Proceedings of 15th International Marine Design Conference (IMDC-2024)
June 2-6, 2024
Amsterdam, the Netherlands

Large Uncrewed Surface Vessel: An opportunity for Energy Transition?

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ABSTRACT

Driven by the IMO target to make the maritime industry net-zero in its carbon emissions by 2050, the maritime industry now has the question of how to create both technically feasible and economically viable solutions. While many are looking at how this can be achieved for currently crewed vessels, even those service vessels such as naval combatants, there is also a real benefit that could be had by combining autonomy with the challenge of meeting the energy transition. Without people onboard there are options to completely change assumptions on layout, deck height and operations that could provide greater available space and counter energy density challenges. Additionally the removal of human life could open the line for other fuels such as ammonia with significant toxicity concerns. This paper investigates the benefits and difficulties that a Large Unmanned Surface Vessel (LUSV) utilising alternative fuel can bring, building on the recent BMT LUSV vision.

KEY WORDS

Autonomous Vessels; Energy Transition; Alternative Fuels; Modularity.

INTRODUCTION

The maritime industry accounts for ~3% of global emissions (EU Horizon, 2022), if it were a country it would rank 6th, although accounting for ~90% of global trade. Clearly reducing maritime emissions will have a significant impact on global warming. The updated IMO GHG emissions strategy is for a ~50% reduction by 2030 and net zero by 2050 (IMO, 2023). There is also a clear ambition globally to maximise the opportunity of autonomy, thus reducing people in hazardous scenarios and increasing the ability to conduct tasks in a world with a skills shortage across many industries (World Economic Forum, 2023).

BMT have created a vision known as the Large Uncrewed Surface Vessel (LUSV). This is exploring not only an autonomous vessel, but how it can contribute to the maritime net zero targets. By combining autonomy with the energy transition there are many advantages to be gained. However, there are some technical challenges that must be overcome to ensure not only compliance with regulations, but also ensuring safe operation.

This paper introduces the BMT LUSV concept, which while it has been designed for a specific purpose the lessons learnt are applicable across the autonomous vessel range of operations and sizes. The advantages an LUSV has for supporting the energy transition are explored, alongside the general technical challenges.

One of the major advantages of autonomy is the removal of people. This not only provides more space it also has the added benefit of significantly reducing the energy demands of a vessel. This is due to the reduction in hotel load, which could around 15% of the required power compared to a crewed vessel and is explored in more detail in subsequent sections.

This provides two options for an owner/operator. The vessel could be reduced in size or endurance while cargo capacity could also be increased. Although it is likely that a combination of both of these will be sensible. However, one of the likely key drivers when starting out is acknowledging that the key ship impact of fuel would no longer be internal space but the impact of the mass of the fuel at the start of deployment.

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Submitted: 24 February 2024, Revised: 2 April 2024, Accepted: 1 May 2024, Published: 21 May 2024

Conference paper, DOI: https://doi.org/10.59490/imdc.2024.872 e-ISSN: 3050-4864

LARGE UNCREWED SURFACE VESSEL (LUSV)

The LUSV vision is a simplified supporting vessel that can utilise the full benefits of autonomy to help reduce costs. The concept of a LUSV is not new; LUSVs have been seen as the key component of the United States (US) Navy's ASW Continuous Trail Unmanned Surface Vessel programme since 2010. More recently, the US Navy has also looked at LUSVs to address the projected reduction in vertical launch strike missile capacity as their Ticonderoga Class cruisers are retired. The key element which makes these systems "large" is their requirement to operate on open ocean and higher sea states as well as the scale/size required to host the modular capability and support it for long durations of time. While the Royal Navy is keen to integrate and exploit uncrewed systems and is making significant progress in areas such as mine warfare and maritime air power, it has yet to formally consider the use of LUSVs to enhance its surface fleet. This means there is an opportunity to take a holistic design approach to the challenge; to outline the design drivers and help fuel discussion on the topic.

