Highly Autonomous Warship Technology: Bridging the Gap to Autonomy

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Synopsis

Highly Autonomous Warship Technologies: Underpinning Safe, Secure and Cost-effective lean-crewed warships. Embracing the future of maritime autonomy this paper explores the core enabling technologies that will facilitate lean crewing on warships. There are many ethical and practical constraints that currently make a completely unmanned surface combatant unfeasible; therefore the near future solutions may utilise highly autonomous vessels alongside smaller unmanned counterparts to create an optimal force structure. In this thought leadership piece, BMT breaks down the challenges of autonomy in warship design into seven core development areas and creates a vision for how a warship in 2040 could operate.

Keywords: Autonomy; Warship; Technology; Maritime; Artificial Intelligence

1. Introduction: Underpinning Safe, Secure and Available Lean-Crewed Warships

Artificial Intelligence and Autonomous Systems offer a wealth of possibilities and opportunities to counter and embrace the future battlespace. Autonomy can be used to transition naval design into a new paradigm where the hypersonic threat can be successfully neutralised and the days of sending many hundreds of people to sea on a single ship are consigned to history. While large uncrewed naval vessels are still some way off, the use of elevated levels of automation to significantly reduce crewing levels is vital to the defence modernisation plans of many maritime nations. The Highly Autonomous Warship Vision outlined in this paper is not fully autonomous but minimally crewed, using autonomy where it is cost effective to do so. Looking across to other engineering sectors it is clear that autonomy alone is not the answer, instead a combined Human-Autonomy Teaming approach is required to maximise efficiency. As an example, the car manufacturing industry is being revolutionised by “Cobotics” using robotic systems in collaboration with a minimal highly skilled human team. However, the opportunities created by autonomy are not without risks which will need to be carefully managed. The introduction of new technologies and techniques will cause significant technical and cultural changes. To understand the impact of these changes it is important to recognise the possible future battlespace in which naval vessels will operate. This project assumed a 20-year timeframe with all proposed technologies having the possibility to mature before 2040. It is believed that the future battlespace will be **continuous**. There will be an Integrated Operating Concept that will persist from periods of peace, through the grey zone, to periods of conflict. There will be changes in tempo, but there will be persistent threats below the threshold of conflict. The future battlespace will be **global**. The battlespace will span from close to home, defending our infrastructure to overseas protecting our important trading partners in areas of tension. The future battlespace will be **uncertain**. Threats will vary over time as tensions increase and diminish. They will evolve into many different forms and utilise new highspeed weaponry including hypersonic missiles. The future battlespace will be **collaborative**. Missions will move beyond Joint towards Multi-Domain Integration (MDI), where success will depend on the ability to exchange information at the speed of relevance and coordinate activity in a cluttered, degraded and potentially in GPS denied environment.

BMT have conducted this umbrella activity to develop and capture a deeper level of understanding of the development / integration of Highly Autonomous Warships (i.e. very lean-crewed) and AI/Automation. This will allow us to support the development not only of a Highly Autonomous Ship in the future, but it will also allow us to integrate greater levels of autonomy both onboard and offboard in any emergent platform design programmes.

The information laid out in this paper is not a concept design. It is a vision of the technological philosophies that enable partial autonomy in a lean-crewed warship design. It is a solutions-focused thought leadership project to identify the current state-of-the-art and outline the future development path ahead.

Author’s Biography

Jake Rigby is the Research and Development Lead, responsible for the portfolio management of internal research projects in defence. He is a charted engineer and Member of the Royal Institute of Naval Architects originally training as a Naval Architect specialising in ship signatures before his current role of R&D lead. Jake is also responsible for Academic Engagement at BMT. In recognition of his work to progress Academic Engagement in the maritime sector he was recently awarded the title of Honorary Associate Professor at the University of Exeter, and continues to engage in a range of collaborative research projects.

Ian Savage is a Naval Engineering Chief Engineer within BMT Defence and Security UK, he has a BEng in Maritime Technology, an MSc in Marine Engineering and is a Chartered Engineer and Full Member of the Institute of Marine Engineers, Scientists and Technologists.

