Realising the Integrated Operating Concept 25: How the UK MAPLE architecture is evolving to meet the Royal Navy's and Royal Marines' requirements at the heart of Joint and Coalition operations.

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Building on previous papers that have introduced and then updated on progress of the Dstl Maritime Autonomous Platform Exploitation (MAPLE) project, this paper will set out how MAPLE is being exploited by the Royal Navy and Royal Marines. Explaining the linkages between MAPLE and the new Naval Strike Network (NSN), the authors will set out how NSN as a common, core communications, command and control (C2) and information architecture will accelerate the exploitation of Maritime Autonomous Systems. The paper will explain the phased approach, developing and baselining a Minimum Viable Product, testing an instantiation of the MAPLE information architecture and codifying the communications and information flows required to transition prototype warfare concepts into service such that they are robust, resilient and reliable. The agile and spiral path to achieve integration into operational combat systems on RN warships will be set out, including the approach to security and assurance. The paper will also set out the next stage in the development of the MAPLE Information Architecture, showing the expansion from a Platform centric to a Force information architecture, which will enable the realisation of the vision of the Integrated Operation Concept 25. This Force level approach, at the heart of the UK/US Interchangeability to Interoperability (I2I) initiative, and the outcomes from the first demonstration of this interface at the NATO Maritime Unmanned Systems Initiative (MUSI) REP(MUS) exercise, taking place in Portugal in September 2021, will be presented.

1 Introduction

As outlined in past papers (Smith et al, 2015 - 20), the Royal Navy and Dstl have had a long standing focus on securing benefit from the use of multiple uncrewed systems (UxV) operating in concert from RN warships. At the heart of this work is the Maritime Autonomous Platform Exploitation (MAPLE) project; MAPLE is a multi-phase Defence Science and Technology Laboratory (Dstl) programme, now in its fifth phase and seventh year. MAPLE as a research programme continues to develop, operating a twin track approach, both developing the core architecture and deploying and testing a prototype exploitation (referred to as ACER: Autonomous Control Exploitation and Realisation).

The MAPLE premise is that this 'buying back mass' through uncrewed systems demands careful integration, minimising workload, and a set of software applications decoupling the ship Combat Management System from the challenge of managing a fast evolving landscape of uncrewed assets and payloads. Through this MAPLE architecture and a compliant solution, Operations Rooms crews will be able to task, deploy, manage and exploit increasing numbers of uncrewed assets (UxV), all without driving up cognitive workload or operator numbers.

Authors' Biographies

Philip Smith is Chief Above Water Systems at Dstl and the Technical Strategy Lead for the Above Water Systems capability area. He has a technical leadership role in the Chief Scientific Advisors Science & Technology Portfolio, and has an active role in the effective integration and exploitation of maritime autonomous systems by the Royal Navy.

Commander Stuart Ker is a surface Weapon Engineer whose last role as the Fleet Robotics Officer saw him lead the development of Naval Strike Network within the Royal Navy. Advancing the Royal Navy's and Royal Marines' adoption of Remote, Automated and Autonomous systems through exploiting the MAPLE programme of work.

Jon Astle is a highly experienced Combat Systems Engineer with over 6 years' experience of technical leadership of Command and Control and Autonomy related projects in the maritime environment. He is the QinetiQ Lead Engineer for MAPLE.

Bill Biggs leads QinetiQ's work on Autonomy across all environments. Prior to joining QinetiQ, he enjoyed an interesting and varied first career in the Royal Navy as a surface Weapon Engineer. His service included several roles in acquisition and systems engineering and sea appointments in HMS INVINCIBLE and HMS MONTROSE. Most recently, he was Deputy Assistant Chief of Staff, in Maritime Capability in Navy Command.

MAPLE's central role in supporting international maritime UxV experimentation has been covered previously and its extensive use of open and common standards have made it the de facto reference architecture and a routine framework for the UK's (maritime) multinational integration and experimentation activities. Such work, with its ever greater operator involvement and operational realism is key to the maturing of concepts and technology prior to fuller deployment, increasingly as part of a more agile approach to acquisition. These agile approaches and their implications for naval engineering deserve a paper in their own right, particularly noting the challenge they pose for regulators and approvers, but for this paper it is sufficient to note that they are an increasing feature of the RN's programme for technology and innovation and this is fully recognised in the Defence Equipment & Support Maritime Mission System Strategy. So agile development and experimentation is central to the RN's maritime autonomous systems (MAS) journey and MAPLE has remained central on that pathway; it is therefore perhaps no surprise that the need to deploy MAPLE functionality onto operational RN warships should be seen as the next logical step.

