Unlocking the Potential of Sustainable Submarine Design

L Hammock, BMT, UK

SUMMARY

Submarines are designed for a service life of more than 25 years and therefore they need to be designed to meet the needs of tomorrow as well as today. This not only means a flexible operational capability but also implies increased importance should be placed on areas such as sustainability and climate resilience in design. Although submarines, through low signature requirements, often present a lower environmental footprint than their larger ship counterparts there is still a considerable concerted effort required to ensure the platform is environmentally sustainable, throughout its entire life: from concept to end of life disposal. This paper will explore the key drivers and factors behind environmental sustainability in submarine design, with examples demonstrating how sustainable principles may be used to improve the environmental impact of the platform, without compromising the mission and whilst improving performance. The paper will also discuss the role of teamwork in achieving this goal, including how designers, customers, shipyards and suppliers can all work together to maximise the benefits of a sustainable submarine design.

1. INTRODUCTION

The term 'sustainability' is increasingly used but can have differing interpretations. The United Nations (UN) Bruntland Commission Report, (UN, 1987), defines sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs.".

The UN has identified seventeen Sustainable Development Goals (SDGs) (UN, 2021): recognising the need to work together globally and holistically. Many of the SDGs require a change of mindset and behaviour, for successful implementation.

Figure 1 – UN Sustainable Development Goals - Figure reproduced from the UN (2021)

Focusing in on Environmental Sustainability; it is more than simply Environmental Protection. There are various technologies available to reduce a platform's immediate impact upon the environment, however, to be Environmentally Sustainable the designer must assess the environmental impact over the whole lifecycle.

2. SUSTAINABILITY IN DEFENCE

An important consideration for Defence activities and assets is the ability to remain operationally effective. But this can be achieved in synergy with environmental sustainability. In fact, following a sustainable approach to asset design, procurement, operation, and disposal, can also provide opportunities for improvements and more efficient operation throughout the platform lifecycle. This was recognised in the recently published Ministry of Defence Climate Change and Sustainability Strategic Approach (MoD, 2021); "In widening and embedding sustainability, we will look at our impact on the environment in a whole different way. This will reveal opportunities for building greater resilience and creating new types of partnership."

Climate change has, and will continue to have, an impact on the way that Defence, as a whole, protects, operates and fights. All sectors of Defence have a part to play in reducing the contribution to climate change and biodiversity loss.

3. ASSET LIFECYCLE

The asset lifecycle is considered to follow the path of Concept, Assessment, Demonstration, Manufacture, In-Service, Disposal (CADMID). Using this lifecycle framework allows the designer to assess and minimise the overall impact upon the environment. It applies equally to components, equipment, systems, and platforms.

Figure 2 – CADMID lifecycle reproduced from Interaction (2021)

By undertaking an Environmental Impact Assessment (EIA) early in the lifecycle, the full environmental impact of the platform can be understood and mitigated. The impacts of the production, transportation and disposal aspects of a programme are often overlooked yet are easily designed-out during the early phases and by reassessing throughout the lifecycle, rather than attempting to remedy the impacts of equipment or platforms once in service. By starting with the end in mind, the design of the platform may be optimised throughout its life.

An EIA should be conducted at key milestones throughout the design process (for example, at design reviews and when a key design change is made), to assess the impact of the platform at each phase of its lifecycle. The cost of designing in mitigations at the front-end is almost always lower, and simpler, than attempting to rectify later. Refrigerant systems are a good example of this. The 2014 EU F-Gas Regulation (517/2014) controls the use and emissions of F-Gases. Hydrofluorocarbons (HFCs) will be phased down in the UK, to achieve a reduction of 79% by 2030, compared with average use between 2009 – 2012. Systems and equipment suitable for lower Global Warming Potential (GWP) refrigerants can be significantly different from those used in previous designs and can be complex and expensive to retrofit. Given the length of the CADMID cycle of a platform, consideration should be given to the likely availability of refrigerants during the platform's life, in order to design out issues of obsolescence, or increased cost, at a later stage. It may be reasonably assumed that some of the common refrigerants being used today with higher GWP will be phased out during the lifecycle of a platform. This can lead to increased operating costs during the phase out period, before the refrigerant becomes unavailable. The financial and environmental costs of retrofitting a different system during the platform's life must be considered at the front-end of the CADMID cycle, to allow the designer to investigate alternative refrigerants and systems, to future-proof the design.

