Integrating maritime autonomous systems (MAS) into the future force, how the UK MAPLE architecture is being developed to enable generation after next capabilities.

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The Dstl Maritime Autonomous Platform Exploitation (MAPLE) project has played a leading role in shaping Royal Navy thinking about the integration of MAS into at sea platforms and in support of forces ashore. This paper touches briefly on the MAPLE context and the work being done to translate MAPLE research and development into an initial fielded solution under the Naval Strike Network programme, but the principle focus is on the next phase of the Dstl MAPLE 5 programme as it explores the challenges of exploiting a rapidly advancing technology base, looking beyond near term deployments and meeting MOD direction to unlock the potential of the generation-after-next. The paper explores: the integration of increasingly autonomous effectors and swarming systems and the need to consider MAS as force assets, operating across multi-national task groups and supporting new deployment patterns such as airborne crewed uncrewed teaming. As part of the ongoing MAPLE programme, the paper also will cover how international experimentation is moving beyond low level information integration to achieve a higher level interface, including recent work in Australian as part of Autonomous Warrior 22, as well as making extensive use of synthetic trials and federated facilities.

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

1 Introduction

Navies globally have been actively exploring the use of uncrewed, increasingly autonomous systems, seeking to unlock competitive advantage through increased mass, faster operational tempo and reduced risk. This exploration has accelerated over the last 10 years and been given added urgency by events in the Ukraine. For their part, the Royal Navy and Dstl have long recognised the importance of unlocking the benefits of operating multiple uncrewed vehicles (UxV) or Maritime Autonomous Systems (MAS), in concert from RN warships. At the heart of what is an active UK programme of research and development and autonomy experimentation, the Maritime Autonomous Platform Exploitation (MAPLE) project has been central to the UK's goal of 'buying back mass' through uncrewed systems.

As outlined previously (Smith et al, 2015 - 21), the MAPLE premise is that securing the desired benefits 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. This approach enables the tasking, deployment, management and exploitation of increasing numbers of uncrewed assets (UxV), all without driving up cognitive workload or operator numbers.

Now in its fifth phase and eighth year, MAPLE as a research programme operates 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). MAPLE is a collaboration between Dstl, QinetiQ, BAE Systems, Thales, Seebyte and latterly others including BMT and Diem Analytics. The previous 4 previous phases have covered extensive ground, all outlined in past papers:

- **Phase 1:** Uninhabited vehicle (UXV) command and control (C2) study: A feasibility study into Maritime UXV focussing on their management and governance, UXV C2 requirements and architectures, and the potential for exploitation of UXV capability into the Royal Navy (RN) (2013 – 2014).

Authors' Biographies

James McIntyre is the Principal Advisor for Future Maritime Concepts at Dstl and has over 20 years experience leading research on above water systems. He is currently the technical authority for Maritime Concepts which includes leading the MAPLE S&T project for the past 5 years.

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Until very recently Bill Biggs led QinetiQ's work on Autonomy across all environments; he is currently working in DE&S, leading the definition of the Mine Hunting Capability Block 2 programme. 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.

- **Phase 2:** The main output was the development of the persistent architecture for the C2 of autonomous systems and a better understanding of the role of the human as part of delivering the autonomous capability on a warship (2014 – 2016).

- **Phase 3:** Autonomous Control, Exploitation and Realisation (ACER). An early concept demonstrator of UXV C2 capability that was deployed at Unmanned Warrior 2016 (UW16) (2015 – 2016).

- **Phase 4:** Building on the previous phases, the aim was to improve and mature the architecture and understanding of systems used to control UXVs such that they could be operated from a Royal Navy (RN) Operations Room. Through live and synthetic events, incremental improvements in the C2 of UXVs was demonstrated particularly at the Autonomous Warrior 2018 (AW18) and Cardigan Bay 2019 (CB19) live events (2017 - 2019).

2 Current MAPLE focus

The primary aim for MAPLE 5 is to rapidly enable the exploitation of maritime autonomous systems (MAS) through the specification of the information architecture, further maturation of MAS requirements and development of the Concept of Operation (CONOPS), Employment (CONEMP) and Use (CONUSE). The human component of the combat system containing MAS is also being addressed through experimentation centred on the 'Ways of Working' with a UXV C2 capability and the production of a set of Human Factors Integration (HFI) documents for a procurable solution.

