Future Royal Navy Warships: Delaminating Capability and Systems

A paper by the UKNEST Science & Technology Working Group

Issue 1

August 2019

Foreword

The world is becoming increasingly interconnected by technology and globalisation both of which have been, and will continue to be, powered by activity at sea. Technology is central to what the Royal Navy does, right across the organisation. The outsourcing of technology and the tradition of technically de-scoping Programmes to manage delivery risk over the years have resulted in a reduced focus on technology to inform and shape the direction of capability development and delivery. The rapid pace of technology change in the commercial market and steep upward curve on technology dependency means the Royal Navy really needs to change its approach to, and relationship with, technology.

The Royal Navy recognises that the period between emerging science and technology breakthrough is shortening, which in turn shortens the effective life and operational advantage of any sensor or effector or a system of systems existing within a closed architectural framework. The rate of technological change will continue to be challenging with capabilities having increasingly shorter effective service life, or requiring regular improvement as they become obsolete or countermeasures are developed more quickly. Industry frequently leads disruptive technology development and at ever faster rates.

This challenge is compounded by a surge in enabling technologies that has lowered the entry barrier to the market place, allowing inventors and innovators to flood the market with technology at a pace that is unparalleled in Defence procurement. Rather than exploiting emerging science this aspect of innovation often seeks to re-purpose existing technology in a way that disrupts the ability to plan, operate and respond. The emergence of adversaries who use technology in new and innovative ways (e.g. a truck as a weapon or an off-the-shelf UAV to deliver explosives) will disrupt traditional planning processes and the Royal Navy needs to be able to respond within the required tempo with an able and agile force structure. Potential adversaries are already capitalising on this paradigm shift in access to technology and are beginning to challenge capability areas that are traditionally preserved for high-end military forces. Yet, there is also greater integration of technology and greater interconnection between the Royal Navy's systems as well as with the systems of suppliers and allies. This means that technology delivery is becoming complex, challenging and requires a good understanding of the Enterprise architecture and supplier base interaction.

The Royal Navy recognises that the military no longer leads technological development across its portfolio and that there is a growing requirement to adopt commercially available or off-the-shelf equipment as enablers to achieve military effect. It also accepts the changing approach to software and hardware design, with crowd-sourcing, collaboration and Small & Medium Enterprise challenges, is underpinning significant areas of technological innovation.

The ability of the Royal Navy to adapt, in harness with industry, is vital to its ability to retain technological parity with adversaries, achieving an edge where possible. This technology shift is not an isolated incidence; the global adoption of socio-technical design-thinking has resulted in a workplace culture of rapid and iterative design, further relegating the utility of some current procurement methods, business models and processes for developing, delivering and sustaining world-beating equipment and capability.

Against this backdrop, the Royal Navy accepts that the military must become more agile in its approach to procurement, more open to the adoption of emerging technologies and able to integrate systems within the Royal Navy architecture across a much larger supplier base. The Royal Navy needs to be technically agile and commercially aware and must be responsive to internal developments and external market influences.

Executive Summary

This paper sets out a vision for the development of the UK's future naval capability. Its overarching theme is one of "delaminating capability and systems". In other words, we mean moving away from the procurement of highly specialised platforms to a model that is more agile in its approach to procurement, enables an earlier adoption of emerging technologies and is more readily able to integrate systems within an overarching Royal Navy (RN) architecture. This will require the Ministry of Defence (MOD) and Industry to be aware of technological advances across defence and commercial sectors, including advances in on-board and off-board autonomy, novel weapons and information handling.

On-board automated systems are starting to be introduced onto RN and civil platforms with consequential savings in crew numbers and costs being realised. Examples include advanced ship steering control technology, being fitted to cruise ships and the mechanised weapons handling system fitted to the QEC aircraft carrier. However, current in-service examples in the RN tend to be at lower levels of automation despite the significant level of research and development of systems with higher levels of autonomy. Frequently the approach to training and reversionary modes will require large numbers of staff despite the potential reductions through automation, thereby negating the benefits accrued. Hence, non-technology blockers remain the biggest barrier to the wider introduction of on-board system autonomy.

The rapid emergence of new combinations of technology is expected to result in manned platforms becoming non-specialised vessels with significant elements of capability provided by unmanned and autonomous Off-board Systems (OBS). Task groups are anticipated to be a mix of unmanned long endurance OBS nodes (e.g. sensor and possibly weapon nodes) mixed with few central "basic" host Command and Control (C2) platforms. Critical elements will include high bandwidth, robust and secure connectivity, robotic and intelligent systems for deployment, recovery and reconfiguration of OBS, and links to traditional human-centric decision making with C2 exercised from a range of platforms and facilities. The ways in which warfare activities will be conducted are likely to be fundamentally different, requiring new concepts of operation and concepts of use for adaptable and scalable systems of systems. Furthermore, the procurement and support of warships will need to change to enable the full benefits to be realised.

A number of the novel weapon systems are being developed including Laser Direct Energy Weapon (LDEW) and electromagnetic rail gun which may have significant impact on the design of future warships. Such systems will certainly pose significant integration challenges particularly around high energy pulsed power and cooling solutions. The key challenge is platform integration driven by increased demand for transient power and cooling, integration with the command and control systems, and integration with other weapon and soft kill solutions. This becomes substantially more complex to address for defence against higher end threats and swarm attack scenarios.

The operation of the modern warship is driven by generation and processing of large volumes of data. More sophisticated sensors, systems and off-board autonomy capabilities are creating ever more data, with the risk of overwhelming the crew and limiting delivering full capability. The RN is not making best use of the latent capability of the data within its platform systems, which could be better harnessed through the application and human presentation of effective data analytics to improve platform and system support services and operational effectiveness. The establishment of a common data and information access platform and services, would unleash the use of modern

data analytics and machine learning techniques to maintain and stretch the Royal Navy Information Advantage.

Recommendations

NEAR TERM / EPOCH 1

1. **Experimentation**. MOD and industry should promote and actively support aggressive programmes of experimentation (including with in-service platforms) to de-risk technology from ideas into operational capability, giving full consideration of standards and Defence Lines of Development (DLoDs) and how final acceptance is achieved. This will cause non-effective technologies to fail fast (reducing wasted time/funding), highlight effective technologies for investment and rapidly demonstrate which DLoDs require concentrated investment/effort.
2. **Procurement**. Current procurement processes must be made applicable to the increased rate at which technological development is now happening (e.g. weeks/a few months instead of many months/years) and recognise how technology is enabling capabilities to become delaminated from platforms. This must be initiated in the near term to enable immediate quick wins to be realised (sustaining current capabilities against adversaries) and to allow future capability improvements (above those of adversaries).
3. **Autonomy**. Autonomy can provide benefits to the RN (capability, safety, cost), but where and how are still to be determined. MOD must address these autonomous "unknown unknowns" through experimentation of autonomy applications on extant platforms and in use on Off Board Systems (OBS). This will in a short time scale develop Concept of Employment (CONEMP) and Concept of Use (CONUSE) documents for future EPOCH Capability Planning and demonstrate where immediate quick wins can be gained.
4. **Information Exploitation**. There is great latent capability that can be released from the data currently collected and stored on RN platforms, but as with autonomy, what this capability is and how it can be used is still to be determined. MOD must address these data "unknown unknowns" through wargame directed hackathons. This will rapidly demonstrate where quick wins can be gained and help direct future work streams and Capability Planning.
5. **Novel Weapons**. MOD must draft CONEMP and CONUSE for novel weapons. These must be developed in the near term to support planning for effective initial at-sea integration and deployment. The draft CONEMP and CONUSE should be expected to be refined by the Dragon Fire LDEW project and planned at-sea trials/demonstrations.