Under a programme described as the Naval Strike Network (NSN), this step is now being taken forwards[1] (R Scott, Sep 21). Based on its MAPLE heritage, NSN will offer an overarching information architecture that will enable a mix of crewed and uncrewed assets to work together within a single integrated network. As such, NSN in large part mirrors the aims of the US Navy's Project Overmatch initiative. Project Overmatch is intended to deliver the USN with an integrated, multi-domain battle network for communications and information sharing across all platforms. Recent announcements in Sep 21 at DSEI 2021 confirmed the RN's plans to proceed further with NSN and the explicit linkage to Overmatch. Wider reporting (R Scott, Oct 21), also signalled NSN's role in perhaps an even more dramatic shift to disaggregate and distribute future capabilities away from the partitioning that is currently recognised as being standard for a complex warship.

2 NSN Unpacked

NSN is proposed as a common, core communications, command and control (C2) and information architecture to enable the coherent, consistent, secure and repeatable execution of Maritime operations when augmented with MAS, building on iterative developments demonstrated by the MAPLE team during numerous exercises/trials. It builds on the output of these exercises and codifies the communications and information flows required to transition these prototype warfare concepts into service such that they are robust, resilient and reliable. NSN delivers a core set of components, exploiting the developments that have been undertaken during the previous MAPLE activities. These comprise of the following 4 activities;

1. Ship Integration – MAPLE;
2. Royal Marines Battle-Net C2 node;
3. Work on US/NATO Interoperability[2]; and
4. Specific support to UxV integration.

The full scope of NSN is being delivered by a team comprising NavyX, Navy Digital, MarWorks, Dstl and an industry team co-ordinated by an NSN Programme Manager. The industry team that has delivered the initial NSN development, referred to as NSN(MAS) Tranche 1 has been led by QinetiQ and is outlined in Figure 1 below. It has remained the same core team as under the existing MAPLE 5 contract, but with the inclusion of Leonardo.

Figure 1: NSN(MAS) contributors

[1] MAPLE continues to be an S&T focused activity addressing the conceptual development of an Information Architecture for Maritime Autonomous Systems. In contrast, the Naval Strike Network is the "operationalisation" of this information architecture into the Royal Navy's Surface Flotilla.
[2] The UK/US work is explicitly described as covering a span from Interchangeability to Interoperability (I2I), underlining the depth of the ambition.

The NSN(MAS) goal is to design, develop, integrate, trial, iterate and field a Minimum Viable Capability (MVC) capable of supporting rapid exploitation of MAS as Military Task Equipment (MTE). The project was broken down into four development spirals, developing a Minimum Viable Product (MVP) in the first instance before further iterations to deliver a MVC; Tranche 1 was successfully initiated in January 2021. The overall aim is to achieve ship integration of MAPLE, into a T23 in the first instance, which is a critical component to achieving the fielding of MVP through to MVC.

Recognising that the acquisition of T31 and the ORCA command system (for the Hunt Class) now means there is again diversity of CMS manufacturer across RN platforms, the NSN project will also likely feature a Tacticos integration, demonstrating the MAPLE architecture's agnosticism of any hardware and software infrastructure solution.

3 Progress towards NSN implementation and relevance to wider defence

NSN(MAS) Tranche 1 has successfully completed, covering off early design and development activity, and follow on Tranche 2 work is anticipated, but not yet initiated. The Tranche 1 work has already successfully informed and enabled highly successful experimentation work at Autonomous Advance Force 4 (AAF 4) and Robotic Experimentation & Prototyping augmented by Maritime Unmanned Systems 2021 (REP(MUS) 21), advancing the UK and international interoperability agenda and progressing a number of key objectives relating to the RN's wider adoption of MAS.