Many designers are now considering ammonia and CO2 as viable alternatives to higher GWP refrigerants. Ammonia and CO2 have inherent safety hazards, however these hazards may be mitigated early in the platform design phase, making these options feasible. When selecting these options, it is important to investigate the supply chain of the ammonia or CO2: historically, the production of ammonia involved high temperatures and pressures, and was a very energy intensive process. The traditional Haber-Bosch method of producing ammonia is estimated to contribute around 1% of global Greenhouse Gas (GHG) emissions (Brown, 2016). However, greener methods of ammonia production are in development, which could improve its overall carbon footprint and make it a more sustainable product, as well as having a lower direct environmental impact.

Similar supply chain analysis should be undertaken when considering any system design or design change: including future fuel selections. Working closely with suppliers and shipyards to reduce the environmental impact throughout the supply and production chains, the further reaching environmental impact of the platform may be reduced.

4. WATER TREATMENT STREAMS

There are elements that the designer might consider when designing systems, to enable the end user to operate the platform in a more environmentally sustainable manner, during the in-service part of the platform lifecycle. Bilge management is one area where good operating practices may be encouraged through the design of the system. There are two types of bilge water that accumulates on ships and submarines: clean and oily.

Discharge of oily water is regulated under MARPOL Annex I (IMO, 1983). Bilge water with an oil content greater than 15 parts per million (ppm) shall not be discharged overboard. From a mission perspective, a submarine could also be compromised by oil sheen on the water surface, by discharge overboard of bilge water with oil content. Therefore, effective bilge management is important on a submarine from the perspective of environmental sustainability and operational sustainability.

Designing for a dry bilge concept, for example, involves the piping designer routes clean drainages directly into small collecting tanks in the bilge. Designing this in from the start means that the contents of these small tanks is guaranteed to be oil free and so there is no risk of compromise to the environment or the mission when discharged.

Because the remaining bilge water with potential oil content will be a smaller volume, the designer will have increased options available for treatment or storage solutions.

5. WASTE NOT WANT NOT

Another example of using the design process to instil sustainable practises during the in-service phase, is reducing wasted energy.

When designing exothermic processes, designers should consider the possibilities of harnessing waste heat. Waste heat recovery systems do not have to be large and, when designed in from an early stage, may be easily integrated into a compact system design. Waste heat may be used for various applications such as heating water or spaces. This careful use of energy is particularly applicable to diesel powered submarines. In addition to energy recovery, a mindset to reduce energy consumption on board is also important. The responsibility for sustainable submarine operations belongs to everyone on board, as

well as the design and procurement teams. Switching off lights and non-essential equipment will help in the overall energy savings. Energy consumption reduction strategies in operation are also beneficial for the mission, as well as the environment: operational sustainability and environmental sustainability often work together.
For the designer: low energy equipment may be designed in. Low energy lighting, reduced flow shower heads, low flush toilets and treated grey water reuse on board for non-potable purposes are all ways to design in a manner that encourages environmentally sustainable operations in-service. By designing sustainably from the front-end, improvements to the maintainability of equipment and therefore operations are often also improved.

With regards to nuclear powered submarines; considering the whole lifecycle provides a wider understanding of the 'hidden' environmental impact of nuclear power: the mining and processing of uranium and the radioactive waste handling should be considered when assessing the overall environmental impact of the platform. Whilst nuclear energy is often considered to be 'clean' and 'free' in environmental terms, it should still be used mindfully. When using energy on board a submarine, the overall environmental 'cost' per kW of energy should be kept in mind.

6. STARTING WITH THE END IN MIND

An important, yet often overlooked, part of the lifecycle is disposal. Disposal impacts are evident throughout the life of the platform. There are operational wastes generated from product or equipment packaging and waste generated by personnel. Waste is produced during design changes, when older equipment is removed, and in the packaging of new equipment to replace it. Finally, waste is generated at the end of the platform lifecycle, when the platform and its assets are removed from service.