MID TERM / EPOCH 2

1. **Delamination of capabilities**. Moving beyond the near term there will be a drive for modular capability from a platform/system which will support rapid technology development and implementation. MOD must design future systems and platforms to have delaminated capabilities (starting from pre-concept design).
2. **Autonomy**. Once initial versions of autonomy CONEMP and CONUSE have been created and blockers (to effective acquisition, integration, operation and support) have been highlighted through experimentation, detailed Capability Planning for autonomy should be undertaken by MOD. This should then be used to direct further technology development and trials to de-risk the requirements for acquisition and support of autonomy to go onto serving and future RN platforms.

3. **Novel Weapons**. Following creation and refinement of CONEMP and CONUSE, MOD will need to integrate the plan for any novel weapons into its Capability Plan. This will in turn direct further technology development work and trials to de-risk the requirement(s) for acquisition and support of weapons to go onto serving and future RN platforms.

LONG TERM / EPOCH 3

For the long-term, technology spiral development and integration will be commonplace if the recommendations in the near and medium term are implemented effectively by MOD. The replacement for the Type 45 Destroyer (T45) capability will likely be the first to fall into this long-term timescale; however de-risking of technology for this capability will have to be undertaken by MOD in the medium term to enable effective exploitation (throughout the life of the platform) of autonomy, information exploitation, novel weapons and sensors.

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Introduction

Faced with the changing nature and scale of threat, reduced RN force structures and pressures on budgets, the replication of previous methods of acquisition are likely to result in poor value for money and operationally constrained naval assets that introduce operational risk, potentially leading to mission failure. The rapid pace of technological change is not always reflected in UK naval capability. This can result in capabilities having increasingly shorter effective service life, or requiring regular improvement or refresh as they become obsolete or new threats and countermeasures are developed more quickly.

This paper sets out a vision for the development of the UK's future naval capability. Its overarching theme is one of "delaminating capability and systems". In other words, we mean moving away from the procurement of highly specialised platforms to a model that is more agile in its approach to procurement, enables an earlier adoption of emerging technologies and is more readily able to integrate systems within an overarching RN architecture. This will require the MOD and Industry to be aware of technological advances across defence and commercial sectors, including advances in autonomy, unmanned systems and information technology. Additionally, they will need to build on these trends, adapting them into cost-effective naval capabilities while understanding the interaction with existing afloat and ashore infrastructure and assets.

The topics discussed in this paper have arisen from a series of workshops conducted by the UK NEST Science and Technology Working Group. The membership of this working group provides a unique combination of industrial and MOD/RN perspectives. We aim to produce a "thinkpiece" that poses a number of questions and challenges to be considered by UK MOD and Naval Defence Industry, so that cost and acquisition cycle times can be reduced, future capabilities delivered more quickly and the UK Prosperity Agenda supported.

How to effectively, efficiently and rapidly initiate, develop, trial/test, demonstrate, exploit and support science and technology (S&T) is the core challenge facing the enterprise. There are a number of potential barriers to this that emerge from the discussion including: intellectual property and collaborative working, contractual frameworks and procurement processes, the need for greater experimentation and evaluation, the approvals process, and attitude to risk (both MOD and Industry). UK NEST is committed to working in partnership with MOD to discuss these issues and identify potential solutions.

Delaminating Capabilities and Systems

Driving Factors

This 'thinkpiece' explores how military capabilities might be delaminated from highly specialised platforms and systems. In particular, it will focus on enhancing the ability to meet changing requirements through life (Adaptability[1]) and support a range of non-concurrent roles (Flexibility[2]), whilst also reducing cost and acquisition cycle times in order to deliver future capabilities more quickly.

The key factors that are driving change are:

The Nature of Military Manpower and Associated Personnel Line of Development Constraints Military manpower is costly and fatigued due to the pace and complexity of modern warfare. This can result in sources of error. Modern societal views are changing. The introduction of Combat Safety as a concept has reduced the appetite for asking highly trained personnel to conduct avoidable dangerous activities, whilst dirty and mundane tasking remains retention negative. Caps on headcount mean that manpower must be dispersed carefully within the military ORBAT; where automation can cost-effectively replace the person, it should do so.

Reducing Cost of Ownership The naval budget remains under considerable pressure – acquisition and through life costs must be reduced through the capitalisation of innovative technologies and capability topologies.

Faster Capability Management and Upgrade Greater military benefit can be derived from those systems and platforms that can be modified or re-roled in the face of changing operational tasking or emerging threats, so making maritime capabilities more Versatile[3].

Enabling Technologies

A number of technology concepts have matured sufficiently to support the reduction of dependencies between systems/platforms and their associated capability. These include:

Open System Architectures Open System Architectures decompose systems to enable system modules to be interchanged. They reduce through life cost and training burden by the re-use of enterprise wide components, whilst enhancing interoperability and enabling more rapid reactivity to changing user requirements, some of which may be urgent. Open System Architectures have been successfully demonstrated as enabling far greater Adaptability, reduced modification cycle times and introduce opportunities for Small to Medium Enterprises (SMEs).

Adoption of Standardisation Standardised methods of enabling platform capability must be adopted wherever possible. This enables effective and unambiguous interface standards. While acknowledging the risk that imposed standards are not always successful, they should enable cost effective and timely integration of MAS, Open Architectures, Launch & Recovery standardisation, and the operational use of modularised capability. Furthermore, industry

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[1] **Adaptability:** Measure of the ease with which the ship or a system can be altered in order to respond to changing requirements, and to maintain functionality and performance through life.

[2] **Flexibility (General):** Measure of the ease with which the ship or a system can be reconfigured to accommodate a range of non-concurrent requirements/roles. **Flexible** Space: Design features that enable Adaptability involving the use of un-defined interfaces and boundaries, which may be varied to suit different requirements. Comparison can be made with an aircraft carrier that is able to accommodate a range of aircraft without modification within a hangar space.

