Securing interoperable and integrated command and control of unmanned systems – building on the successes of Unmanned Warrior

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SYNOPSIS

The objective of more complete integration of unmanned vehicles into maritime command and control systems has been set out in previous papers, as has the progress made through the MAPLE (Maritime Autonomous Platform Exploitation) and the demonstrations undertaken at Unmanned Warrior in 2016. This paper details the significant progress that has subsequently been achieved in the fourth phase of MAPLE, in the run up to a further set of demonstrations in Australia in late 2018. Using a comprehensive synthetic environment and a process of iterative development, the ACER (Autonomy Control Exploitation & Realisation) demonstrator is being updated to include new functionality that closes gaps in the MAPLE visionary Persistent Architecture (PA). Specifically this will introduce enhanced Situational Awareness for the operator during Mission Execution, providing details of UxV asset and payload status. Additional functionality will also provide Payload control. Summarising these developments and outlining their significance, the paper will give illustrations of potential applications. Ahead of the Australian Wizard of Aus demonstrations, under the multinational technology co-operation programme (TTCP) and part of Autonomous Warrior, the MAPLE team will further support the STANAG 4586 interface and will undertake derisking work in preparation for the integration of TTCP vehicles provided by Australia, New Zealand and the US. The paper outlines the relevance of this development and how it will be utilised in the Australian demonstration. Finally, the paper will look forward to the developments planned in both future phase of MAPLE and under QinetiQ's participation with the multinational EU Ocean 2020 programme.

INTRODUCTION

As a direct result of the hugely successful integrated demonstrations during Unmanned Warrior 16 (UW16), confidence in the technological maturity and the operational utility of unmanned vehicles (UxVs) or maritime autonomous systems[1, 2] (MAS), has significantly increased throughout the UK maritime stakeholder community.

As previously noted, UxVs have been identified as a route by which the Royal Navy can "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, so that a single warship can truly dominate an area of sea thousands of square miles in size. Currently the deployment and operation of such a collection of off board systems would require multiple operators per vehicle. Consequently, realising the future vision of a MAS enabled Royal Navy will require increased levels of both integration and tiered autonomy, reducing workload and taking the operator out of direct control of the unmanned vehicles, so that a single operator can plan, task and manage missions involving multiple vehicles.

Defence Science and Technology Laboratory (Dstl) is addressing this need for increased integration and autonomy,

[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

Philip Smith is the Above Water Systems Programme Manager in Dstl, directing research conducted by Dstl and Industry focused on de-risking technologies and processes to enable the Royal Navy to build Affordable, Available and Survivable surface ships, which are able to operate freely in International and Territorial waters in support of UK interests.

Bill Biggs leads QinetiQ's work on Autonomy including the QinetiQ Maritime Autonomy Centre, with its particular focus on unmanned systems in the maritime environment. 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.

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following a "Strategy for Autonomy", with a mixture of study, design, experimentation and demonstration. Maritime Autonomous PLatform Exploitation (MAPLE) is central to this strategy. Preceding papers have introduced the MAPLE programme, its architecture, its demonstrator (autonomy exploitation and realisation (ACER)) and its role in UW16. MAPLE 4 is the current phase of the programme running forward in to 2019 and building on the previously reported progress made in Phases 1 to 3.

MAPLE 4 SCOPE

A key part of the MAPLE vision has been the creation of a core of open architecture functionality that addresses multi-vehicle missions, MAPLE 3 demonstrated the limits of what could be achieved with rapid integration of existing components, but the goal was always based on a vision or persistent architecture[3] (PA) that introduced new components. MAPLE 4 is maturing and completing this PA baselined in Phase 2, focusing on areas where application development or enhancement over that which exists in bespoke UxV management systems is most likely to yield results. A high level schematic of MAPLE 4 functionality is shown in Figure 1. The programme of MAPLE4 includes a series of synthetic and live events that will both validate the PA and show incremental improvements to the realisable C2 of autonomous vehicles from a Royal Navy (RN) Operations Room.

