Towards deployment, how the UK MAPLE architecture is being developed ready for exploitation and its role at the centre of international experimentation involving maritime unmanned systems.

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SYNOPSIS

Previous papers have set out the importance of maritime unmanned vehicle command and control in unlocking future maritime capability and the progress made under the Maritime Autonomous Platform Exploitation (MAPLE) project. The relentless pace of technological development is now seeing a number of unmanned systems readied for deployment and the Dstl lead MAPLE project actively involved in increasingly realistic and robust operational experimentation; and there are active plans for a minimum viable product implementation under Agile principles at sea in the coming year. As MAPLE enters a fifth phase, the ambition is a baseline capability that will enable the UK MOD to procure a full Maritime Autonomous Systems Command and Control system. This paper will talk to progress in developing and de-risking the technology and systems enablers and the plan to generate requirements documentation and Concepts of Operation, Use and Employment for a range of military tasks. It will also explain how the project is deepening understanding of the human factors implications of managing human machine teams alongside the conduct of existing warfare tasks. Continuing a long running MAPLE theme of end-to-end command and control, an overview will be given of how Phase 5 is developing the persistent architecture to address use of multiple MAPLE systems in a Force, and the use of effector systems deployed from unmanned systems. More widely, the paper will touch on how UK projects including MAPLE are at the forefront of an international effort to exploit maritime unmanned systems (MUS) and to secure interoperability and interchangeability, under a new NATO sponsored initiative.

Keywords: Maritime; Autonomy; Unmanned; Command and Control.

1 Introduction

Maritime Autonomous Platform Exploitation (MAPLE) is a multi-phase Defence Science and Technology Laboratory (Dstl) programme, now in its fifth phase and sixth year. The central premise of the MAPLE programme is that the benefits offered by unmanned vehicles (UxVs) or maritime autonomous systems[1, 2] (MAS) can only be secured if operator workload is not increased. UxVs enable navies to “buy back mass”, so that a single ship can have the same impact as multiple ships which are not operating unmanned vehicles. But “buying back mass” in this manner is only achieved by operating a squad or swarm of unmanned systems. Currently the deployment and operation of such a collection of off-board systems would require multiple operators per vehicle – impractical and unsustainable for anything other than short term operations. Realising the future vision of a MAS enabled Royal Navy therefore requires increased levels of integration and tiered autonomy, reducing workload. This will take the operator out of direct control of the unmanned vehicles, moving progressively from human control to human supervision, and ultimately to higher level instruction and true human autonomy teaming. The goal is a single operator, within a current RN operations room, planning, tasking and managing missions involving multiple vehicles. MAPLE is addressing this need for increased integration and autonomy, and whilst MAPLE is maritime focussed, the need and principles apply equally to land and air environments.

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[1]MAS (Ref 6) are defined as off-board vehicles or equipments that operate in the maritime and littoral environment without the physical presence of human operators, although this does not preclude operators being necessarily engaged with the remote operation of the system, and the associated C2, handling and maintenance facilities. This is distinct from the autonomy increasingly being introduced for the control of onboard systems such as propulsion machinery or for remote compartment monitoring.

[2]An autonomous system (Ref 6) is capable of understanding higher level intent and direction. From this understanding and perception of its environment, such a system is able to take appropriate action to bring about a desired state. It is capable of deciding a course of action, from a number of alternatives (sic), without depending on human oversight and control, although these may still be present. Although the overall activity of an autonomous system will be predictable, individual actions may not be.

Authors’ Biographies

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A second driver for the MAPLE programme is the recognition that the lifecycle of unmanned systems is significantly shorter than that of host platforms, with many iterations and instances of UxV requiring integration over the life of a warship. Consequently, reducing the burden of integration and increasing the commonality and durability of interfaces, including those with the operator is highly desirable if agility and rapid updates cycles are to be achievable and affordable. A high-level schematic of MAPLE flow of control is shown in Figure 1, where each of the functional blocks adheres to the interface standards defined by the MAPLE information architecture.