Tranche 1 addressed the security requirements for MAS by devising the system enablers required to transition the capability onto warships, whilst also supporting the above mentioned operational exercises and experimentation. The key enabler for exploitation is to allow MAS asset and payload product data to be passed into the combat system of a warship, whilst also allowing planning data, track data and other control information to flow in the other direction. To facilitate this, security enforcing functions in the form of deep-inspection guards have been developed to allow the bi-directional flow of information from the combat system that is 'system-high' to a MAS GCS (that connects to the asset and payload), which is at a lower level of classification (most likely UK OFFICIAL or unclassified). In addition in support of trials and experimentation, commercial hardware firewalls are utilised to protect the accredited MAPLE system from other MAS systems that may not necessarily have the required security and cyber processes in place.

Whilst the early spirals of NSN have focused on complex warship integration, it has been designed from the outset to support deployed forces and disadvantaged units, hence the inclusion of the Royal Marines Battle-Net C2 node. Demonstration at AAF 4 experimentation demonstrated the multi domain credentials of NSN and showed that a coherent information architecture approach with user focused front ends enables user needs to be met whilst enabling the seamless transfer of information and control to be passed through the force.

AAF4 tested MAPLE and the MarWorks team with a disaggregated implementation, reflecting a more realistic Land environment laydown, with C2 nodes and uncrewed assets spread across the country at RAF Spadeadam, Winfrith Defence Battle Lab (DBL) and Lulworth exercise areas. A range of assets including the Navy-X uncrewed surface vehicle MADFOX, a Hydroid REMUS 100 and a Malloy TRV-150 were deployed from RFA Mounts Bay, executing multiple mission plans sent from planning software hosted on MAPLE in Winfrith DBL. This experimentation was a first use of the Winfrith DBL and represented the first successful demonstration of disaggregated C2 and interoperability of multiple, complimentary UXVs over the Air, Surface and Sub-Surface domains.

AAF4.0 also broke other new ground, integrating for the first time the centralised C2 provided by MAPLE with the de-centralised execution of swarming missions exploiting BlueBear software, the latter already being developed for a number of projects in the Air domain. Exploring swarm deployment of uncrewed air vehicles for a range of mission types in support of Littoral Strike, AAF4 achieved a deployment of six Malloy TRV-150s using a BlueBear Ground Control Station (GCS). The Blue Bear GCS was successfully integrated with MAPLE and the TRV-150s undertaking a number of flights and demonstrating swarming with up to 4 aircraft. The significant effort expended by all parties to maximise the outputs of the experimentation yielded valuable lessons learned and identified a number of exciting areas for future development. Developing this relationship between maritime, land and air C2 workstreams, and particularly the linkage between maritime UxV C2 and air work on swarming is perhaps likely to be of particularly relevance to the recently announced Multi-Domain Integrated Swarming (MDIS) project sponsored by the UK's Strategic Command.

4 Achieving US & NATO interoperability as part of NCN

As part of the NATO Maritime Unmanned Systems Initiative (MUSI), the UK and the US have been working closely to achieve Maritime Autonomous Systems (MAS) interoperability. Following on from and informed by NSN(MAS) Tranche 1, the work has seen the UK utilising a MAPLE based command & control node, while the US utilised their recent development of the Common Control Station (CCS) C2 node. Achieving interoperability between these UK and US C2 nodes required the development of a new set of interfaces for the MAPLE Information Architecture. Up until this point the MAPLE information architecture has been developed around the command and control of MAS assets from a single C2 node. For this new phase, and guided by the higher level objective of asset interchangeability, interfaces were required to enable multiple C2 nodes to plan missions for and share MAS assets.