This LUSV vision has been created predominantly with an Anti-Submarine Warfare (ASW) application in mind but it could be utilised for a range of other surface warfare functions. ASW is especially appealing as it is a resource intensive endeavour. In order to counter a threat from entering a sensitive area, such as the Greenland Iceland UK (GIUK) Gap, a mixed fleet approach will often be used deploying a combination of submarines, Maritime Patrol Aircraft and expensive, high-performance front-line warships (UK Defence Journal, 2023). In the future LUSVs could be deployed to cover the GIUK Gap or similar maritime area on a permanent / near-permanent basis as required by intelligence-led indicators and warnings. Equipped with towed array and sonar buoys, these vessels would be capable of proceeding to a patrol station and maintaining a pre-planned patrol pattern (or respond to remote orders) to conduct either barrier operations or search functions. They would be capable of exchanging real-time data with both shore-based control centres and other assets (crewed and uncrewed) including those from other NATO countries. In this scenario, the crewed assets need only be activated once a positive detection is made. This means other more complex assets spend less time away from other, planned, commitments and the impact on personnel is also reduced.

Key Requirements

Following the creation of a potential Concept of Operations (CONOPS) for the LUSV, Table 1 below outlines the key driving requirements for the vessel that became the input to the vision.

Title	**Requirement**	**Measure of Performance**
Endurance / Duration	Remain on mission for the duration of a mission with no physical maintenance or support required	Threshold 1 month
Seaworthiness	Maintain all systems operation in deep ocean conditions and survive extreme conditions,	Upper SS6 full performance
Speed loiter	Maintain a loiter speed on mission for extended duration	10kts – 12kts
Speed cruise	Deploy to AoA or maintain deployment with TG ships	20kts
Speed sprint	Sprint speed for short period to avoid obstacle or threat	Objective 25kts
Payload	Provide ability to deploy towed array over the stern and flexible mission modules	Space for 6+ TEU
Above Water Signature	Low observable, IR, and radar signature	tbd
Below Water Signature	Low in water acoustic noise and magnetic signature	Commercial ICES standard with margin
Command and Control	A constant connection to a human in/on the loop is required, this drives the need for a layered approach to communication and connection.	tbd
Offboard Systems	Although the primary function does not require an organic airborne capability it may be advantageous to facilitate modular drone capabilities.	tbd
Cost	Provide added mass to the fleet at less than half the cost of a traditional vessel. Through Life Cost should also be minimised, although onboard crew may be removed from the scenario, there is still a significant shore based maintenance crew.	£50m - £100m per vessel UPC TLC tbd

Table 1: Key Requirements

The LUSV concept is not constrained by the requirement to have humans onboard; there will be humans in the loop but not onboard. This unlocks huge potential to design a flexible and adaptable ship optimised for its operational roles, free of the compromises usually made to accommodate humans. Additionally it breaks the link between fleet mass and number of trained personnel; not all LUSVs need to be exercised all the time and they can be kept ready for a future surge in requirement (with suitable minor re-activation/work up). Autonomy opens the door to synergies that combine to bring significant operational, financial, sustainability and safety benefits.

Whilst there are benefits, there are also a number of challenges to overcome in order to provide a credible autonomous solution. These include, the increased cost of autonomy, ongoing ethical, security risk of capture and a requirement for a person in the loop for command and control. As part of our wider work we looked at all of these issues, categorising them into six key themes of development as outlined in Figure 1.