[3] **Versatility:** A ship that is able to perform a wide variety of roles without alteration.

standards, such as the Mk 41 launcher and ISO container footprint, offer interoperability and collaborative opportunities whilst reducing development and support costs through economies of scale.

Modularity[4] Modularity is understood as a concept by which capability elements of a ship can be readily delivered to and from a platform through an implementation akin to "plug-and-play". This is often achieved through mission modules, which conform to a standardised format that can be hosted on a ship. These ships are purpose built to receive them according to a particular specification. The use of Modularity enhances Adaptability and Flexibility of naval assets, therefore the agility of the maritime force is increased through rapid re-role.

Further to the above, there are a number of emerging technologies that now need to be pursued and incorporated into the future naval capability concepts:

- **Autonomy of on-board systems** – to support efficient operations, reduce complexity and workload. This needs to address system monitoring and reliability in order to reduce the burden of Marine Engineering manpower, and also the challenge operators' face in exploiting the increasing volume of sensor data.
- **Autonomous (unmanned) off-board systems** – a key means of dislocating capability from expensive platforms, offering reduced risk to personnel, increased operational agility and Flexibility with smaller support teams. Increased use of autonomous systems could be considered as a means of recovering RN Fleet mass.
- **Information exploitation** – unlocking the latent capability if information can be made more Accessible – within security constraints – to improve decision making and exploit the benefits of initiatives such as "big data". Again, modern sensor technology is increasingly overwhelming RN operators with increased data, which is a challenge to fully interpret and exploit without appropriate automation.
- **Novel weapons** – to be able to respond to new threats in an agile fashion.

These emerging technology concepts are gathering momentum and are already being incorporated into some maritime capabilities, or demonstrated at relatively high readiness levels. As a result, headmarks are clearly stated within the RN's Capability Management Strategy and associated lower-level specialist area strategies such as the Mission System strategy (championing Open System Architectures), Modularity strategy, and Maritime Autonomous Systems Capability Management Strategy.

These technologies are explored further in the following sections preceded by a discussion on how development of Concepts of Operations (CONOPS) is fundamental to supporting naval innovation.

[4] **Modularity:** Design features that enable Adaptability involving the setting of defined interfaces within rigidly defined boundaries

Concept of Operations

In the military context, a Concept of Operations (CONOPS) provides operational context under a higher level strategy that will identify defence capabilities that are required to support the UK's interests globally. It will be used, along with other information and data sources, to pull together multiple subordinate documents including (but not limited to) a CONEMP (Concept of Employment), CONUSE (Concept of Use) and User Requirements Document.

With scientific and technological advancement continuing at a rapid pace, the UK's interests and the threats to those interests are changing rapidly. If UK defence is to keep a battle winning edge, it must become more dynamic and agile across the board, from capability planning in the strategic space to implementation of capability change at the front line. The CONOPS must be detailed enough to help set clear requirements, but must also not rule out or set reliance on particular technologies. In a relatively short space of time – well within that bridged by the assessment design and manufacture phases of a capability – the capability is increasingly likely to be out of date.

The RN is directed to develop a navy, as part of Joint Force 25, that is capable of winning when "War Fighting at Scale", and articulates a Naval Service headmark for SDSR 2030. This is further articulated in Maritime Strategy 35, which provides a coherent direction to the RN for the development of plans and programmes out to 2035. These policy documents are used to form the basis of the Maritime Capability Management Strategy (CMS) and Maritime Capability Management Plan (CMP)[5].

There are seven Conceptual Maritime Force guiding principles[6] which provide a strategic direction of travel, most of which are relevant to the topics discussed in this paper. These are:

- Man an Unmanned Navy
- Exploit remote and autonomous off board systems
- Exploitation of Commercial Off The Shelf (COTS) and Military Off The Shelf (MOTS) solutions combined with alternative acquisition strategies.
- Integrate Cyber and Space Domains into the MTG
- Focus on developing capabilities to meet the existing ambiguous competition and asymmetric threats
- Operations in satellite and EMS denied environments
- Disaggregation and dispersion of the "sensors, deciders, and shooters" at sea for future capability programmes.

The time scales relevant to the guiding principles need to be considered in the context of major capabilities (e.g. Carrier Task Group), build programmes/alignment with the National Ship Building Strategy, level and rate of technology development and importance to/impact on the UK's interests. UK industry and academia must ask itself how and to what timescales it must work to support each guiding principle under a major capability and engage with UK defence to benefit all sides.

The RN has developed essential top level conceptual guidance, however, the relationship between CONOPS and technology warrants investigation. While detailed CONOPS may not always be sharable, suitable examples are required to support and influence experimentation and against which technology can be tested. The CONOPS provides the context against which the S&T can be

[5] The CMP provides a consolidated view of the capability plans across the Maritime Capability (MARCAP) and represents the output of the Capability Planning Groups in the Maritime area
[6] Taken from Maritime Capability Management Plan 2018, v1.1, 18/10/17, ACOS MARCAP

developed and tested. This relationship will be iterative, but if managed appropriately can support the "innovation agenda" by reducing the time from idea to operational capability.

On-board System Autonomy

Why Develop Autonomous Systems?

Significant advances in the application of autonomy to platform systems have been made in the commercial marine sector, driven largely by cost and safety considerations. While the RN perspective is somewhat different, cost of acquisition and ownership is still a key driver when procuring future capability. This in turn is driven by a range of challenges including:

- The need to maximise capability and maintain an advantage over the threat
- The trend for increasing performance and system complexity leading to higher demands on crew members to process an increasing amount of data
- The need to flexibly move from one ship to another
- Dealing with legislation or policy such as the Combat Safety concept
- Changes in culture and society creating recruitment and retention challenges.

Increasing the level of autonomous operation is one route that would address these challenges. The benefits include removing the need for the human to undertake dull, dirty or dangerous tasks; reducing manning levels, and dealing with complexity by providing decision aids to reduce operator workload and improve decision making.

Examples

There are examples of autonomous and automated systems already in service in both the commercial marine and naval sectors.

Unmanned machinery spaces are common in merchant ships and increasingly so in military shipping. There are also increasingly sophisticated navigation and control systems that reduce the need for bridge personnel aboard merchant vessels. However, these are not yet sufficiently reliable or capable to remove the need for personnel altogether. In a military context, there may be a balance to be struck between the minimum number of personnel required to sustain critical mass of particular branches and the skill sets required. For example, it may be difficult to automate (reliably) some of the more mundane/dirty tasks aboard ship (e.g. strainer/filter cleaning) which might require a branch or personnel stream performing such tasks, but missing the requirement for more highly skilled staff. Some examples follow, demonstrating where increased automation has been achieved.

In the commercial sector, autopilot systems are already fitted to many commercial vessels. In most cases, these are relatively simple systems which are used to maintain heading control or simple navigation commands. More recently, a range of increasingly sophisticated autopilot systems have been developed which can be integrated into the ship's navigation systems and are capable of more complex route piloting controls.