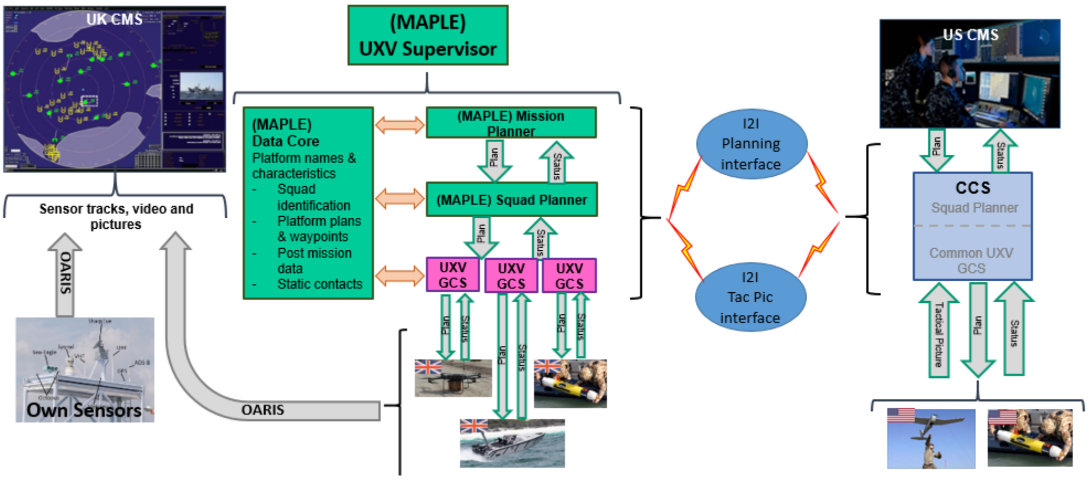

Figure 2: I2I interface between the UK MAPLE C2 node and the US CCS C2 node.

Termed the "I2I" interfaces, these interfaces are a central component in enabling the vision of Interchangeability to Interoperability between the UK and the US navies. The philosophy of these interfaces has followed the tactical doctrine of "Centralised decision making and dis-aggregated execution", under which one of the C2 nodes can request the other C2 node to under-take a goal based mission. Once this mission has been assigned the receiving C2 node will control its own assets to complete the mission, with tactical information generated as part of the mission passed back to the requesting C2 node. It is straight-forward to see how this can be extended to a multi-national ship group, with one of the C2 nodes taking the role of the Force Commander, and passing out Missions to the rest of the C2 nodes that are deployed across the ship group. This development to put MAPLE on a force footing, is a significant progression from work to date which has been constrained to a single host platform focus. The direct control of assets is covered by the Interchangeability aspect of I2I, building on existing standard interfaces, such as STANAG 4586 for UAVs and Joint Architecture for Unmanned Systems (JAUS) primarily for UUVs. Further standardisation is planned focussed at a STANAG for USVs. The I2I initiative may also reinvigorate and influence the direction of STANAG 4817 (Multi-Domain Control Station).

The first opportunity to trial the new I2I interfaces was as part of the REP(MUS) 21 exercise that took place just south of Lisbon, Portugal, in September 2021. As part of this exercise UK and US assets were successfully tasked by each other's C2 nodes, where one of the UK MAPLE C2 nodes was located at the Troia Research and Experimentation Centre (a second MAPLE C2 node was located at a Forward Operating Base (FOB) on the Atlantic side of the Troia Peninsula), and the US CCS C2 node was located on USS Carson City. The laydown for one of the 3 scenarios used is shown in Figure 3 and the MAPLE force picture from the same scenario is shown in Figure 4.