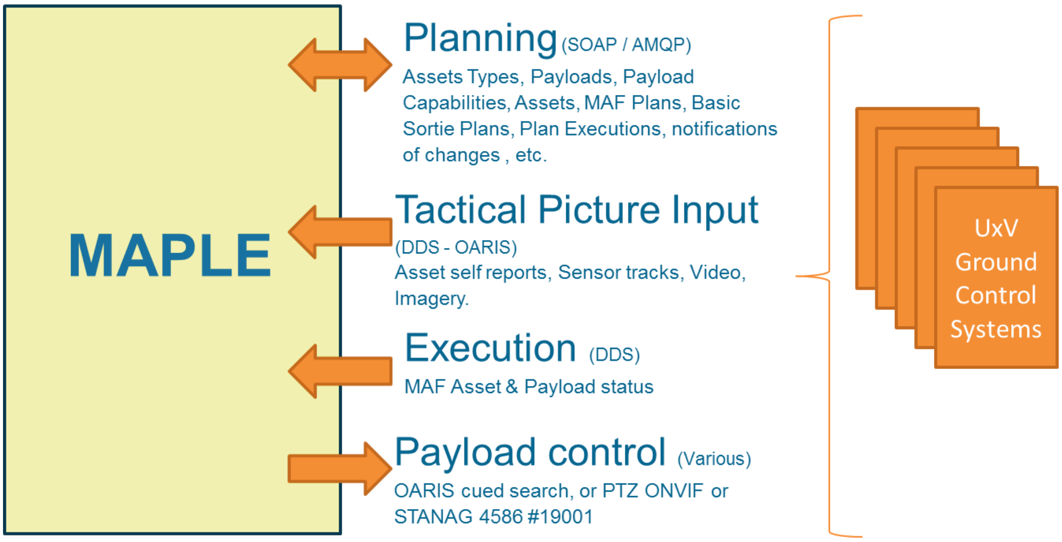

Figure 1: High level schematic of MAPLE 4 functionality

In addition MAPLE 4 is enhancing its interface to STANAG 4586, increasing the number of vehicle systems that can be integrated[4], and expanding core functionality in the ACER demonstrator including by exploiting autonomy software developed in other Science and Technology programmes sponsored by MOD and international partners. The latter include Pyramid, Maritime Autonomy Framework (MAF), Collaborative Autonomy. From an international perspective, the close ties through the technology co-operation programme (TTCP) have brought in additional functionality, most notably through the US IMPACT system.

Looking to some of the wider challenges to multi-vehicle multi-environment operation, MAPLE 4 also includes investigation of the communications architecture for RN use of UxVs and is maturing the non-functional architectural elements which are not yet sufficiently well understood. The key areas include security and safety.

On completion of MAPLE 4 the overall technology readiness level (TRL) of MAPLE will be TRL 5/6. To achieve this the system configuration tested will match closely the intended implementation on an RN warship. At phase end, Dstl will also have a roadmap describing a recommended approach to bring into service the integration of UxVs into the Command Chain of an RN platform. As the ACER system is hosted on the Open Architecture Combat System (OACS) Shared

[3] A Persistent Architecture is an enduring architecture description which enables and informs the development and consideration of different architectural forms and epochs within a domain. These may include current solutions, future developments, demonstrator rigs and prototypes, and envisioned concepts. Typically it is used to capture and control the evolution of current solutions towards an envisioned architecture-based form.

[4] Dstl are determined to reduce time and costs of integration through the use of recognised open standards or NATO STANAGs, eliminating the proliferation of bespoke solutions and ensuring interoperability with coalition partners. There are already a number of STANAGs employed to define the connectivity interface between UAVs and their ground control stations, such as STANAG 4586 – Control of UAS motion imagery payloads, or STANAG 4609 – Digital motion imagery standard. This is in addition to existing support to the OMG (Object Management Group) endorsed OARIS (Open Architecture RADAR Interface Standard) which includes the concept of a track table owned by the UxV, or the ability to share the track table between the UxV and a central tactical picture.

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Infrastructure a natural progression would be to be put subsequent implementations of MAPLE (an enhanced ACER) on the OACS sandpit proposed for the T23. The sandpit would allow MAPLE to be demonstrated in the same operating environment as the platform and facilitate integration with operational UxV feeds, such as from Watchkeeper.

DELIVERING THE PROGRAMME

The existing MAPLE Team of QinetiQ, BAE Systems, Thales and SeeByte have continued to work together on MAPLE 4, taking maximum advantage of the deep knowledge gained during earlier phases of the MAPLE Programme, including the experience and understanding gained during UW16, and also of experience gained in other national and international autonomy related programmes.

Phase 4 has adopted an iterative and spiral development approach whereby small increments of "autonomy" can be envisaged, tested with a Stakeholder community and then assessed in terms of operational utility and feasibility of delivery. The plan is for a three staged programme.

The baseline is the ACER system as deployed at UW16. This is undergoing a number of incremental updates in line with the staged approach of MAPLE 4. From an engineering governance perspective, the programme features three iterations, co-ordinated with other WP activities requiring independent design review.