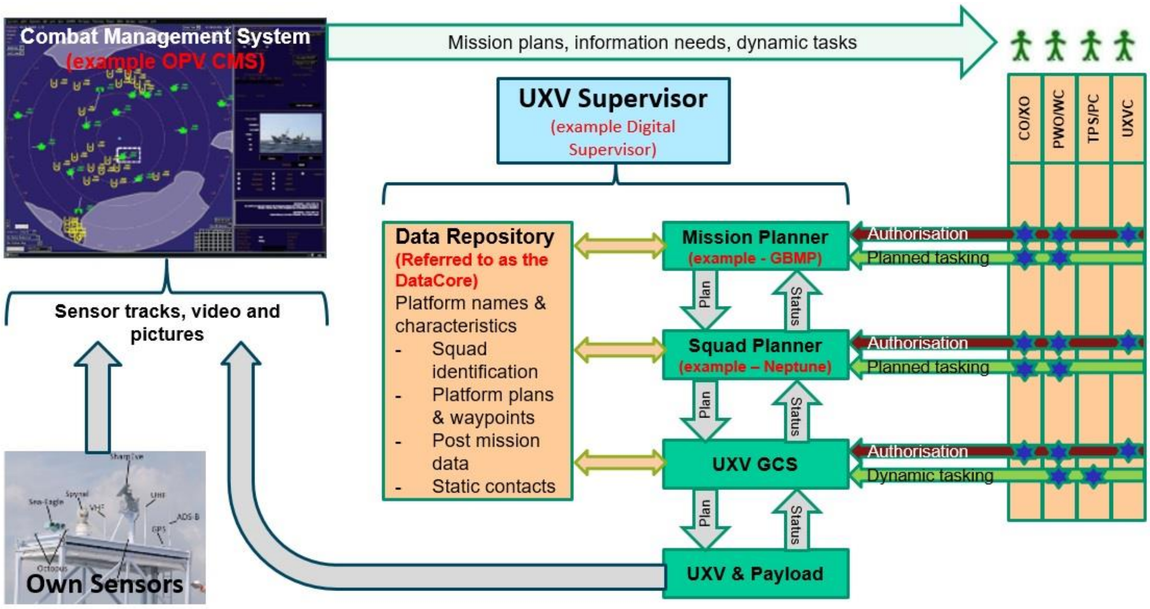

Figure 1: High level schematic of MAPLE functionality

In line with the Modular Open Systems Architecture (MOSA) approach adopted by MAPLE, the combat management systems (CMS) element is treated as a loosely coupled C2 node. This approach and the addition of new UxV related functionality in MAPLE applications decouples the CMS from the rapid changes associated with MAS related capabilities, enabling faster and lower cost update cycles. This MOSA approach also means that each of the functional blocks shown in Figure 1 is replaceable by an alternative, so long as the new block adheres to the MAPLE interface standards and information flow.

2. A Phased Approach

At its core, MAPLE is an Information Architecture; a collection of interface control documents and interface specifications developed over a phased programme that define the information flows for the C2 (planning and execution) of MAS. Components that implement the interfaces are hence able to exploit relevant information in order to implement their required functionality. Underpinning the architecture are a number of architecture principles, to include modularity, openness and open standards, inherited from a wide body of previous work undertaken across the UK maritime enterprise. These principles were then expanded and developed during MAPLE Phases 1 to 4, which was delivered by a joint team of Dstl, QinetiQ, BAE Systems, Thales and SeeByte:

- **MAPLE 1**: Phase 1 of the programme was a feasibility study into Maritime UxV focussing on their management and governance, UxV command and control (C2) requirements and architectures, and the potential for exploitation of UxV capability into the RN (Biggs et al, 2015).
- **MAPLE 2**: Phase 2 developed the persistent architecture (PA) for the C2 of autonomous systems and also established a better understanding of the role of the human as an integral part of the autonomous capability on a warship (Smith et al, 2016).
- **MAPLE 3**: Phase 3 was designated Autonomous Control, Exploitation and Realisation (ACER), the initial prototype instantiation; it rapidly integrated existing capability as part of Unmanned Warrior 2016 (UW16) thereby demonstrating an early implementation of the RN approach to integrating off-board assets and their payloads into the combat system (Smith et al, 2017).
- **MAPLE 4:** Phase 4 concluded in June 2019 (Smith et al, 2018, 2019). It featured three iterations, the first of which matured the PA, established a comprehensive Synthetic Environment (SE) and enhanced the ACER system for a major synthetic event (Syn Bay) in Autumn 2017. The second stage of Phase 4 focused on the continued maturation and validation of the PA and enhancements to ACER, culminating in a 5-eyes The Technical Cooperation