In early 2022, a revised scope for the MAPLE 5 Programme was agreed, shifting away from the very successful 'exploitation' agenda that has now seen the start of MAPLE operationalisation. This exploitation of MAPLE capability into the RN surface fleet will continue to be sponsored by the Naval Strike Network (NSN) Programme in Navy Command supported by the Maritime Combat Systems Integration Authority (MCS IA). MAPLE 5 Year 3, running into 2023, is instead focusing on research related goals to support Navy Develop's longer-term vision for Generation after Next (GAN) capabilities, exploring the Force level context as detailed below:

- Force level Command and Control - putting in place effective "Force level" digital MAS C2 in the context of a Carrier Strike Group;

- Lethal and non-lethal effectors - adjusting MAS C2 in order to fully cater for the deployment of lethal and non-lethal effectors from MAS assets (as a preliminary step and to enable human oversight and control this is within Radar horizon);

- Hybrid human-robotic fleet - Synthetic trials to investigate 'Ways of Working' in order to effectively manage and exploit swarms of un-crewed assets.

- In support of the above, Year 3 is also taking into account specific Autonomous Aviation, Future Commando and Anti-Submarine Warfare requirements.

Experimentation and demonstration in what is Year 3 of MAPLE 5 is continuing to address Force-level issues, but broadened to reflect both crewed and un-crewed systems as part of a hybrid human-robotic fleet. Further MAS opportunities with the TTCP[1] nations are also planned covering Force level coalition interoperability.

3 Linkages to NSN

As outlined above, NSN is being taken forward separately, a clear exploitation of MAPLE research to date. NSN is a concept for integrating uncrewed/autonomous systems into Combat operations. As documented elsewhere, it is envisaged that NSN will provide a modular, scalable framework that covers:

1. Command and control (C2) of uncrewed/autonomous systems across all domains: on land, in the

[1] The Technical Cooperation Program (TTCP), a collaborative R&D programme involving UK, Australia, Canada, US and New Zealand.

air, on the water and below the water.
2. In-theatre communications between 'sense' and 'strike' elements and C2 nodes. NSN will use currently-available comms channels and be poised to exploit new capabilities as they become operational—including meshed networks and software-defined radio systems.
3. Integration of data from connected sensors to support operational decision making, so legitimate targets may be rapidly identified.
4. Integration of ISTAR and weapons systems (including existing combat systems) so targets may be engaged or neutralised in a timely manner. Seamlessly connecting available systems will be key to achieving the rapid responses needed for superiority in future combat operations.

As such, NSN lays the foundation for future uncrewed/autonomous systems to be deployed into the fleet at pace. Its modular approach will allow operational systems to be continually enhanced, enabling integration of new capabilities in response to emerging threats and capitalising on opportunities as they arise. Through Dstl, linkages between NSN and the MAPLE team will remain strong, with an expectation of active engagement and pull through of MAPLE R&D. The overall delivery model for researching, operationalisation and acquiring MAPLE capability is shown in Figure 1.

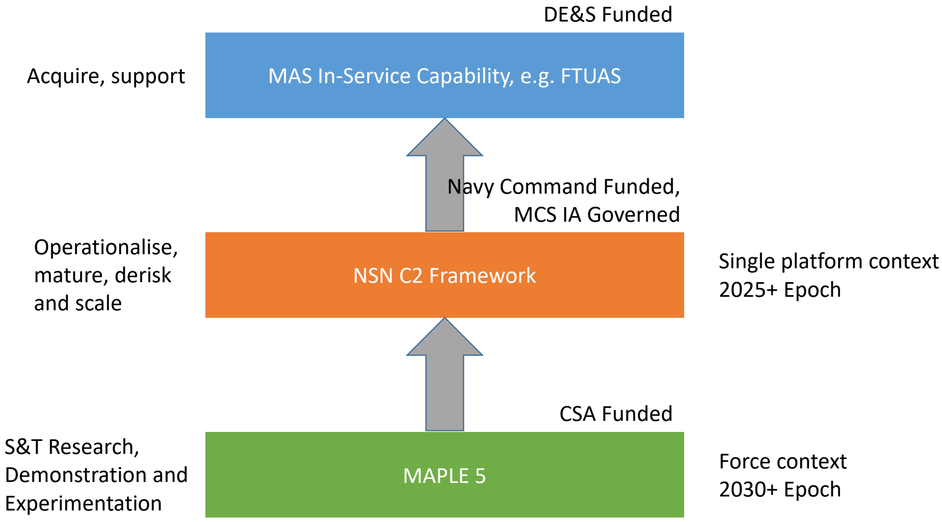

Figure 1: Overall delivery model for researching, operationalisation and acquiring MAPLE capability

4 A new focus for MAPLE experimentation

Reflecting the objectives outlined for MAPLE 5, experimental definition was undertaken in the earlier phase of the current, ultimately leading to a force experiment which was conducted in Jan and Feb 2022. The focus was on force co-ordination which was identified as a high priority from a stakeholder prioritisation exercise. The experiment was conducted in two sessions; an initial workshop which focused on the planning phase followed by experimental runs which focused on mission execution. The 3 hypotheses tested were selected from those identified in a separate Force Concept and Technical Study report exploring the level of C2 for a MAPLE Enabled Force experiment. The selected hypotheses were:

- Hypothesis 1. The Officer in Tactical Command (OTC) is not able to use currently available systems to effectively act as the Maritime Autonomous System Coordinator (MASC) (to prioritise and allocate uncrewed assets to missions across the Force within their workload capacity);
- Hypothesis 2. The Principal Warfare Commanders (Anti-Air Warfare Commander, Anti-Surface Warfare Commander, Anti-Submarine Warfare Commander) are able to use currently available systems to prioritise and allocate missions to UxVs, sharing UxV assets amongst themselves with no increase in workload; and
- Hypothesis 3.. A MAPLE based capability could act as a MASC by supporting uncrewed assets operation and can be used effectively for existing coordination functions (Air Resource Element Coordinator (AREC) / Helicopter Element Coordinator (HEC) / Submarine Advisory Team (SAT)) without causing additional conflict with crewed asset operations or additional workload to the existing Component Command Coordinators.

The workshop activity generated insights but could not conclusively answer the questions within the 3 hypotheses. For the second session, the experimental runs were successfully conducted in the Force context, using 2 operations rooms and Exercise Control (EXCON). Three vignettes were used, one relating to carrier strike group defence, one relating to the protection of critical infrastructure; and a third focussed on freedom of access operations; all 3 involved a mix of surface naval platforms and a mix of UxVs, operating across the force. Although there were some issues in the earlier runs, later runs were completed successfully and a number of conclusions were made with respect to both resource co-ordination and co-ordinating the delivery of effect during tactical operations. This Force information environment, which was created with 2 operations rooms and EXCON, was also found to provide a good basis going forwards for the conduct of further Force related experiments. More widely, the experiments highlighted the challenge with sourcing experienced warfare / operations room personnel and a need to test alternative approaches to obtaining participants. This could take the form of requesting Young Officers, or personnel who are attending Collingwood for the Principal Warfare Officer (PWO) course (training pipeline allowing). It may also be worthwhile investigating recruitment of reservists or recently retired Royal Naval (RN) personnel (e.g. from consortia companies).

With respect to future work the team identified that there was a need for an increased focus on developing credible UxV Tactics Techniques and Procedures (TTPs) that can be used within the Force context; this is largely a reflection of the uncharted and ground breaking nature of the research area. Similarly, given novelty and unfamiliar nature of the area, more time in rehearsal and walkthroughs need to be allocated in any schedule.

Moving forwards, the experimental definition is now focusing on the 'Ways of Working' for a hybrid human-robotic fleet. This is exploring ways of working in a Force context comprising:

- Exploration of ways of working during planning and mission execution including crewed and uncrewed assets (incorporating swarms), task to role mapping, level of autonomy in assets;
- Definition of scope of synthetic experiments to investigate comparison of alternative operations room configurations (e.g. distributed vs centralised task conduct) / other options identified during exploration of ways of working;
- Defining objectives, scenario requirements, systems requirements, experimental design, measurement and analysis building on Force scenarios / vignettes and systems already developed within MAPLE 5 Year 2.
- In addition the experimentation will test to ensure that MAS C2 can cater for the deployment of lethal and non-lethal effectors from MAS assets (within Radar horizon). The scope will consider decoy effects and will pull-through any development from other projects to include the relevant Payload Goals added to Maritime Autonomy Framework.

5 Wider MAPLE work

In addition to the MAPLE 5 focus areas outlined above, the team have also been applying learning from earlier studies and experimentation, updating the goal or Persistent Architecture (PA) and developing an implementation model to support a subsequent acquisition programme. To enable the overall programme, the team have also been updating the supporting synthetic environment to enable force aspects to be explored. Finally, in support of wider international goals and the RN's autonomy experimentation programme, the MAPLE team have also been tasked to deliver objectives on a number of large scale international events. This wider work is set out in more detail below.

a. Developing the MAPLE Architecture

The PA was developed during the early phases of MAPLE and was incorporated into the Enterprise Architecture (EA) tool during MAPLE 4. It is continuing to be updated and reviewed, taking into account the studies in MAPLE 5 to include effectors and force issues. The PA is currently partitioned into 11 functional blocks as depicted by the Squad-level Planning centric view in Figure 2. There are hence 11 of these views in the EA model.