- Stage 4A: Alongside the maturation of the PA this stage focused on the establishment of the Synthetic Environment (SE) and the enhancement needed to the ACER system to support a major synthetic event (Syn Bay) which took place in Autumn 2017;
- Stage 4B: This stage has focused on the continued maturation and validation of the PA and enhancements to ACER. This stage culminated in a SE Demonstration trial to help prepare for The Technical Cooperation Programme (TTCP) event in 2018, Autonomous Warrior 2018 (AW18). The TTCP event scheduled for Jervis Bay in Australia in 2018 presents a unique opportunity to demonstrate the MAPLE capability;
- Stage 4C: This stage will focus on more advanced tiered autonomy, folding in the non-functional and comms work and culminating in a final live event in May 2019.

Each iteration is part of a spiral, as shown in Figure 2. Figure 2 includes the major design artefacts that will be updated from ACER together with the design gates. The requirements phase of each spiral has seen the concept of employment (CONEMP) and the MAPLE user and system requirements documents (URD and SRD) reviewed and updated.

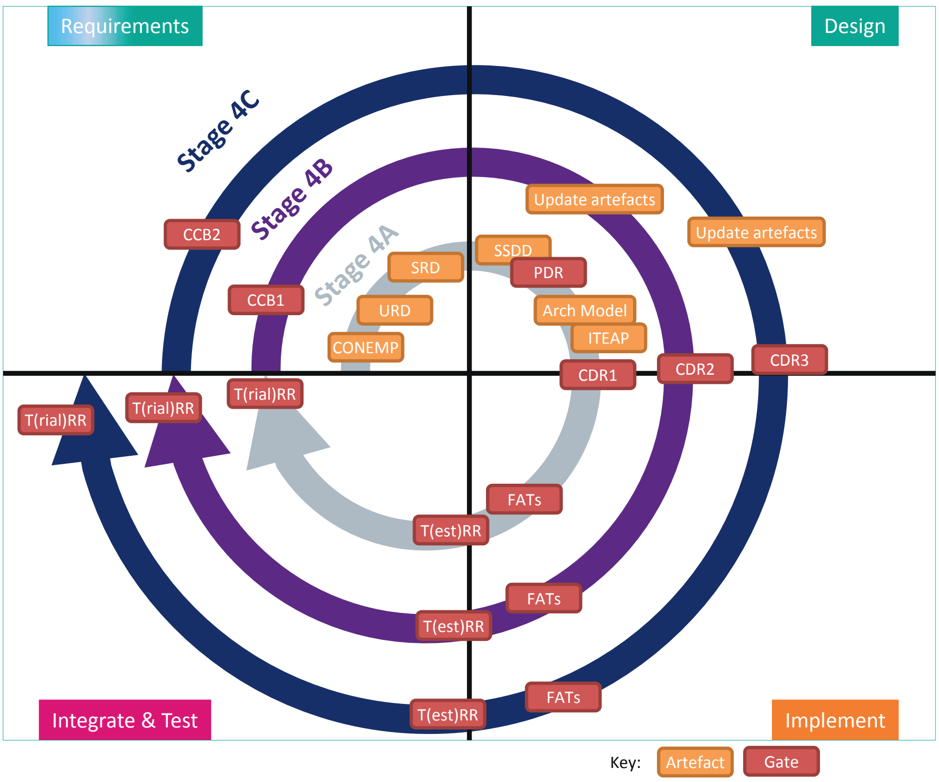

Figure 2: MAPLE 4 Spiral Development Approach

The design phase has entailed sub system definition (SSDD), architectural modelling and planning for integrated test and evaluation (ITEAP), as well as preliminary and critical design reviews (PDR & CDR). This has been followed in the implementation phase by factory acceptance tests (FATs) and a test readiness review. Once integration and test is complete the increment has then undergone a trials readiness review.

DEVELOPING AND VALIDATING THE ARCHITECTURE

The PA developed during MAPLE Phase 2 captured the main functionality for the Common UxV Mission System in 13 functional blocks. In addition, an 'embryonic' data architecture and an interface compendium were developed. Towards the end of Phase 2, 5 of these blocks (seen as the most important to the MAPLE concept) were further elaborated. Some validation of the architecture was undertaken during Phase 2, but this was largely subjective. MAPLE 4 has seen this architecture captured as a 'PA Model' in a specialist tool, Enterprise Architect with functional blocks completed to a common level of detail (including data model, interface compendium and standards profile); furthermore the architecture has been elaborated to include communications and views relating to security, safety and human factors views.

Use of a specialist tool has enabled the PA to be subjected to more rigorous and objective validation against a set of criteria set out in a Validation Plan, a critical document as it is central to establishing the utility of the core functionality.

The realisation architecture for the enhanced ACER has been updated and mapped to the PA, through a deployment model, in order to assist with its validation. The development of MAPLE artefacts is shown in Figure 3. The dark red components from MAPLE2 include the initial iteration of the PA and a set of user requirements. These have informed the PA and MAPLE 4 URD respectively.