An example of this more sophisticated system is the Sperry Marine NAVPILOT 4000 Autopilot, currently fitted to the Royal Caribbean cruise ship Allure of the Seas, which uses advanced ship steering control technology to steer a ship safely and efficiently. It is also capable of tuning itself to adapt automatically to the ship's load characteristics and weather conditions. What's more, the system is capable of automatic track control when interfaced to a voyage plan programmed into an ECDIS system. The autopilot system receives its orders from ECDIS, which may be manual changes of wanted heading, turn radius or rate of turn or it may be orders originating from track control along a selected route. Manual override is provided to immediately take control of the steering in the event that an evasive manoeuvre is necessary or a malfunction occurs at the autopilot. When activated, the control is transferred to the Override Non-Follow-Up Controller and the vessel is steered in manual control (non-follow up), until the Override mode is ended by the operator.

The Type 45 and Queen Elizabeth-class (QEC) both make extensive use of closed circuit TV and remote sensing systems to meet platform surveillance requirements for fire and flooding safety. These systems report to the ship control centre (HQ1) and reduce the amount of manpower required to conduct daily compartment and system inspections (rounds).

The UK's new QEC aircraft carriers are a prime example of where Babcock's Highly Mechanised Weapons Handling System (HMWHS) provides an extremely efficient, high-density automated stowage and retrieval system, as well as improving on-board safety (in comparison to manual handling) and reducing through-life costs.

An automated system was designed that was mechanically capable of moving six tonne pallets of munitions, via dedicated lifts, from stowage spaces in deep magazines to weapon preparation cells several hundred metres away in the ship. The design achieved magazine safety certification of an electrically powered handling system and is robust enough to withstand a non-contact underwater explosive shock event.

A system Inventory Management System (IMS) was developed to manage stores data. This IMS facility was the basis for the development of functional mission software for the system, which allows the operator to input a specific mission requirement. The software contains algorithms that analyse weapon delivery requirements and automatically calculates the most efficient means to deliver the required munitions. This includes suggested shuffling of the magazine stores from a 'safe stow' arrangement to a 'mission specific' stow arrangement. The algorithms are dynamic and adapt continually to changing mission requirements, suggesting magazine re-arrangements when required.

The automated Weapons Handling system developed for QEC Carriers represents a step change in the approach to on board logistics for the Royal Navy. The level of automation of the system saw the number of operators required to deliver munitions fall from 100 to 50. The project also demonstrates how land-based technology may be adapted to be effective on Surface Ships and improve operational safety for system operators.

The Future

Current in-service examples tend to be at the lower levels of automation i.e. either providing decision support to operators/command, or with a "human in/on the loop" – see *Autonomy Levels* table below. Increasing the levels of automation would be expected to reduce the workload on warship crew and could be applied across the full spectrum of on-board operations ranging from the mundane to the highly sophisticated, and to functions in any of the Float, Move, Fight, and Survive categories.

The trend for increasing performance, e.g. from advanced sensors and increasing system complexity, can result in higher demands on ship's staff to extract operationally useful information from an increasing amount of data. Autonomous systems will, therefore, need to be able to filter and process this data to provide advice that allows the crew to take on broader roles that are more associated with strategic decisions than lower level prescriptive actions.

One of the most significant areas where autonomy would be beneficial is if the crew are not required to maintain a 24 hour watch on patrol, except where there is a mission demand. If continuous manning of machinery spaces is no longer required, then only a small set of "day workers" could provide daily supervision and respond in the event of a system upset. This would require a major change to operational practice. However, it can only be achieved through systems that can be demonstrated as reliable and trustworthy.

A critical element to any decision advisory system is that it has to provide an auditable and human understandable rationale for the decision advice provided. This is recognised as a challenge for state of the art, deep learning-based aids, which are natively opaque.

An increase in the intelligence and capability of the crew is beneficial. This has been demonstrated through examples such as damage control and firefighting; in particular the ability to detect/fight fires and respond to floods.

However, the crew are still expected to fulfil traditional firefighting roles rather than trusting their systems to extinguish fires, or respond appropriately to floods on their behalf. For example, the need to undertake traditional damage control and firefighting roles led to additional seagoing trainees to the Astute class manning requirement over the qualified crew that are required for normal operations.[7] If this expectation can be relaxed, a fraction of the crew's resource demand will be required to monitor and perform smaller "mop up" operations.

Other examples where on-board autonomy is expected to lead to improvements in capability include:

- Remote monitoring and diagnostics systems (tele-engineering)
- Autonomous launch and recovery systems
- Automated defensive aids suite
- Self-monitoring and self-repairing systems
- Autonomous navigation and collision avoidance
- Dynamic voyage management and propulsion optimisation
- Anomalous track behaviour and enhanced sensor target identification to improve tactical picture

[7] Astute Basic Manning Requirement, eDMS 8002540 Rev 9.

Autonomy Levels

Autonomy can cover a broad spectrum of levels. Although there is a lack of a formal, commonly agreed definition of key terms, Lloyd's Register proposes the following definitions*:

Level	Title	Description
AL 0	Manual – no autonomous function	All action and decision making is performed manually, a human controls all actions at the ship level. Note: systems on board may have a level of autonomy, with 'human in/on the loop'; for example, pms and engine control. Straight readouts, for example, gauge readings, wind direction and sea current, are not considered to be decision support.
AL 1	On-ship decision support	All actions at the ship level are taken by a human operator, but a decision support tool can present options or otherwise influence the actions chosen, for example DP Capability plots and route planning.
AL 2	On and off-ship decision support	All actions at the ship level taken by human operator on board the vessel, but decision support tool can present options or otherwise influence the actions chosen. Data may be provided by systems on or off the ship, for example DP capability plots, OEM configuration recommendations, weather routing.
AL 3	'Active' Human in the loop	Decisions and actions at the ship level are performed autonomously with human supervision. High impact decisions are implemented in a way to give human operators the opportunity to intercede and over-ride them. Data may be provided by systems on or off the ship.
AL 4	Human on the loop, operator/supervisory	Decisions and actions are performed autonomously with human supervision. High impact decisions are implemented in a way to give human operators the opportunity to intercede and over-ride them.
AL 5	Fully autonomous, Some access possible	Unsupervised or rarely supervised operation where decisions are made and actioned by the system, i.e. impact is at the total ship level.
AL 6	Fully autonomous, No access possible	Unsupervised operation where decisions are made and actioned by the system, i.e. impact is at the total ship level.