Since joining BMT in 1997 Ian has developed extensive experience in the design and specification of engineering systems, fire protection systems and submarine in-service support. Ian has demonstrated an ability to develop concept designs and mature these to a level of detail suitable for pre-build design integration, both on build programmes and detailed design investigations.

The aim of the still ongoing research project is to bridge the gap to autonomy; recognising the potentially ‘awkward step’ from crewed to un-crewed vessels and potential step changes that future technologies might drive. The transition from the current conventional concepts to a stage dominated by autonomous, lean-crewed ships is expected to take place over the next couple of decades. During this technological transition period BMT anticipates there being a mixture of vessels with different levels of autonomy at sea (both commercial and military). We are particularly interested in the “tipping point” in the design evolution process. Is it possible to incrementally introduce autonomy in an evolutionary approach or does there come a time where the platform implications are so large that a revolutionary approach is required to dramatically transform the platform? Could it be that by implementing a cautious evolutionary approach the full benefits of autonomy cannot be realised? Furthermore, what are the key enabling technologies and components that are required to create a Highly Autonomous Warship? This paper cannot claim to have all the answers, but understanding the challenges, benefits and risks is the first step towards the solution.

2. Benefits

The transition towards a Highly Autonomous Warship can provide many exciting and distinct advantages for the future naval fleet, however the flexibility of maintaining an optimised crew also has significant advantages. Can a Highly Autonomous Warship Maintain the best of both worlds?
Because of Autonomy the vessel has:

- Reduced through-life cost of the platform – With personnel costs being one of the main cost elements and maintenance tasks costing up to 50% to resolve alongside
- Increased endurance compared to crewed vessels
- Faster reaction times – With automated responses
- Removes personnel from the line of fire
- Improves quality of life and retention

Because of an optimised crew presence the vessel:

- Maintains asset flexibility
- Provides command and control for Offboard Autonomy
- Maintained force protection
- Cost effective implication of autonomy – Still higher upfront costs than a crewed vessel but allows you to implement autonomy where it is cost effective

3. Development Areas

In order to focus investigation and research 7 key development areas were identified, Navigation, Warfare, Recoverability, Logistics and Maintenance, Platform Systems, Human Factors and Cyber Security. The following section lays out the core research questions and challenges uncovered by the project. Each of these topic areas all have their own in depth technical papers which are available on request from the corresponding author.

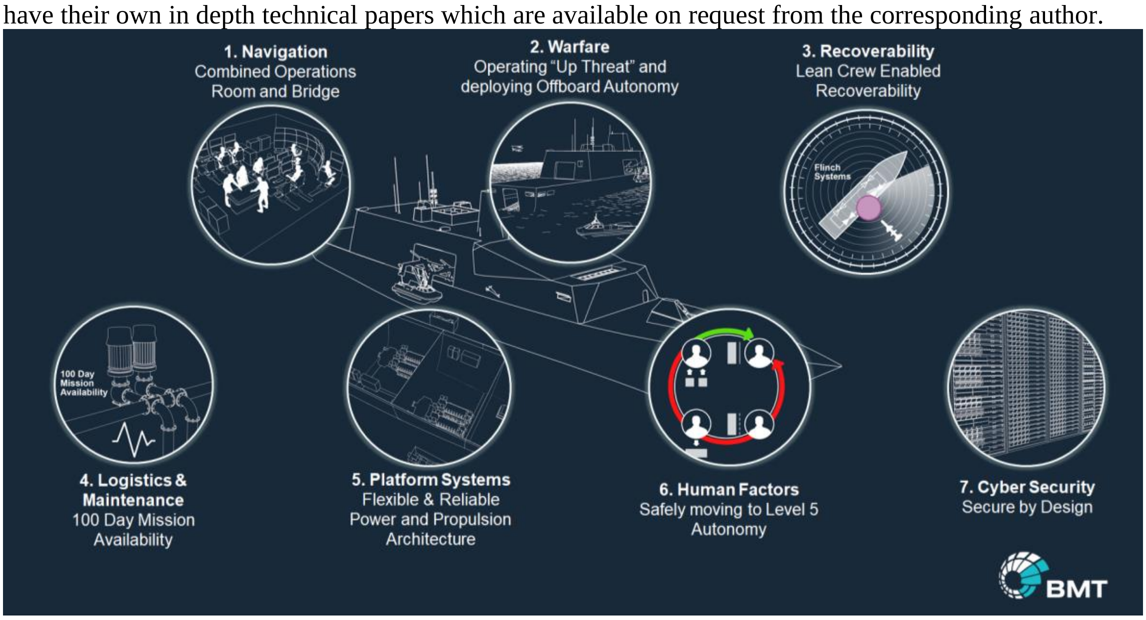

Figure 1: The Seven Key Development Areas of Highly Autonomous Warship Technologies

3.1. Navigation

"How can navigation be safely automated in contested and GPS-denied environments?"