The Phase 3 instantiation of ACER (light blue), its system requirements and realisation architecture have been the baseline for the enhanced ACER system (ACER ++) and its realisation architecture. The Phase 4 components (in purple) pohave ultimately informed the validation plan for test in live and synthetic events.

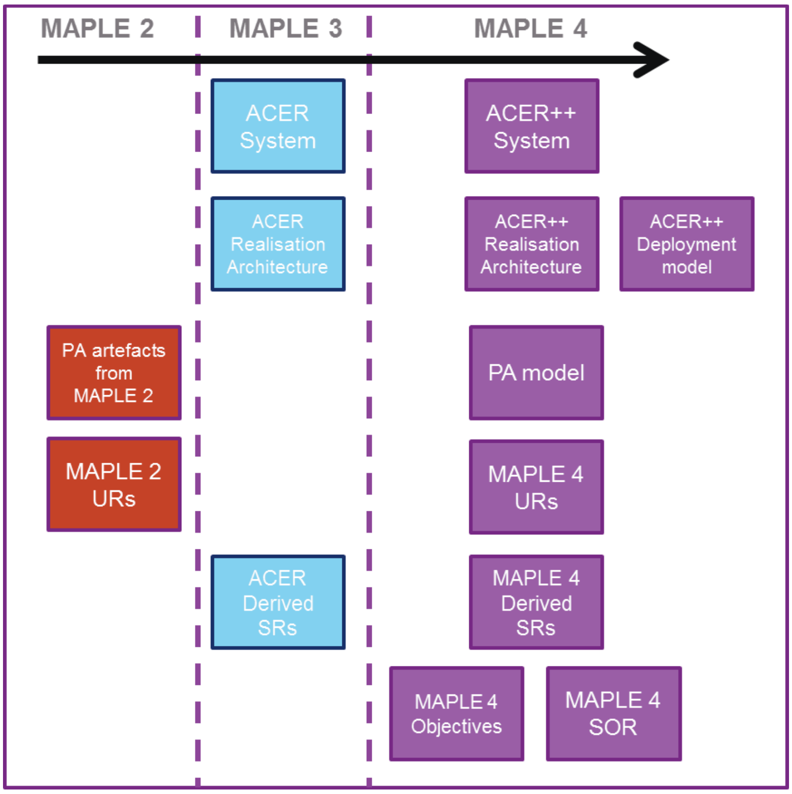

Figure 3: MAPLE 4 Key Artefacts

Validation of the architecture has taken place to date in a major synthetic event (Syn Bay) at Portsdown Technology Park and a number of smaller synthetic experiments. The most recent synthetic event took place in late May and early June 2018 (ahead of deployment to Australia for the live event). The use of synthetic events offers an opportunity to exercise scenarios and technologies that are not practical or feasible to demonstrate in live trials. They have also provided vital preparation for the live event and a chance to demonstrate early integration with the enhanced ACER.

EXPLORING POTENTIAL APPLICATIONS OF MAPLE

In order to develop and test the MAPLE Phase 4 architecture and the ACER ++ demonstrator, a set of scenarios has been developed; these scenarios were developed with end users to ensure operational credibility and to expose the key information flows and operational processes. Building on and expanding an initial and similar piece of work in MAPLE 2[5], these scenarios:

- Show the end-to-end command chain (including tasking, planning, execution, monitoring, re-planning, analysis and reporting), including both bounded and un-bounded objectives;
- Include multi-domain assets (surface, air, underwater) operating concurrently and collaboratively;
- Facilitate the assessment that the UxVC2 facilities are vehicle agnostic;
- Facilitate the assessment of robustness/resilience (to communications limits, unpredictable events, vehicle failures, etc.), particularly in respect of maintaining an operational capability and support of valid command decision making;
- Facilitate the assessment of scalability (small/large area, number of vehicles etc.);
- Facilitate the assessment of the ability to operate the UxVC2 integrated with the RN's in-service CMS whether in warship or portable mode
- Illustrate complexity/stress/diversity;
- Be based on recognisable but novel subjects, facilitating the assessment of operability improvement;

Three candidate scenarios were selected from a wide range of potential scenarios during MAPLE Phase 2. The features of each scenario were examined against the required scenario characteristics above to ensure that the combination of these scenarios would allow validation of the PA and demonstrate capabilities of the MAPLE system. The three scenario types that were of particular interest to the customer were:

- Extended range situational awareness (ERSA);
- Mine countermeasures (MCM) in support of littoral manoeuvre;
- Harbour protection.

The intention was to build on the work carried out during MAPLE Phase 2 using experience gained during UW16. Customer direction was to increase scenario relevance by introducing a realistic level of background activity as well as:

- Surveillance and arms smuggling;
- Counter piracy operations;
- Infrastructure attack from surface craft.