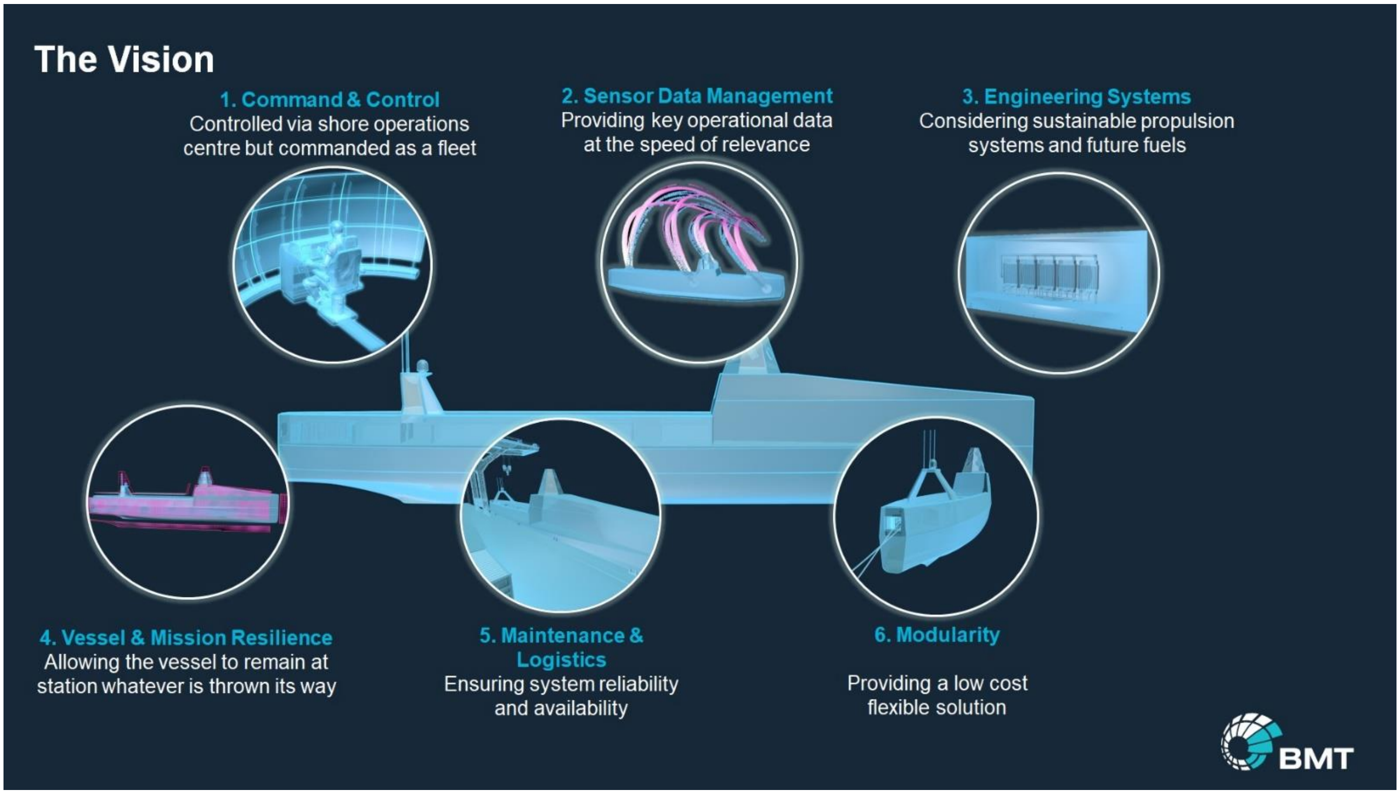

Figure 1: The Six Core Challenges of a Large Uncrewed Surface Vessel

Although six different and complex challenge areas have been investigated as part of the project, this paper only explores one, the engineering systems and the opportunity for future fuel insertion.

Engineering Systems

By creating a vision for the future, it is important to consider that the regulatory and operational environment of the future will likely require alternative power and energy solutions. The LUSV provides an opportunity to incorporate alternative fuel solutions, without the same safety concerns of a crewed vessel. Although removing people from the vessel allows a re-evaluation of space for machinery and/or fuel, the energy density of alternative fuels still causes a significant headache for Naval Architects, with the alternative being more frequent replenishment. The minimum requirement is for 30 days operation, but greater endurance could provide even greater capability and perhaps reduce the number of hulls required.