One of the first areas you think about when considering autonomous maritime operations is vessel navigation. As well as learning from commercial maritime best practice and developments this workstream also considered the additional threat of electromagnetic and AIS deception, Global Navigation Satellite System (GNSS) degradation or denial. Considering a broad range of alternative-navigation technologies we have developed a layered approach to GNSS denied navigation, using a range of novel technologies including but not limited to:

- Image/LiDAR/Doppler radar aiding of inertial
- Beacon-based navigation (including pseudolites)
- Navigation using signals of opportunity (Radio frequency signals nor normally intended for navigation)
- Quantum Sensing of earth phenomena
- Visual odometry
- Automated Celestial navigation

There is no one single technology that can completely replace GNSS, but there are different methods that have different levels of accuracy depending on the situation. For example, signals of opportunity are not always apparent by when they are there, they can be extremely useful. The same can be said again for automated celestial navigation which is only truly effective at night time. By utilising this layered approach you can have greater confidence in your assured position at any one time, having a range of sources for your location. If one of those technologies is unavailable or being spoofed then you can highlight it quickly and utilise the others.

3.2. Warfare

"What future warfare scenarios are we designing against; what will naval warfare look like in 2040?"

The future battlespace is likely to be in the persistent Grey Zone between peace and conflict, where tensions might escalate and subside quickly, the Threats are uncertain and the operations evolve unpredictably. Maritime forces operating in this environment must be capable of persistent surveillance in a variable threat environment, as well as being able to provide a rapid response to hostile activity. They must be able to operate alone or collaboratively with other maritime, air or land assets, and be able to share information across a wide area at the speed of relevance. Minimally Crewed Highly Autonomous Warships will form part of a layered approach to manpower within the task force. Operating "Up Threat" over long durations, these vessels will be able to deploy and recover numerous unmanned vehicles to conduct Dull, Dangerous & Difficult operations in Dirty and Deep environments (5Ds). As part of a network of communications they will operate collaboratively with other units, sharing and analysing "Big Data". Significant autonomy with the ship systems, as well as with self defence and C2 systems will enable the operators to focus on only those tasks needing local human intervention. This will require the development of Automated Threat Evaluation systems that are capable of operating without direct user oversight. Each of the Air, Surface and Underwater Battlespaces will require vessels with different technologies and capabilities, but the principles of reducing manpower close to the threat and being able to conduct persistent, collaborative and flexible operations will remain.

3.3. Recoverability

"How can a lean-crewed vessel still respond to the challenges of damage control?"

One of the strongest arguments against reducing the complement of a warship has always been the need for flexible crew deployment during damage control scenarios. Traditional damage control measures rely on human led firefighting, flood control and repair.

These tasks are challenging enough for human led teams, but are even more difficult to automate. Therefore, the challenge on a lean crewed platform is not just about how we automate these tasks, but how can we utilise greater engineering situational awareness together with robust design philosophies to deliver enhanced levels of automation in this area. Some areas such as fixed firefighting systems are relatively mature already in other domains, using technology transfer to bring it to the maritime environment. Other areas such as flood control systems will require new ideas and new thinking.

3.4. Logistics and Maintenance

"What Availability can be achieved, with lean-crewing, for a 100 day mission? What information and management systems do you need?"

In order to focus our feasibility study we set the challenge of enabling a 100 day low maintenance mission period. This mission period would of course vary depending on role and requirement but it is a high level figure to enable us to compare current system reliability. In order to implement a predictive maintenance approach system testability is key, providing the ability to identify which systems are working and which systems are encountering issues. The core enabling technologies in this area are inherent system/equipment health monitoring to capture the sensor data, autonomous machinery control systems and remote operating centres/Digital Twins to help monitor and diagnose issues before the breakdown occurs, with the application of asset management to ensure that support is available, when required.