* Cyber-enabled ships, ShipRight procedure – autonomous ships, Lloyd's Register, July 2016, http://info.lr.org/l/12702/2016-07-07/32rrbk

Manning Implications – Moving Away from Traditional Roles and Mind-sets

It is increasingly difficult to both recruit and retain RN personnel. In particular, the engineering branches and nuclear qualified marine engineers are bottom-fed organisations that rely on increasing levels of qualifications and experience to progress individuals to a more senior position. Fast track programmes are being developed to alleviate these problems. However, attrition rates are increased by the attractive opportunities for highly qualified RN engineer civilian jobs. Changes are needed to recognise the need for more rapid qualification as well as to address the likely reduction in service duration.

The traditional Royal Navy branch structures and training and qualification regimes need to be challenged such that the crew of the future do not necessarily need to match those of the present.

For example, the current need to qualify the majority of submarine roles through seagoing experience results in high numbers of trainees on board requiring additional accommodation. A reduction in the need to qualify at sea will reduce the requirement for accommodation space, thus reducing the platform cost.

It is inevitable that emergencies will occur at sea. Traditionally, it is expected that the crew will "step up to the mark" in order to maintain levels of performance in the result of equipment failure.

Reversionary operations following system failure tend to require the crew to take on additional tasks involving monitoring and controlling discrete instrumentation and local operations involving the use of gauges, valves and local control panels. Unless system failure can be sufficiently predicted and managed to avoid the reversion to conventional methods of operation, then it will not be possible to move away from conventional manning methods.

On-board autonomous technologies such as those identified above offer the potential to reduce workload and crew numbers on RN warships and submarines, thereby addressing key issues of crew availability and cost. Realising these benefits will require current branches and roles for future platforms to be challenged. However, these changes will place a high reliance on future warship design to demonstrate capable, autonomous systems that can be trusted, provide situational awareness and respond effectively in the event of failure such that they do not place excessive demands on the person.

Implications for the Future

It is clear that the ability to automate/autonomise on-board operations is developing rapidly and extensively. This offers the potential to reduce cost, maximise availability and capability, deal with legislation and cultural acceptance challenges, and supplement skills requirements. A continuous cycle of development with open and flexible system architectures to maximise the early exploitation of emerging solutions is necessary. To help plan future developments, the following activities should be undertaken:

- Fleet evaluation of the requirements, needs and appetite for autonomous on-board operations
- Assessment of the technology readiness and development timescales for potential solutions
- Consider reversionary/backup to autonomous systems e.g. can the platform management system provide a basic command management function.

Although technical challenges remain, the biggest hurdle to adoption remains cultural in the acceptance of alternative ways of working, including open systems, manning, CONOPS and trust.

Integration with Off-board Systems

Technology Trends

The nature of warfare is progressively changing. Over the next 30 years we can expect to see new emergent threats, new forms of conflict (cyber and beyond), together with the emergence of game changing technologies beyond traditional ICT such as Biotech, AI and materials[8]. These will arrive from industries such as the consumer industry, where estimates suggest that the world's 1000 largest corporate R&D spenders in 2017 totalled some $702 billion.

Throughout the life of planned warships, we can expect to see the rapid emergence of new combinations of technology, ever increasing computing power, together with the proliferation of systems capable of generating enormous volumes of real time data and information with the development of intelligent systems and novel human system interfaces. The widespread adoption of the Internet of Things, along with multifaceted and deeply connected systems will require the development of highly agile and adaptable architectures, capable of supporting new configurations of systems and tuneable systems according to the platform role.

Manned vessels are likely to become non-specialised, with significant elements of capability provided by unmanned and increasingly autonomous off-board systems (OBS). Increased use of unmanned vehicles, with task groups being a mix of unmanned long endurance sensor (and possible weapons) nodes and few central C2 platforms, is one way of returning mass to the Fleet. Against this backdrop, warships will need to constantly evolve to counter new and emergent threats that exploit this globally accessible technology in order to change the nature of conflict.

Therefore, the challenge is quite clear: how can we rapidly evolve the capabilities delivered through our warships by exploiting technologies and developing novel concepts for warfighting in the maritime arena? Warships will need to adapt as technologies emerge. Meanwhile, they must remain a "basic" host platform with the capability to deliver through frequent technological refresh and increase the use of off-board based systems.

Integrating these systems will be a critical aspect. More importantly, the information they generate and the ability of the vessel (initially) to host and deploy them will be crucial. For the vessel we can see that at some point during its expected life (unless we adopt a shorter life), it will develop into an unmanned platform, capable of supporting:

- High bandwidth, robust, secure connectivity
- Robotic and intelligent systems for the operation and deployment of off-board systems
- Links to traditional human-centred decision making and command and control exercise from facilities increasingly distant from the notional warfighting front line.

Warship Capabilities

While the "ways" and "means" of conducting warfare may evolve, the "ends" in relation to the opponent remain relatively constant. Therefore, we can anticipate that future warships will still be required to exercise sea control, sea denial and power projection through conducting (or at least supporting) activities including surface warfare, ISR, information warfare, UW warfare, maritime interdiction, humanitarian aid and disaster relief. The ways in which these activities will be

8 See for example GMTT2030 report and the MIA Technology Roadmap

conducted are likely to be fundamentally different as illustrated in the table below for ISR and littoral water ASW.

ISR	Littoral ASW
• Operations at range using long endurance off-board systems • Local picture to be fused with information from other assets • Rotation of host platforms requiring transfer of C2 • Emerging sensor technologies require innovative information architecture • Advanced automation and machine learning as part of the "human-machine team"	• Broad spectrum of threats – manned/unmanned • Deployed mission packages with wide range of sensing technology • Multiple distributed, long endurance, small sensors (IoT) • Large USV/UUV requiring logistic support • UAV to fix/strike • Co-operative operations – data/information sharing and cueing

We envisage an evolution of warship design based upon the premise of maximising the use of autonomous technology and close integration with OBS. A new class of unmanned surface platforms could be considered which do not require any human hospitality, have reduced organic safety standards and are optimised to host modular off-board sensors/weapon mixes. They will support payload evolution through innovative architectures for areas such as power distribution and management, with clear separation of the vessel structures from its installed systems. Use of modular solutions including, for example, robotic systems for deployment and recovery of off-board systems will enable automatic reconfiguration (at sea) to meet the capability demands. The balance of OBS and stand-off versus survivability will need to be assessed to minimise the risk to personnel by operating at a greater range from the threat (a new safety paradigm).

The ability to act as a focus for a (RN) wide information architecture will need to be developed, specifically tailored and self-adapting to fuse and exploit data, from multiple distributed intelligent sensors, with communications of limited bandwidth and of an uncertain provenance. It will be necessary to perform autonomous environmental sense making in order to support robust autonomous decision and to operate co-operatively with secure data/information sharing and cueing.

An adaptable and scalable system, as well as network complexity will enable the right balance of manned and unmanned assets, and the migration of command and control to other nodes including potentially shore-based operations centres.

