molland et al. 2017). It also allows the generators to be placed more freely within the hull, allowing for a better weight distribution. Using several generators spaced out across the ship also provides redundancy in case of one generator malfunctioning of being damaged by an attack there is redundancy in the system.

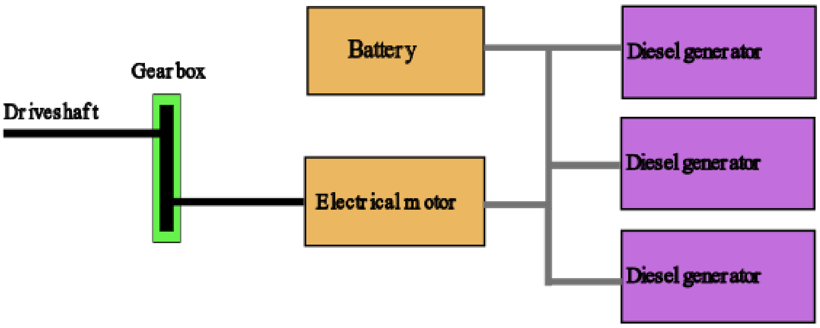


Figure 5.14: Schematic layout of a diesel electric propulsion system with additional energy storage in the form of a battery.

Molland et al. (2017) suggests that another advantage of using a diesel electric propulsion system is the increased efficiency gained from running the generators at optimum load, especially when coupled with a battery system. As previously stated placing the diesel generators on floating mounts also minimizes the acoustic signature.

The main drawbacks of a diesel electric solution is that the solution increases the system mass as there needs to be both diesel generators and electrical motors, as well as a slight decrease in efficiency due to additional transmission losses (Molland et al. 2017).

5.4 Chosen machinery system

The machinery system that is deemed the most suitable is the CODLAG system as described in Section 5.3.3. This machinery system is chosen as the gas turbines used for the high speed machinery are very compact relative to the amount of power produced. In Fig. 5.15 the volume of different machinery systems can be seen, with a turbine solution requiring significantly less space than any other solution. It is clear that a fully electric solution relying solely on batteries is not feasible purely from a volumetric consideration. It is also clear that using gensets of different sizes as shown in yellow, green, and red respectively also prove difficult to effectively locate within the hull.

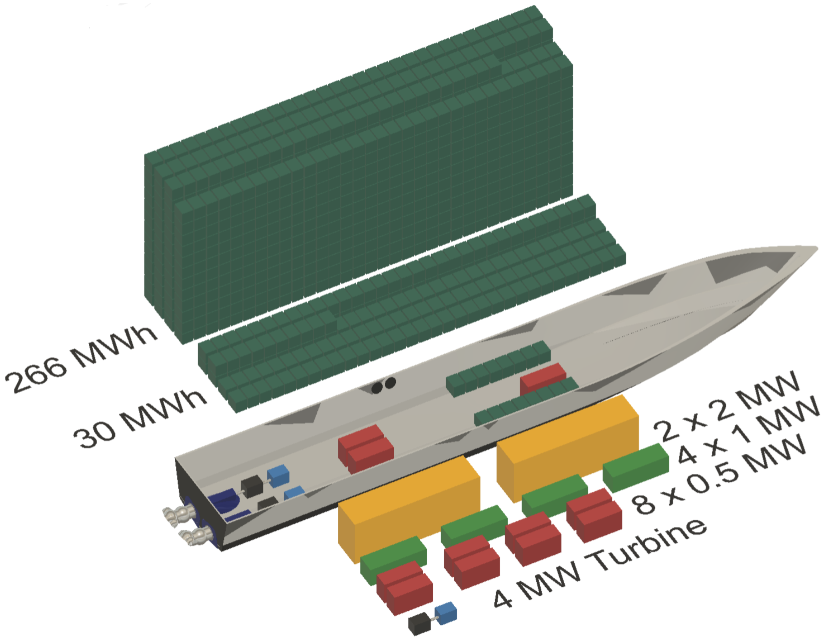


Figure 5.15: Comparison of different machinery system volume requirements. A 50 m monohull is shown in the middle as a reference.

The high speed gas turbines are supplemented by electrical motors to operate at low speeds. The electrical motors are driven either by stored energy from a battery pack, or from power generated by the auxiliary engines. The auxiliary engines also provide power for the navigational and sensor systems.

5.5 Modularity and flexibility

The definition of modularity and flexibility is described in Chapter 2. Flexibility allows the ship to quickly change its payload to suit individual missions. Flexibility is further beneficial for USVs in the current regulatory environment as it allows crewed modules to be placed aboard the ship instead of a payload, that can later be replaced by mission specific equipment. As the vessel is intended to operate fully autonomously, it is assumed that control systems and sensors needed to enable autonomous operations will be permanently mounted to the ship. In this section different concepts of flexibility will be discussed.

5.5.1 Platform with tailor made modules

Tailor made modules are beneficial as they allow the interior spaces to be better optimized to fit the vessel. Tailor made modules are also beneficial from a structural point of view as they can aid with the structural integrity of the vessel according to Schank et al. (2016), and can be designed in such a way that the modules are not exposed to environmental factors more than necessary.

Tailor made modules are however more expensive to design and manufacture and they cannot easily be transferred between different ships. Schank et al. (2016) state that the cost of developing tailor made modules might be so high that it is not feasible to develop alternative modules, thus making the modular aspect of the ship redundant.

5.5.2 Platform with internal standardized modules

One concept that retains a high level of flexibility is the use of internal modules with standard interfaces. In this concept the vessel is able to open up hatches to swap out mission specific modules. As the modules are housed inside the ship they are well protected from the environment, and the standard interface ensures easy connectivity and securing of the module.

Systems such as this already exist, such as the STANFLEX system, as described in Section 2.5.1. It consists of a standardized interface with the module either housing everything internally, or alternatively there is an external interface such as a gun or a sensor. With this type of system the ship provides the structural integrity, meaning that the module can be lighter.

5.5.3 Platform with space for standardized modules on deck

Another concept is the use of standardized modules on deck. This concept is similar to what is described in Section 5.5.2 above, however in this concept the modules are placed externally on a cargo deck. This concept is utilized in the Cube system from SH Defence (2023). The Cube system is based on the dimensions of ISO shipping containers, which allows for easy logistics and brings down costs.

By placing the modules on deck the flexibility is increased as swapping out different modules is made simpler as they are more accessible. Depending on the placement of the modules on the ship, the modules can also be allowed to extend beyond the standard interface to increase effectiveness.

One of the downsides of using modules placed on deck is that the modules are more exposed to the environment and must therefore be designed to withstand harsher conditions. A system such as the Cube that is based on ISO containers is also restricted in certain areas as equipment that does not require a full container will be an inefficient use of space.

5.6 Crew compartments

As previously stated in chapter Chapter 3, current regulations mandate there being some crew aboard the vessel while it is at sea, and the number of crew is after the initial literature study assumed to be six crew on the longer multiple-day missions. As the vessel is intended to have a range of around 14 days, this means that there needs to be made significant space for the crew. They need workstations to be able to keep watch and perform other duties, they require accommodation and some form of recreational space, and some form of food preservation and preparation possibilities is required.

5.6.1 Container based

ISO shipping containers are a well proven system for flexibility in commercial trade. A container vessel has the possibility to change a substantial part of its displaced mass quickly in each port. Incorporating ISO shipping containers as housing modules is a cost effective solution that allows for easy adaptability to changing needs and requirements.

ISO standardization of fastening equipment and loading of ISO containers provides high flexibility and ease of incorporating new modules. In Table 2.1 it is shown that under current regulations there would be enough space to fit six berths inside one 20 ft container, meaning that container based crew compartments can easily be incorporated in a design.

Container based accommodation exists, for example from SH Defence (2023), and can then easily be integrated with other modules. One of the downsides of container based crew is that the modules will be high above the waterline which can be uncomfortable in rough seas.

5.6.2 Integrated within hull

To integrate the crew spaces into the hull, such as the autonomous Chinese vessel JARI-USV-A, see Appendix B, removes the possibility for flexibility in that part of the platform as the vessel becomes at most modular, per the definition Schank et al. (2016) offers. One of the main advantages of directly integrating the different subsystems into the hull, is the density of systems within the structure increases. If every environment within the hull is planned and tailor made the amount of wasted space will be reduced. Comparing with ISO containers, where each container is limited as it is constrained by the limits of the standardized dimensions. The increased item density that a fully integrated design offers allow for a smaller vessel with the same capabilities.

5.7 Water treatment

The Baltic Sea is seen as a Special Area under MARPOL Annex IV (2011), which creates the need for a water treatment plant in order to be allowed to discharge black water overboard. This opens up for a discussion regarding the increased maintenance requirement that incorporating yet another subsystem into the vessel. Four alternatives are discussed, the first alternative is for the black water treatment system to be directly built into the crew modules, thus being removed from the vessel along with the crew modules when the ship is reconfigured into autonomous operations. The second alternative is to allow for internal tanks large enough for storing the entire calculated volume. These internal tanks could either be located within the ISO containers, located within the hull of the ship, or as a last alternative be placed on the cargo deck as an external tank. The required 5-8 m^3 for black water holding tanks is a large volume to incorporate within an ISO container. The ISO Container approximately contains 34 m^3, and allocating close to 15% of the internal volume within one of the containers for sewage is deemed unfeasible.

This volume is however feasible to house within the confines of the hull without encroaching too much on volumes needed by other systems.

Fresh water

The size requirement for a fresh water system that can provide for a crew of 6-10 people is small in comparison to the water need for a 14 day mission, for example the Spot Zero (2025) have a capacity of producing 340 L fresh water per hour while only occupying 0.05 m^3 of volume for the unit itself. This means that the fresh water required far exceeds any practical tank based solution, rendering the need for a fresh water treatment plant.

However if a freshwater system is placed within the crew modules the vessel still needs access to sea water.

There are more uses for fresh water as well, as the vessel will operate in the sea and saline water corrodes equipment faster some parts or equipment might need to be cleaned after exposure or used in other onboard processes.

6

Final concept

The final concept takes the individual concepts discussed in Chapter 5 and combines them into a complete solution. Assuming that all previously discussed concepts could be freely combined, there are thousands of different permutations possible, however many of these permutations would not be possible due to interfering requirements. For example a podded propeller solution would require an electrical driveline solution.

Cost is another important factor to consider, especially as an autonomous vessel is inherently more expendable than a crewed vessel, it is important to keep the cost as low as possible. Another factor closely related to this is maintenance needs. Maintenance takes the vessel out of commission for a time and requires a great deal of material and manpower, thus increasing the lifetime cost of the ship. Closely related to cost is of course the importance of reduced structural complexity. A multi-hull vessel increases the complexity as well as the material needed to displace a similarly sized vessel of monohull construction.

While Saab Kockums AB has requested the ship to maintain a high degree of flexibility, where time it takes to reconfigure in port is a measured and valuable parameter. It must also be considered that the effectiveness of the ship must also be considered and takes priority as a ship that is very good at a small number of tasks is preferred over one that is not very good at a large number of tasks.

6.1 Chosen concept

Based on the selection criteria previously discussed the chosen concept is a monohull with two waterjets for propulsion, driven by a CODLAG propulsion system, consisting of one gas turbine and one electrical motor connected to each waterjet. Parts of the vessels functions and capabilities are integrated directly in to the hull, such the sensor suite and systems needed for autonomous operations, as well as the machinery and propulsion systems. It is also concluded that a container based accommodation concept provide the most benefits for the vessel while at the same time keeping costs to a minimum. This ensures that sufficient crew compartments can be placed aboard the ship until regulations allow for unmanned operations. This concept also allows for a wide range of payloads to easily be placed on the ship, increasing the scope of operations the vessel can perform.

The crew compartments and payload are housed in ISO containers on a deck that can be covered with a signature-decreasing cover that also protects the containers and crew from weather and green water on deck. This is a concept that strikes a balance between being affordable to construct and maintain, as well as providing a large degree of operational flexibility. The fact that Crew compartments and payloads are housed in ISO containers means that they can quickly be swapped out in almost any port around the world. This also means that it is possible for the ship to quickly adapt to changing needs, as well as introducing uncertainty for adversaries about the current capabilities of the ship.

While a signature reducing cover makes swapping out modules more complex, the positives still outweigh the negatives. A cover reduces the radar cross-section of the ship, meaning that it can be put in a position where it is difficult to detect for an adversary. In figure Fig. 6.1 the reader can find an early conceptual rendition of the concept, without any silhouette lowering covers attached to the cargo deck, illustrating the high IR-visibility the area would yield.

