Alternative Future Visions for NATO Maritime Operational Energy & Power

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Abstract. There has been much discussion regarding the global maritime energy transition and what this will mean for NATO maritime forces. Whilst there is potential for it to present major challenges in sustainment and freedom of action and manoeuvre, there are also opportunities which could deliver enhanced operational capability – through identifying ways to operate differently with new technology. To mitigate risks and exploit opportunities, NATO maritime forces will need a shared headmark for the future maritime operational energy system. Building on previous work in this area, this concept study proposes a selection of alternative future visions for NATO Maritime power and energy, in the 2045-2055 timescale, in the form of five 'Operational View (OV-1)' and energy flow diagrams. The intent is to bring these options to life to assist in stimulating structured discussion and debate, including drawing out national perspectives. This in turn should assist in prioritizing areas for NATO and national S&T, including consideration of potential 'moon-shot' higher risk ideas.

Keywords. Operational Energy; Fuel; Climate Change; Sustainability; Energy Vectors; Nuclear Power

1. Introduction

It is now widely recognised that a global energy transition is underway in response to climate change and a move towards greater sustainability [1] with many NATO member states and partner countries committed to achieving Net Zero by 2050 [2]. Aligned with the International Maritime Organisation's Strategy [3], the global shipping community is at the early stages of reducing emissions. Major reductions in emissions will require a move away from fossil fuels with platforms designed for alternative energy sources [4]. The impact this diversification of maritime fuel supplies will challenge the current model of sustainment and freedom of action and manoeuvre for NATO maritime forces. However, it has also been argued that changes represent a 'moment of maritime opportunity'[5] for operational energy. When considered alongside other developments in the maritime battlespace, including Artificial Intelligence, increasingly autonomous systems and future sensors and effectors, there is potential to move from thinking about platforms to a 'force mix of complex or simple, crewed or uncrewed assets to meet capability needs'[6], leveraging dual-use technology developments.

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NATO's 2023 Climate Change and Security Impact Assessment[7] notes that a priority for the NATO naval armaments community will be research into alternative fuels whilst reducing the Carbon Intensity (CI) of warships. The way in which NATO maritime forces operate and are sustained through replenishment of common fuels means that any future operational energy solution must be taken forward with interoperability as a priority[8].
To mitigate risks and exploit opportunities, NATO maritime forces will need a common vision of the future maritime operational energy [2] [9] system and to consider how capabilities will be delivered from future platforms and achieve 'Energy transition by design'[10]. This shared vision should enable coherence in NATO and member state S&T activity in addition to leveraging commercial developments to achieve operational advantage.
This concept study proposes a selection of alternative future visions for NATO maritime energy and power, building on previous work to present future options in the 2045-55 timescale. These are shown in the form of five 'Operational View (OV-1)' and energy flow diagrams, with associated Science and Technology (S&T) focus areas. The aim is to bring future maritime operational energy vector options to life and assist in stimulating structured discussion and debate, drawing out national perspectives and shaping NATO S&T priorities.
In generating these visions, the aim has been to represent options which NATO maritime forces can directly influence or address. This accepts that defence has limited ability to predict and influence the future geographic availability, net quality, CI and production volumes of alternative energy sources and fuels.
The selected visions aim to capture the S&T enablers that would allow navies to respond to these potential changes to markets and technology. These responses include options that allow them to better adapt and follow the market, or to become more independent of the market, through energy efficiency, generation of their own energy or fuels, or by delivering future capability in new, less energy intensive ways. Vector options range from those that impact whole fleet design and interoperability within NATO to those which are more platform focused. Whilst presented as 5 courses of action, multiple combinations would be possible and, to an extent, desirable.
OV-1 diagrams aim to illustrate impacts to naval operation and capabilities. Each energy vector diagram illustrates a 'well to platform wake or effect'[3] energy flow (key at Figure 1), highlighting the scale and scope of the vector discussed. Based on baseline supporting commercial technology and potential energy market in 2045-2055 and expected needs of naval forces, navy specific S&T needs to make the vector viable are drawn out. Both the minimum S&T technology and analysis needs are highlighted, along with higher-risk 'moon-shot' S&T options that could radically change the applicability and achievability of the energy vector.