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Programme (TTCP)[3] event in Jervis Bay Australia in November 2018, called Autonomous Warrior 18. Following this trial the final stage focused on more advanced tiered autonomy, folding in the non-functional and communications work, culminating in a final live event: Cardigan Bay 19 (CB19) in May 2019.

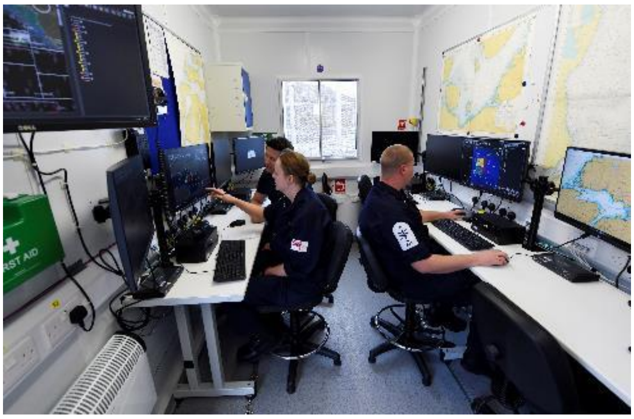

Figure 2 and 3: ACER Demonstrator at Unmanned Warrior 2016

By the conclusion of Phase 4, the MAPLE team had developed and validated an architecture (the PA) that described a solution which could integrate multiple heterogeneous unmanned systems together operating across warfare disciplines and domains without either driving up operator numbers[4] or, within limits, overloading existing operations room teams. Moreover, they had developed and promulgated a common set of open standards and interfaces which were ready to inform and support the agile and flexible delivery of interoperable solutions for the Royal Navy. The programme had introduced novel components into the PA and ACER demonstrator that allowed team based planning, tasking, management and exploitation of multiple unmanned systems. These included a hierarchy of planners, a data core, data analysis and exploitation using AI, functionality to allow dynamic re-planning and in mission tasking of systems from within the core C2, and the introduction of a policy manager to underpin trust and provide user assurance.

Finally, in diversity of UxV alone, the achievement was significant and is believed to be unmatched: 48 different vehicles integrated from 23 organisations representing 8 countries in 5 environments[5]. Literature suggests others have developed some similar components, but nowhere else internationally has there been the same consistent focus on multi-vehicle C2 within an open architecture, and on the practical components required to unlock the potential benefits of solutions employing large numbers of unmanned systems in the maritime.

3. MAPLE the next phase

In late 2019, Dstl contracted for a fifth MAPLE phase, led by QinetiQ in partnership with BAE Systems, SeeByte, BMT, L3 Harris, DIEM analytics and Thales. This phase of MAPLE has 3 main objectives, 2 of which will be delivered through the core tasking and the third through a variety of tasking mechanisms, reflecting the increasing integration of Dstl and RN Technology & Innovation (T&I) programmes. The 3 objectives are:

1. **Operationalisation:** Under MAPLE 3 & 4 there was a significant emphasis on accelerating the concept in order to meet the timelines for international trials. A key focus of MAPLE 5 is to revisit the Information Architecture, and functionality, following the 3 years of rapid development, and to generate a specification that will enable the MoD to procure a Maritime Autonomous Systems Command and Control (C2) system, producing and validating a robust set of User and System Requirements and a validated and developed architecture. The latter will include a set of procurable modules for the C2 aspects of unmanned systems, specifying their functionality and performance characteristics and the services they will provide and consume using open interfaces. The requirement set will be informed by a detailed set of concepts of operation, use and employment, setting out how MAPLE solutions will