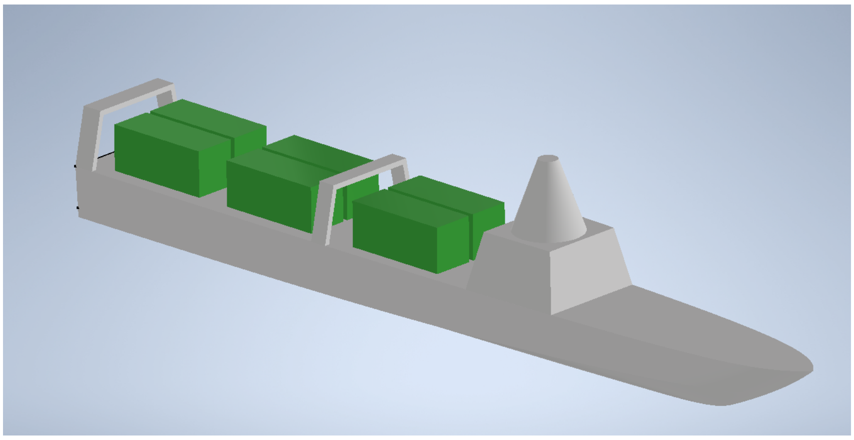


Figure 6.1: Conceptual layout of the ship. Six 20 ft containers for payload or crew compartments shown in green, without the signature reducing cover of the cargo deck.

6.1.1 Hull

In this design process the hull type that proved to be best suited for the task is the monohull configuration. Reducing complexity is seen as one of the most important aspect of this design. The monohull offers adequate stability and performance in many sea states, while also being less complex than a multihull vessel. Additionally a low resistance is vital to this vessel as the estimated Froude number is approximately 0.7, Eq. 4.3. This indicates that the hull must be quite slim in order to keep resistance low. With approximately 7 m beam and 50 m length the length to beam ratio is 7.14, which offers a low wave making resistance in order to reduce the power needed to propel the vessel at higher speeds. Fig. 6.2 shows the hull shape from the side and 6.3 shows the v-bottom and bow section from a frontal perspective.

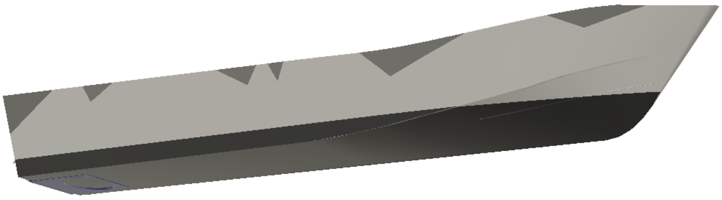


Figure 6.2: Rendered image of the hull, design and colours are influenced by the Visby-class corvettes.

To increase the safety and increase structural integrity of the vessel the hull is designed with a double bottom and sides. This creates voids in between the outer and inner hulls where different tanks can be housed, as well as creating sections that reduce the chances of flooding in case of damage to the hull. The hull is that of a high speed performance craft, incorporating a V-shaped bottom that with a deep V-shape at the bow that taper towards a flatter form towards the stern.

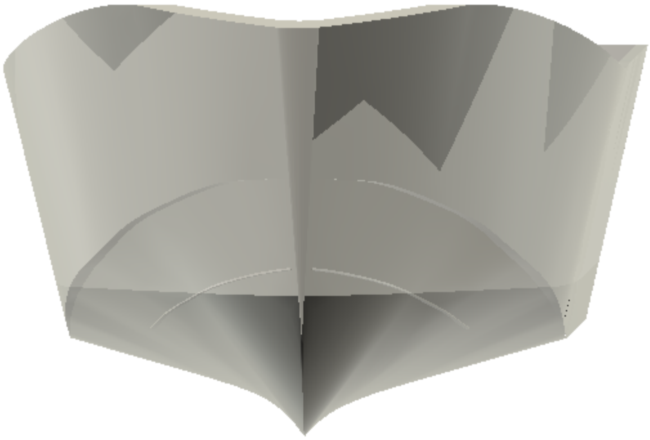


Figure 6.3: Image showing the bow of the vessel, a classical bow for a larger high speed vessel.

6.1.2 Propulsion system

For the propulsion a water jet system with two water jets is chosen as the best suited option for this thesis. The low acoustic profile, the high efficiency at higher speeds as well as the high manoeuvrability at low speed gained from the vectorized thrust capabilities of waterjets. As stated in Section 5.2.2, waterjet propulsion has the further advantage of low draught, shown in Fig. 6.4, reducing the risk of damage from underwater obstacles and allows the vessel to operate in shallow waters.

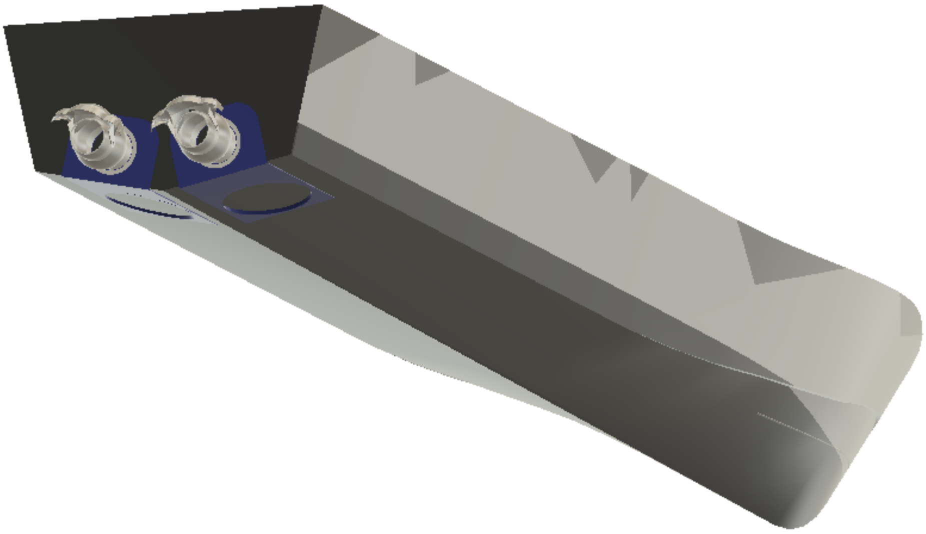


Figure 6.4: Rendered images of the aft section of the vessel, displaying the Water jet propulsion systems.

6.1.3 Machinery

The selected machinery system is a CODLAG propulsion system as described in Section 5.3.3. This is chosen as the gas turbines making up the high speed machinery create a large amount of power in a very compact package, a diesel or diesel electric propulsion setup would take up considerably more space, making packaging the system a challenge. The low speed machinery consists of an electric motor that is driven by either stored battery power, or from electricity generated from the auxiliary engines.

This type of setup offers several levels of redundancy, and as there are several auxiliary engines it is very unlikely that all machinery systems will fail at the same time. Furthermore the battery pack with an installed capacity of 2.68 MWh, allows the vessel to operate at 5 kt for up to four hours in calm water, with the added benefit that the batteries can be used to facilitate silent operations with a very low acoustic signature. Another advantage for this type of machinery system is that the placement of the different components can be changed to achieve a better weight distribution. As the batteries and auxiliary engines only require electrical cables to be connected to the electrical motor, these can be placed freely within the ship.

The TF50B gas turbine from Vericor (2025) is used by the Visby-class corvette and is seen as an appropriate choice for the gas turbine for this vessel as well. In the Visby-class there are four turbines installed, with two turbines powering each waterjet as stated by FMV (2025). As this vessel is smaller and lighter, only one turbine is required for each waterjet. This will still allow for 8000 kW of power to be delivered, more than the 6400 kW required as stated in Section 4.3.1. In addition to the turbines, the electrical motors can provide additional power to the high speed machinery, yielding another 2000 kW, resulting in a total of 10 MW of potential propulsive power available in short burst. In Fig. 6.5 the intended internal infrastructure and machinery is shown, note that this is purely on the conceptual stage and several necessary items such as water purification, exhaust cooling and gearboxes are not included at this stage. As seen in Fig. 6.6 the space available for machinery, bunker tanks and batteries. The central black rectangle is the proportions a Scania Marinediesel D16 500kW genset takes. Note that any optimization of the spaces is not done.

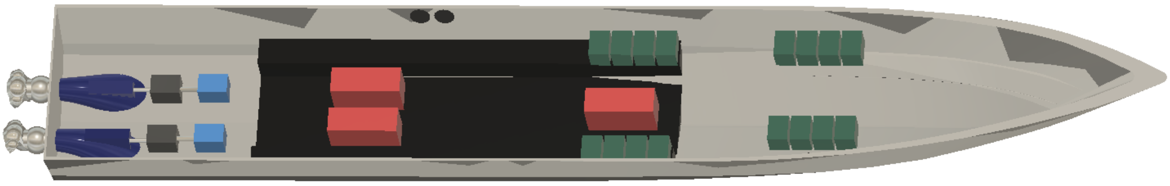


Figure 6.5: Internal systems of the vessel, to the aft the water jets are shown, connected to the shaft generators in black and the turbines coloured in light blue. The black inner structure is the fuel and different water tanks, the red cubes illustrate the size of the diesel generators, the green cubes illustrate batteries.

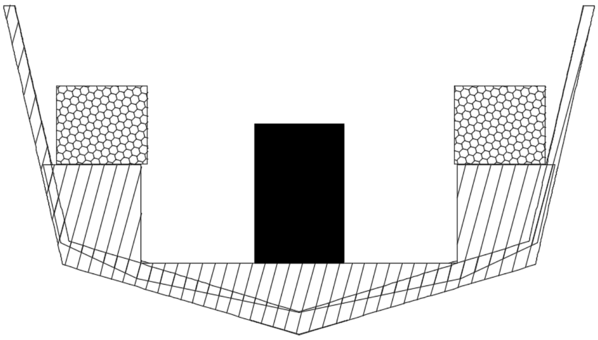


Figure 6.6: Illustrative cross-section of the vessel where the diesel tanks, diesel electric generator and battery modules are shown. This image shows how the volumes between the outer hull and the inner bottom can be utilized for diesel tanks, while at the same time creating a flat surface for a better work environment and ease of maintenance. Note this is just an preliminary draft.

6.1.3.1 Auxiliary engines

The auxiliary engines provide power to the ships sensors and navigational instruments as well as the modules on the ship. The auxiliary engines also generate power to charge the battery pack and are used to drive the low speed electrical propulsion. As the power demand of the low speed propulsion varies greatly depending on the speed the vessel is travelling, a setup with three auxiliary engines, each with a power rating of 470 kWe (Scania 2025), is chosen. This allows one or more gensets to be powered down when not needed. With three gensets operating at full power enough power is generated to drive the ship at 9 kt before additional power from either the high speed machinery or batter is needed.

6.1.4 Flexible modules with cover

In order to fully grasp the opportunity a flexible vessel can offer, the choice of incorporating crew modules within ISO containers were selected. The ISO containers themselves offer good protection from the environment and come with anchor points to firmly secure the container to the deck. When the vessel is operational in naval use, and the signature of the radar cross-section is of high importance, the container deck is intended to be covered by side wall panels.

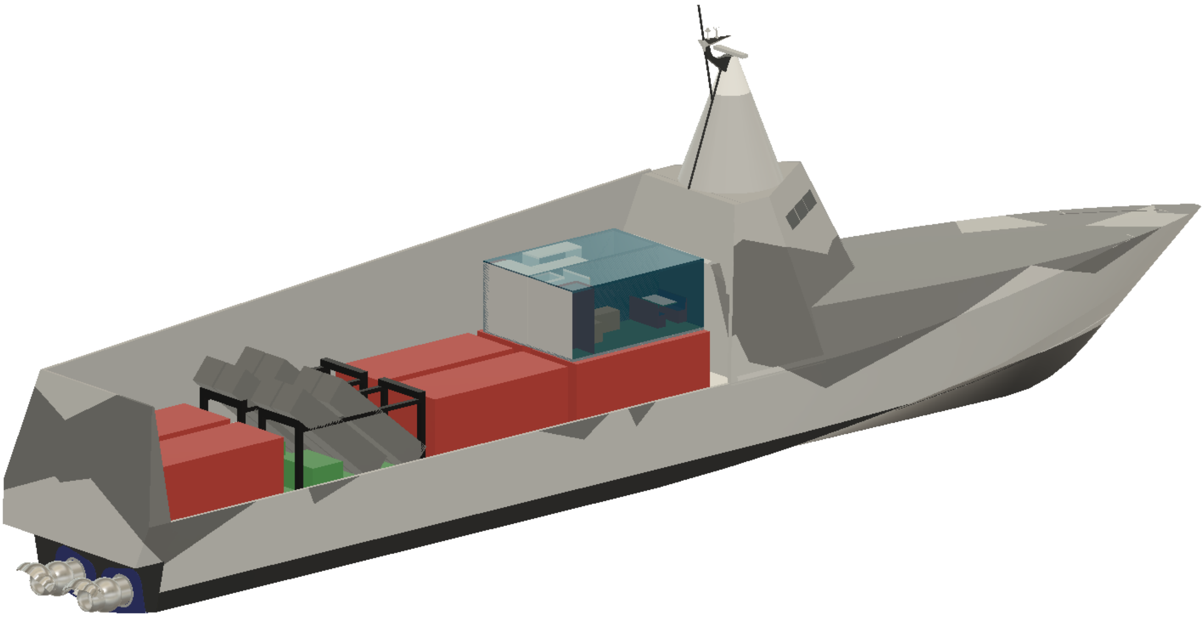


Figure 6.7: Rendered image of the cargo deck with the port side cover visible and the starboard side cover removed in order to better see the internals of the hold. All items located on the cargo deck follow dimensions for 20TEU ISO cargo containers, placement is arbitrary to showcase capabilities.