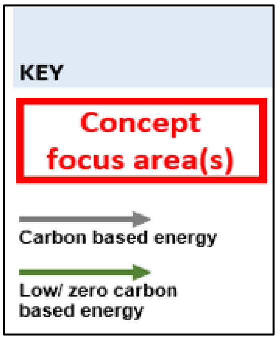

Figure 1. Key for energy vector flow diagrams

[2] Defined by the US Navy as: 'Operational energy is required for training, moving, and sustaining military forces and weapons platforms for military operations. It includes energy used by ships, aircraft, combat vehicles, and tactical power generators.'
[3] Including power and energy requirements of offboard platforms and systems

2. Concept 1: NATO 'Owns' More of the Energy Supply Chain

Retaining operational benefits of carbon-based fuels while decreasing Well-To-Tank (WTT) CI; utilising common fuels across full range of platforms.

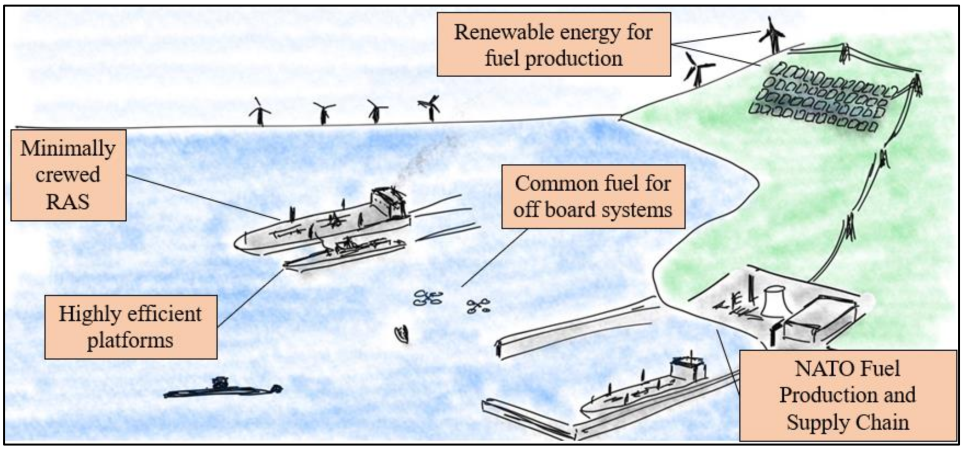

Figure 2. Concept 1 Operational View

2.1. Concept Overview

Continue to use carbon-based liquid fuel (for interoperability, energy density and survivability benefits), but 'own' aspects of the supply chain to manage WTT CI & availability risks. Platforms use a mix of drop-in fuels, allowing growth in use of bio-derived or synthetic fuels as availability increases. Potential for single NATO fuel across domains via global NATO fuel network. Minimise net impact to platforms & capability.

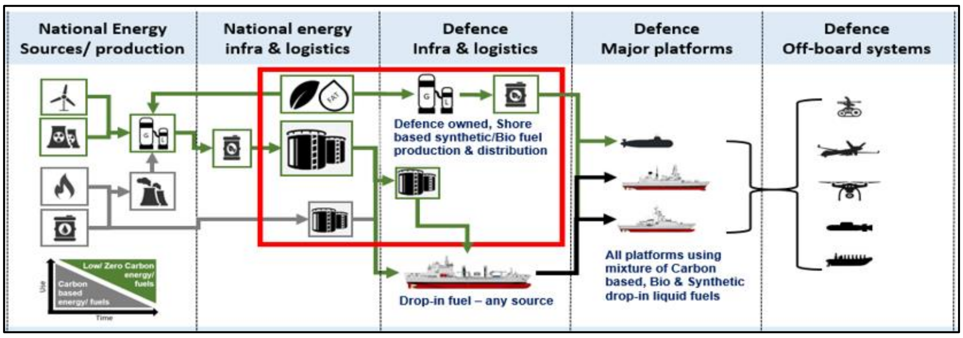

Figure 3. Concept 1: Energy Flow

2.2. Key enablers for concept:

- NATO fuel strategies and infrastructure.
- Effective use of NATO real-estate to support energy generation and fuel synthesis.
- Ability to manage and track CI of supply chains.