[3] The UK involvement in Autonomous Warrior 18 was in response to an "Autonomy Strategic Challenge" set by the TTCP Principals. This challenge has the intent of bringing together work from across the TTCP community to drive the pace of unmanned vehicle exploitation. As well as bringing together a range of unmanned vehicles that cover the full spectrum of air, surface, underwater and ground vehicles, the event also integrated a set of C2 tools from Australia, USA, Canada & UK to deliver a significant level of autonomous and digital command and control. The build up to the live event included a series of international synthetic serials, referred to as Wizards, the last of which was Wizard 4 in Sydney in Summer 18.

[4] But noting the need for some rebalancing and reallocation of existing roles to achieve this.

[5] Including but not limited to: UW16: 25 vehicles, 12 organisations, 7 countries; AW18: 14 vehicles, 10 organisations, 5 countries, 5 environments (including human); CB19: 11 vehicles, 5 organisations. A number of vehicles and organisations featured in more than one of the serials.

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be employed in the key warfare disciplines and sub-domains.

2. **Force level operations:** The MAPLE Information Architecture has to date been about enabling C2 from a single ship, integrating the operation of many maritime autonomous systems into that ship's maritime mission system, and the exploitation of data sourced from the off-board systems into a single recognised tactical picture. This next phase of S&T will be seeking to augment the Persistent Architecture in order to address Force level operations, with multiple C2 nodes.

3. **Warfighting functionality:** MAPLE phases 1 through 4 primarily focused on the development of the information architecture that enabled the command and control of a heterogeneous collection of maritime autonomous systems. Now that this is largely in place it has formed a basis from which to develop an increasing number of MAPLE compliant applications that can support delivery of warfighting capability: integrated surveillance target acquisition and reconnaissance (ISTAR), anti-ship missile defence (ASMD), anti-surface warfare (ASuW), littoral manoeuvre (LitM) and anti-submarine warfare (ASW). Informed by the concepts generated in the MAPLE 5 core, all of these will be in the conduct of specific military tasks and these activities will lead to a refinement of the agreed interface standards to enable reliable and efficient integration of a diverse range of unmanned systems. Recognising the pivotal role of human factors in securing the control of multiple systems from a single operations room, MAPLE activities will feature further work of this nature, shaping the emerging applications and including the outputs that support the mandated MOD human factors document set.

The increased emphasis on military tasks has led to a shift in focus onto the vehicle payloads. This reflects a more general move seeing the unmanned vehicle and its location as often a means to an end, not the end itself. This has seen vehicle positioning increasingly become a matter for autonomy, whilst the payload tasking commands develop in richness and the detail supporting payload reporting increase. As an illustration, the Maritime Autonomy Framework command set, implemented in the MAPLE PA now feature a new set of goal based plan (GBP) commands[6] for smart payloads. These plans will work with squads or single assets, so that more than one asset could be fitted with the required payload and the planner can select one or more assets as required to optimally deliver the mission. The set of MAF commands, shown in Figure 4, covering location, area and now payload related tasking, are being developed further as part of this phase of MAPLE. This will see their utilisation within the emerging concepts documentation, refining the scope and detail of the associated plan descriptions with end users, noting that many of the verbs employed are chosen deliberately to resonate, and precision will be key in securing operator confidence. A subset of commands (in bold) have already been instantiated within the ACER demonstrator to enable experimentation. A key question in terms of more detailed implementation will be around the effective management of assets with multiple payloads, such as a UAS with both comms gateways and cameras.