6.2 Crew Modules

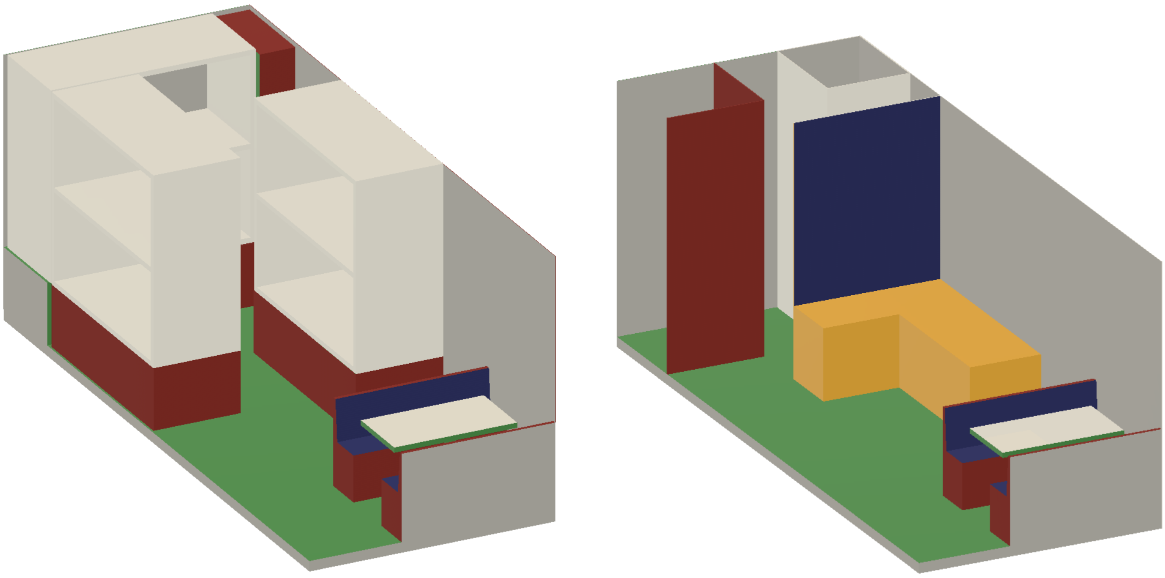
In Chapter 3 the dimensions needed for the crew modules are identified. These requirements are used to dimension the housing units for the vessel. The concept design of the crew modules is based ISO containers as described in Section 5.6.1.

6.2.1 Dimensional requirements adjusted to number of crew

The crew requirement for the vessel is concluded to be 6 crew. Many of the dimensions given in Chapter 3 are dependent on the number of crew and the mission length. From these figures the dimensions of subsystems such as gray and black water tanks and food storage are calculated, a summary of the requirements is found in Table 6.1.

Item	Norm	Need	Want
Fresh Water capacity	152 L	12,768 L	13 m^3
Cold Food Storage	10	840 L	1 m^3
Freezer Food Storage	0.5 L	42 L	0.5 m^3
Black Water Capacity	60 L	5,040 L	5 m^3
Showers	1	1	1
Toilets	1	1	2
Sink	1	1	2
Washing Machine	1	1	1
Dryer	1	1	1

Table 6.1: Volumetric and item requirements for the crew modules.



(a) Crew accommodation module. **(b)** Utilities module.

Figure 6.8: Rendered images of 20TEU ISO container-based modules: (a) crew accommodation with accommodations for 6 crew, and (b) utilities, with galley area marked in yellow, the red corner intended for toiletry, white corner a shower, the space between shower and toilet will hold utilises such as water pumps, washing machines and dryers.

6.2.2 Superstructure

The superstructure serves several purposes. The main purpose is to facilitate a place a smaller bridge where navigation and ship control can be managed from. By implementing a smaller bridge as a permanent, albeit modular, feature on the vessel is important since it will increase the cohesiveness of incorporating an unmanned vessel into service if it is possible for minor operations such as changing mooring locations within a harbour or for a crew to locally take over control when servicing the vessel. A secondary purpose is to act as foundation for the sensor suite of the vessel, a higher position of radar units increases the range of these systems since line of sight over the horizon increases when the height over water increases. As a tertiary purpose the superstructure serves as a security measure, as the cargo on board is of higher importance than that of any cargo vessel, since it carries either personnel or sophisticated military equipment, the risk of losing cargo over deck is reduced by using the superstructure as a green water on deck diverter, in Fig. 6.9 the secure environment for the crew modules created by the superstructure is shown.

Figure 6.9: Caption

Lastly the wide foundation the roof of the bridge offers could act as a platform to mount different point defence systems, thus increasing the effective angles of these systems. Naval point defence systems can house substantiation mass and therefore an adequate hull and superstructure beneath vital to the accuracy and safety of both the vessel and systems. This is discussed more in Section 7.3, with illustrations showing the different sectors in Fig. 7.3. Using the superstructure as a platform for the point defence would require much internal space to be used for the system, as ammunition would be required to be either stored within the superstructure itself, or preferably further down in the hull structure as ship stability can be affected with excessive large masses high up in the vessel. In Fig. 6.10 a concept with a potential placement of the point defence systems is shown, where the weapons suite is supported via an ammunitions elevator lifting shells from the storage below deck. Implementing a system like this might have implications on internal placements of gensets, batteries and bunker tanks, this further illustrates the benefits of the diesel-electric system.

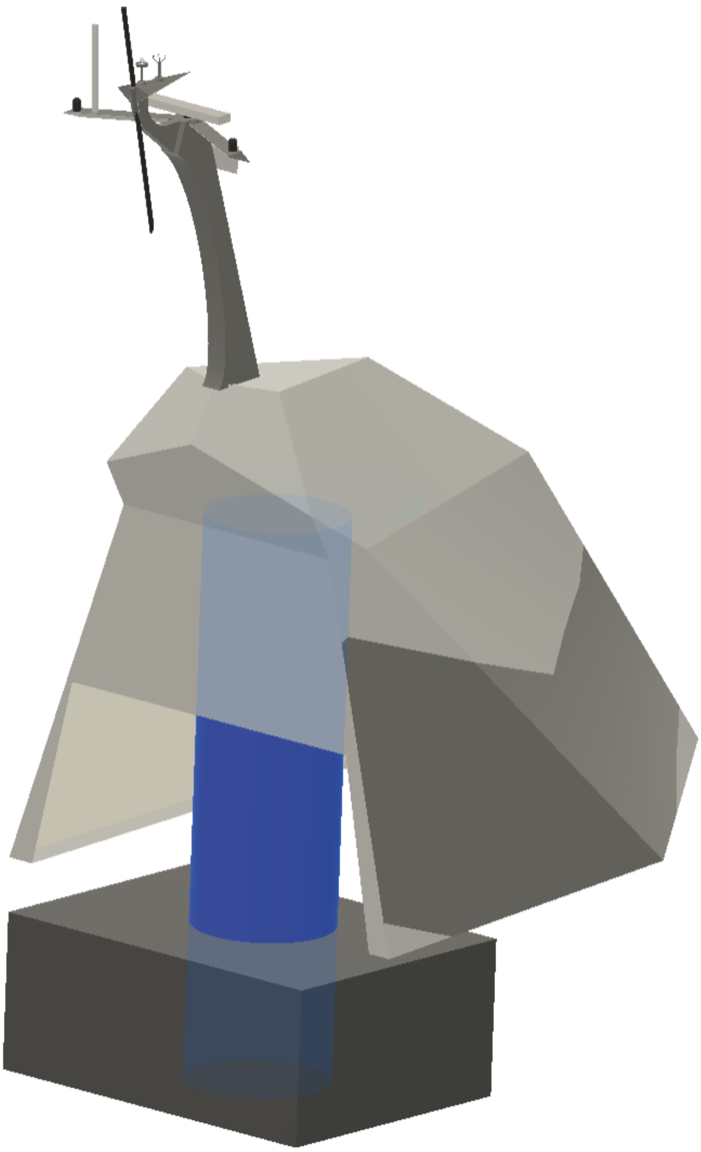


Figure 6.10: Rendition of a concept where the point defence weapons suite is located in top of the superstructure. The blue marked pillar represents volumes needed for the autoloader and ammunitions elevator required going through the space intended for the bridge.

Placing the point defence system on top of the superstructure replaces the sensor suite, which is vital for the function of the vessel, thus requiring another placement. This concept suggests the housing of the weapon is built with adequate strength to support the sensor suite on top of the housing of the weapon, as seen in Fig. 6.10, also possibly incorporating possibility to rotate the tower in order to counteract the rotation of the weapon, as important features and systems might need a set observational direction. This is however suggested for future works and mentioned in the discussion section.

6.2.3 Tank plan

The required fuel is calculated to approximately 60 m^3. The double bottom gives room to store different tanks without taking up usable space within the hull. As mentioned previously the hull shape is of a semi displacement monohull and the 50 meter long hull has ample room to locate the the tanks within the double hulls structure. In Fig. 6.11 the tanks are shown, starting in front of the engine room reaching a little over midships. The illustrated volume hold approximately 90 m^3, this volume will be reduced due to internal hull structures, but are still expected to be adequate for the 60 m^3 needed for fuel and water supply. If proven not sufficient there still exists the possibility to extend the tanks even further into the bow are for more stored fuel.

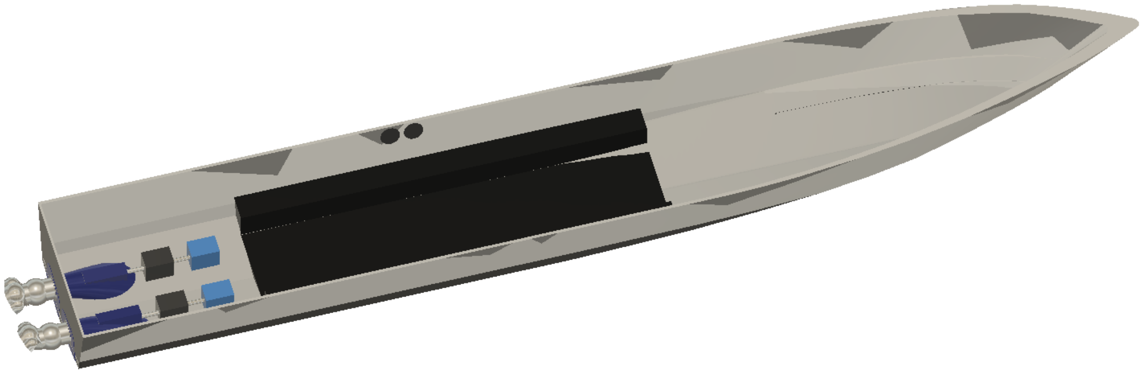


Figure 6.11: Rendered image of the internals of the hull with the intended fuel and water tanks coloured in black.

Water tanks

Black and gray water tanks will be housed in hull with the possibility to revert the black and gray water tanks to ballast or fuel tanks when future regulations remove the necessity.

Fresh water system

The route chosen in this project is to house a water treatment plant within the hull as a permanent feature of the USV, with fresh water tanks. This provides the ability for easy cleaning of equipment when the vessel is serviced by human crew in remote bases or out at sea, as well as it provides for less complex piping and reduces the access need for crew modules to salt water.

7

Discussion

This thesis defines the current challenges for LUSVs and proposes a solution by having removable crew modules. However there are still many uncertainties that remain to be solved. With the current regulations there are challenges for a large USV to enter into service in the Swedish navy, but with the IMO working on regulations for autonomous ships this is expected to change. This chapter will discuss the operational profile of large USVs compared to smaller USVs as well as operational security issues.

7.1 IMO MASS regulation

While the IMO MASS regulations, IMO (2025), are still under development and have yet to be implemented, it can be assumed that these regulations will be used as a framework for many nations and will therefore have to be studied in depth. While some countries such as Norway have implemented their own regulations and exemptions to allow for implementation of USVs already, many shipbuilders are still waiting for cohesive regulations to be implemented internationally before committing fully.

The MASS regulation system regarding the different levels of unmanned surface vessels is intended to create a scale of the practical aspects of the unmanned vessels. This system was intended to be ready for draft by summer 2025, but has been postponed to summer 2026. Furthermore the full implementation was scheduled to 2030, however seeing the delay generated by the draft, the date of implementation is likely to be postponed as well. Given that the timeline is quite long, this is a factor that new construction projects must pay attention to.

7.2 Level of flexibility

In this design process the level of flexibility has intentionally been kept low, opting of keeping the fuel tanks, gensets and EES compartments as permanent installations within the hull. Making them modular at most, where if one were to fail or needing to be upgraded, it could be changed into another, but extracting it could mean intrusive actions on the hull. While exploring the different levels of flexibility of the vessel, some discussions of exactly where the limit of flexibility was. The conclusion was that in fact the stored electrical power, or even the power generation on board the vessel is not as given as it have previously been on crewed vessels. The only systems or features of this unmanned vessel that need to be permanently installed are the propulsion units, motors, fuel pumps, autonomous systems and sensors as well as fuel tanks. The fuel tanks benefit from being permanently installed as they utilize the geometry of the dubble bottom hull to not waste spaces that could otherwise be used for other equipment.