2.3. Essential S&T and Analysis needs:

- Focus on efficiency – minimise the energy demand.
- Limited materials compatibility work and trials.
- Analysis: scale/locations of fuel production/storage/distribution systems.
- By 2050: S&T may need to support continued use of Internal Combustion Engines if commercial maritime move to alternative fuels.
- **Higher Risk 'moon-shot' S&T: None required.**

3. Concept 2: NATO Aligns to Commercial Shipping

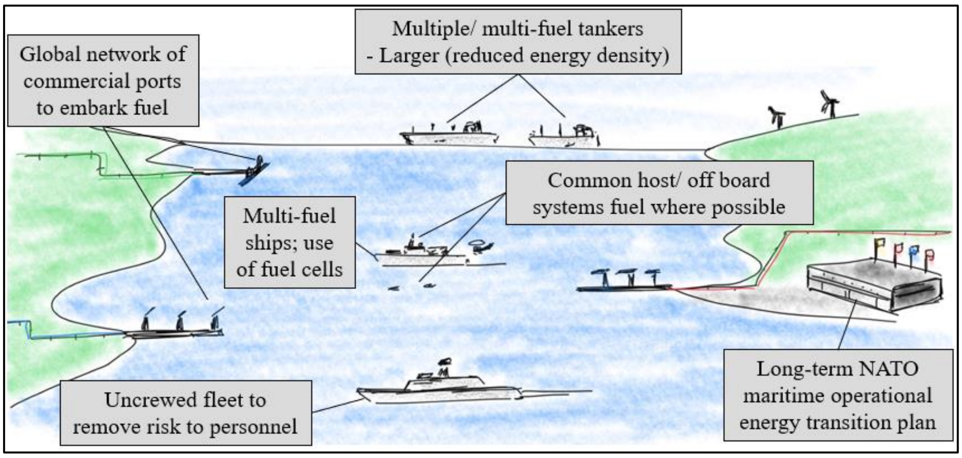

Figure 4. Concept 2 Operational View

3.1. Concept Overview

Follow and benefit from commercial developments and availability in alternative fuels (gaseous & liquid) that reduce Well-To-Wake (WTW) CI. May also require intervention in supply chains, or ownership of key parts of supply chains. Significant impacts to platform design and defence logistics to manage changes in energy density, replenishment, safety & survivability aspects.

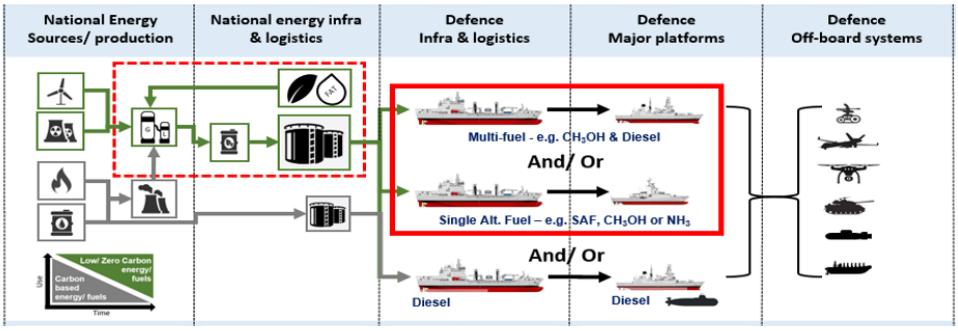

Figure 5. Concept 2 Energy Flow

3.2. Key enablers for concept:

- NATO energy/ fuel strategies and infrastructure; alignment of transition.
- Technologies and design options to manage survivability of naval platforms with selected alternative fuels.
- Replenishment technologies for selected alternative fuels.

3.3. Essential S&T and Analysis needs:

- Technologies and design options to manage survivability of naval platforms.
- Replenishment technologies for selected alternative fuels.
- **Higher Risk 'moon-shot' S&T:**
  - **Use of autonomy, system of systems approach to reduce risk to life.**
  - **More automated, faster replenishment of selected alternative fuels.**