MAF Goal Based Plan Task Types v4.0

Location		Area	Payload
Assess	*Picket*	CommunicationRelay	**Arrest**
BuoyDeployment	Reacquire	Exploration	Decoy
Communications-Gateway	**Shadow**	OverheadCover	Deploy
DippingSonar-Deployment	TargetAcquisition	**Patrol**	**Deter**
Escort	TargetTracking	Reconnaissance	Gateway
Inspection	Target-Identification	Survey	Identification
Intercept	TaxiDropOff	Sweep	Neutralisation
Investigate	TaxiLaunch	TargetAcquisition	Observe
MineRemoval	TaxiPickup	TargetTracking	Removal (for mine clearance)
Neutralization	TaxiBoarding	TargetIdentifiation	Search
			Survey
			Tracking

1. Bold denotes ACER implementation
   a. Location: Shadow & Inspection
   b. Area: Patrol
   c. Payload: Arrest & Deter, including: Counter USV (line arrestor); Counter UUV (net); Deter divers (underwater loudhailer); Deter surface targets – loudhailer
2. Italics denote tasks under consideration for adoption into MAF, all other tasks are supported by MAF.

Figure 4: MAF Task Types in the MAPLE PA

[6] The MAPLE planning process as distinct from separate functionality supporting execution or in-mission control. MAPLE planning entails a MAF Goal Based Plan being created by a given high-level tactical planner. Squad and asset planners will then generate rehearsal tracks for all assets in the MAF Goal Based Plan prior to review and approval.

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As part of this phase of MAPLE, the team are continuing the parallel track programme of architecting and experimenting, evolving the ACER demonstrator design and using it to validate the architecture, extending the implementation as required. Advances in capability will be demonstrated through a series of planned synthetic experiments at QinetiQ's Portsdown site and where the opportunity arises through live demonstrations.

4. Exploitation of MAPLE by the Royal Navy

In April 2019 the UK Secretary of State for Defence announced the stand-up of the RN's new Autonomy and Lethality Accelerator called NavyX with the remit to rapidly exploit MAS into service across all environments. *"NavyX will exponentially accelerate our speed of learning, our capacity to procure and integrate these best-in-class technologies, our ability to prove them in the real world at pace, and deliver into the hands of our war fighters"*. In parallel the RN had been developing its wider approach to information exploitation under Programme NELSON, codifying this through the NELSON data platform and app store. Both developments have led to an acceleration of plans to address unmanned systems C2, captured with the RN's updated MAS Campaign Plan, issued earlier this year. The MAPLE architecture is at the centre of these plans, as shown by the schematic in Figure 5.

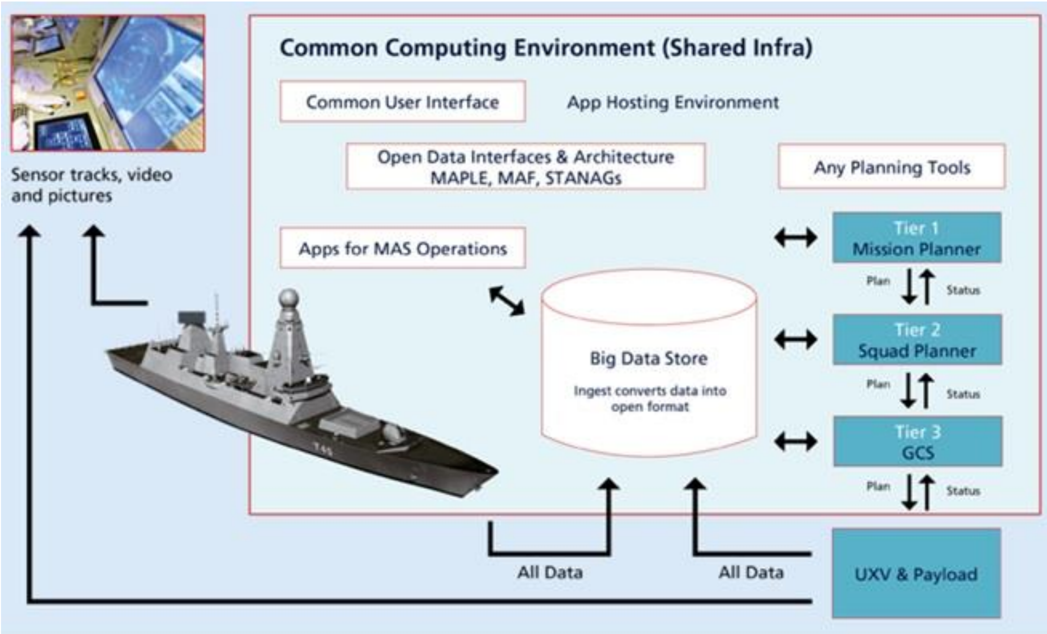

Figure 5: Vision for the RN Mission System Information Architecture, enabled by the NELSON data platform, MAF and MAPLE mission planning tools and UXV interfaces