By way of example, the ERSA scenario is described thus and in Figure 4:

Her Majesty's Ship (HMS) TURBINIA, operating detached as part of a task unit (TU) of two escorts to provide force protection for a convoy of merchant shipping transiting through a strait choke point on route to a littoral manoeuvres exercise. In the approaches to the choke point there is a potential surface and sub-surface threat from hostile naval forces, piracy poses a significant risk to unescorted shipping and commercial offshore infrastructure (oil platforms). Within the choke point the threat is believed to consist mainly of fast inshore attack craft (FIAC) operating from concealed bases. The risk of terrorist attack cannot be discounted, with truck-based anti-ship missile (ASM) a realistic threat possibility, using UAV to assist with identification and provide propaganda footage. Traffic within the area includes a full spectrum of commercial and leisure craft, including:

- *Local fishing fleet;*
- *Surface and helicopter resupply of nearby oil platforms (OPLAT);*
- *Civilian air traffic traversing the area in recognised air lanes;*
- *Civilian vessels passing through the area and using recognised shipping lanes.*

Both HMS TURBINIA and the cooperating escort (which might be a NATO or coalition platform) are equipped with organic UAV, USV and UUV assets, including associated command and control facilities integrated with the platforms' CMS. Other assets available include the ships' maritime attack helicopters (MAH) conducting surface surveillance, which, together with the ships' sensors and effectors contribute to the compilation of the recognised maritime and air pictures. MAH are also available to support boarding and counter FIAC operations. A satellite communications (SATCOM) link provides connectivity with the Commander Task Group (CTG).

The scenario features developments to explore the use of UxVs for tactical effect, using the ship's UxVC2 to employ UxV assets to deliver the following tactical effects, acting either individually or in squads:

- *Surveillance (anti-submarine warfare (ASW))*
- *Surveillance (convoy lead-through)*
- *Threat investigation and targeting*

[5] Noting that the MAPLE programme is essentially a series of spiral developments and therefore scenarios and requirements are progressively developed and updated based on experience in the previous spiral.

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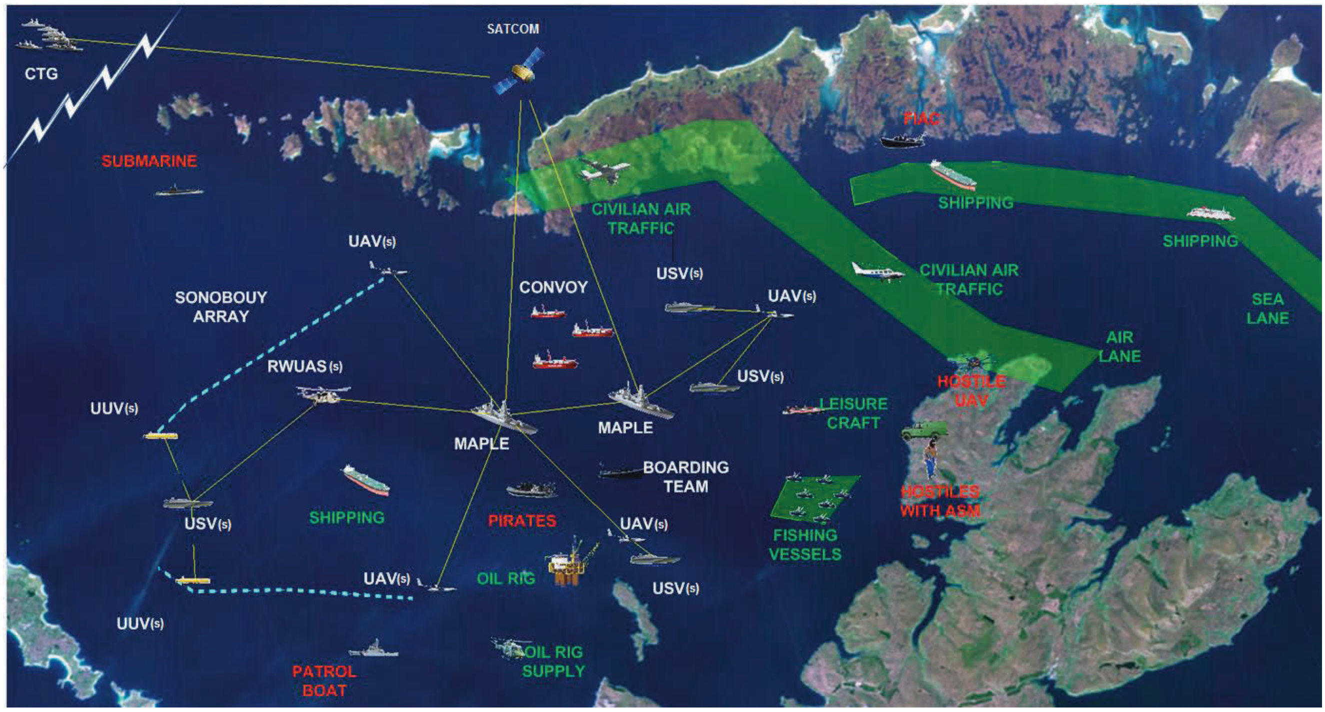