4. Concept 3: NATO Interoperability is ‘Electrical by Default’

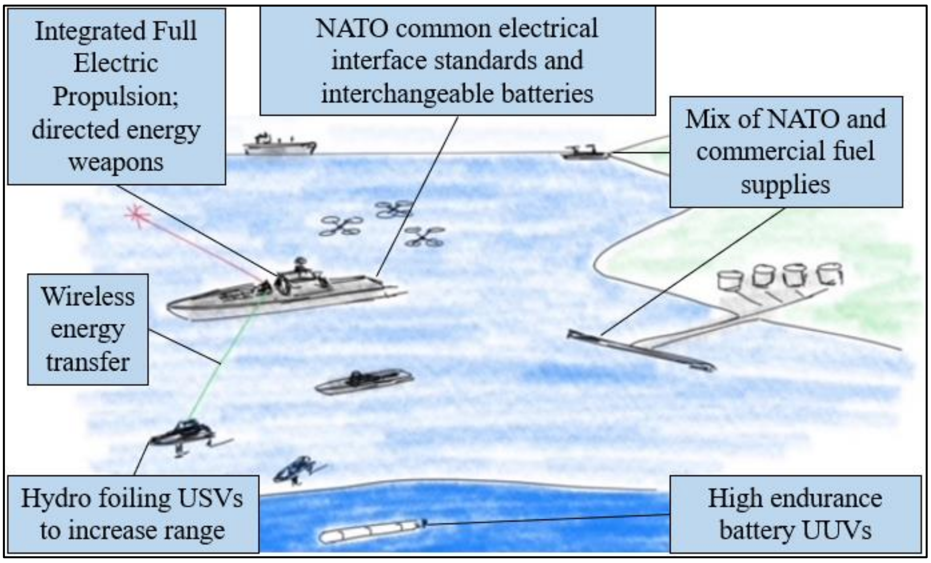

Figure 6. Concept 3 Operational View

4.1. Concept Overview

Key energy enabler to manage complex networks of platforms & highly capable, long endurance off-board systems. Independent of fuels used throughout any green transition. At-sea micro-grids providing power, energy storage, connectivity to a range of platforms with defined and common interface/ battery standards, assuming electricity is the default energy vector. Leverage commercial advances in technology; military S&T if required.

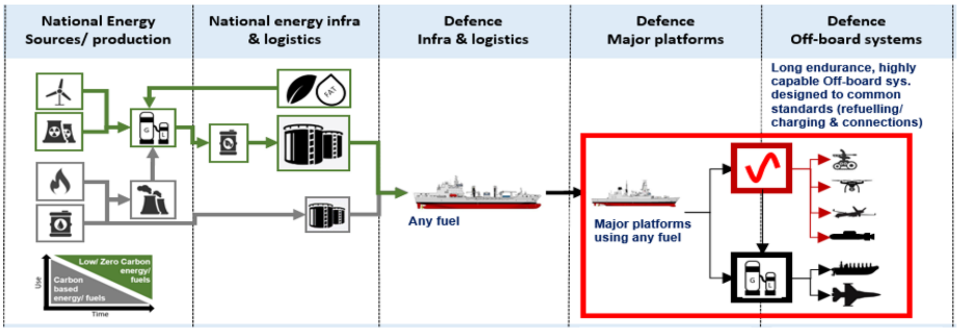

Figure 7. Concept 3 Energy Flow

4.2. Key enablers for concept:

- NATO interface standards and policies.
- Technologies and design options to manage survivability of energy storage/ transfer.

4.3. Essential S&T and Analysis needs:

- Focus on platform efficiency – minimise energy demand.
- High density energy storage – technologies beyond commercial requirements.
- Development of charging/ battery exchange systems to reduce interface risks.
- **Higher Risk ‘moon-shot’ S&T:**
  - **Use Smart ‘fleet’ energy management in connected platforms and UxVs.**
  - **Ultra dense energy storage to maximise capability/ reduce transfers.**
  - **Develop concepts such as wireless energy beaming.**