Operational waste can be significantly reduced through careful analysis of the supply chain and working closely with suppliers. Increasing numbers of production companies are now looking at their impacts on the environment and sustainable production. Many are finding ways to reduce the volumes of packaging used and to use recyclable packaging. Selecting suppliers with sustainable credentials, and working together with suppliers and manufacturers to maintain and improve these credentials, will reduce the waste associated with the platform.

Operational waste should always be separated to allow recycling when disposed of ashore. But the responsibility does not end there: the waste contractor should also be carefully selected for their 'green' credentials, to ensure that the waste generated by the platform will be handled in a sustainable manner.

There are some inherently difficult wastes generated on board a platform, which are difficult to store safely during a mission. Food waste and, where women are present on board, sanitary waste present a health hazard if stored incorrectly. When considered from the initial design phase, there are several solutions to a reduced waste production: from chilled storage, to dehydrators and auto-gasification units, which produce an inert, compact by-product for standard storage and landing ashore. More recent waste handling technologies are compact and quiet: making them ideal alternatives for submarines.

Submarine endurance is a key driver of operational effectiveness, and waste storage may be a limiting factor. By considering the whole life-cycle of waste on the platform: i.e. reducing the packaging of consumables to allow more stores, processing the waste in a way to safely minimise it's stored volume onboard; it may be possible to extend patrol length.

By assessing the volumes and types of waste anticipated, at an early design phase, and through the careful selection of the most appropriate equipment for the type and volume of waste, sufficient space may be allocated from the outset to provide an appropriate solution.

Ultimate disposal of the platform and onboard equipment should be considered throughout the entire CADMID cycle of the platform. Whether equipment is being procured in the design phase or as a design change part way through the life of the platform, consideration should be given to how the materials will be handled at the platform or equipment end of life.

The Sustainable MOD Strategy Waste Management 2015 – 2025 (MoD, 2015) follows the waste hierarchy set out in the European Waste Framework Directive, as transposed into UK law by The Waste (Circular Economy) (Amendment) Regulations 2020 (UK Gov, 2020). This hierarchy declares the highest priority is the prevention of waste, followed by reuse and recycle. These elements should be explored with prospective suppliers to ensure that sustainable disposal is planned for at an early stage.

As well as designing for reduced waste and reusable or recyclable materials, the impact of waste should also be considered. Whilst toxic materials are inherently restricted onboard a submarine, some materials are hazardous to the environment, or require energy intensive processes to recycle or dispose of them. By avoiding the use of such materials, the overall environmental footprint of the platform is improved. Where the use of these materials cannot be avoided they must be documented, along with volumes and locations, and a plan put in place for handling their disposal.

The security aspects of components and equipment should also be considered at the design phase to ensure that any security restrictions upon recycling / reuse are included in the disposal plan. Creating a disposal plan at an early point in the design phase, and maintaining the plan throughout the lifecycle, will ensure a clear picture of waste management and reduce the amount of waste consigned to disposal processes.

This is increasingly important for nuclear powered submarines, which require a coherent strategy for managing laid-up submarines. In particular, the handling and storage of High Level Nuclear Waste.

7. CONCLUSIONS

Environmental Sustainability involves a holistic view of the platform across its lifecycle. It is about a mindset shift in the design, operation and disposal of a submarine. There are many systems and equipment available to reduce the environmental impact of a platform. However, often these options are not practicable for installation on board a submarine, due to space constraints, noise restrictions, weight considerations and atmospheric conditions. By using sustainability principles from an early stage in the design process, elements of the platform requiring environmental impact mitigation can be reduced by design, resulting in a greater selection of environmental protection equipment, more suitable to the submarine environment.

Applying sustainability principles further, across the entire lifecycle of the platform, it is possible to reduce the environmental impact of a submarine, without compromising its mission capability. Indeed, in many of the examples cited in this paper, implementing sustainability practices at the front-end of the design process is also beneficial to operational effectiveness.

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