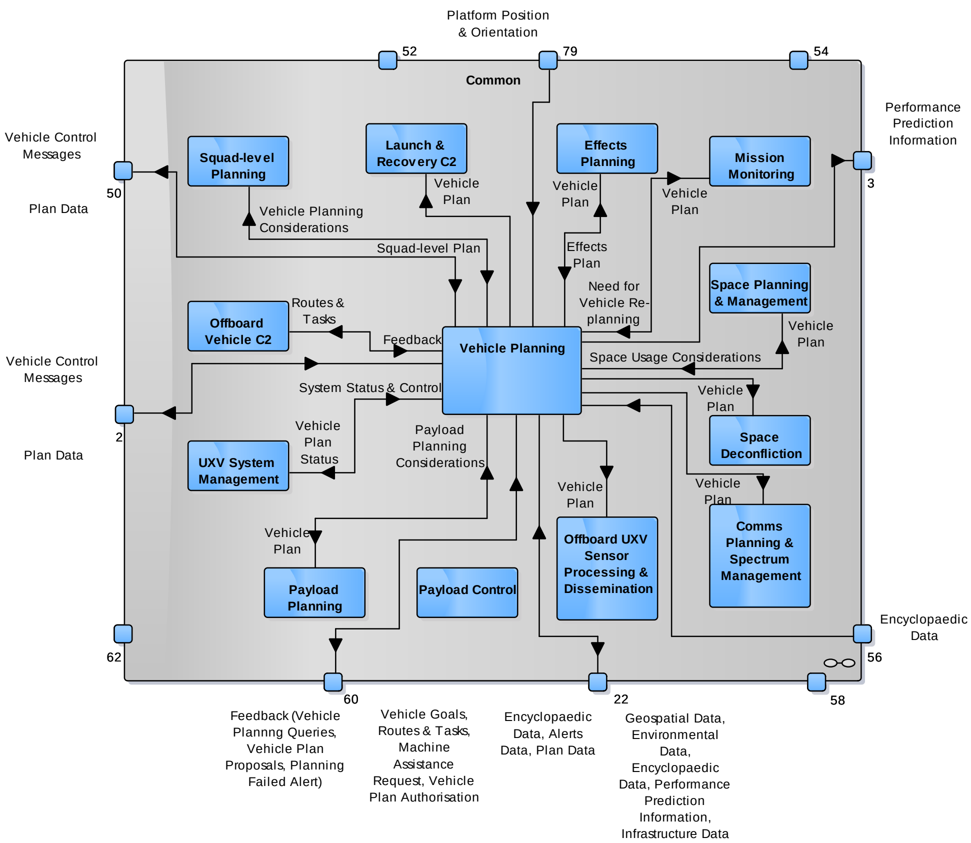

Figure 2: Vehicle planning centric view in the MAPLE PA

The current PA is reasonably mature based on the PA validation exercise conducted during MAPLE Phase 4, however the latter identified the following potential changes, which are now being addressed:

- Combining Squad-level and Vehicle Planning, as these are intrinsically interlinked from an operator perspective;
- Update the Communications Planning and Spectrum Management function and the information flows with the material generated in the Communications Report produced under MAPLE 4 ;
- Update to system / resource management - it was suggested that from an architectural viewpoint this functional block could provide the interlinking mechanism whereby not everything needs to talk to everything else thus reducing the interactions between functional blocks; and
- Consider renaming the Mission Monitoring functional block as Mission Command.

The Technical Studies such as the Force study may not necessarily introduce a new functional block, but will test the ability of the existing PA to accommodate additional functionality and information flows. In addition a further package of work is describing the logical architecture, focusing on describing the autonomy functionality and explicitly the logical connectivity between the functions. This will build on the existing PA model that has been captured in the EA tool using the SysML notation.

b. Generating a functional implementation model

During MAPLE 5, a functional implementation model is being developed and updated to include the physical layout, functional descriptions, interfaces, standards, and the services required in order to deploy the MAPLE capability in the RN surface fleet. The current realisation architecture captured in EA that uses SysML Block Definition Diagrams (BDDs) and Internal Block Diagrams (IBDs), but the intention is to move away from the current specific Company products to generic functionality linked to the functional blocks defined in the PA. The modularity of the generic functionality will be such that they are procurable by MOD; that is the functionality is encapsulated, cohesive and coupling between components is kept to a minimum. The functionality is being clearly defined, with interfaces and services identified.

c. A supporting synthetic environment

Phase 4 of MAPLE introduced a synthetic environment (SE) for use during experimentation and live trials. Thales provided an Outer Synthetic Environment (Outer-SE), based around the Virtual Battlespace 3 (VBS3) Computer Generated Forces capability. The Outer-SE was introduced to stimulate the ACER environment in terms of location, sensor traffic and connected UxVs. This connectivity allows an operational Command Team within the ACER C2 cabin to utilise the ACER realisation architecture during the synthetic experimentation scenarios that are developed.

SeeByte provided an Inner-SE capability, which can travel with the ACER system to live events and enhance levels of experimentation by augmenting live assets with simulated sensors and squads of simulated UxVs. The Inner-SE can also be used to task Neptune MAF simulators providing a capability to experiment with goal based squad planning and mission execution for squads of dynamic high autonomy UxVs. Figure 3 below illustrates the current architecture of the Inner and Outer SEs.