5. Concept 4: Operational Energy Independence via at-sea Nuclear

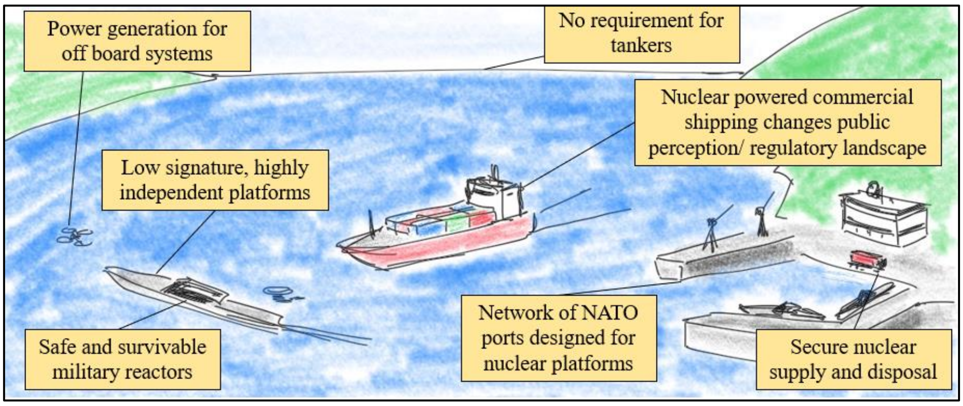

Figure 8. Concept 4 Operational View

5.1. Concept Overview

Utilising developments in civil nuclear industry and wider defence nuclear enterprises to achieve operational energy independence for key platforms. Includes the potential use of Gen4 and micro reactors as direct power sources on major platforms. Potential opportunity to produce synthetic low, or zero-carbon fuels either at sea on generation-after-next replenishment platforms.

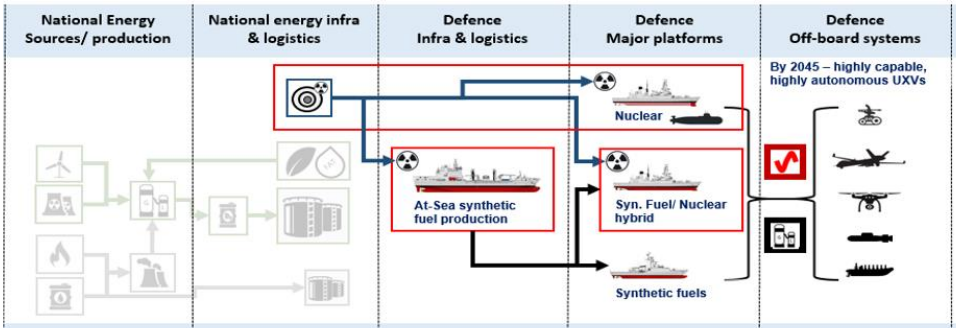

Figure 9. Concept 4 Energy Flow

5.2. Key enablers for concept:

- Surface platform nuclear based designs to meet political, regulatory, safety, survivability and disposal needs.
- More favourable political, public and regulatory environment.
- Compact and efficient nuclear powered synthetic fuel production.

5.3. Essential S&T and Analysis needs:

- Analysis of regulatory issues of portable reactors.
- Platform designs that safely and effectively integrate civil nuclear technologies.
- Low SWaP, marine synthetic fuel production systems.
- Analysis to inform/ understand concept of operations for ‘more’ nuclear fleets.
- **Higher Risk ‘moon-shot’ S&T:**
  - **More radical platform designs optimized for integration of emerging reactor technologies.**
  - **Technologies that radically improve efficiency of nuclear-to-electricity energy conversion.**