3.5. Platform Systems

"How can the power and propulsion system be adapted to embrace and enable lean-crewing?"

Power & Propulsion (P&P) is the most critical platform system, delivering the Move function and enabling Fight & Float functions though electrical power generation. The reliability of modern P&P equipment is generally intrinsically high, provided routine "husbandry" maintenance & inspections are performed – these however demand a minimum level of crew. Reliability will need to be maximised at the earliest stages; starting with robust design principles, the selection of proven equipment, best-quality installation and commissioning practices, and more-involved testing & setting-to-work periods to flush out latent defects. Reduced husbandry can be achieved by the adoption of modern remote monitoring technologies (e.g. for leak detection), and by a move to real-time, adaptive condition based maintenance.

3.6. Human Factors

"What is the pathway to allow the cultural and social adoption of safe and secure autonomous systems?"

Autonomy will not exist in isolation, but rather as part of a larger system. As such there will always be a system boundary for the autonomy, and at this boundary will undoubtedly be an interface with human operators.

Systems thinking is required to ensure that system boundaries are drawn appropriately and that potential risks are assessed on a system scale. It is important to ensure that any relationship between autonomy and humans plays to the strengths of each. The Society of Automotive Engineering (SAE) International(2018) lays out a 6-level scale of autonomy; with 0 being fully crew controlled to 5 being fully autonomous. There are many lessons that we can learn from the autonomous car industry and there are key relationships to avoid. Specific levels of autonomy that should be avoided are 3 and 4 on the SAE scale. These are where the human user is preforming a watchkeeping role but is required to step in last minute in the event of an incident or a crash. This is a huge ask for the human user who is disengaged with the task at hand but is still required to maintain full awareness of what is happening so that they can step in. The human should not be required to monitor the autonomy, instead the system must be trusted to operate without constant human oversight.

3.7. Cyber Security

"In this highly automated future world, how can we ensure our systems are 'secure by design'?"

A Highly Autonomous Warship will by definition necessitate a greater reliance on and use of digital systems to achieve its goals. Automating many of the systems which are currently human-controlled will offer huge benefits to the user community, but as with every system that operates in the cyber domain there is a potential cyber security risk that needs to be managed. Increasing the level of autonomous systems in a platform potentially increases its attack surface, providing new opportunities for an adversary to gain an understanding of the physical system, or to have a malign effect on its operational capability by exploiting a technical vulnerability. However, by starting with a blank canvas of ship and network design allowed us to turn this vessel into a real case study for what "secure by design" actually means in the maritime domain and outlining exactly what can be done. The key to the solution is effective design of resilient and flexible networks, not just designing for the initial arrangement anticipating future upgrades and additions.

4. Technology Roadmap

What needs to be true for this vision to work? The roadmap below outlines the key enabling technologies to enable a Highly Autonomous Warship to be built. For the full interactive technology roadmap please visit the BMT website.