Figure 4: Extend Range Situational Awareness Chokepoint Scenario – MAPLE4

This process of scenario development has been undertaken for the other scenarios and used to inform the synthetic event trials design. Whilst the scenarios were deliberately stressing, they are also considered realistic and have been informed by experimentation to date, including UW16. They illustrate the very broad range of applications now being considered for UxVs, the multi-vehicle, multi-environment nature of many of the missions and the pace of conceptual change. Whilst warships feature at the heart of these scenarios, other implementations see similar toolkits deployed from the quayside or from platforms of opportunity, creating a further challenge for overall UxVC2.

NEW FUNCTIONALITY IN PHASE4

The updates to ACER have adhered to principles developed in MAPLE 2.

	ACER Architecting Principles
A	All persistent data is stored in the Data Core; point-to-point interfacing is discouraged
B	All transient data uses appropriate open federated messaging, such as OARIS
C	Already integrated applications that do not conform to A and B perfectly will not be changed
D	Any new modules will conform to A and B
E	Modification to existing functions will conform to A and B

Table 1: Architecting Principles Devised for MAPLE 3 will continue into MAPLE 4

The updated ACER ++ configuration is shown in Figure 5. Key advances include: more advanced autonomy, much greater integration between the Tier 1 (high level) and Tier 2 mission planners, underpinned by an expanded data core; greatly improved asset (UxV) visibility and tell backs[6] to enhance operator situational awareness; the ability to task[7] (or vary tasking of) assets in mission 'on station'; and recently introduced support for STANAG 4586 payload control.

[6] Examples include Mission, last and next waypoint, fuel status, % of mission complete, payload mode, sensor angle of sight.
[7] Both from within the CMS using a 'Cue Search' function and using a digital supervisor function that offers both a single user interface for all UxV data and a relatively rich range of instructions for direct tasking of the tasked vehicles. The latter is part of a new rapid prototyping capability.

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In terms of new components, the most immediately obvious change is the inclusion of the Collaborative Autonomy components (in white) comprising COMPACT and IMPACT; the latter is a product of the US Air Force Research Labs and demonstrates international interoperability as part of the wider TTCP programme culminating in Australian demonstrations later in 2018. COMPACT provides a policy management capability that automatically tests proposed plans for policy compliance (a good example being air space deconfliction).