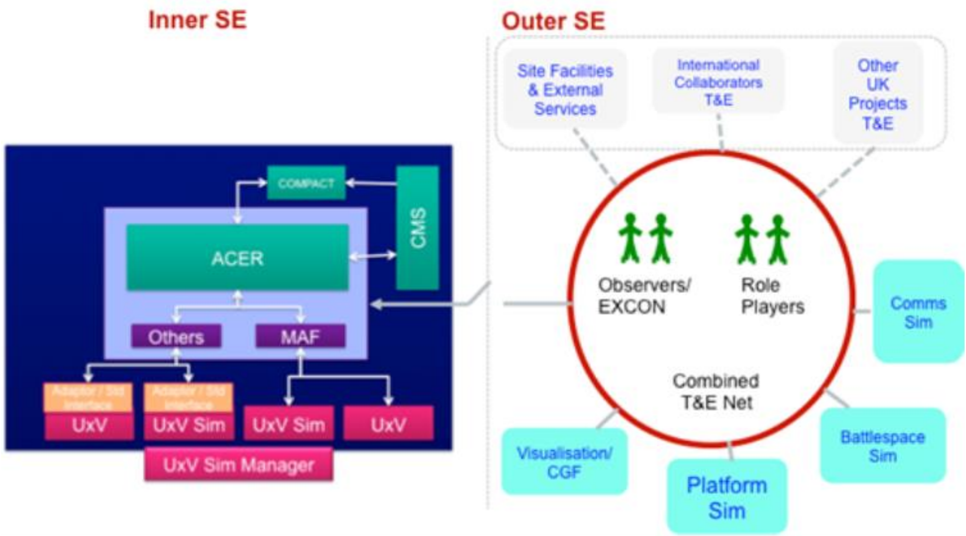

Figure 3: MAPLE Inner and Outer-SE

During the course of MAPLE 5 the Outer-SE has gone through a number of adaptations to meet the need of the HF and technical experiments, including the ability to support a Force context, providing MAS and sensed data into multiple C2 systems. Areas under consideration for modifications to the SE are:

- The provision of multiple 'ownships' (MAPLE 4 has only considered single ship operations thus far);
- UxV handover capability between multiple ships;
- The provision of effectors on UxVs (such as a heavy calibre machine gun mounted on a USV); and
- The provision of AIS in-feed via data distribution service (DDS) messaging (a more generic and extensible version of current capability so that the synthetic AIS data can be received by multiple MAPLE applications).

6 Continuing support to international R&D

As outlined earlier, and in earlier papers, international work, and the path towards ' Interoperability to Interchangeability (I2I)' has been an integral part of MAPLE activity. I2I is an evolving standard that will enable interoperability between coalition nations employing MAS. The aim is for the standard to influence NATO STANAG development. I2I is split into 3 parts:

1. The exchange of plans for MAS operations
2. The transfer of Tactical Control of MAS between C2 nodes hosted on warships that are part of a Force grouping
3. The discovery of squads of assets and their capabilities, to enable 1 & 2.

All 3 parts of the standard are specified in Interface Control Documents (ICDs), but only the planning aspects are currently implemented. I2I is currently a concept but has been successfully deployed at REPMUS 21 (Robotic Experimentation and Prototyping for Maritime Unmanned Systems) in Portugal by the UK MAPLE and US Common Control Systems (CCS).

Most recently this international work has been focused on work in Australia. Building on the successful work undertaken in Autonomous Warrior 2018 (AW18) and their involvement in the NATO Maritime Unmanned Systems Initiative (MUSI), the Royal Australian Navy invited UK particpation in a new event Autonomous Warrior 2022 (AW22). Whilst AW22's wider remit was to demonstrate the latest developments in autonomous technology with particular attention given to the underwater battlespace, the RAN also prioritised progressing I2I, expanding the already proven UK/US linkages to include Australian assets and C2. To meet this request, and as part of separately tasked activity, a small UK team supporting RAN access to the MAPLE interfaces and architecture (through Dstl); and provided a MAPLE deployable capability in Jervis Bay Australia for the duration of the exercise, working to achieve experimental objectives.

The core objectives for the QinetiQ led team at AW22 were:

- To provide a UK MAPLE implementation based on a MAPLE compliant Autonomy Planning Tool (QUASAR) to read/write, and execute goal based plans (GBP); a representative combat management system (CMISE) to read in sensor tracks, collate a Tactical Picture and subsequently promulgate a joint operational picture (JOP) to C2 nodes or MAS assets that require it (over DDS or XML).

