Maritime Uncrewed Air System Solution Architecture

E B Timpson* BEng(Hons) MIET

** QinetiQ, UK*
* Corresponding Author. Email: etimpson1@qinetiq.com

Synopsis

The Royal Navy's Future Maritime Aviation Force (FMAF) programme calls for widespread fielding of Uncrewed Air Systems across the surface fleet, with a specific focus on future carrier aviation. Leveraging the investment in crewed aircraft and the carriers themselves, FMAF seeks to achieve mass, tempo and risk reduction by teaming crewed assets with large numbers of uncrewed systems. The Vampire project and early derisking work are at the vanguard of this programme, with a likely future focus on development and prototype deployment of the air systems, software and network to achieve the vision. This paper explores a potential roadmap, the likely features of the mission systems architecture, the implications for ship integration and some of the key risks. Noting the desire for widespread deployment across platforms, the paper will conclude with ideas for achieving a modular, podded and integrated UAS solution.

Keywords: Hybrid; UAS; UAV; Attritable; Integration; Maritime systems

1. Introduction: Uncrewed Air Systems

Uncrewed Air Systems (UAS) and in particular Attritable air systems have enabled the drive towards achieving combat mass and will changed the way military operations are conducted. Although no definition has been agreed, in military terms attritable means trading off reliability and maintainability for cost (John Colombi, 2017). This is only achievable when the person(s) is removed from the system, as losing the asset no longer means potential loss of life.

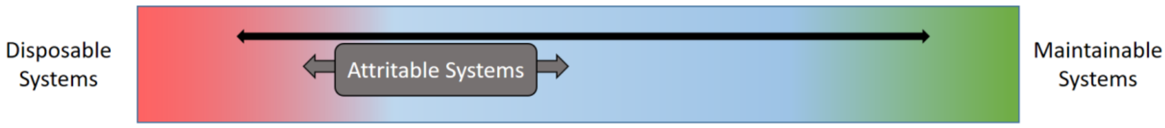

Figure 1 Attritable Systems located on 'Continuum of Maintainability'

The cost of uncrewed systems varies vastly, with a United States Air Force MQ-9 Reaper drone costing approx. $32 million US Dollars (Hambling, David, n.d.), whilst the ubiquitous DJI Phantom costs approximately $1950.00 US Dollars. Although there is limited benefit in comparing these systems, as examples they illustrate the cost range for UAS, a range which does not exist to the same extent with crewed Air Vehicles (AV). Defence budgets tend to be significant percentages of any given country's spending, but even so, no nation can sustain large losses of assets such as MQ-9 on an ongoing basis.

The Future Maritime Aviation Force (FMAF) is the Royal Navy's vision for using uncrewed and autonomous systems to supplement existing crewed air platforms. A number of technology and innovation teams within the Royal Navy are seeking to collaborate with industry partners to help integrate technology faster. HMS Prince of Wales was identified as a testbed for un-crewed aerial vehicles by the First Sea Lord (George Allison , 2020). FMAF is not about a single platform delivering all requirements, but rather it seeks a balanced fleet of UAS, operating seamlessly with crewed vehicles. Each of these UAS are anticipated to possess characteristics suited to their use case, but working as a set to deliver increased operational effectiveness and availability to the warfighters.

Author's Biography
Edward Timpson is a Principal Systems Engineer at QinetiQ. Specialising in trials and experimentation, his previous career was 11 years on Royal Navy Submarines as a Weapons Engineer. Now leading on developing novel technology solutions within QinetiQ Future Systems, Robotics & Autonomy team.

2. Current Capability

The Banshee Jet80+ is a high speed Remotely Piloted Air System originally designed to be used for weapon system testing and Air Defence Exercises (ADEX). The Jet80+ is a composite delta wing monoplane with two rear mounted JetCat™ P400+ engines, producing 870 N total thrust. Operated in a range of environments, the Jet80+ is parachute recovered to land or sea. By design the Jet80+ is attritable with components being interchangeable between air vehicles, and airframe modifications being completed with limited tools.