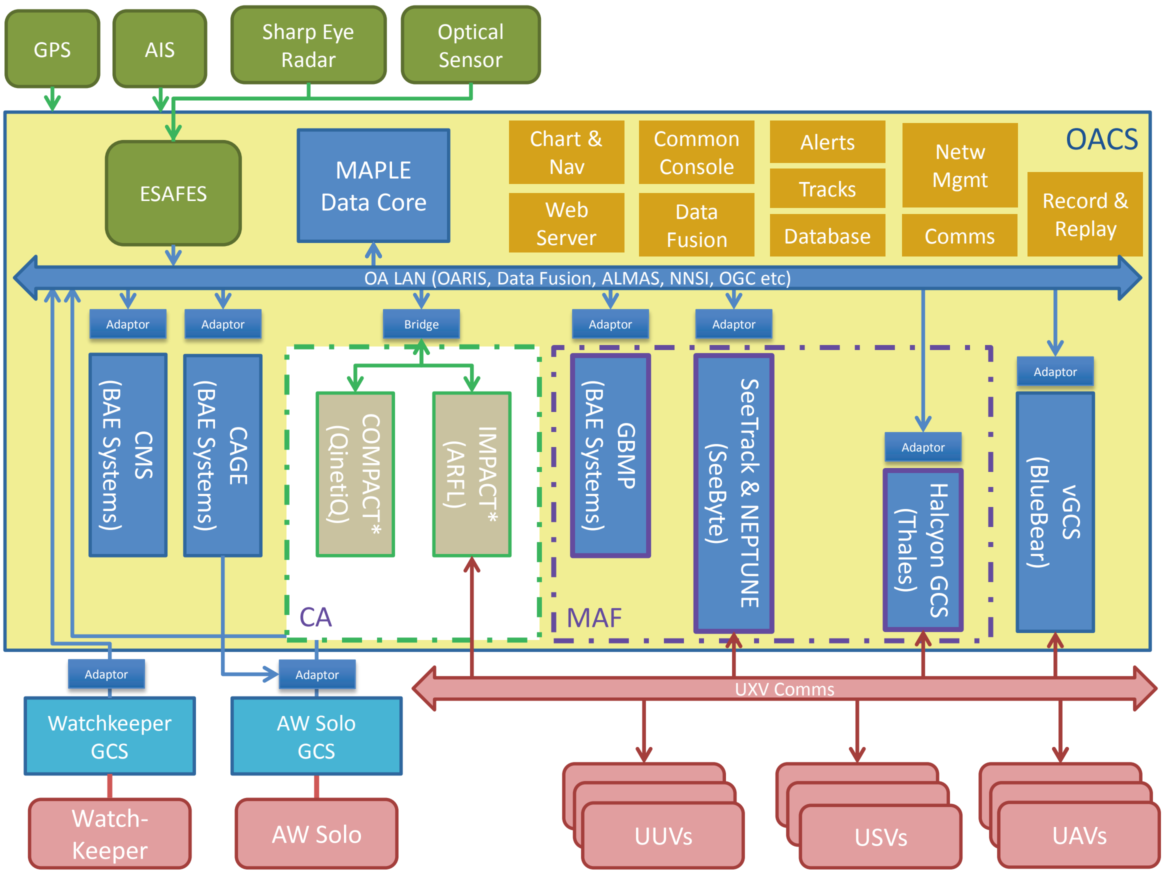

Figure 5: MAPLE 4 - ACER++ Schematic

DEMONSTRATION IN AUSTRALIA

Since Unmanned Warrior Dstl have been preparing to participate in the Australian equivalent of UW16 called Autonomous Warrior 18. The UK involvement in this event has arisen out of the TTCP five eyes forum, and is 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.

The Australian Defence organisation of the Royal Australian Navy and the DST Group are very deliberately focusing on Autonomous Warrior 18 picking up where Unmanned Warrior 16 left off. So this will not be a simple repeat, it is aiming to raise the bar from the UK event in October 2016. As well as bringing together a range of unmanned vehicles that cover the full spectrum of UAVs, USVs, UUVs and UGVs. The event is also bringing together a variety of Command and Control tools from Australia, USA, Canada & UK where the intent is for these to be fully integrated to deliver a significant level of autonomous and digital command and control.

This trial will be undertaken at Jervis Bay which is located just south of Sydney Australia in November 2018. Unlike UW16, the event will all be taking place in a relatively confined volume of air and water space, which presents opportunities as well as challenges. MAPLE will be located at HMAS Creswell serving to demonstrate the use of MAPLE in a littoral environment.

Exercise planning is already well advanced and integration and de-risking work is planned in advance of the live demonstrations. The build up to the live event has seen a series of international serials, referred to as Wizards, the last of which is Wizard 4 in Sydney in Summer 18.

Figure 6: Autonomous Warrior 18 Location

In UW16 MAPLE achieved Digital Command and Control for Mine Counter Measures. At Autonomous Warrior 18 (AW18) the intent is to pull this through into the ISTAR and ASW roles. In contrast to MCM, ISTAR and ASW are dynamic events, where this will require an enhancement in human/autonomy teaming to achieve. The inclusion of ASW is also a new development from UW16, with the aspiration to triangulate bearing only tracks to achieve location tracking of ASW contacts. Another area where there is a plan for clear progression on from UW16 is in the concurrency and integration of events, with ISTAR activities providing cues to the conduct of MCM.

In terms of international integration, AW18 is also building on the existing MAPLE flow of control: the Mission Planner provides the top level of functionality, assigning tasks to squads of unmanned vehicles; the Task planner then provides the lower level tasking to the vehicles within the squad which are undertaking the assigned task or mission; and product from the unmanned vehicles is then fed into the tactical picture, which provides situation awareness to the operators who are in control of the mission. The international dimension will see MAPLE provide the top level Mission planning, assigning tasks to multiple C2 nodes. The C2 nodes will then provide the lower level tasking to control the unmanned vehicles in the conduct of the task. In effect the Mission planning will work through multiple Tier 2 or task planners in order to conduct the variety of warfighting tasks required. These Tier 2 planners, from across the TTCP community, have differing strengths and weakness, which it is intended to experiment with and exploit during the conduct of AW 18. This is shown in Figure 7.