To future proof the vessel and allow for through life alterations, an all-electric propulsion solution is proposed; this has the primary benefit of reducing mechanical maintenance, but it will also allow for changes in the power generation plant as technology develops. In addition, by utilising modular prime movers it can simplify the maintenance process in port allowing the key equipment to be removed and replaced with working items, this has an added bonus of enabling greater flexibility in the choice of future fuel. This modular design allows for the use of Fuel Cells, which would decrease vessel signatures whilst allowing for improved maintainability and reliability. However, it should be noted current fuel cells (e.g. Proton-exchange membrane) require dehydrogenation for any alternative fuel except pure (99.999%) hydrogen. Solid Oxide Fuel Cells (SOFCs) can utilize various alternative fuels such as methanol, LNG or ammonia. Although the technology readiness level is lower, with a score of 7 given by IEA Fuel Cells (2024).

As previously discussed, removing people frees up space for more fuel, but the hull size will still limit the weight. Different fuels change the volume, weight and energy density balance, but alternatives to fossil fuels will have a lower volumetric energy density and this will create a challenge when the objective is to increase range beyond the baseline 30days at 10kts. It is also hard to select a specific fuel option as the apparent best systems are also the most immature.

The energy demand for the vessel will be different to a crewed variant, whilst the propulsive power required is anticipated to be equivalent or similar, the hotel load profile will vary. A comparison between crewed and uncrewed vessels for key sub-categories of the hotel load is provided in Table 2. This is an average over three operating climates and as such there is some variability for some of the sub-systems.

Hotel Load Sub Category	**Crewed Energy Demand (%)**	**Uncrewed Energy Demand (%)**
Hull	5	5
Propulsion & Generation	8	8
General Distribution & Lighting	5	0
Command & Control (including Communication)	15	20
Auxiliary Systems	30 ± 10	30 ± 10
HVAC	30 ± 10	15
Outfit & Furnishings	2	0
Armament	5	5
TOTAL	**100**	**83**

Table 2 Hotel Load analysis and comparison for Crewed and Uncrewed vessels

The following steps are a breakdown of the energy demand changes for the hotel load due to the removal of people, this is the view of the authors.

1. Hull load is likely to remain constant with potential for a minor decrease;
2. Propulsion & generation is likely to remain constant, although this could decrease as less power is required overall;
3. General distribution and lighting will be negligible;
4. Command and Control will increase due to a requirement to relay more information as well as computing power to execute decisions;
5. Auxiliary systems will remain constant, there is variability depending on the operating climate.
6. HVAC will decrease but there will still be a requirement for some HVAC to be onboard. This is because there will be a need to maintain suitable conditions for machinery and equipment;
7. Outfit & furnishings will be negligible as no people are onboard;
8. Armament is kept constant for this analysis but could change increase to account for the decrease in other demand.

This change in the energy demand is likely to result in a reduction required to maintain the vessel, which could be leveraged for the energy density reduction of the novel fuels. Conversely, this could lead to an increase in the mission systems onboard the vessel.