Implications for Future Warship Procurement

The overall procurement and support of warships will need to change to enable the benefits of OBS to be realised. Current practices with lengthy acquisition cycles will not be responsive enough to deliver these changes, and the rise of the agile SME technology-centred business will fundamentally change traditional supply chains. Budgets will become increasingly stretched and thus the adoption of consumer technology will take place, often at a pace to keep up with highly agile exploiters creating new threats.

Increased exploitation of autonomous OBS provides an opportunity to do things differently. To support this, there is a clear need for increased experimentation, new standards and acceptance procedures. This will require a framework to be developed to drive technology from ideas towards in-service, drawing on and extending the ideas from previous initiatives such as the original

Niteworks and Unmanned Warrior 2016. Such investigations will also need to seek clarity regarding ethical frameworks and the potential for the weaponisation of such vessels.

Handling Information

Information is a key asset

In a warship, we rely on information to a huge degree – it supports decision processes ranging from the mundane to those that have life and death implications. To a large degree, the way that we handle and compartmentalise information hasn't changed for several decades. It is driven by a combination of systems engineering practices, software object orientated data encapsulation concerns, security considerations and the ability of the human to process and gain benefit from the information. However, expectations are increasingly changing, driven by technological developments that are routinely being deployed in other sectors; for example, machine learning and big data analytics.

The challenges that relate to the handling and exploitation of information can be summarised in the following three themes:

> **Ever larger volumes of information**. Human operators are expected to function effectively in an environment where there is more sensor information available and make decisions in increasingly short timescales.
>
> **Persistent data collection**. Data collected over a long period of time can, if accessible, provide a range of insights which will allow future designs and operations to be better informed.
>
> **Growth in machine to machine information exchange**. Artificial intelligence technologies, such as machine learning, have the potential to assimilate and operate on very large volumes of information at exceedingly high speeds and often need access to huge volumes and diversity of information to be effective. This is a direct contrast to the limited ability of the human to process and assimilate information.

The extent to which information collected within individual ship systems is shared and made available to other on-board users, or even off the platform, is currently limited and certainly not consistent. There are good examples underpinned by effective standards. Having said that, in many cases these are outdated as they were put in place a long time ago and the scope and coverage reflects the historical systems engineering constraints. The establishment of a common combat equipment, platform and enterprise wide information sharing platform would unlock opportunities to exploit modern data analytics and machine learning techniques. It is envisaged that additional data sharing interfaces would be introduced alongside, and in addition to, the existing established high integrity system interfaces to maintain, and not perturb, existing critical combat capability.

For example the sharing of contact / track data within a warship's Combat System, ensuring that the Combat Management System provides real-time situation awareness, is highly effective and enables the core mission's critical functionality. However, most sensor systems only expose a small proportion of the information they hold on real-world objects, based on architectural approaches developed decades ago. Equally, combat systems may internally hold large amounts of information on their health status and performance but only expose very limited status flags outside their equipment boundary.

Releasing Latent Capability

There is a huge amount of "latent capability" that could be unlocked if the information held on a platform was made more widely accessible. This premise reflects the benefits that are being derived from "big data" initiatives elsewhere; that simply by making more and more data available to analysis tools we enable functionality based on correlation of different information sources, the identification of trends over time etc.

We shouldn't expect to predict all of the potential benefits at the outset; however, it is easy to think of general concepts. For example, by combining ship data with that relating to the external environment (i.e. navigation and weather etc.) it would be possible to generate advice to enable better decisions especially in times of combat, which may lead to a safer ship and a ship with a better fighting capability.

The commercial marine sector is already realising the benefits of increased availability and use of digital information (and better connectivity between the ship and shore). The improved data usage permits better ship management, both on-board and ashore. Ship operators are already monitoring their equipment from shore-based monitoring stations and can detect faults before the on-board crew would be aware of anything wrong, as well as guiding remedial actions and programming any work that may be necessary. Whilst condition monitoring has always allowed incipient equipment mortality to be estimated, this can now be used to influence utilisation and usage patterns so that the equipment lasts until it can be repaired and to inform the provision of spares etc.

Given this huge scope for improvement, it is useful to understand what is preventing change and what could be done differently in the future. Making changes to existing operational platforms and their systems as well as ways of working implies additional cost and risk which needs to be offset against the benefits. Even with new-build / future platforms it is likely that many of the existing commercial and systems engineering approaches, architectures and standards will continue to be applied unless a deliberate step is taken to reassess these.

The compartmentalisation of systems and data that is linked to this legacy has been important in the past as an enabler. Having said that, we will need a different approach in the future to avoid "stove-piping". Realising the full value of data analytics and information exploitation will only be through the wider capture and distribution of combat system equipment and platform data to data analytical practitioners. System providers will need to be commercially motivated to make their internal system data more widely available. A wider capability, as well as platform, view of the information architecture is required that mirrors some of the approaches from "big data" in other sectors. In other sectors / domains there has often been a specific example that has acted as the catalyst; it isn't clear that we have yet identified that "driving" use case in the naval domain. The problem may well be compounded by the relatively small size of the fleet, as many of the benefits in the space of condition monitoring and prognosis will be more pronounced where there is a large number of ships with the same equipment.

Traditionally, the defence world has been more concerned about security, resilience and assurance than in other sectors. Nevertheless, there remain legitimate concerns on appropriate protection of access to information (it goes directly against principles of open access sharing), strict control of system configurations for "mission critical" elements, and the need to protect against the ever increasing cyber threats. An open Information sharing architecture will need to demonstrate that it maintains robust cyber security, data access protection controls and data providence characteristics.

A New Information Architecture

It is clear that there is a huge scope to improve the way information is handled and to extract more value from what is already available, even before we start thinking about ways to generate more. Initiatives such as Project Nelson are starting to address this topic, for example through the development of a fleet-wide, ship-agnostic big data layer to "rapidly accelerate the exploitation of advanced data analytics and machine learning techniques in the RN. In addition the Maritime

Combat System Design Authority (MCSDA) has sponsored development of a Total Information View from the Architecture, Standards, Policy, Information Authority (ASPIA).

Future platforms should provide an ideal opportunity to adopt a different approach from the outset but this would result in challenging many accepted principles. Ideally, a platform-wide information architecture would be the starting point, rather than working with a pre-defined set of building blocks. On legacy platforms there will be scope to address elements incrementally; if we follow the examples from other sectors then the challenge is to identify where the biggest benefits can be delivered.

Future Implications

The establishment of a common data and information access platform and services will unleash the use of modern data analytics and machine learning techniques to maintain and stretch the Royal Navy Information Advantage. A deeper awareness and understanding of system, platform and team behaviours and performance will drive more responsive action, reduced through life support costs and enhanced maritime capabilities.

This isn't just a technology problem (and by implication a technology fix). There are many challenges here that are not in the technology space, including the way we approach the value and use of information. There are enterprise-wide cultural, organisational and commercial issues all of which need to be addressed to enable us to achieve the full benefits of information exploitation technologies.