A genset can be placed anywhere within the hull and be connected via electrical cables and hoses for the fuel lines. This could be done within the base before each mission, making it possible to take advantage of the true range of flexibility by adjusting the level of power needed for the mission. A logistical mission where replenishment were to be transported and the time is less relevant genset and fuel modules could be removed to incorporate more cargo capacity.

7.3 Point defence

All naval vessels need some sort of self defence, this is often solved by the main gun, like the BAE 57mm Naval gun 7.1, On the typical naval vessel the main guns are located in the bow in front of the superstructure. This reduces the effective range of the main weapon in the aft facing direction, creating the need for either another weapon system facing aft, or accepting the vulnerability in that sector. An autonomous vessel does not have the need of housing any crew in the superstructure, nor not any real need for a superstructure at all, simply rendering the superstructure into a mast for the sensor equipment, much like on the NOMARS Defiant.

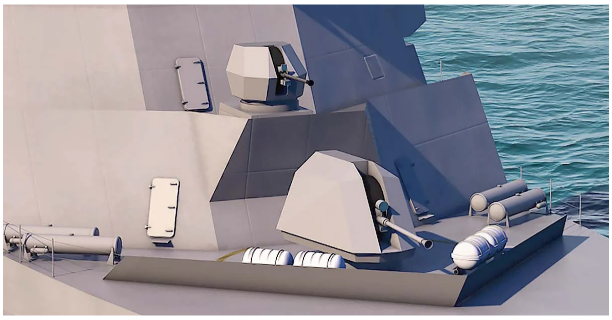


Figure 7.1: Rendered image of the BAE 57mm Naval gun on the Royal Navy's Type31 frigate (Navy Lookout 2022).

If a point defence weapon system were to be implemented within the superstructure, replacing the bridge and supporting the mast with sensors on top, the coverage of the main weapons would increase significantly, increasing the effectiveness of the weapon system and increasing survivability of the vessel. 7.2 illustrates what the system might look like. Note the sensor suite on this rendition is intended to be the same as that of the Visby-class corvette, which might not be the case or best solution for an unmanned vessel, which might instead house external flexible sensor systems, instead illustrated extending from the cargo hold.

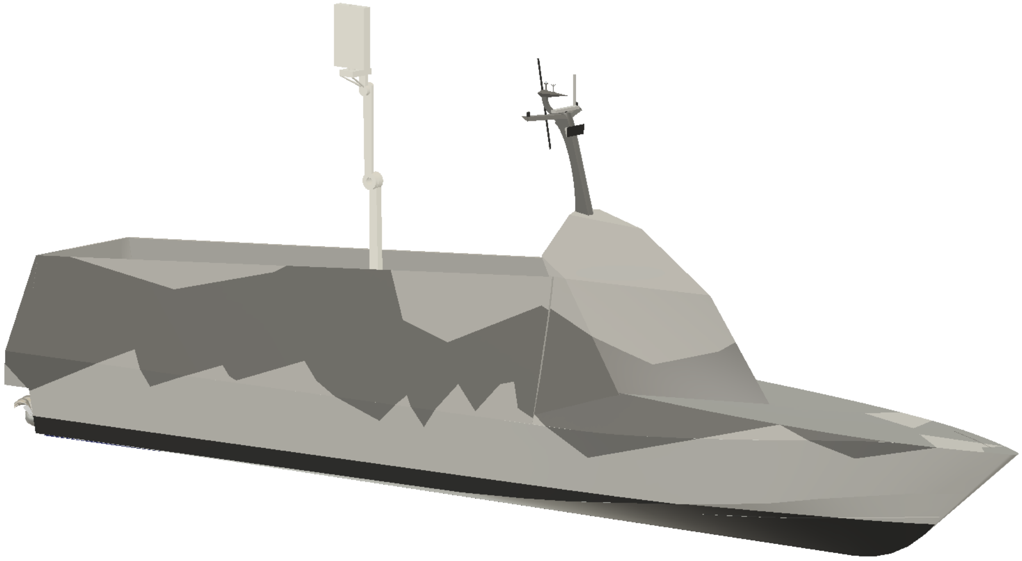


Figure 7.2: Rendered image of the vessel but with a BAE 57mm main gun from the Visby corvette on top of the superstructure, sensor suite as that of the Visby corvette added on top to illustrate.

This would reduce the space in the superstructure for an potential smaller bridge that the vessel within this design study is designed for, due to the weapons equipment reaching below the rotating body into the superstructure. In addition, this system would preferably be supported by an automatic ammunition elevator that can bring specific ammunition for different purposes from spaces within the hull up to the weapon on demand. Fig. 7.3 attempts to illustrate the increase of the aft sector coverage. The images on the top row illustrate the Visby-class corvettes coverage from the main gun, the bottom row illustrate the coverage on an USV with the main gun on top of the superstructure.

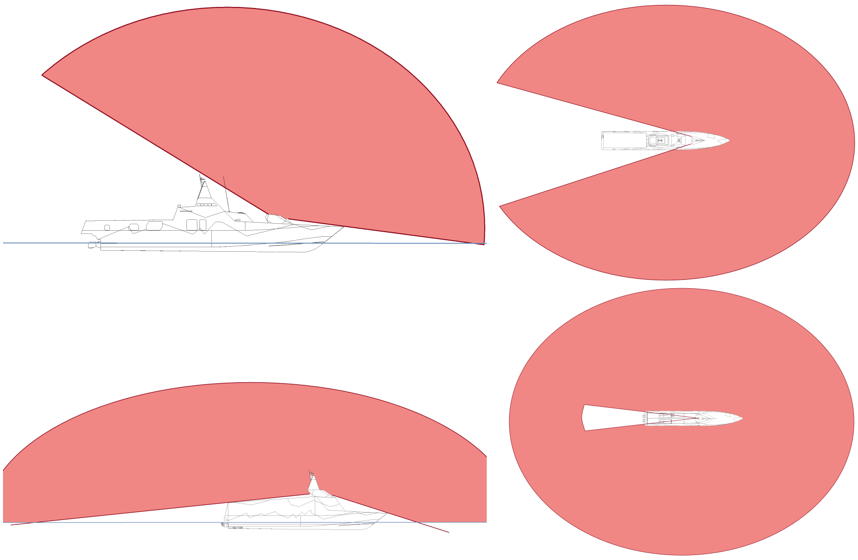


Figure 7.3: Images illustrating the increased sector coverage gained from placing the point defence system on top of the superstructure, replacing the bridge. Note: The lack of coverage in the front section is not illustrated within these images.

7.4 Scope of operations

This thesis focuses mainly on the overarching challenges a vessel of this type faces, however it is also important to consider the operations the vessel will actually carry out. While the increased flexibility afforded by using standard containerized modules can increase the scope of operations the vessel can perform, it must still be designed to focus on certain types of missions. Otherwise the vessel could easily end up in a situation similar to the US Navy Zumwalt class destroyers[1] where an unclear mission profile and incorporation of brand new technologies led to high costs and vessels that performed worse than their predecessors.

While trying to have one vessel able to preform all types of missions might be unwise, there might be room to design it instead as a class platform, where the main dimensions and structure is similar, but each vessel is specifically designed to excel in one task. This could possibly strike a balance between keeping production and maintenance costs low while at the same time providing the customer with the required performance.

7.4.1 Size considerations

As has been previously discussed in Section 2.3 there are some other USVs of similar size being developed by other nations, however most of the development work within naval USVs focuses on significantly smaller vessels. These smaller vessels are much cheaper to construct and maintain, allowing navies to instead operate a fleet of vessels instead of a single large ship. This then raises the question about the role a larger USV can play in the future.

Figure 7.4: Image of an Ukrainian man assisting a recently launched Magura V5, image sourced from Trinko (2023).

While smaller USVs can be quick and cheap to produce, they are also severely limited in their mission capabilities compared to larger crewed naval vessels. Most smaller USVs are limited to a range that forces them to either stay close to its home base, or it will be used as a one way attacking craft that will not return home after delivering its payload. They are also limited to relatively small weapons whereas a larger USV would be able to carry significantly more firepower and operate over a greater distance, thus greatly increasing the effective reach of the vessel.

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[1] https://nationalinterest.org/blog/buzz/navys-zumwalt-class-destroyer-245-billion-failure-213132

Another potential use for larger USVs comes from the logistical help they can provide. As they are able to carry a large payload this could also be used to transport materiel to allies, alternatively the vessel could be used as an escort for civilian ships, something that would otherwise require a manned ship to be away from missions where it could be more effective.

7.5 Technological readiness

For any novel concept it is important to ensure that the incorporated technology has reached sufficient maturity that it can safely be put into service without any risk of critical failures. For an autonomous ship this is especially important as it is intended to operate without any crew aboard, and it will potentially operate far from any assistance, making any salvage operations more complicated.

For many of the ship systems such as the main machinery the civilian shipping segments have long had an interest in pushing this development as well to save on crew and maintenance costs, and many machinery rooms can today operate in regular conditions without any supervision. It is however important to consider the type of machinery being used in this case, for example a diesel or diesel-electric power plant requires significantly less maintenance than a gas turbine. This means that even though the gas turbine might offer better performance in certain categories such as power density, it might not be the best suited to an autonomous vessel.

For the autonomous control system there are very few examples of autonomous systems in use today, suggesting that the technology has not yet reached the required maturity, although this can change quickly with enough incentives from the industry. Although there are several examples of remotely controlled ships, these can not be classified as autonomous as there is still a human making all decisions, just from a remote location. Yara Birkeland, an autonomous vessel that began commercial operations in 2022, was supposed to have a supervising crew aboard for the first two years, Yara (2024), however the removal of the crew has been delayed due to safety concerns.

This shows that even though the technology is capable of functioning autonomously in most situations, there is still a long way to go before a vessel can be used fully autonomously without any crew ready to step in. This means that being able to house crew in compartments that would otherwise be used for weapons or other equipment might be a very useful compromise as weapons will not have to be used in peacetime other than for testing purposes, and should a conflict arise the vessel will still be able to be controlled remotely.

7.5.1 Interface between ship and modules

To be able to communicate with the different modules there will need to be some form of interface between the vessel and the modules in order to connect them and provide for the infrastructural needs of the modules. This includes electricity, water, waste, data etc. This also needs to be standardized in the same way the modules and containers themselves are standardized to simplify logistics. At a minimum all modules will need some form of communications and power interface, however some modules might require additional interfaces, such as the crew modules that will need water and possibly some waste treatment system.

7.6 Autonomous USV, a Vessel or Equipment?

One interesting idea that comes up in the discussions surrounding unmanned surface vessels is whether the vessels actually are vessels, or since there is no crew on board, it instead would be better suited to class them as equipment, making them to an object closer related to buoys than ships. This would significantly ease the incorporation of unmanned equipment since many of the regulations grounded in the IMO, ILO, STCW, etc would for all intents and purposes be circumvented. There is however still some regulatory challenges for this scenario to come to fruition as there are regulations that already actually define what a ship is. This is some times done to distinguish the difference between a boat and a ship, in order to be able to apply the aforementioned regulations from IMO, ILO, STCW, etc, for one and not the other.

8

Conclusion

This thesis proposes a concept of an autonomous naval vessel with exchangeable modules for Saab Kockums AB. The thesis investigates the current regulatory challenges that large USVs face to be able to enter service in Swedish waters. As crew is currently required onboard, the requirements for the crew is investigated with regards to amenities and accommodation. To gauge what other actors are currently exploring in the field a study of similar ships is conducted, while mainly focusing on naval vessels, some civilian projects are also of interest. The requirements from Saab Kockums AB regarding size, design speed, and endurance are used to generate a concept design that fulfils all regulatory requirements. The concept generation follows naval architectural principles however only conceptual solutions are considered due to scope constraints of the thesis.

It is concluded that

- A vessel such as this has the potential to be effectively implemented in the Swedish navy, and although current regulations might restrict certain aspects of the design, a modular design approach can mitigate many of these restrictions.

- Crewed operations will likely be required for trials and safety even after regulations allow for unmanned operations.

- A modular design approach has the potential to increase the scope of operations the vessel can perform, however there are certain mission types that large USVs are better suited for.

9

Recommendations for future work

This thesis is beginning to explore the possibilities of an autonomous and modular naval vessel, however there is still a lot of work to be done before such a vessel is ready to be constructed. In this chapter recommendations for future work in the area will be discussed.

9.1 Detailed design of the vessel

As this thesis only covers the initial concept design of the vessel work still needs to be conducted to create a detailed design of the vessel. This includes specifying the intended operations and capabilities of the vessel, as these will influence design choices greatly.

9.1.1 Placements within the hull

In this study there have been no adequate moment and load optimization have been performed. As the project progresses the placement of the internal systems must be optimized in order to reduce stress on the hull and provide for a good load distribution for the type of vessel this is. One of the major benefits of utilizing diesel generators for electric propulsion in low speed demand is the ability to freely place the diesel generators within the hull.