- To provide appropriate I2I functionality for the exchange of MAS plans, JOP and sensor data, with the US Common Control System and theAustralian Defence Science & Technology Weapons and Combat Systems Team (DST WCSD) C2 systems.

- To integrate the Australian Ocius C2 capability into MAPLE. The Ocius C2 capability includes BlueBottle uncrewed surface vehicles (USVs) and REMUS uncrewed underwater vehicles (UUVs). The USVs had radar, AIS and ADSB sensor payloads which provide sensed tracks into MAPLE. The UUVs had side-scan sonar (SSS). The goal was to fully integrate the Ocius control system with the MAPLE Data Core (v4.0) and read/write goal-based plans (GBPs) using XML/SOAP, exchanging sensed tracks using the Open Management Group's (OMG) Open Architecture Radar Interface Specification (OARIS) sensor track format (v1.1) and the DDS middleware. The expectation was for the OCIUS GCS to also read the JOP from MAPLE.

These objectives were met in full with the exception of contact data from the UUVs which was not achieved. A number of assets were integrated across the UK, Australian and US C2 environment, including:

- OCIUS BlueBottle USVs (callsigns BBOT-01 to 08)
- PUMA UAVs AE and LE variants (callsigns PUMA-01 to 04)
- Saildrone USVs 01 & 02
- MARTAC T-38 USV
- MARTAC T-12 USV
- Silvertone Flamingo UAV 01 & 02

During week 1 of AW22, the exchange of I2I plans between the UK MAPLE, US CCS and AUS WCSD C2 systems was successfully achieved.The laydown was as shown in Figure 4 with a representative tactical picture at Figure 5. Moreover, following the successful test and integration of the Ocius BlueBottles, MAPLE/ QUASAR was used to command a live mission for the BlueBottles operating for the Australian Border Force out of Broome (NW Australia, 320km from the mainland). This is the first time that MAPLE/ QUASAR has been used to execute missions for live assets (as opposed to during Operational exercises). Below is a screenshot (Figure 6) (kindly provided by OCIUS) of the BlueBottle ("Bluey") on operation under the control of a MAPLE execution using a Point Inspect Goal Based Plan.