To assist with securing coherence, the Dstl Technical Authority for MAPLE has been an integral member of the NavyX team. Moreover, a key aspect of NavyX is live trials and operational experimentation, putting equipment into the hands of the user and the ACER demonstrator has been at the heart of a series of these experiments, de-risking exploitation, informing CONOPS and MAS requirements, but also supporting an Agile programme of development.

More widely, the landscape for the exploitation of MAS capability into the RN Surface Flotilla has also changed. Previously, the roadmap for the integration of MAS into RN combat systems was based exclusively on Shared Infrastructure (SI) supplied by BAE Systems as installed on the Type 23, Type 45, LPX, and planned for the Type 26 classes of warships. With the selection of the Thales M-Cube combat management system for the HUNT and SANDOWN class MCMVs and the Babcock Arrowhead 140 design winning through on the Type 31e Programme, the autonomy roadmap now needs to support greater diversity of combat management system and combat system. The loosely coupled, open architecture design of the MAPLE architecture is agnostic to CMS implementation, and therefore readily able to manage such changes. Indeed the ACER demonstrator has already operated with different CMS solutions.

5. MAPLE's role in enabling & supporting RN experimentation & fielding of autonomy

The move of RN T&I on to an increasingly Agile footing and a recognition that a Prototype Warfare approach[7] is required if disruptive technology is to be harnessed at sufficient pace to secure operational advantage has demanded new thinking, posing a challenge to traditional models of acquisition and defence R&D. The MAPLE architecture is well positioned to capitalise on this shift, as it holds the key to the large-scale exploitation and adoption of maritime autonomous

[7] 'A willingness to engage in military operations with capabilities that are not normally considered ready for operational deployment. It is experimentation in contact – albeit with the right safety measures in place.' Deploying Prototype Warfare, QineitQ 2019

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systems. In addition, it has a deployable demonstrator featuring a number of high TRL components that has already been deployed on a series of high profile NavyX operational experiments such as:

- **NATO REPMUS 2019**
  The Recognised Environmental Picture Augmented by Maritime Unmanned Systems exercise (Figure 6) was held in September 2019 at Troia, Portugal as part of UK participation in the NATO Maritime Unmanned Systems Initiative.
- **Autonomous Advance Force (AAF)**
  The AAF series of exercises is aimed promoting innovation and the exploitation of autonomous system by the Royal Marines. There have been a number of exercises, the most recent being AAF2.5, a challenging experiment conducted in the high north of Norway in November 2019 involving a Royal Marines deployment and operations with HMS ALBION (Figure 7).

Figure 6: ACER deployment at REPMUS 19

These experimental deployments are generating user confidence, refining operational concepts and accelerating progress towards operational fielding of specific systems. Experimentation is becoming more challenging, more user centred and more dynamic, with serials undertaken in challenging conditions, often over extended range and at night. From the initial involvement in Unmanned Warrior 16, the MAPLE activities have always had an emphasis on promoting the interoperability of Maritime Autonomous Systems with coalition nations. As part of the RN experimentation this emphasis on international co-operation is continuing, both amongst the 5-eyes community and within the new NATO Maritime Unmanned Systems Initiative; increasingly the emphasis on moving from interoperability to interchangeability (I2I), the ability to operate in a fully mixed force, creating greater operational freedom of action and increasing combat mass within a coalition. The work this year continues with further iterations of the AAF series and more serials planned with the US on a MAPLE related programme, Autonomous Maritime Asset Protection System (AMAPS), using UxVs to protect a high value asset. Given the challenges imposed by COVID 19, this work will make extensive use of live virtual and constructive serials and integration of activities across geographically distributed sites; the intent is to transpose live assets to enable synchronised operations in a single environment.