FUEL OPTIONS

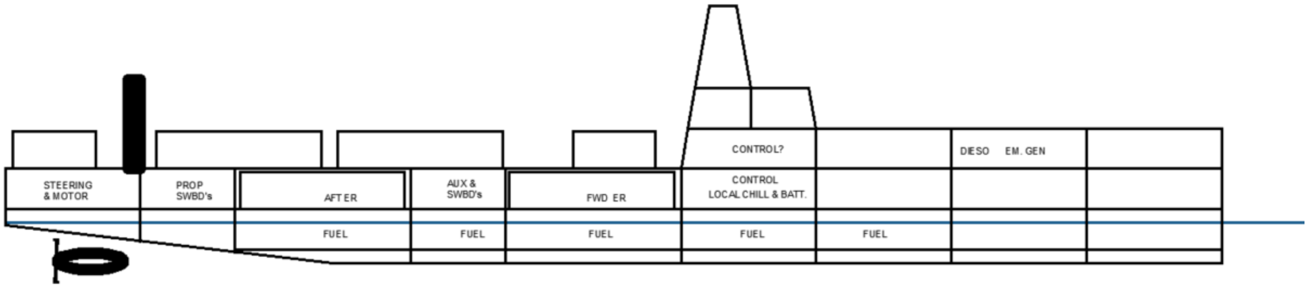

Figure 2: Cross section of potential LUSV

The LUSV has the space to potentially consider almost an entire deck for alternative fuel. Basing the fuel quantity on volume would provide circa 1000 m^3 of space for liquid (stored at or near ambient conditions), based on a LOA of 80m and a beam of 10m. However, when accounting for standalone storage tanks (pressurised or cryogenic/refrigerated) then the space significantly decreases to ~300 m^3. However, the volume available is no longer the driving case for the quantity of fuel, instead the mass is now the driver. When accounting for mass of fuel required, one should be cognisant not to base any calculations on diesel alone and should at least account for the gravimetric energy density ratios.

There are a number of potential future fuel options offering different levels of future viability:

- Methanol is a viable alternative but is not completely emission free, emitting carbon locally and only being low carbon when the production is taken into consideration, but it remains a near term solution.
- Compressed or liquid forms of hydrogen are not considered viable due to the spatial constraints of stand-alone tanks.
- Ammonia may have potential if it can be stored in such a way that it can avoid the stand-alone tanks, this is only possible on a LUSV due to the lack of people onboard. Utilising associated Solid Oxide Fuel Cells (SOFC) would also overcome the challenges of dehydrogenation as it is not required.
- Liquid Organic Hydrogen Carriers (LOHC) could be the best long term solution. It supports the vessel efficiency by having a minimal impact on trim due to storing the dehydrogenated carrier liquid onboard. However, it will always require dehydrogenation but this could be supported with associated technology developments.

The fuels chosen for investigation on the LUSV to be operating at end of life are ammonia and Liquid Organic Hydrogen Carriers (LOHCs). This is because methanol can only be net zero, whilst these have the potential to be truly zero. Hydrogen was ruled out due to the spatial constraints previously mentioned since it requires standalone tanks.

Whilst normally ammonia requires standalone tanks, there is potential to utilise pressurised ammonia rather than refrigerated. Pressurised ammonia at ~10 bar has similar storage to refrigerated ammonia (Engineering Toolbox, 2024). This would require the plate structure to be 23 mm thick, for a plate with spans 2100mm long and 600mm wide. This could be optimized by altering the stiffener spacing such that it can withstand this pressure and any operating constraints as well.

The use of a LOHC provides an opportune method to utilise hydrogen whilst having minimal impact on the vessel design. This is also truly zero since only hydrogen is utililsed. LOHCs are generally aromatic carbon compounds that are cyclic in nature. They hydrogenate (replace carbon double bonds with hydrogen) and dehydrogenate (replace hydrogen with carbon double bonds)

However, it is acknowledged that these fuels may not be available in the near future, or at least not globally. Therefore the use of modularity for power generation should be incorporated into the design. This allows the vessel to be designed to utilise any ambient liquid fuel through the life of the vessel. The use of modularity for power generation does require an electrical architecture for the propulsion system. However, this is now encouraged to minimise risk of obsolescence and ability to change prime mover moving forwards.

Placing power generation equipment just below the weather deck is advisable, since it is then possible to locate soft patches to support the removal of the equipment when required. This also minimises the spatial impact on the cargo/equipment onboard the LUSV.

BENEFITS & RISKS

There are several benefits to utilizing a uncrewed vessel but there are also risks that need to be accounted for, both of which will be expanded on further within this section.