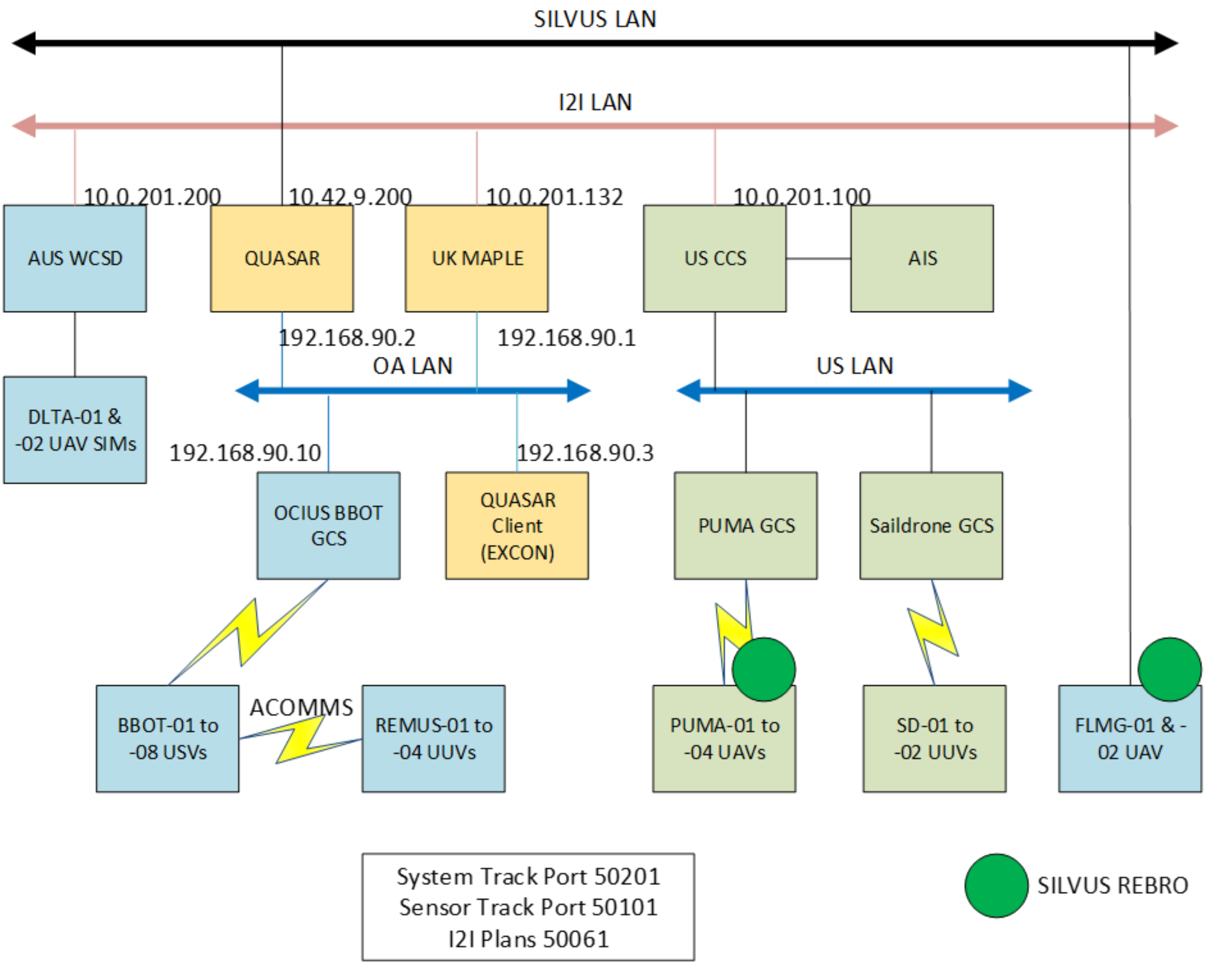

Figure 4: AW22 deployment showing C2 nodes, GCS and UXV Assets.

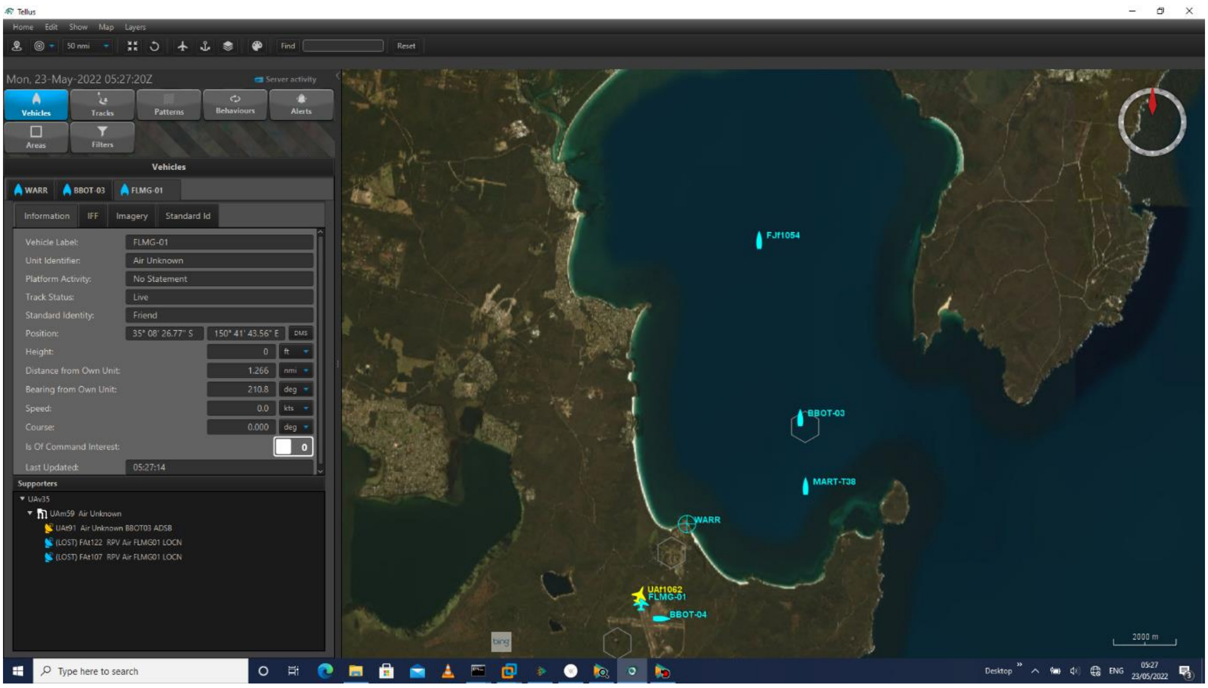

Figure 5: CMISE CMS showing Tactical Picture compiled during AW22.