9.1.2 Cover sizes and detailed construction

In this design study the side covers for the cargo deck was designed without any regard to the equipment or modules. Different systems might have need of removing the covers, such as the capability to davits to launch a smaller boats or cranes to operate submerged umbilical controlled ROVs.

9.1.3 Roof of cover

In this design study the roof over the cargo hold was not included within the design. This is because each of the cargo or capability extending modules might have different needs. For example a radar unit will have to extend it's antennae and a missile launching system will for obvious reasons also have the need of access to open air. For future studies the consideration of how the radar signature can be further reduced by implementing a top cover and how this can comply with the internally stored equipment and capabilities.

9.1.4 Exhaust Management

The Visby-class corvette is a stealth vessel which reduces the IR signature of the exhaust gases from the turbines via cooling them before release. This is something that is of interest for this vessel as well, depending on what type of operations it is intended to execute and what the risk of detection is. The space needed for the systems is available within the hull.

9.2 Other concepts to consider

In this design project the simplicity of the design was a key factor that mandated many of the design decisions. By reconsidering some of the key aspects of the vessel there might be several other concepts that could have other performance aspects of greater interest for an unmanned vessel. The hull shape for example, where several other USV projects have chosen a multihull alternative for their larger USVs.

9.2.1 Request a preliminary notification regarding decision on minimum safe manning from the Swedish Transportation Agency.

The Swedish transportation administration offer a service where a company or other actor can submit details about a prospected vessel along with motivation for the desired crew, and then receive a preliminary verdict from the agency Transportstyrelsen (2020). This is a feasible way to test the readiness of the laws and regulations. If a detailed application that describes the capabilities of the USV, combined with the exemptions needed from current rules is submitted it might give good input for the administration on how they can form future rules etc.

9.2.2 The distributed warship

The concept of a distributed warship have been discussed before, with the emerging technology within unmanned surface vessels the concept becomes more feasible. A platform like the one in this design study could be well suited as a base for a distributed warship concept.

9.2.3 Semi-submersible

To lower the radar signature the vessel might benefit from a semi-submersible configuration in order to lower the vessels potential radar signature. For a vessel equipped with a passive radar system, or only used as a forward launch platform, this would potentially reduce the distance the vessel could hide behind the curvature of the earth, and even by line of sight visuals, thus increasing the range or effectiveness of it's own systems. One big problem with submerging a vessel is that the amount of internal space needed for ballast water tanks to induce enough ballast to submerge an otherwise displacing hull structure into the water is proportionate to the entire internal volume of the hull. One solution to this might be that the vessel is built with a very small hull and instead rely on hydro planes or an SES configuration, for lifting the hull out of the water when moving.

Another solution could be to enclose all vital components in water tight enclosures and fill up the entire internals of the hull with water. Since no humans are onboard, essentially all spaces where the crew were to operate in the vessel was crewed could be converted into volumes instead used as ballast tanks. This includes all of the volume surrounding internal components, cable ducts, ventilation etc. With equipment that is sufficiently safe from water exposure the entire air volume within the hull could be replaced, resulting in the vessels adjusting buoyancy on demand.

Repurpose bunker tanks to ballast tanks and vice versa

Another idea to lower the vessel into the water to reduce the radar signature One problem with this is that the volume of the bunker tanks not filled with fuel is creating unnecessary buoyant force. One possible solution to this would be to house double inlets, one for fuel and one for ballast water, within the same bunker tank compartment, but connect the ballast water (or bunker fuel) to a collapsible rubber or plastic inner tank liner that can line the insides of the tank, and collapse to make room for ballast water when fuel is consumed. This concept was discussed during a phase in the project within the greater discussions of a semi-submersible vessel. The idea to have internal collapsible "bags" for either fuel or ballast water is to protect the environment from unnecessary pollution by just filling an empty diesel tank with ballast water, that when needs emptying would pollute the surrounding water. Keeping the vessel as technologically simple as possible is key for the unmanned vessel, this drew the conclusion that adding water purifying equipment would increase the complexity of the vessel. Thus eliminating the problem by strictly separating the water and fuel would circumvent the greater complexity.

Bibliography

Bolbot, Victor, Martin Bergström, Marko Rahikainen, and Osiris A. Valdez Banda. 2025. "Investigation into safety acceptance principles for autonomous ships." *Reliability Engineering & System Safety* 257:110810. ISSN: 0951-8320. https://doi.org/https://doi.org/10.1016/j.ress.2025.110810. https://www.sciencedirect.com/science/article/pii/S0951832025000134.

Burden, Håkan, Susanne Stenberg, Lisa Carlgren, and Ted Sjöblom. 2022. *Policylabb Smarta Fartyg.* Technical report. RISE Research Institutes of Sweden. https://www.transportstyrelsen.se/globalassets/global/sjofart/autonom-sjofart/plsf-slutrapport.pdf.

Clapper, James, John Young, James Cartwright, and John Grimes. 2007. *DoD Unmanned Systems Roadmap 2007 2032.* https://www.globalsecurity.org/intell/library/reports/2007/dod-unmanned-systems-roadmap_2007-2032.pdf.

DARPA. 2022. https://www.darpa.mil/news/2022/nomars.

English, Georgie. 2025. "'NEW ERA OF WAR' Ukraine blasts £38million Russian fighter jet out sky over Black Sea using missile-armed sea drone in 'world first'," May. https://www.thesun.co.uk/news/34782196/ukraine-drone-blasts-russian-jet/.

Eslamdoost, Arash, Lars Larsson, and Rickard Bensow. 2018. "Analysis of the thrust deduction in waterjet propulsion – The Froude number dependence." *Ocean Engineering* 152:100–112. ISSN: 0029-8018. https://doi.org/https://doi.org/10.1016/j.oceaneng.2018.01.037. https://www.sciencedirect.com/science/article/pii/S0029801818300374.

FIB. 2018. *Försvarsmaktens interna bestämmelser om militär sjöfart – bemanning och behörighet.* https://www.forsvarsmakten.se/siteassets/2-om-forsvarsmakten/dokument/lagrum/gallande-fib/fib-2018-4.pdf.

FMV. 2025. *Korvett Visby.* https://www.fmv.se/projekt/visby/.

Forsvaret. 2023. https://www.forsvaret.no/om-forsvaret/utstyr-og-materiell/sjo.

Försvarsmakten. 2002. *Regler för militär sjöfart - Fartygssäkerhet - normer.*

Freutel, Aleksandr. 2022. https://www.dvidshub.net/image/7342122/rimpac-2022-fleet-sails-formation.

Gong, Jie, Junjun Su, and Zhongwan Wu. 2025. “Euler-Lagrange study on the bubble wake of a ship with waterjet propulsion.” *Ocean Engineering* 318:120173. ISSN: 0029-8018. https://doi.org/https://doi.org/10.1016/j.oceaneng.2024.120173. https://www.sciencedirect.com/science/article/pii/S002980182403511X.

Harboe-Hansen, Hans. 1992. https://www.marinehist.dk/orlogsbib/h/StanFlex.pdf.

Hurst, Robert. https://www.navsource.org/archives/12/1601.htm.

IMO. 2025. *Autonomous shipping.* Accessed: 2025-01-09. https://www.imo.org/en/MediaCentre/HotTopics/Pages/Autonomous-shipping.aspx.

ITTC. 2008. *ITTC - Recommended Procedurec and Guidelines.* https://ittc.info/media/1237/75-02-03-015.pdf.

Joseph Trevithick, Tyler Rogoway. 2024. *Russia Now Looks To Be Using Wire-Guided Kamikaze Drones In Ukraine,* March. https://www.twz.com/air/russia-now-looks-to-be-using-wire-guided-kamikaze-drones-in-ukraine.

JUNO. 2025. “Sök Lagtext.” https://www.nj.se/juno.

Adaptable Design of an Efficient Naval Combatant Vessel. 2017. Vol. Day 3 Thu, October 26, 2017. SNAME Maritime Convention. October. https://onepetro.org/SNAMESMC/proceedings-pdf/SMC17/3-SMC17/D033S011R002/1253689/sname-smc-2017-033.pdf.

Kretschmann, Lutz, Hans-Christoph Burmeister, and Carlos Jahn. 2017. “Analyzing the economic benefit of unmanned autonomous ships: An exploratory cost-comparison between an autonomous and a conventional bulk carrier.” New developments in the Global Transport of Commodity Products, *Research in Transportation Business & Management* 25:76–86. ISSN: 2210-5395. https://doi.org/https://doi.org/10.1016/j.rtbm.2017.06.002. https://www.sciencedirect.com/science/article/pii/S2210539516301328.

Lamb, Thomas. 2004. *Ship Design and Construction, Volumes 1-2.* Society of Naval Architects / Marine Engineers (SNAME). ISBN: 978-0-939773-40-4. https://app.knovel.com/hotlink/toc/id:kpSDCV0001/ship-design-construction/ship-design-construction.

Largiadèr, Andri. 2001. “Modular platform based surface ship design” (November).

Latarche, Malcolm. 2021. *Pounder’s Marine Diesel Engines and Gas Turbines (10th Edition).* Elsevier. ISBN: 978-0-08-102748-6. https://app.knovel.com/hotlink/khtml/id:kt012KLWAL/pounders-marine-diesel.

Lewis, Edward V. 1989. *Principles of Naval Architecture (Second Revision), Volume III - Motions in Waves and Controllability.* Society of Naval Architects / Marine Engineers (SNAME). ISBN: 978-0-939773-02-2. https://app.knovel.com/hotlink/toc/id:kpPNASRV01/principles-naval-architecture-3/principles-naval-architecture-3.

LTD, Rafael Advanced Defence Systems. 2019. *PROTECTOR®USV SSM.* https://he.rafael.co.il/wp-content/uploads/2019/03/PROTECTOR-SSM.pdf.

MAN Energy Solutions. 2023. https://www.man-es.com/docs/default-source/document-sync/basic-principles-of-ship-propulsion-eng.pdf.

MARPOL Annex IV. 2011. *RESOLUTION MEPC.200(62).* https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/200(62).pdf.

MEGURI2040. 2020. "The Nippon Foundation MEGURI2040 Fully Autonomous Ship Program." https://en.nippon-foundation.or.jp/what/projects/ocean/meguri2040.

Molland, Anthony F., Stephen R. Turnock, and Dominic A. Hudson. 2017. *Ship Resistance and Propulsion: Practical Estimation of Ship Propulsive Power.* 2nd ed. Cambridge University Press.

Nakashima, Takuya, Bryan Moser, and Kazuo Hiekata. 2023. "Accelerated adoption of maritime autonomous vessels by simulating the interplay of stakeholder decisions and learning." *Technological Forecasting and Social Change* 194:122710. ISSN: 0040-1625. https://doi.org/https://doi.org/10.1016/j.techfore.2023.122710. https://www.sciencedirect.com/science/article/pii/S0040162523003955.

Naval Sea Systems Command. 2016. *Shipboard Habitability Design Criteria and Practices Manual (Suface Ships) For new Ship Dsigns and Modernization.* https://habitability.net/WebData/T9640-AC-DSP-010_HAB.pdf.

Naval Technology. 2014. https://www.naval-technology.com/projects/sigma-class-corvettes/.

Navy Lookout. 2022. "In focus: the Bofors 57mm Mk 3 gun that will equip the Type 31 frigates." https://www.navylookout.com/in-focus-the-bofors-57mm-mk-3-gun-that-will-equip-the-type-31-frigates/.

Papanikolaou, Apostolos. 2014. *Ship Design.* Springer Dordrecht. ISBN: 978-94-017-8751-2. https://doi.org/https://doi.org/10.1007/978-94-017-8751-2.

Parken, Oliver. 2024. "Darpas Defiant full uncrewed demonstrator ship will hit the seas later this year." *The WarZone,* https://www.twz.com/sea/darpas-defiant-fully-uncrewed-demonstrator-ship-will-hit-the-seas-later-this-year.

Regeringen. 2003. *Fartygssäkerhetslag (2003:364).* https://www.riksdagen.se/sv/dokument-och-lagar/dokument/svensk-forfattningssamling/fartygssakerhetslag-2003364_sfs-2003-364/.

Regeringen. 2025. *Sök Lagtext.* https://www.riksdagen.se/sv/dokument-och-lagar/.

RISE. 2024. *Arbetsmiljöverkets föreskrifter.* Accessed: 2025-04-25. https://www.ri.se/sites/default/files/2024-02/quick-guide_EN_2024_v2_0.pdf.

Rishko, Vitalii. 2024. "Undermining Russia's Naval Dominance: Ukraine's Strategic Campaign in the Black Sea and Crimea," July. https://tdcenter.org/2024/08/08/undermining-russias-naval-dominance-ukraines-strategic-campaign-in-the-black-sea-and-crimea/.

Saab. 2024. *Saab brings new autonomous capability to naval vessels.* https://www.saab.com/globalassets/cision/documents/2024/20241105-saab-brings-new-autonomous-capability-to-naval-vessels-en-0-4932146.pdf.

SAAB GlobalEye. 2025. *GlobalEye AEW&C.* https://www.saab.com/products/globaleye.