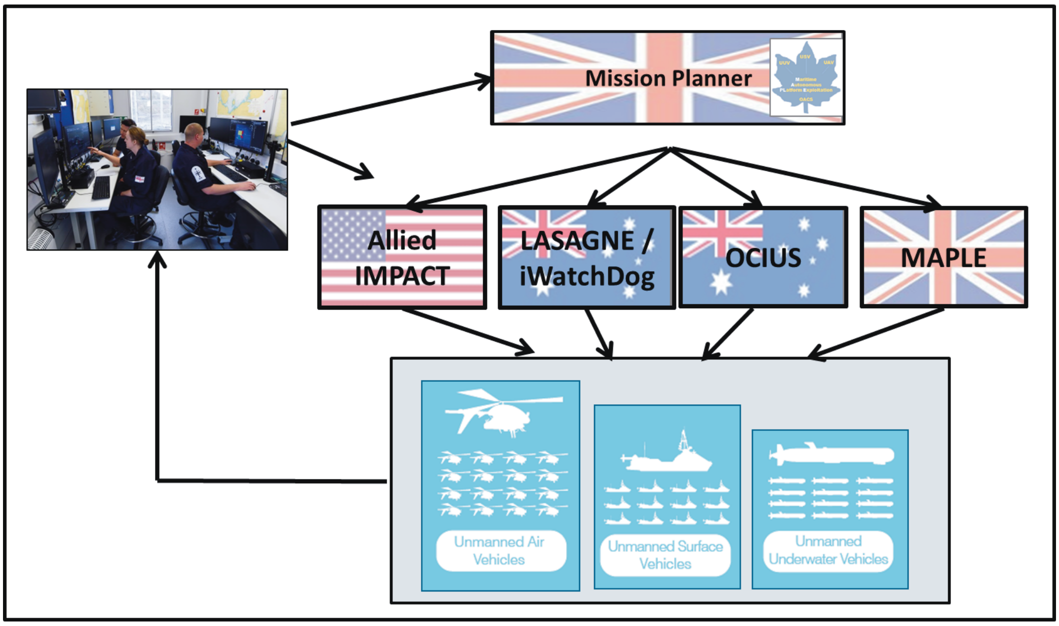

Figure 7: Autonomous Warrior 18 - Flow of Control

Of key importance from the MAPLE perspective is that the information from all the vehicles, controlled from these Tier 2 planners will be integrated into a single tactical picture. And that a recognised tactical picture will be exported to all of the C2 nodes. Through this route these Tier 2 planners will not be operating in complete isolation, but all will be a component of building, and exploiting, the wider situation awareness.

LOOKING TO THE FUTURE

Elsewhere in MAPLE 4, detailed work on safety, security, human factors and communications is being completed, giving greater confidence in readiness for deployment and supporting the assertion that this is a set of technologies now ready for further development and inclusion as products and applications. Learning from this work will be folded into the last of the 3 spirals and tested synthetically and in the final live event. Beyond the excitement of coming months and the final May demonstration, there is already talk about further developments and closer integration with RN platforms and operators.

Elsewhere, building on the successes of UW16 and MAPLE 3, QinetiQ, working with support from the RN and Dstl, are now working on a European project based on technologies and expertise developed within MAPLE. The project breaks new ground for the European Union in terms of its size and nature. The largest of a number of Preparatory Actions on Defence Research, Ocean 2020 addresses the opportunities presented by UxVs for surveillance and situational awareness in the maritime domain. With demonstrations planned in the Mediterranean (2019) and Baltic (2020), the project has 42 partners including a number of EU navies and research institutes. QinetiQ are focusing on command and control and will be working closely with partners to incorporate a number of new developments, very much in keeping with the MAPLE vision. With Dstl's permission, the intention is to host these new applications in an ACER demonstrator. Ocean 2020 has a number of aims relating to developing European technology, but it will also force the pace of interoperability, not just at the vehicle level, but also at the C2 and information level.

CONCLUSIONS

MAPLE 4 has built on the successes of MAPLE3 in UW16, underpinning the project with a robust architecture and a formal process of experimentation and evaluation. The work in synthetic trials to date has progressively validated the principles and detail of the PA. More broadly the international nature of the TTCP trials has seen a broad based consensus emerge on the nature of future UxV C2 and increasing levels of interoperability. The MAPLE 4 CONEMP has provoked discussion and debate, helping drive operator engagement and allowing wider communication and debate on the role of UxVs in future naval operations.

New functionality in the enhanced ACER demonstrator is bringing to life key parts of the PA and these will be tested fully in live experiments later this year and in May 19. The vision of a single small team managing a large number of heterogeneous vehicles undertaking a range of different missions is being brought closer through greatly improved C2 functionality that supports integrated planning, in mission oversight and in mission control.

Post AW18, there is an ongoing programme of trials and experimentation and the new prospect of a European dimension to development, under Ocean 2020. Perhaps most exciting is the prospect of a progressive shift to experimentation and trials conducted at sea on RN warships.

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