Figure 3: Laydown for the REP(MUS) Amphibious Landing Scenario

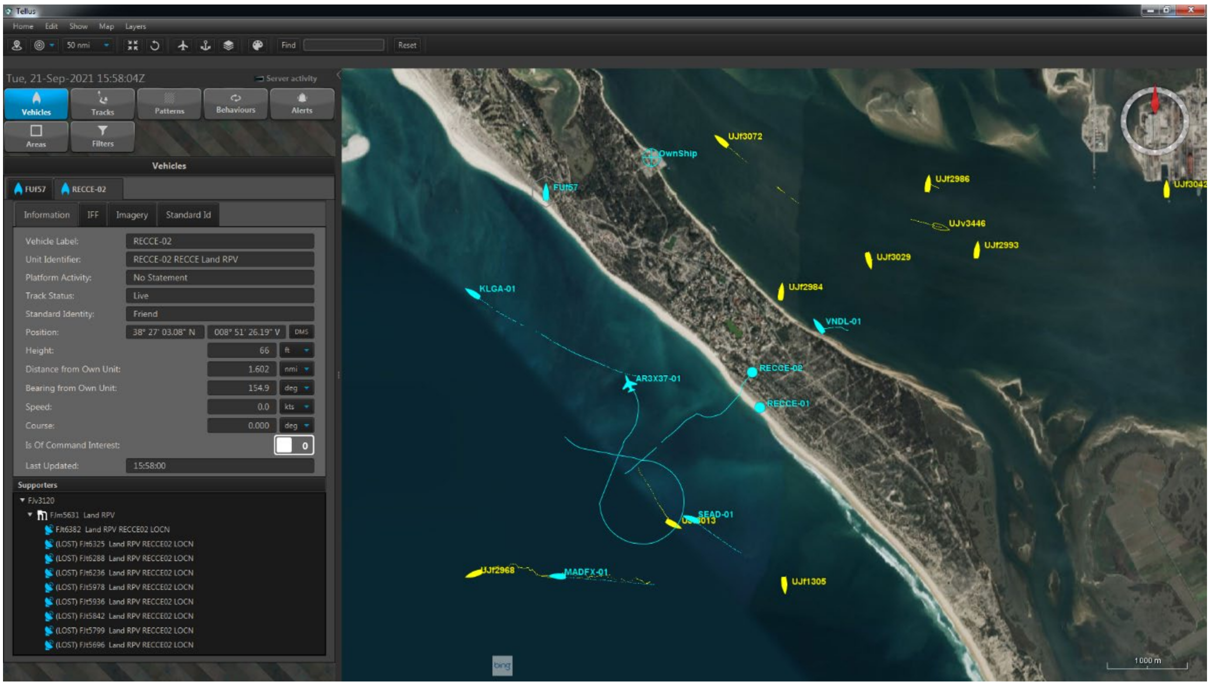

Figure 4: MAPLE Force Tactical Picture disseminated during the Amphibious Landing

The primary objectives of REP(MUS) 21, all achieved, are listed below:

	Primary Objectives
1	Trial and demonstrate Interoperability to Interchangeability (I2I) with the US Navy
2	Trial and demonstrate Extended Line of Sight UXV C2 via communications relays (hosted on a tethered drone and on UAV PUMA) to distributed units
3	Trial and demonstrate distribution of RN maritime tactical picture, UXV sensor feeds, data products, and targeting information across Allied C2 nodes
4	Conduct Rapid Environmental Assessment (REA) / intelligence, surveillance, and reconnaissance (ISR) using UXV, in particular but not limited to MADFOX and Dstl assets (TRV-80, SkyJib)
5	Enable dynamic re-tasking of UXVs and directed control of non-organic UXV assets of opportunity
6	Transfer control of UXV system / payloads for priority missions
7	Provide opportunities for advanced UXV capability demonstrations
8	Trial and demonstrate digital tasking of USV operating at ranges over 7KM
9	Integrate NATO allies with MAPLE to develop enhanced coalition interoperability and further

	Primary Objectives
	develop MUS scenarios
10	Perform cooperative multi-national IPOE operations to select best candidate approach lane, assess risk, and support planning
11	Provide uncrewed / autonomous FIAC / force protection / harbour protection
12	Perform LZ (Landing Zone) preparation and engagement of targets
13	Contribute to the ASW phase of the exercise, notably through Glider contribution, networks and software tools
14	Conduct a Sensor to Shooter activity with AV SwitchBlade

Table 1: Objectives Achieved at REP(MUS) 21

In terms of vehicle integration, REP(MUS) 21 achieved new levels of depth, with a much increased focus on high level tasking of vehicles and track level integration of outputs, this is illustrated in Table 2 below.

Organisation	UXV	Type	Status	Self-report	Sensed Tracks	Video	Goal-based Plans
NavyX	MADFOX	USV		X	X	X	X
AV	PUMA	UAV		X		X	X
Dstl	TRV 80	UAV		X	X	X	X
Dstl	SkyJib	UAV		X	X	X	X
US 6th Fleet	REMUS 100	UUV		X			X
US 6th Fleet	IVER	UUV		X			X
Aerialworx	LTAR 6	Tethered UAV/ Rebro					

Table 2: UXV asset integration with MAPLE

The newly developed I2I interfaces were only used for the UK/US bilateral activities at this stage. However, a wide range of other NATO assets were also integrated into the UK C2 node via the previously developed MAPLE interfaces. The complete list of assets integrated into the MAPLE C2 node at REP(MUS) 21 is shown in Table 3 below.