Scania. 2025. *Scania power solutions product range.* https://www.scania.com/content/dam/www/market/master/pdf/engines/power-solutions-product-range-brochure.pdf.

Schank, John F., Scott Savitz, Ken Munson, Brian Perkinson, James McGee, and Jerry M. Sollinger. 2016. *Designing Adaptable Ships: Modularity and Flexibility in Future Ship Designs.* Santa Monica, CA: RAND Corporation. https://doi.org/10.7249/RR696.

Scopus. 2025. "Start exploring." https://www.scopus.com/pages/home#basic.

Serco. 2022. *Serco's NOMARS team is reshaping the future of unmanned maritime operations.* https://www.serco.com/na/media-and-news/2022/sercos-nomars-team-is-reshaping-the-future-of-unmanned-maritime-operations#:~:text=The%20NOMARS%20Defiant%20platform%20is%20designed%20to%20drastically,lower%20maintenance%20costs%2C%20and%20stay%20on%20mission%20longer..

Seyyedi, Seyyed Mostafa, and Rouzbeh Shafaghat. 2020. "A review on the Surface-Piercing Propeller: Challenges and opportunities." *Proceedings of the Institution of Mechanical Engineers, Part M* 234 (4): 743–770. https://doi.org/10.1177/1475090220906917. eprint: https://doi.org/10.1177/1475090220906917. https://doi.org/10.1177/1475090220906917.

SH Defence. 2023. *The Cube system.* https://shdefence.com/wp-content/uploads/2023/09/SH-Defence_The-Cube-System_General-description-1.pdf.

Sjøfartsdirektoratet. 2020. https://www.sdir.no/en/regelverk/circulars/guidance-in-connection-with-the-construction-or-installation-of-automated-functionality-aimed-at-performing-unmanned-or-partially-unmanned-operations/.

Spot Zero. 2025. https://www.spotzerowater.com/products/built-ins/watermakers/xtcii-series/.

Städje, Jörgen. 2024. "Att se utan att synas - korvett av Visby-klass." *Teknikaliteter,* https://www.teknikaliteter.se/2024/05/17/att-se-utan-att-synas-korvett-typ-visby/.

Sutton, H I. 2024a. "Uncrewed Platforms Have Been Critical to Ukraine's Success in the Black Sea." *RUSI,* https://www.rusi.org/explore-our-research/publications/commentary/uncrewed-platforms-have-been-critical-ukraines-success-black-sea.

Sutton, H I. 2024b. *World First: Ukraine's Newest Naval Drone In Unique Attack On Russian Positions,* December. https://www.navalnews.com/naval-news/2024/12/world-first-ukraines-newest-naval-drone-in-unique-attack-on-russian-positions/.

Sutton, H.I. 2024. http://www.hisutton.com/Chinese-JARI-USV-A.html.

Considerations regarding SMART Ships. 2021. Svensk Sjöfart. https://www.sweship.se/wp-content/uploads/2021/12/Swedish-Shipowners-Associations-position-regarding-SMART-ships-version-two.pdf.

Swiftships. 2022. "Ghost Fleet: The Unmanned Surface Vessel Nomad (aka Riley Claire)."

Takaishi, Tatsuo, Akira Numata, Ryouji Nakano, and Katsuhiko Sakaguchi. 2008. *Approach to High Efficiency Diesel and Gas Engines.* https://www.mhi.co.jp/technology/review/pdf/e451/e451021.pdf?utm_source=chatgpt.com.

Teh, Lung. 2019. https://www.janes.com/osint-insights/defence-news/taiwan-begins-work-on-improved-variant-of-tuo-jiang-class-corvette.

Transportstyrelsen. 2020. *Ansökan om förhandsbesked om beslut om säkerhetsbesättning.* Accessed: 2025-05-28. https://www.transportstyrelsen.se/sv/sjofart/e-tjanster-och-blanketter/blanketter-for-sjofart/ombordanstallda/Ansokan-om-forhandsbesked-om-beslut-om-sakerhetsbestattning/.

Transportstyrelsen. 2025. *Sök TS Föreskrifter.* https://www.transportstyrelsen.se/sv/om-oss/dina-rattigheter-lagar-och-regler/forfattningssamling/sok-ts-foreskrifter/.

Trinko, Myroslav. 2023. *The AFU showed the Ukrainian marine drone MAGURA V5, which can hit targets at a distance of up to 800 kilometres (video).* Accessed: 2025-05-29. https://gagadget.com/en/287918-the-afu-showed-the-ukrainian-marine-drone-magura-v5-which-can-hit-targets-at-a-distance-of-up-to-800-kilometres-video/.

Turner, Julian. 2018. “Sea Hunter: inside the US Navy’s autonomous submarine tracking vessel.” *Naval Technology,* https://www.naval-technology.com/features/sea-hunter-inside-us-navys-autonomous-submarine-tracking-vessel/.

Umoe Mandal. 2025. https://www.um.no/about-us/our-heritage/.

Vard. 2025. https://www.vard.com/seaq-remote.

Vericor. 2025. https://www.vericor.com/wp-content/uploads/2023/12/02-23-TFMARINE-ENG-P03.pdf.

Voldsund, Elisabeth. 2022. https://www.mtlogistikk.no/autonomi-jushjornet-miljo/autonome-farvann/648936.

Wärtsila. 2023. *The Wärtsila 34DF.* https://brandhub.wartsila.com/m/3dc296c240d32dcd/original/Wartsila-34DF-brochure.pdf.

Web of Sience. 2025. “Basic Search.” https://www.webofscience.com/wos/woscc/basic-search.

Yara. 2020. https://www.yara.com/news-and-media/media-library/image-library/.

Yara. 2024. *Yara Birkeland, two years on.* https://www.yara.com/knowledge-grows/yara-birkeland-two-years-on/.

Yeung, Ronald W. 2005. *Interference Resistance of Multi-Hulls per Thin-Ship Theory.* Technical report. University of California, Berkeley.

Yun, Liang, and Alan Bliault. 2012. *High Performance Marine vessels.* Springer. ISBN: 978-1-4614-0868-0. https://doi.org/10.1007/978-1-4614-0869-7.

Zakharchenko, Kateryna. 2025. “Ukraine Naval Drone Shoots Down Two Russian Warplanes in 24 Hours: First-Ever USV Fighter Jet Kills (Updated),” May. https://www.kyivpost.com/post/51994.

Zamiatina, Nadežda. 2016. “Comparative Overview of Marine Fuel Quality on Diesel Engine Operation.” *Elesiever Ltd,* https://doi.org/10.1016/j.proeng.2016.01.055.

A

Appendix Thought Experiment

A.1 Alternative C – Medium Sized Unmanned Surface Ship

Premises MUSV

These vessels have a total length of $12 < L_{OA} \leq 50$ m, a breadth of approximately $3 < B \leq 8$ m, and displaces $20 \leq \Delta \leq 300$ tonnes (where rules differentiate depending on length that falls within the for mentioned spectrum, the harsher requirements will be assumed). They can operate in unmanned states, being both remote controlled or autonomously. The vessels does not carry any passengers, but can potentially be equipped with a smaller crew/bridge unit to facilitate bridge control on the vessel. The vessel is intended to reach a speed of 30 kn, rendering a power requirement between $\geq$750kW to $\leq 3000kW$. (These values are governed by rules regarding manning of the engine room onboard vessels, aswell as the needed power to propel the vessel in this speed.)

1. Length: $12 < L_{OA} \leq 50m$
2. Breadth: $3 < B \leq 8m$
3. Displacement: $20GT < \Delta \leq 300GT$
4. Main propulsory Power: $750kW < Power \leq 3000kW$

Note however that these questions are answered within the context of applying to the law in it's strictest form, without any room for interpretation. A naval vessel have the possibility to be exempt from any rules mandated on civilian trade traffic.

Does the vessel need to be registered?

Yes - Since this ship exceeds 5m and is going to be used in professional purposes they do need registration.
This does not raise any legal challenges due to the autonomous aspects of the vessel.

Does this vessel need a tonnage certificate?

Yes - These ships are per definition larger than maximum permissions so they need a tonnage certificate to operate in civilian traffic. The verdict of the tonnage certificate might be used as a cause for further administrative certification and documentation,

mainly being the "Beslut om Säkerhetsbesättning", the "Fartcertificat" and possibly the "specifika hamnavgifter".
This does raise legal challenges due to the need of a crew is not compatible with the autonomous aspects of the vessel.

Does the vessel need certification?

Yes - For vessels exceeding 15 meters in length needs Trading certificate (Fartcertificat) which determines what waters the vessel is cleared for operating within.

Does the vessel need minimum safe manning documents (MSMD)?

Yes - Since the vessels are longer than 6m and will be used in professional purposes they do need a review for minimum safe manning.

Will the vessel need yearly inspection?

Yes - The vessels are both longer than 5 meters (and possibly larger than 20 GT) and are used in professional purposes. Since no passengers are on board but the vessel is planned to operate in all trading or operational areas the vessel needs an inspection at least every 36 months, as stated by TSFS 2017:26. This can also induce a further inspection by the Transportstyrelsen.

Challenges from directives and regulations.

From the regulations stipulated in the STCW Manilla accords, the regulations on watchkeeping are the most strictly formulated when it comes to personnel onboard vessels. Specifically the VIII/2.1 and VIII/2.3 regulations.

> STCW Manilla Reg. VIII/2.1 - officers in charge of the navigational watch are responsible for navigating the ship safely during their periods of duty, when they shall be physically present on the navigating bridge or in a directly associated location such as the chartroom or bridge control room at all times;
>
> STCW Manilla Reg. VIII/2.3 - officers in charge of an engineering watch, as defined in the STCW Code, under the direction of the chief engineer officer, shall be immediately available and on call to attend the machinery spaces and, when required, shall be physically present in the machinery space during their periods of responsibility;

Here it clearly states that an appropriately skilled operator must be physically on the bridge or prepared to enter the machine room. With an USV the position of the bridge could be argued, that is if the USV is in fact remotely controlled the actual bridge is not located on the vessel and still manned. However the possibility to enter the machine room is quite impossible to achieve remotely. Some machine rooms are vetted as partially unmanned,

Utmaningar kopplat till föreskrifter:

TSFS 2009:44 (Sjövägsregler) - Att uppfylla kraven i föreskriften kan bli en utmaning om fartyget är obemannat och inte har någon befälhavare ombord.

TSFS 2017:26 (Nationell sjöfart) - Att verifiera kraven på fartygets utformning och utrustning samt på fartygets systematiska säkerhetsarbete. Kraven verifieras lämpligen genom t.ex. en säkerhetsargumentation eller en riskanalys. En utmaning blir då att kunna släcka alla identifierade risker med koppling till båtarnas smarta funktioner.

TSFS 2010:102 (bemanningsföreskrifter) och TSFS 2012:67 (Vakthållning och utkik) – Dessa föreskrifter är inte aktuella om båtarna inte transporterar gods eller passagerare utan endast användas vid tester av system inom militär verksamhet. Men om båtarna kommer att användas som handelsfartyg i civil verksamhet blir det svårt att uppfylla kraven i föreskrifterna utan att ha bemanning ombord. Även om man leker med tanken att ”bemanningen” finns i land skulle det bli svårt att uppfylla intentionen i vakthållningsföreskriften.

Legislative challenges (Law)

- Generally the laws are written in very broad and unspecific ways in order to spark interpretation for best utilization within the applied reality. The challenges for implementing larger USV's comes from the fact that larger ships used in professional purposes and with engine size larger than 750kW need to have a chief onboard when operating in civilian traffic, but the specific requirements first come from the STCW Manilla accords, not from the Swedish law. Naval vessels of course have the possibility for being excepted from these laws, but depending on level of compliance with the maritime laws there are theoretical arguments even for civilian vessels that would be possible to explore. However in practicality the long history of how the legislation is interpreted does not give any real room for unmanned larger vessels.

> SFS 1994:1009 (Sjölagen) - 1 kap 9§:
> ”Ett fartyg skall, när det hålls i drift, vara sjövärdigt, vari också innefattas att det är försett med nödvändiga anordningar till förebyggande av ohälsa och olycksfall, bemannat på betryggande sätt...”

The removal of personnel radically lowers the risk connected to life and limb, reducing the argument further for many of the arguments regarding safety of crew.

> - 6 kap 6§: ”Om fartyget råkar i sjönöd, är befälhavaren skyldig att göra allt som står i hans makt för att rädda de ombordvarande och bevara fartyget och lasten”... ”Så länge som det finns rimlig utsikt att fartyget kan räddas får befälhavaren inte överge det utan att hans liv är i allvarlig fara”...”Anträffar befälhavaren någon i sjönöd är han skyldig att lämna all hjälp som är möjlig och behövlig för att rädda den nödställde”...”Om befälhavaren i annat fall får kännedom om att någon är i sjönöd eller om han får kännedom om någon fara som hotar sjötrafiken, är han under de förutsättningar som nyss angetts skyldig att vidta åtgärder för att rädda den nödställde eller avvärja faran...”.

The text is written in such a way as to be implementable for each and every vessel. That means that the means an unmanned vessel in fact can assist in distress situations by several different aspects, for instance just marking the location of a person in water would be helpful for a rescue operation, therefore this rule can be argued as not being an obstacle for any USV.