Novel Weapons

Traditionally, weapon systems are significant drivers of warship and submarine design. A number of novel weapon systems are currently being developed (such as laser directed energy and electromagnetic railgun weapons discussed below) that differ significantly in characteristics compared to in-service weapons and that pose significant integration challenges. Ideally, there is a need to divorce the platform from the weapon and break the cycle of prevarication over the adoption of such new weapon types.

Laser Directed Energy Weapons

The military's utility of high power lasers to defeat military targets has been widely considered since the 1950s, but none of the early chemical laser based programmes could deliver an affordable solution and all have been terminated. The development of the fibre laser in the mid-1980s fuelled the commercial development of compact laser cutting and welding systems at the kW power level. Such lasers are now robust and affordable (in the 10 - 100 kW range) and the maturing ability to maintain a focused beam on a target at km ranges in a turbulent atmosphere has reawakened military interest.

The Laser Directed Energy Weapon (LDEW) is a rapidly emerging disruptive capability which offers significant advantages for anti-air defence, especially in naval platforms. Such systems are affordable, particularly against asymmetric threats and swarm attacks, and provide a scalable response ranging from dissuade to defeat with potentially an unlimited magazine.

The US, Europe, Israel, China and India are all exploring the potential of fielding demonstration systems which can counter a wider range of threats ranging from conventional rockets and mortars to UAVs and other soft targets. The US has fielded an experimental 30kW Laser Weapon System (LaWS) on the USS Ponce in the Gulf since 2015 and early operational feedback would appear to be favourable.

Figure 1 LaWS mounted on USS Ponce

Dstl has recently contracted MBDA to build a LDEW Capability Demonstrator (Dragonfire) and test it against representative targets. If successful, the UK could be in a position to field useful LDEW systems in the ~100kW range by the mid-2020s. In the longer term, LDEW could contribute to an all-electric weapons based warship with significant benefits for future ship design, survivability and logistics.

At the low power end, LDEW systems can be relatively easily integrated with existing ship power and cooling systems and if manually controlled (to counter slow moving threats) can effectively be bolted on and controlled with little platform impact. Operational use will bring with it the need to demonstrate safe use of such a system and controlled arcs of fire.

As power levels rise and the utility of such systems expand to address a wider target set, the integration challenges will grow. Ships services will need to adapt to increased demand for transient power and cooling demands, while a closer integration with the command and control systems, and integration with other weapon and soft kill solutions becomes substantially more complex to address for defence against higher end threats and swarm attack scenarios. High power and longer range will require increased consideration of safety and potential for collateral damage, not just in the vicinity of the target. Physical integration of LDEW may also be more of a challenge when retrofitting to an existing warship, as available space may not be in the most appropriate places and typically will require a degree of compromise. New designs may lead to radical changes to traditional topside arrangements to make more effective use of the LDEW systems.

Operational experience will dictate the extent to which LDEW will completely replace more traditional gun and missile systems. It is expected that early systems will augment existing defensive solutions whilst offering a wider set of response strategies to counter and dissuade potential threats. The adoption of such systems offers the longer term potential to completely rebalance the defensive fit of a future warship, where LDEW deals with the lower end threats and a smaller number of missiles may be sufficient to address the outstanding high end threat space (hypersonic, high g manoeuvring and ballistic anti-ship missiles), creating space for other payloads.

Electromagnetic Railguns

Railguns are potential contenders for future naval indirect gun fire systems because of their high stand-off capability, lethality and their inert magazine. With muzzle velocities in excess of $2kms^{-1}$, they have the ability to overcome the speed limitations of chemically propelled shells to provide a range far in excess of current gun systems. What's more, with a likely kinetic energy (KE) of over 60 MJ, they will provide significant destructive effect on the target. Although there are challenges with its accuracy, these are being addressed through smart-projectiles with in-built wings and communications, which can withstand the very high acceleration at launch. Launch effects on the rails such as erosion, plasma burning and local melting are significant, but are slowly being addressed to ensure such a system has sufficient life in service.

Figure 2 Full-scale laboratory testing of an EM Gun

A 20 kg projectile requires in excess of 200 MJ of stored electrical power, together with an allocation of up to 20 MW steady power supply, to sustain a firing rate of six rounds per minute. In addition, the heat deposited into the launch rails of the gun is likely to be very significant. All these aspects, power generation, energy storage and heat management, will pose very significant challenges for ship systems integration. In addition, the combat system will need to be able to cope with long range target selection and management of any collateral fire risks and potentially be able to correct/update the terminal path of shells in flight over the horizon.

Such systems could also be configured to provide effective ship defence against high end threats (General Atomic are developing a railgun launch payload with multiple KE rounds similar to a shot gun cartridge and so a balance of LDEW and railgun systems could lead to a truly all-electric warship, reducing the need for vulnerable main magazines and leading to significant changes in power installations.

Future Implications

The progressive application of more electric weapons has already started with at-sea deployments of LDEW demonstrators at modest power. The next step is likely to be the fielding of more capable, medium power, systems with wider utility against low end threats and swarm attacks by low cost weapons.

The RN will need to explore how best to exploit such weapons, initially through minor sea trials, and subsequently to mature its confidence and concepts of operations through longer term experimentation.

The move to high power systems such as rail guns is still a way off and may await a next generation platform rather than being retrofitted to an existing warship as the associated power and cooling systems will require considerable space and will need to be suitably adapted to the marine operating environment.

RN/UK Industry Relationship with Rest of World

Since the 18th Century, maritime trade has always had great importance for the United Kingdom. Our maritime industry has been at the forefront of international commercial and military marine technology since that time and continues to lead in many areas.

The UK government set an Industrial Strategy vision for 2030 outlining the UK's aim:

'by 2030 we will have transformed the productivity and earning power across the UK to become the world's most innovative economy and the best placed to start and grow a business, with upgraded infrastructure and prosperous communities across the country[9]*'*.

In support of the UK Industrial Strategy, the UKNEST brings together experts from across defence, academia, science and industry in a collaborative space to respond to the need for innovative and tailored Defence maritime solutions.

The UK has the most significant maritime sector in Europe with 95% of trade facilitated by the marine industry. Therefore, the UK economy depends upon its Sea Lines of Communication (SLOC) and trade routes that facilitated 481.8 million tonnes of goods passing through UK ports in 2017[10] with 300.9 million tonnes imported into the UK. This figure has been estabilised since 2010 with marginal year on year fluctuations. There are also 400,000+ UK jobs that directly depend on the maritime industrial sector.

In realising the strength and our reliance on the maritime industry, the UK Government recently unveiled an ambitious new National Shipbuilding Strategy[11] which has become an essential part of the government's broader industrial initiatives. It focuses on increasing economic growth across the country while investing in an already highly skilled workforce, while simultaneously promoting UK's industrial capabilities to overseas customers. Further, the UK Government will continue to work collaboratively with the industry to provide strategic leadership, certainty and provide the support required to deliver their commitment to the evolution of Maritime Science and Technology. The strategic drive will prove to be of great benefit to Customers seeking to exploit leading edge maritime capability and those seeking a collaborative, reliable, committed and enduring partner.