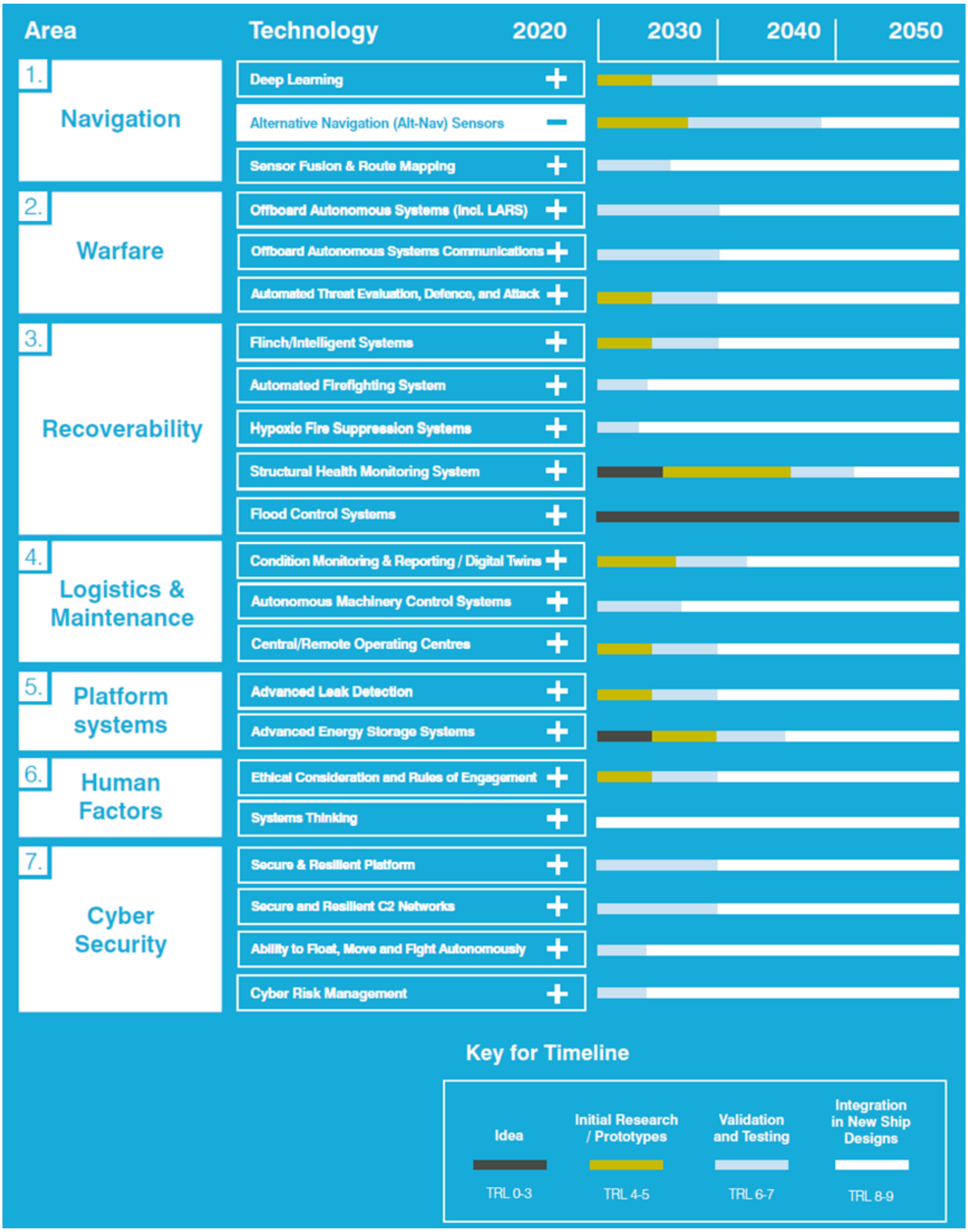

Figure 2: Technology Roadmap

5. Conclusions

In summary, although a Highly Autonomous Warship may look similar to existing surface combatants, its role, design, and internal technological philosophies are significantly different to current operational concepts. Throughout the project we have tried to identify the enabling technologies that instil three core overarching values; to ensure the vessel is Safe, Secure and Cost-Effective:

- **Safe -** To ensure the reduced crew can continue to operate in a safe environment and have a reduced risk profile taking them out of a high-risk environment using autonomy for Dull, Dangerous and Dirty tasks.
- **Secure –** Ensuring that the system is cyber secure by design, and the greater reliance of digital systems does not reduce the capability or resilience of the vessel.
- **Cost-Effective** – As with commercial shipping, introducing autonomy only when it is cost effective to do so. Using Autonomy to reduce overall through life costs.

Some of the technologies identified are already onboard some vessels or could easily be introduced to existing/upcoming platforms with minimal interruption. On the other hand, there is also a definite tipping point where the full integration of low maintenance platform systems, and lean crew enabled recoverability features will require a dramatically different platform design. It is therefore proposed that Highly Autonomous Warship Technologies could be implemented both on their own revelational design for 2040 as well as evolutional concepts outlined in the meantime. Some of the biggest changes for the Highly Autonomous Warship are not technological, but organisational and cultural to shift away from existing processes and embrace the full benefits of new technology.

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