Figure 7: UxV deployment in AAF2.5

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Serials such as AMAPS, AAF and further iterations of multinational exercises such as REPMUS represent increasing demand for a deployable MAPLE core, but there is also a need to make it increasingly robust[8] and for greater operator driven experimentation, this has led to emerging plans for an operational deployable (and deployed) Minimum Viable Product (MVP) core solution to replace the current ACER MAPLE instantiation and to host the emerging applications on a range of in-service RN platforms. Plans are still at an early stage, but this is not intended to replace the mid-term acquisition programme, nor is it anticipated to be a static solution, rather Agile methods will be used to ensure the MVP core is developed as part of the overall RN T&I and Dstl R&D programmes, reinforced by MAPLE science and technology. By this route the RN will be able to much more robustly test and adjust the detail in implementation, rapidly iterating with the real end user constantly in the loop.

5. Conclusion

The last 12 months have seen the MAPLE programme move into its fifth phase, pushing new boundaries in terms of functionality and readying the way for a core programme acquisition. At the same time, the landscape has shifted and the pace of work accelerated. MAPLE and ACER increasingly find themselves at the heart of RN and multi-national operational experimentation involving disruptive autonomy related technologies as part of a global race to adapt to and adopt autonomous systems. The coming year sees more experimentation in parallel with the MAPLE 5 programme and an emerging need for a more robust and widely deployable MVP solution. Whilst MAPLE has had a very successful 6 year history and is now a cornerstone for the RN's plans for autonomy into the future, the next phase will be the most critical, achieving the pivot from R&D into mainstream adoption.

References

1. P Smith et al, 'Securing interoperable and integrated command and control of unmanned systems – validating the UK MAPLE architecture', EAAW 2019
2. P Smith et al, 'Securing interoperable and integrated command and control of unmanned systems – building on the successes of Unmanned Warrior', INEC 2018 Glasgow
3. P Smith et al, 'Achieving integrated command and control of unmanned systems – the Unmanned Warrior experience', EAAW 2017 Bristol
4. P Smith et al, 'Architectural developments to enable the integration of unmanned vehicles into the maritime system of systems', INEC 2016 Bristol
5. W Biggs et al, 'Systems engineering enablers for maritime intelligent systems', EAAW 2015 Bath

Bibliography

1. J Astle et al, 'MAPLE 5 Information Architecture Guidance', dated 12 Aug 20
2. Royal Navy Maritime Autonomous Systems Campaign Plan, dated May 20
3. QinetiQ, Deploying Prototype Warfare, 2019
4. US DoD 'Unmanned Systems Integrated Roadmap 2017-2042', dated 28 Aug 18
5. UK MOD Joint Concept Note 1/18: Human Machine Teaming, dated 18 May 18
6. Royal Navy vision for Maritime Autonomous Systems D/Navy//MARCAP/SCCS/10-14 dated 5 Aug 14
7. R E J Westgarth et al, 'Human interaction and integration with future warships', Warship 2015: Future Surface Vessels, 10-11 June 2015, Bath
8. DCDC, Joint Doctrine Publication (JDP) 0-01.1 United Kingdom Supplement to the NATO Terminology Database 8th Edition dated September 2011
9. 2012 NRAC Study – How Autonomy Can Transform Naval Operations
10. T Rabbets et al, 'Developing a new Combat System architecture for Royal Navy surface combatants', MAST 2007 Genoa

[8] Noting that ACER was not intended to be a complete implementation of the PA, only allowing sufficient coverage for validation and research purposes. Further, beyond limitations in scope, ACER has not been designed for operational use, and therefore it does not currently meet the necessary requirement for availability and resilience. Whilst many of the components utilised within the solution are already operational, the Technology Readiness Level (TRL) for the set of integrated components deployed on the ACER system is TRL 5/6 with all of the components are to be operated by the component provider. Finally, to confirm its current role as a demonstrator, ACER operates at no higher than OS classification in accordance with the specific Authority or Customer requirements.

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