Supplier	UXV	Type	Name
PN Navy	NOPTILUS x3	UUV	NPTL
PN Navy	XPLORE x5	UUV	XPLR
PN Navy	Tekever	UAV	AR3X
Spanish Navy	KALUGA	USV	KLGA
Spanish Navy	VENDAVAL	USV	VNDL
Spanish Navy	SEAD 23	USV	SEAD
Spanish Navy	M5D AirFox	UAV	AIRFOX
Nederland Navy	Acecore NEO x4	UAV Octocopter	
Nederland Navy	Acecore ZEO	UAV Quad-copter	
CMRE	OEXC 40”	UUV	HARPO
CMRE	OEXC 40”	UUV	GROUCHO
CMRE	WaveGlider	USV	LISA

Supplier	UXV	Type	Name
CMRE	WaveGlider	USV	CAROL
CMRE	ALLIANCE	Naval Vessel	NRVA
CMRE	DISSUB	Naval Vessel	DSUB
CMRE	Gateway Buoy x2	C2 Infra	GWBX
CMRE	Bottom Node x2	C2 Infra	BONX
CMRE	TNO Tracker	C2 Infra	TNOA
CMRE	ITN GraalTech x2 UUV	UUV	ITGTU
CMRE	ITN GraalTech USV	USV	ITGTS

Table 3: NATO assets integrated into the MAPLE C2 node as part of REP(MUS) 21.

Since REP(MUS), the MAPLE team have also supported another major demonstration of autonomous assets, the Autonomous Maritime Asset Protection System (AMAPS). Working again as a joint industry team, this work was significant as it represented a first live deployment of a number of the high level tasking commands (Maritime Autonomy Framework based commands) that were first outlined last year (Smith et al, 2020). These commands, issued by a C2 operator to the payload on a vehicle, were successfully used to enable the payload to autonomously manoeuvre its host vehicle into position, before then successfully deploying the required effect (in the case of AMAPS this included a net system to capture a underwater vehicle or an arrestor line to stop a surface vehicle).

5 Next Steps

The continued development of NSN and establishing the growth programme through MVP, MVC to Full Operational Capability is central to the Royal Navy establishing a vendor agnostic, adaptable and configurable UxV Command and Control architecture that enables the integration of MAS across the force. The priority attached to this development is evidenced by the statements made by the Second Sea Lord at DSEI. Establishing the framework to enable quick and seamless integration as UxVs iterate, and allowing the integration across domains within the UK MOD and wider with allies is seen as a critical enabler to future advantage. As such, NSN is already a declared enabler and vital pre-requisite for other RN programmes to deliver their goals; these include the Future Maritime Aviation Force (FMAF) and Future Commando Force (FCF). NSN is similarly an in-built feature of the RN's vision for podded capabilities. The linkage to the wider joint force and to allies will be paramount as NSN develops and the linkage with MDIS is likely to remain important.

International co-operation and evidence of development will continue to be achieved through the use of experimental events both within the NATO MUSI (REP(MUS)), wider NATO (including the proposed Dynamic Messenger 22 event) and allied opportunities (including the proposed International Maritime Exercise (IMX) led by the US Task Force 59); the exact nature of the forward programme is yet to be agreed, but the international nature of the work is already clear. It is this rich user feedback from a diverse range of operational experimentation activities that is so important in ensuring the development path meets the needs of the operational user. Managed correctly, it allows rapid and timely alterations to the development path to be made without the inertia, cost and delay of fielding a completed product that does not deliver what the operator needs.

The minimum viable product approach being adopted to gain user feedback does though present challenges to the traditional accreditation and procurement model. Whilst test environments enabled by sandbox installations enable early testing to be achieved, there remains a desire, indeed an imperative to see future work undertaken in conjunction with accreditation and assurance organisations. This will ensure an appropriate and achievable route to accreditation; this involvement of the assurance community as part of an agile assurance pathfinder is therefore seen as core to future delivery success.

6 Conclusions

The progression of MAPLE has continued and its feed into the new NSN project represents an important step towards practical and sustained deployment on sea-going warships. The MAPLE vision remains central to the RN's plans for autonomy and NSN is a fundamental enabler for future capability advantage. The linkage to the joint world is likely to be increasingly important in the coming year and there is an expectation that the team will build on the international I2I successes of REP(MUS) 21.

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