> - 6 kap 7§: ”Lämnar befälhavaren fartyget skall han underrätta den främste av de närvarande styrmännen eller, om någon styrman inte är närvarande, någon annan av besättningen och ge de föreskrifter som behövs. När fartyget inte ligger förtöjt i hamn eller på en säker ankarplats får befälhavaren inte lämna fartyget utan att det är nödvändigt. Om fara hotar, får han inte vara borta från fartyget”.

This rule does not specifically mandate physical pressence, however it is written in the most firm manner possible, some argument would be possible to form since the text states "if the commander leaves the ship", and the commander in fact never boarded the ship in the strictest physicall sence. In addition a remote or virtual presence might arguably be valid since it with modern systems can create an even better situational awareness than physical pressence, with Radars, Lidar, night vision, thermal cameras, and all other technical equipment that have been developed after the writing of these rules.

> SFS 2003:364 (Fartygssäkerhetslagen) - 2 kap. 1§: ”Ett fartyg är sjövärdigt bara om det är så konstruerat, byggt, utrustat och hållet i stånd så att det med hänsyn till sitt ändamål och den fart som det används i eller avses att användas i ger betryggande säkerhet mot sjöolyckor”.
>
> - 2 kap 4§: ”Ett fartyg ska vara bemannat på ett betryggande sätt”.

If an unmanned vessel is built with the specific purpose of being unmanned, the entire system must be designed in such a way as when implemented it at least proves as reliable and safe as a manned platform. This is an argument that the builder must take in account for, as the vessel must be proven to be equally as safe as or even safer than conventional vessels.

> SFS 2003:438 (Fartygssäkerhetsförordningen) personal - 4 kap 19§: ”När ett fartygs säkerhetsbesättning bestäms skall det särskilt beaktas... om tillräcklig personal finns för att sköta livbåtar, livflottar och annan livräddningsutrustning.”

The safe manning is a vetting process that directly involves Transportstyrelsen. This aspect, the amount of life rafts on board an unmanned vessel should not be an issue since no personnel is on board, therefore rendering the necessity mute. However some automatic deployment of liferafts could indeed be helpful when the vessel is assisting in emergency situations.

> - 4 kap 20§: ”En säkerhetsbesättning ska ha en sådan storlek och sammansättning att fartyget får tillräcklig personal för manövrering och navigering, för drift och övervakning av maskineriet, för sådant nödvändigt underhåll av far-

> tyget och dess utrustning som har betydelse för säkerheten, för brandskydds- och livräddningstjänsten, för radiotjänsten samt för intendenturtjänsten."

This text is formulated more vague than the STCW Manilla Rule VIII/2.3. While the STCW rule states physical presence this law rather inferes that the overall design of the system must be formulated in such a way as for the intended operational aspect if attainable.

A.2 Alternative D – Large Unmanned Surface Ship

Premises LUSV

These vessels have minimum total length $50 < L_{OA}$ m, a minimum breadth of approximately $6 < B$ m, a Gross Tonnge within $20 \leq GT \leq 400$, (where rules differentiate depending on length that falls within the for mentioned spectrum, the harsher requirements will be assumed). They can operate in unmanned states, being both remote controlled or autonomously. The vessels does not carry any passengers, but can potentially be equipped with a smaller crew/bridge unit to facilitate bridge control on the vessel. The vessel is intended to reach a speed of 30 kn, rendering a power requirement between 3000kW to 6000kW. (These values are governed by rules regarding manning of the engine room onboard vessels, as well as the needed power to propel the vessel in this speed.)

1. Length: $L_{OA} > 50m$
2. Breadth: $B > 6m$
3. Displacement: $20 < GT \leq 400$
4. Main propulsory Power: $3000kW < Power \leq 3000kW$

Note however that these questions are answered within the context of applying to the law in it's strictest form, without any room for interpretation. A naval vessel have the possibility to be exempt from any rules mandated on civilian trade traffic.

Does the vessel need to be registered?

Yes - Since this ship exceeds 5m and is going to be used in professional purposes they do need registration.
This does not raise any legal challenges due to the autonomous aspects of the vessel.

Does this vessel need a tonnage certificate?

Yes - As with the MUSV, these ships are by definition larger than the maximum permitted length to qualify for an exemption, so they need a tonnage certificate to operate in civilian traffic. The verdict of the tonnage certificate will most probably be used as a cause for the Minimum safe Manning Documents (Beslut om Säkerhetsbemanning) and the Trade Certificate (Fartcertificat), etc.
This does raise legal challenges due to the need of a crew is not compatible with the autonomous aspects of the vessel.

Does the vessel need certification?

Yes - For vessels exceeding 15 meters in length needs Trading certificate which determines what waters the vessel is cleared for operating within.

Does the vessel need minimum safe manning documents (MSMD)?

Yes - Since the vessels are longer than 6m and will be used in professional purposes they do need a review for minimum safe manning.

Will the vessel need yearly inspection?

Yes - The vessels are both longer than 5 meters and larger than 20 GT and are used in professional purposes. Since no passengers are on board but the vessel is planned to operate in all trading or operational areas the vessel needs an inspection at least every 36 months, as stated by TSFS 2017:26. This can also induce a further inspection by the Transportstyrelsen.

Challenges from directives and Law.

From the regulations stipulated in the STCW Manilla accords, the regulations on watch-keeping are the most strictly formulated when it comes to personnel onboard vessels. Specifically the VIII/2.1 and VIII/2.3 regulations.

> STCW Manilla Reg. VIII/2.1 - officers in charge of the navigational watch are responsible for navigating the ship safely during their periods of duty, when they shall be physically present on the navigating bridge or in a directly associated location such as the chartroom or bridge control room at all times;
>
> STCW Manilla Reg. VIII/2.3 - officers in charge of an engineering watch, as defined in the STCW Code, under the direction of the chief engineer officer, shall be immediately available and on call to attend the machinery spaces and, when required, shall be physically present in the machinery space during their periods of responsibility;

Here it clearly states that an appropriately skilled operator must physically be located on the bridge or prepared to enter the machine room. With an USV the position of the bridge could be argued, that is if the USV is in fact remotely controlled the actual bridge is not located on the vessel and still manned. However the possibility to physically enter the machine room is quite impossible to achieve remotely. This is also true for those machinery spaces that are classified as unmanned machinery spaces (UMS) or partially unmanned machinery spaces. However, in these cases, a high level of automation in the onboard machinery systems is a prerogative, allowing alarms to be sounded in the cabins of the crew responsible for the machinery instead of requiring constant supervision. That means that the crew is still needed to be physically onboard the vessel.

Challenges from directives and regulations:

TSFS 2009:44 (Sjövägsregler) - Most regulations are still written in broad form, open for interpretation. However the commander of the vessel is directly assumed to be on board the vessel, for example the commander needs to make routine inspection of the entire ship. Actions like these might arguably be done in port.

TSFS 2017:26 (Nationell sjöfart) - Att verifiera kraven på fartygets utformning och utrustning samt på fartygets systematiska säkerhetsarbete. Kraven verifieras lämpligen genom t.ex. en säkerhetsargumentation eller en riskanalys. En utmaning blir då att kunna släcka alla identifierade risker med koppling till båtarnas smarta funktioner.

TSFS 2010:102 (bemanningsföreskrifter) och TSFS 2012:67 (Vakthållning och utkik) – Dessa föreskrifter är inte aktuella om båtarna inte transporterar gods eller passagerare utan endast användas vid tester av system inom militär verksamhet. Men om båtarna kommer att användas som handelsfartyg i civil verksamhet blir det svårt att uppfylla kraven i föreskrifterna utan att ha bemanning ombord. Även om man leker med tanken att ”bemanningen” finns i land skulle det bli svårt att uppfylla intentionen i vakthållningsföreskriften.

Legislative challenges (Law) - Generally the laws are written in very broad and unspecific ways in order to spark interpretation for best utilization within the applied reality. The challenges for implementing larger USV's comes from the fact that larger ships used in professional purposes and with engine size larger than 750kW need to have a chief onboard when operating in civilian traffic, but the specific requirements first come from the STCW Manilla accords, not from the Swedish law. Naval vessels of course have the possibility for being excepted from these laws, but depending on level of compliance with the maritime laws there are theoretical arguments even for civilian vessels that would be possible to explore. However in practicality the long history of how the legislation is interpreted does not give any real room for unmanned larger vessels.

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The removal of personnel radically lowers the risk connected to life and limb, reducing the argument further for many of the arguments regarding safety of crew.

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The text is written in such a way as to be implementable for each and every vessel. That means that the means an unmanned vessel in fact can assist in distress situations by several different aspects, for instance just marking the location of a person in water would be helpful for a rescue operation, therefore this rule can be argued as not being an obstacle for any USV.

> - 6 kap 7§: ”Lämnar befälhavaren fartyget skall han underrätta den främste av de närvarande styrmännen eller, om någon styrman inte är närvarande, någon annan av besättningen och ge de föreskrifter som behövs. När fartyget inte ligger förtöjt i hamn eller på en säker ankarplats får befälhavaren inte lämna fartyget utan att det är nödvändigt. Om fara hotar, får han inte vara borta från fartyget”.

This rule does not specifically mandate physical pressence, however it is written in the most firm manner possible, some argument would be possible to form since the text states "if the commander leaves the ship", and the commander in fact never boarded the ship in the strictest physicall sence. In addition a remote or virtual presence might arguably be valid since it with modern systems can create an even better situational awareness than physical pressence, with Radars, Lidar, night vision, thermal cameras, and all other technical equipment that have been developed after the writing of these rules.

> SFS 2003:364 (Fartygssäkerhetslagen) - 2 kap. 1§: ”Ett fartyg är sjövärdigt bara om det är så konstruerat, byggt, utrustat och hållet i stånd så att det med hänsyn till sitt ändamål och den fart som det används i eller avses att användas i ger betryggande säkerhet mot sjöolyckor”.
>
> - 2 kap 4§: ”Ett fartyg ska vara bemannat på ett betryggande sätt”.

If an unmanned vessel is built with the specific purpose of being unmanned, the entire system must be designed in such a way as when implemented it at least proves as reliable and safe as a manned platform. This is an argument that the builder must take in account for.

> SFS 2003:438 (Fartygssäkerhetsförordningen) personal - 4 kap 19§: ”När ett fartygs säkerhetsbesättning bestäms skall det särskilt beaktas... om tillräcklig personal finns för att sköta livbåtar, livflottar och annan livräddningsutrustning.”

The safe manning is a vetting process that directly involves Transportstyrelsen. This aspect, the amount of life rafts on board an unmanned vessel should not be an issue since no personnel is on board, therefore rendering the necessity mute. However some automatic deployment of liferafts could indeed be helpful when the vessel is assisting in emergency situations.

> - 4 kap 20§: ”En säkerhetsbesättning ska ha en sådan storlek och sammansättning att fartyget får tillräcklig personal för manövrering och navigering, för drift och övervakning av maskineriet, för sådant nödvändigt underhåll av fartyget och dess utrustning som har betydelse för säkerheten, för brandskydds- och livräddningstjänsten, för radiotjänsten samt för intendenturtjänsten.”

This text is formulated more vague than the STCW Manilla Rule VIII/2.3. While the

STCW rule states physical presence this law rather inferes that the overall design of the system must be formulated in such a way as for the intended operational aspect if attainable.

B

Appendix Studied Vessels

In this appendix some vessels and projects have been gathered as part of the literature study within the field. Each vessel is accompanied with a shorter description, an image and some bullet points of main particulars. By estimating the main particulars, readiness level and published intentions and capabilities useful information for the concept development of future vessels can be drawn. The method for categorising and analysing these follows close to the Clapper et al. 2007.

MV YARA Birkeland

Overview

- Length: 80 m
- Beam: 14.8 m
- Draft: 6 m
- Speed: 6 kt
- Displacement: 3200 DWT

Description

The Yara Birkeland is an autonomous electric container ship designed for coastal freight transport in Norway. It measures 80 meters in length with a beam of 14.8 meters and a depth of 12 meters, operating at a 6-meter draft. The vessel has a capacity of 120 TEU (Twenty-foot Equivalent Units). The ship's propulsion system consists of electric motors powering two azimuth pods and two tunnel thrusters, driven by battery packs with a capacity of 6.7 MWh. This configuration enables an optimal operational speed of 6 knots and a maximum speed of 10 knots. The zero-emission design eliminates NOx and CO2 emissions typical of conventional diesel-powered vessels. Developed through collaboration between Yara International and Kongsberg Maritime, the vessel was designed by Marin Teknikk with Kongsberg providing the navigation equipment and autonomous systems. The project received significant governmental support, with the Norwegian Government contributing NOK 133.6 million (approximately one-third of the total NOK 250 million cost, equivalent to $25 million). The Yara Birkeland operates on a specific route between Yara's production facility at Herøya and the ports of Brevik and Larvik, covering approximately 7 nautical miles (13 km). This operation is intended to replace 40,000 diesel truck journeys annually. The vessel was christened on April 29, 2022, in Brevik, though current regulations require crew onboard for two years before transitioning to full remote control operation.