6. Concept 5: Leveraging Novel Technology to Deliver Effects Differently

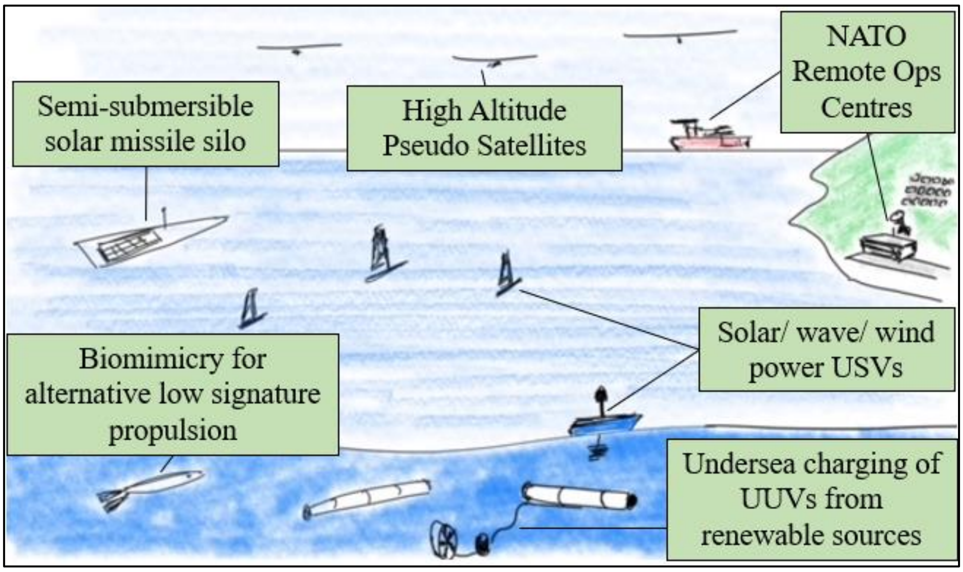

Figure 10. Concept 5 Operational View

6.1. Concept Overview

Take a 'System Of Systems Approach' to maritime capabilities. Reducing overall energy demand through the use of alternative capability delivery approaches – e.g. through the wider use of uncrewed systems, networked systems & novel platforms & sensors. Benefits also arising from decoupling effect from speed and significantly improving persistence & endurance – operational energy delivery becomes less of a limiting factor.

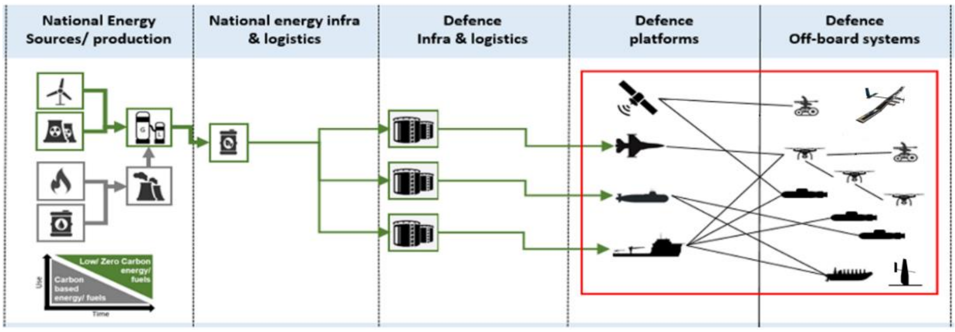

Figure 11. Concept 5 Energy Flow

6.2. Key enablers for concept:

- Command and Control in a Denied or Degraded Environment (C2D2E).
- Novel, compact and energy efficient platform and payload elements (in system of systems).

6.3. Essential S&T and Analysis needs:

- Development of high-density, high-efficiency payloads – e.g. sensors.
- Development of enabling AI, autonomy and controls.
- Analysis to understand operational effectiveness and energy demands of distributed networks of systems.
- **Higher Risk 'moon-shot' S&T: Persistent, long endurance uncrewed platform concepts powered by renewable energy.**

7. Conclusion

As stated in the NATO 2022 Strategic Concept[11], the alliance will reduce emissions, improve energy efficiency and invest in the transition to clean energy sources – leveraging green technologies while ensuring military effectiveness. The global maritime energy transition presents a threat to the current model for naval surface platform sustainment, due to reduced access to current fuels, in addition to tighter restrictions on emissions. Achieving a NATO maritime operational energy transition by design will be shaped and enabled by S&T; to deliver beneficial and timely impact; this will have to be focused on addressing areas where there is a 'defence delta', connecting across borders and links between the S&T and operator communities; the visions in this paper aim to support this. The Compendium of Best Practice[12] is a great example of sharing national perspectives. Whilst this paper presents five separate visions, elements of these could be merged to generate combinations which enable operational advantage, aligning solutions with operating concepts. However, it is unlikely that all visions could be successfully pursued in parallel; there will therefore be choices for NATO in the very near future – noting the enabling changes to energy supply chains, platform designs and operating concepts. A delay in making a decision is, in itself, a decision; in this case to move forward with vision 1 by default. Any transition period will require NATO coordination and management.
Across all courses of action, pursuing greater energy efficiency supported by enhanced energy data and digitization of platforms will enable informed decision making; common methodologies in NATO could assist with this. However, the biggest gains will come from thinking differently and delivering effects through alternative means. Enabled by some of the higher risk moon-shot operational energy S&T ideas proposed in this paper, the next two decades present a 'once in a generation' opportunity to deliver a step change in maritime capability with a more distributed force. It is in the development of alternative CONOPS, enabled by new technology, that there is real potential to exploit opportunities and reduce vulnerabilities to deliver operational advantage in the maritime domain.

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