BENEFITS

Electric propulsion allows the use of modular power generation. This provides flexibility of the fuel, which mitigates the risk of availability. Whilst this requires changes to the prime movers, this can be achieved via suitable removal routes and soft patches. This also gives a planned route to net zero if the chosen fuel is not available at time of build or during in operation.

The fuels chosen for the long term solution are LOHC or ammonia, whilst there can be transitions from MGO via methanol to the end solution. Currently the difference between the fuel is determined by the energy density and storage conditions. The ability to alter fuel through life, allows greater flexibility to accommodate emerging technologies and provides the flexibility to be included in a fleet-wide solution.

The use of the modular power generation provides an increase to the maintenance of the vessel and systems. The removal of equipment also means that there is less risk to operators conducting maintenance.

The removal of crew provides additional power due to the reduction in the hotel load. This could be used to offset the energy density or increase the capability of the vessel.

RISKS

Currently firefighting and damage control are significantly human intensive actions. A USV will require far more information to be created, assessed and actioned to ensure a vessel is operationally still effective. However, the removal of people allows the potential to utilise different firefighting techniques due to a lack of requirement to sustain human life (Savage & Glockling , 2023). The potential to loss of situational awareness and by extension control is a key risk and issue for any autonomous vessel, but more so during the event of damage and fire. The use of hypoxic environments could be a beneficial way to mitigate the fire risks, reducing the oxygen content below 12% v/v for conventional fuels (Savage & Glockling , 2023).

Recoverability is split into seven areas, as shown in Figure 3, some of which are far more difficult to mitigate on a USV. Whilst technology can support some elements, for example situational awareness, it is more difficult to recover the vessel with no humans onboard. The use of external assistance to support recoverability could be more difficult when using novel fuels.

Figure 3: Pillars of recoverability (Savage & Bartlett, 2023)

The recoverability could be supported by the use of robots which could be stored onboard and activated as required. Although this seems like science fiction, humanoid or other robots could support the recoverability and remove potential risks to human life during an emergency.

Similar to crewed vessels inspections would still be required. However, it is possible to utilize drones to support this and as such remove the risk to people. The other option would be to ensure the system is fully safe, by the removal of fuel and ensuring there is no hypoxic environment.

The vessel is designed for no humans onboard and if this were required then it would likely need to be on the mission deck. Otherwise, it removes the benefits of operating a LUSV and the potential benefits that are offered.

CONCLUSIONS

This paper presents a vision for a LUSV that has the potential to significantly contribute to the maritime industry's net-zero targets. The LUSV concept, which combines autonomy with alternative fuels, is adaptable and affordable, and is capable of performing a variety of surface warfare functions, with a particular emphasis on anti-submarine warfare. The engineering systems and fuel options for the LUSV, such as ammonia and liquid organic hydrogen carriers, have been thoroughly examined, and the benefits and risks of operating an uncrewed vessel have been discussed. In conclusion, the LUSV appears to be a promising and feasible solution that could enhance the mass and capability of future blue water fleets, while addressing the challenges associated with the energy transition.

A review of the concept is required to ensure optimal energy transition fuels are more realistic, due to many vessels originally being designed based on mass rather than volume of fuel. The main challenge is the mass of the new fuel which will have a lower energy density. The removal of people supports this due to the decrease in hotel load and increase in available space. Although this doesn’t meet the full decrease in energy density when moving from diesel.

A secondary challenge is the recoverability of such an asset if damage were to occur. Smarter systems are required that can reduce the risk of the asset being lost. For example flood alarm switches that are linked to pressure to allow more information about the state of flooding, that is lost with the removal of people. Graceful degradation of systems would enhance the time for recoverability and allow for human intervention as required.

The use of autonomy has significant potential to support the energy transition of vessels by allowing the use of less energy dense and potentially more hazardous fuels to be used.

CONTRIBUTION STATEMENT

T Beard: Conceptualization; investigation, methodology; writing – original draft. **J Rigby:** conceptualization; supervision; writing – review and editing.

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