Research and Development Environment

The UK is well known for its ability to support academia, education, research and development (R&D) and has created the Industrial Strategy Challenge Fund[12] to boost productivity in R&D through a £31bn Nation Productivity fund. Furthermore, the UK Research and Innovation (UKRI) organisation has been created to oversee the R&D innovation funds, and through Innovate UK supports UK

[9] The United Kingdom's Industrial strategy: Building a Britain fit for the future.
[10] Information drawn from the UK Port Freight statistics: 2017.
[11] National Shipbuilding Strategy: The Future of Naval Shipbuilding in the UK.
[12] Funding opportunities from the Industry Strategic Challenge Fund (ISCF) & Innovate UK.

businesses, to oversee the identification of partners, investors and international partners to develop R&D and to create an environment that supports UK exports overseas, further increasing UK prosperity. However, the UK must capitalise on the funding support to academia, education and R&D to ensure it has capacity to support the UK's Export Strategy.

The UK maritime industry is continually re-shaping its skill base. This is done by investing in innovation, research, technology and developing upskilling programs required for a future workforce to support the UK's economic productivity growth, as outlined in the Industrial Strategy Green Paper[13], and to meet the demands of an increasingly diverse customer base. The commitment from the UK's industrial base by UK NEST is an excellent example of the determination and dedication to maintaining the UK's Maritime capabilities.

Opportunities in the Defence Export Market

The UK is not fulfilling its export potential and has seen exports fall by 1.3% between 2006 – 2016[14]. The adoption of the UK industrial strategic vision and review of the 'Grand Challenges' has highlighted a number of countries that are identified as being marketable for UK defence exports. In particular it is estimated that there is approximately a $311bn market potential distributed across five geographically dispersed areas comprising thirty-two countries. The proportion of the market potential that is attributed to the maritime sector is approximately $79bn. While it is unlikely that the UK will attract all this Maritime work, through projection of our sovereign capabilities, skilled workforce and maritime prowess the UK could attract in excess of 50% of this available maritime work.

Embracing and developing change

As the UK prepares to leave the European Union, long-term decisions about the economic future must be made to ensure the competitiveness of our economy, and these decisions will underpin the ten pillars outlined in the Industrial Strategy Green Paper. The strategy builds on what the UK is good at: research, innovation, skill development and transposing these to the maritime domain by setting the focus broad and innovative. It also focuses on looking forward, with an emphasis on what a future Royal Navy Fleet would resemble.

The UK NEST encourages industry collaborations that are innovative and forward-thinking, and develop evolving technologies while maintaining a market driven competitive advantage. Fundamentally we seek to embrace cross-sector technologies, innovation and capabilities such as robotic and autonomous systems currently utilised in the Merchant Marine sector, and pursue opportunities to incorporate those advancements into the naval maritime domain. Cross-sector innovation is an excellent example of how the UK embraces technology and strives to promote leading-edge solutions. For example adapting Virtual Simulation & Augmentation advancements in the gaming industry: through the UK NEST, we are applying those innovations, developed for the gaming consumer, to the Maritime sector.

We continually seek novel ways to improve and better what we do through digitisation, synthetic testing of our designs before manufacture, up-skill training, virtual simulation and augmentation drawing on the learning experiences from the industrial sector and applying them in a defence maritime environment. It is vital that the UK NEST continues to grow the defence industrial ecosystem as a place of useful learning, where ideas and technological advancements can proliferate and collaborative engagements ensue.

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[13] Building our Industrial Strategy: Green Paper January 2017
[14] IMF BoP Data (2017)

Future Workforce

The UK NEST is well placed to establish itself as both a centre of excellence for science, technology and innovation through collaborations with academia, defence, life sciences and commercial entities, combined with a need to grow the defence ecosystem through a nurturing of the next generation of talented engineers to support the complex nature of future digitisation in the maritime domain.

As we continue our reliance on complex maritime systems commercial enterprises, defence, academia and service providers, we will require a substantial uplift in their digital workforce to not only manage the evolving autonomous systems but also the entire maritime ecosystem. For example: communication networks, developing control systems, generating source code, managing electrical systems, cybersecurity and protecting data, all the while supporting multiple mixed marine fleets. While academia, defence and industry have stable workforce training programmes, they are well entrenched and they accept change gradually, reflecting the requirements of technology change and user requirements. Increased reliance on innovative maritime technologies dictates a monumental shift, and workforce training will need to change significantly.

Our biggest challenge is to prepare our current workforce for the requirements of our future reliance on autonomous technologies. This can be done by delivering Innovative solutions in a complex threat environment with demanding mission profiles. The future of Maritime requirements will be demanding, therefore an agile and flexible approach to a modular system of systems designs will reduce the burden on an already overstretched ecosystem operating in a mixed fleet environment. This will yield more significant benefit to the Customer, enabling a higher degree of flexibility in both mission fit and future upgrade cycles.

Concluding Remarks

It is evident that the pace of technological change prevalent in today's society is not always reflected in naval capability. As well as the inevitable financial constraints, the exploitation of modern technology can also be hindered by the procurement process and the legacy of an acquisition strategy that has relied on specialist platforms to provide specific capabilities. The overarching theme of this paper has been one of delaminating capabilities from systems to provide a more adaptable, flexible and versatile maritime force.

Key enablers such as open systems architectures, standardisation and modularity are already sufficiently mature enough to support this approach. Emerging technologies discussed within this paper – on-board and off-board autonomous systems, alternative information architectures and novel weapons – have been identified by the UK NEST Science & Technology Working Group as having a key role to play but requiring further investment and action within MOD and Industry.

To date, the assessment undertaken has raised a number of key questions that need further analysis and investigation including:

- What appetite the MOD have for on-board autonomy and its willingness to take on associated cultural and structural challenges such as strengthening trust, new ways of working, revised branch structures and training
- How to drive experimentation, particularly with OBS, with supporting CONOPS as a route to more rapid innovation i.e. shortening the timeframe for exploiting this technology into service
- How to define and implement a new information architecture that enables broader sharing and can exploit modern data analytics to reduce workload and improve decision making while still addressing security and assurance concerns
- How to break the cycle of prevarication over the adoption of new weapon systems such as LDEW or railguns
- Whether procurement methods, business models, standards and processes can be revised to support faster adoption and integration of emerging technologies
- How best to clearly and consistently communicate the vision and requirement from the MOD to Industry

The UK has the technological knowledge to pursue an opportunity to lead the world and set the agenda for future warship capability. This is only possible if the right incentives, priorities, processes and commercial relationships can be put in place.