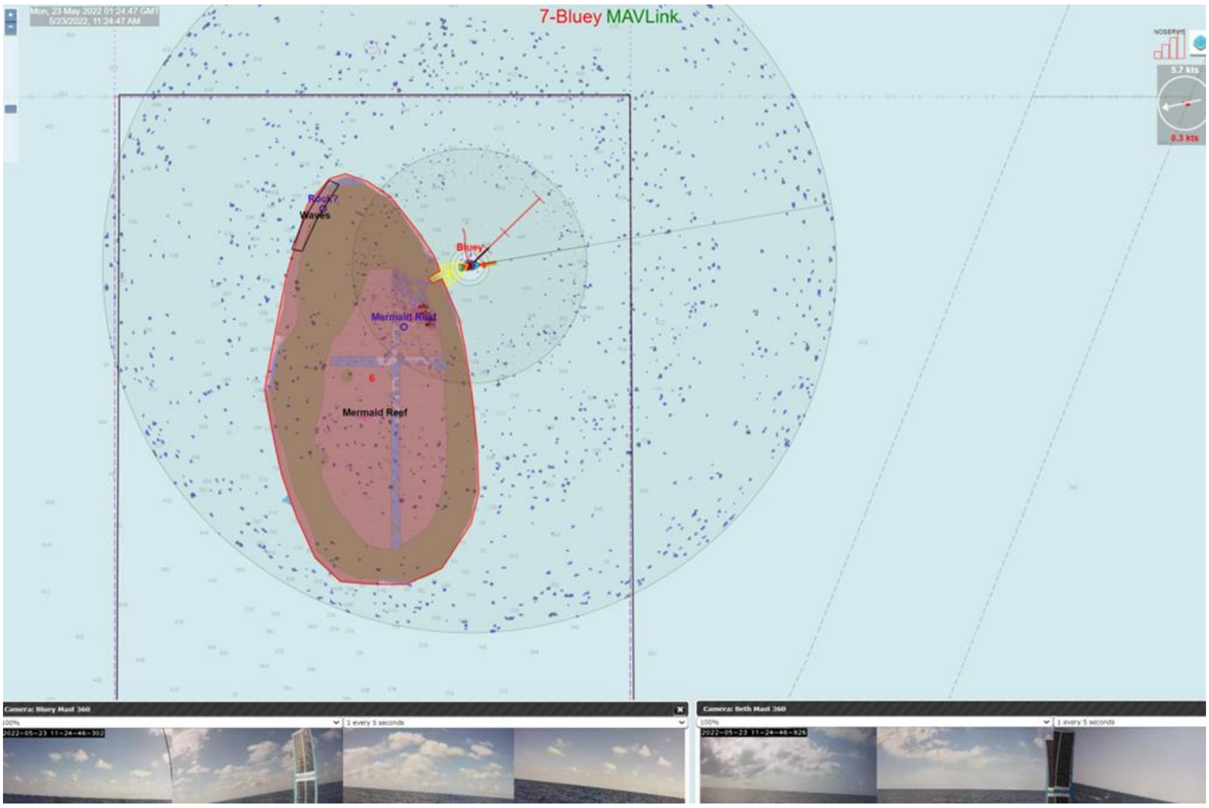

Figure 6: Screenshot of "Bluey" on operation under the control of a MAPLE (courtesy of Ocius).

Overall, AW22 achieved real progress in the conduct of continuous international experimentation in the MAS domain. Beyond the expansion of I2I and the integration of new assets, international cooperation and planning for future activities was discussed in the context of Australian involvement and how this may support the RAN's overall RAS-AI strategy. This included potential future collective efforts across Australia, the UK and US teams in harmonising objectives for experimentation activities.

7 Conclusions

With MAPLE exploitation now being progressed by the NSN programme, the fifth phase of MAPLE is now returning to its roots, pushing R&D boundaries, exploring the employment and C2 of uncrewed assets across the maritime force. Wider work is exploring the tasking of MAS hosted effectors and addressing the means by which I2I can be secured. The twin track approach to MAPLE has been sustained, with further updates to the validated Persistent Architecture and other core enablers such as the MAPLE SE, alongside a busy programme of synthetic and live experimentation. Force level co-ordination of MAS assets is very much in its infancy and further development and experimentation is planned to develop TTPs and explore key hypotheses.

Looking forwards, the MAPLE team are already engaged in the planning for REPMUS 23 in September.

References

1. R Scott, ‘Distributed by design: RN divines for the navy after next’, Janes Navy International, 11 Oct 21
2. R Scott, ‘RN seeds plans for Naval Strike Network as digital backbone’, Janes Navy International, 21 Sep 21
3. P Smith et al, ‘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’, EAAW 2021.
4. P Smith et al, ‘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’, INEC 2020
5. P Smith et al, ‘Securing interoperable and integrated command and control of unmanned systems – validating the UK MAPLE architecture’, EAAW 2019
6. P Smith et al, ‘Securing interoperable and integrated command and control of unmanned systems – building on the successes of Unmanned Warrior’, INEC 2018 Glasgow
7. P Smith et al, ‘Achieving integrated command and control of unmanned systems – the Unmanned Warrior experience’, EAAW 2017 Bristol
8. P Smith et al, ‘Architectural developments to enable the integration of unmanned vehicles into the maritime system of systems’, INEC 2016 Bristol
9. 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