Zhi Fei

Overview

- Length: 117 m
- Beam: 17 m
- Draft: 3 m
- Speed: 8-12 kt
- Displacement: 8000 dwt

Description

China boasts that the Zhi Fei is the world's first autonomous, electric feeder containership in commercial service. The vessel is designed in collaboration by Shanghai Jiahao Ship Design Institute and Dalian Maritime University, and built by Qingdao Shipyard under China Classification Society rules, the vessel is operated by Shandong Port Shipping Group and Navigation Brilliance (BRINAV).

Decisive information about the vessel is hard to find, but the ship seems to have a dead weight within the 5,000 to 8,000 dwt range, and a container capacity of approximately 300 TEU. It is equipped with what is interpreted as some kind of podded propellers, and supposedly a battery electric propulsion system. The top speed is noted at 12.5 knots and a design speed of 8 knots.

Operationally, Zhi Fei can switch between manned, remote-controlled, and fully autonomous modes. It features advanced intelligent systems capable of independent route planning, collision avoidance, and remote operation via 5G, satellite, and other multi-network communication systems. The ship's maiden voyage took place in September 2021, and it entered regular service in April 2022 on a short-sea route between the ports of Qingdao and Dongjiakou in Shandong Province.

This vessel also collects data as a strategic test vessel for autonomous maritime systems with the plan to use the insights gained from Zhi Fei to develop larger autonomous container vessels, with capacities ranging from 500 to 800 TEU.

Sources

https://maritime-executive.com/article/china-reports-first-autonomous-containership-entered-service

Visby class corvette

Overview

- Length: 72.8m
- Beam: 10.4m
- Draft: 2.4m
- Speed: 35kt
- Displacement: 630t

Description

The Visby-class corvette is a Swedish naval vessel featuring a non-magnetic carbon-fibre composite hull. It incorporates numerous technical systems below deck, including titanium piping, active demagnetization coils operating in XYZ axes, air locks, redundant hydraulic systems, and cooled exhaust systems. The vessel utilizes stern interceptors that function both as trim plates and for active roll dampening, contributing to its speed capability of over 35 knots. Safety equipment includes quick-donning smoke diving suits. The ship's systems include a Swedish firewall system called "Läristen." Since its introduction, the corvette class has undergone armament modifications. Initially lacking an area air defense system, the vessels will receive upgraded capabilities as part of Sweden's defense initiatives approved by Parliament in autumn 2020. In November 2023, the Swedish Defence Materiel Administration (FMV) signed a contract with MBDA UK Ltd to equip all five Visby corvettes with CAMM air defense missiles. The Visby-class consists of five vessels: HMS Visby, HMS Helsingborg, HMS Härnösand, HMS Nyköping, and HMS Karlstad.

Sources

https://www.fmv.se/aktuellt--press/aktuella-handelser/avancerad-process-att-installera-luftvarnsrobot
https://www.forsvarsmakten.se/sv/aktuellt/2023/11/luftvarnsrobot-pa-visbykorvetterna/
https://www.teknikaliteter.se/2024/05/17/att-se-utan-att-synas-korvett-typ-visby/

Skjold class corvette

Overview

- Length: 47.5m
- Beam: 13.5m
- Draft: 1.0m
- Speed: 60kt
- Displacement: 274t


Vegard Oen Hatten / Norwegian Armed Forces

Description

The Skjold-class corvette is a Norwegian high speed missile corvette capable of reaching speeds of over 60kt, making it the fastest warship class in the world. The construction is a catamaran SES design, allowing it lo partially lift out of the water at high speeds to reduce drag. The ship is constructed of composite fibres to increase strength and keep the weight low. To further lower the radar signature the vessel is coated in radar absorbing material and most equipment is hidden behind flush hatches in the hull.

The ship is powered by four gas turbines in a combined gas and gas configuration with a total power output of 12000 kW allowing for speeds of 60kt and a range of 800NM at 40kt.

There are currently 6 ships in the class that were commissioned between 1999 and 2012 with KNM Skjold being the lead ship.

Sources

http://www.foils.org/skjold%20brief.pdf http://www.amiinter.com/samples/norway/no1402.html

USX-1 Defiant

Overview

- Length: 55
- Displacement: 240t
- Beam:
- Draft:
- Speed:
- Range:

Description

The USX-1 Defiant is designed with the intentions to reshape naval technology and explore how the US navy can incorporate medium sized unmanned surface vessels (MUSV). Developed under DARPA's No Manning Required Ship (NOMARS) program, the Defiant first launched in February of 2025, this fully autonomous vessel was designed from the ground up to operate without human presence, eliminating all crew-related accommodations and systems. This design philosophy has allegedly allowed for significant improvements in payload capacity, operational efficiency, and cost effectiveness. The Defiant is built by Serco North America at Nichols Brothers Boat Builders shipyard and is currently (2025-04-03) dockside testing with extensive sea trials scheduled for Spring 2025. The program aims to demonstrate unprecedented at-sea reliability with a target of 90% reliability for continuous operation over a full year. Following successful trials, the vessel will be transferred to the Surface Development Group for further operational integration. The Defiant stands apart from previous unmanned vessels such as the previous retrofitted USVs Nomad and Ranger, as it was purpose-built for autonomous operations rather than being retrofitted from existing designs. This approach supports the U.S. Navy's strategic push toward unmanned maritime dominance, particularly for distributed operations in regions like the Indo-Pacific.

Sources

https://www.navalnews.com/naval-news/2025/03/serco-darpa-launch-nomars-usx-1-defiant/
https://defence-industry.eu/darpa-launches-groundbreaking-unmanned-surface-vessel-usx-1-defiant/
#:~:text=The%20Defense%20Advanced%20Research%20Projects%20Agency%20%28DARPA%29%20has,and%20is%20now%20preparing%20for%20extensive%20sea%20trials.
https://www.navalnews.com/naval-news/2025/07/darpa-releases-first-official-video-of-nomars-usx-1-d

JARI USV-A
"Orca"

Overview

- Length: 58 m
- Beam: 23 m
- Draft: 2 m
- Speed: 40 kt
- Displacement: 420 tons
- Range: 4000 naut. miles

Description

The JARI-USV-A is an unmanned surface vessel developed by China State Shipbuilding Corporation (CSSC). The vessel utilizes a trimaran hull, offering low hydrodynamic resistance and a top speed of 40-knots and 4,000 nautical mile range. The vessel incorporates multiple radar systems and the sensor suite is housed within the integrated mast structure that consolidates multiple communication and detection systems. For weapons systems, the Orca is equipped with an HT-1 universal Vertical Launch System (VLS) with 850mm diameter cells. The design includes dedicated space for potential additional VLS units. Additional armament includes two lightweight torpedo tubes and provisions for a remote weapon station. The aft section features a landing platform designed for unmanned helicopter operations and has an opening at the stern that can accommodate towed sonar arrays. The vessel's design includes a small bridge for optional crewed operation while maintaining its primary function as an autonomous platform.

Sources

https://www.armyrecognition.com/news/navy-news/2024/chinas-jari-usv-a-orca-unmanned-vessel-wit
http://www.hisutton.com/Chinese-JARI-USV-A.html

Rafale Protector

Overview

- Length: 9m
- Beam: 3.5m
- Draft: 0.45m
- Speed: 50kt
- Displacement: 4t

Description

The Rafael Protector has been in use in the Singapore Navy since 2005 in various missions, where it mainly has performed as a surveillance and reconnaissance, as well as force protection and as a vessel to protect vital infrastructure like ports. The Protector has also been used in Anti-Piracy operations in the Gulf of Aden. The Protector is now part of a family of USV's ranging from 9m to 11m, where armament and capabilities nowadays differ, but common armament is a Remote Control Weapon System (RCWS), combined with a complete sensor suite. The larger model also boasts a Surface-to-Surface Missile (SSM) system based on the Spike-ER launcher module on the aft part of the hull, capable of engaging targets at a distance of 8km, LTD 2019.

To note is that the current Rafael Protector in service today is a remote controlled USV, that does not explicitly house any autonomous features or capabilities.

Sea Hunter

Overview

- Length: 40m
- Speed: 27kt
- Displacement: 135t

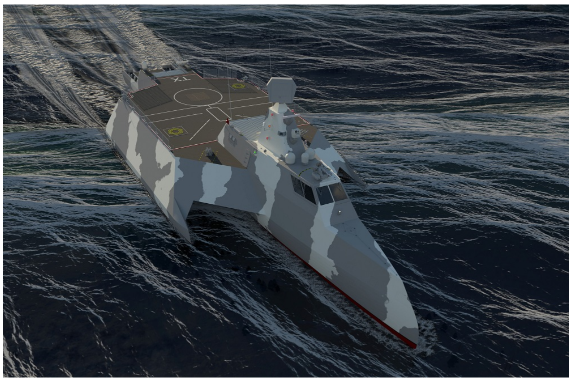
Description

The Sea Hunter is an autonomous unmanned surface vessel launched in 2016. The vessels main purpose is anti-submarine warfare, with the focus on detection, and of course the further technological advancement of autonomous units. The vessel is approximately 40m long and displaces in the range of 135-150 tons. The Sea Hunter has a trimaran configuration and boasts 27kt, which indicates a hull with very low resistance and high length to beam ratio. This is then stabilised by the spondons of the trimaran, creating a stable vessel with support for both equipment and even though the vessel is an autonomous ship, it still have the capability to accommodate for a small crew onboard.

TX Ship

Overview

- Length: 70 m
- Beam: 25 m
- Draft:
- Speed: 30 kt
- Displacement: 600–750 t



Description

Thales and Steller Systems have developed the TX Ship, a 70-meter trimaran designed to support navies in the transition from manned to autonomous operations. The TX Ship is engineered for lean manning (15 crew) or fully unmanned operation, offering a modular, cost-effective solution for expanding naval presence and operational flexibility. Much like the NOMARS Defiant, the TX Ship is designed to represent a stepping stone for operational change, TX Ship is being advanced with credible engineering to offer navies a flexible platform for the transition into next-generation partially unmanned naval warfare.

With a 6000 nm range, top speed of 30 knots, and 20 to 40 days endurance (manned/unmanned), TX Ship is equipped for a broad mission spectrum including Mine Countermeasures (MCM), Intelligence Surveillance and Reconnaissance (ISR), Anti-Submarine Warfare (ASW), and littoral strike. Its full sensor suite integrates with Thales's M-Cube and MAPLE control systems to support autonomous, semi-autonomous, or man-in-the-loop operations.

A standout feature is its automated mission bay and modular design, enabling deployment of various manned/unmanned surface, aerial, and subsurface systems. The trimaran hull ensures deck stability for heavy-lift helicopters like the Royal Navy's Merlin, while containerized payloads support tasks such as covert insertion, field medical care, or land-weapon integration (e.g., MLRS).

Sources

https://www.thalesgroup.com/en/united-kingdom/news/tx-ship-new-concept-autonomous-naval-vesse
https://www.navalnews.com/event-news/dsei-2019/2019/09/dsei-2019-steller-systems-thales-unveil-tx
#:~:text=TX%20Ship%20is%20a%20fully%20sensorised%20multi-role%20trimaran,,multiple%20types,%20of%20manned%20or%20unmanned%20mission%20packages.

Juliette Marine's Ghost

Figure B.1: The Ghost. Source: The Engineer

Overview

- Length: 12 m body, 20 m pontoons
- Beam: 8-12 m
- Draft: 1.3-3.7 m
- Speed: 35 kt
- Displacement: 30 t

Description

Developed between 2007 and 2011 by Juliet Marine Systems (JMS), the Ghost is a high-speed, stealth-capable vessel intended for mainly military applications. The development of the Ghost was motivated by the need to counter small, fast-attack threats, exemplified by the 2000 attack on USS Cole.

The design incorporates a small water plane area twin hull (SWATH) configuration combined with super cavitation to achieve high stability and reduced hydrodynamic drag at speed. The vessel also features articulated dual-strut pontoons. At low speeds, these extend outward, lowering the midsection into the water to reduce draught and radar cross-section. As speed increases, the struts rotate inward, lifting the hull out of the water in order to reduce resistance. Propulsion is provided by twin 1,350 kW gas-powered turbo shaft engines, with demonstrated speeds over 35 knots and theoretical potential up to 70 knots.

Stability is maintained via gyro-stabilization and over 20 underwater control surfaces governed by automated control systems. This enables stable operation in sea states with wave heights up to 2.4 meters. The hull is shaped with angular geometries to minimize radar signature and a versatile internal cargo hold supports varied payloads including personnel, cargo, or mission-specific systems. Proposed roles include force protection, special operations support, ISR, and maritime interdiction. The Ghost remains under further development, with ongoing refinement of its propulsion and mission systems.

Sources

http://julietmarine.com/
https://interestingengineering.com/innovation/meet-the-ghost-the-boat-that-sails-through-bubbles
https://wonderfulengineering.com/the-ghost-is-us-navys-new-stealth-assault-boat/
https://gdmissionsystems.com/-/media/general-dynamics/maritime-and-strategic-systems/pdf/ghost-modular-small-surface-vessel-datasheet.ashx

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