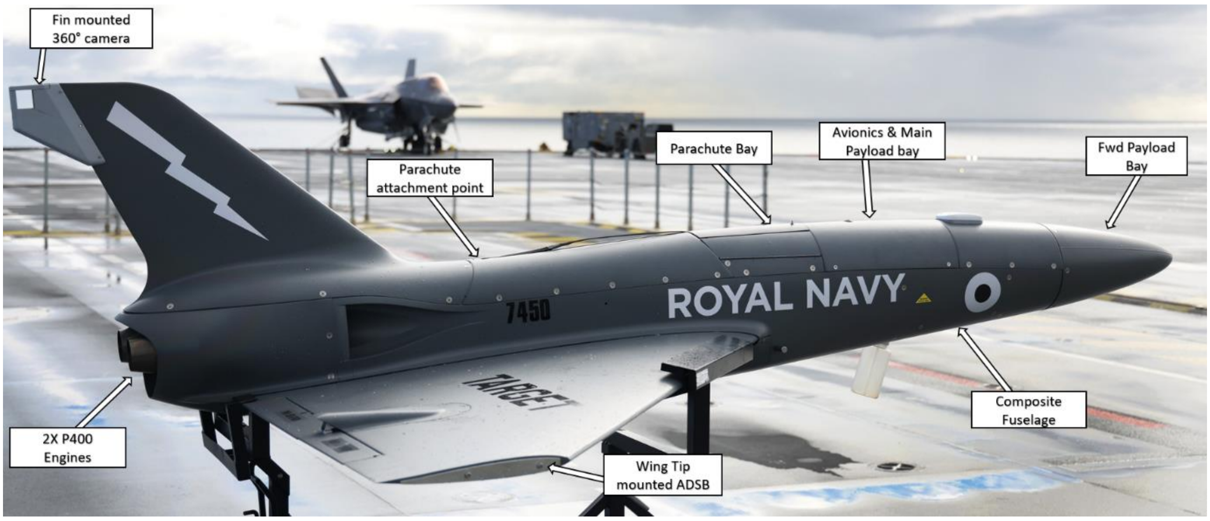

Figure 2: Banshee Jet80+ located on HMS Price of Wales flight deck. *Image Crown Copyright 2021*

Figure 2 shows the available payload spaces and major components of the air vehicle. The Jet80+ is controlled using the Combined Autopilot and Surveillance Payload Avionics (CASPA) system developed by QinetiQ Target Systems (QTS), and each air vehicle is piloted remotely via the Merlin Ground Control Station (GCS) also developed by QTS.

Table 1 - Banshee Jet 80+ performance information

Performance Characteristic	Jet 80+
Speed	50-200m/s, (97-389Kts)
Endurance	>45 MIN
Altitude	5m-10000m, (16-32,000ft)
Manoeuvrability	6G Sustained
Range	>100km, (53NM)
Payload Capacity	25kg (55lb)

3. Project Vampire Demonstration

The intent of this proof of concept trial was to be the first step in a multi stage development roadmap undertaken by the Royal Navy to address a number of capability problem sets. Low cost attritable UAS were identified as offering a prototyping pathway with the potential to address many of the problem areas, in particular this first demonstration focused on the challenge of delivering training to enable operational readiness of ships and aircraft whilst deployed. The ability to deliver a Military Owned, Military Operated organic training capability whilst deployed was identified as a significant achievement and step forward for the Royal Navy (Bernice Healey , 2021).

3.1. Trial Details

The trial was conducted during Exercise Joint Warrior 21 and the area of operations was within the Ministry of Defence (MOD) Hebrides range off the west coast of Scotland. The MOD Hebrides range provided a sanitised airspace and sea surface to ensure segregation from the Jet80+ area of operation.

The AV were launched from the flight deck using a pneumatic catapult and controlled and monitored throughout the sortie from a mobile GCS located onboard HMS PWLS. In essence the AV was treated as a crewed AV with regards to permissions to launch, with the Flight Deck Officer (FDO) providing final permission to the Remote Pilot in Command (RPIC).

On completion of each sortie the AV were recovered to the MOD Hebrides range. Sea recovery was excluded from the trial to reduce complexity, but a series of organic recovery solutions are being currently pursued.

3.2. Sortie Details

3.2.1. Sortie 1 – Air Defence Exercise

Sortie 1 consisted of a single Banshee Jet80+ launch, conducting multiple attack profiles as a representative Red Air threat. This aimed to provide operator training for the ships company with a view to a future organic task group training capability. This use case is well proven with Banshee Jet80+ with active and passive Radar Cross Section (RCS) augmentation devices regularly flown.

3.2.2. Sortie 2 – Dual Air Vehicle Operations

Sortie 2 consisted of a sequential launch of 2 AVs. The priority for the sortie was demonstration of multiple vehicles operating simultaneously. Once both AVs were airborne, a formation flypast of HMS PWLS was conducted before a single vehicle was recovered to range. The other AV then delivered a number of ADEX profiles before recovering to range, successfully completing all planned sorties.

4. Future Systems Architecture

UAS are developing at an never before seen pace due to greater availability of Commercial Off The Shelf components and reduced costs of items that would normally be the preserve of established militaries. This availability is enabling new systems to enter the market at an increasing pace, offering increasing capability. The challenge for any force is to take advantage of this pace to retain the technological advantage, in essence ‘Adapt or be left behind’. If the FMAF program seeks to utilise the best of this technology within a System of Systems (SOS), particular attention must be paid to;

4.1. Mission Tasking & Command & Control (C2)

With every new manufacturer or iteration of UAS comes a new C2 system requiring integration, testing and incorporation. This process offering of vertically integrated solutions is driven by Original Equipment Manufacturers (OEM) who rightly want to protect their investment of time and money into developing proprietary systems; but this approach does not deliver advantage to the warfighter as it drives up operator numbers, increases cognitive loading and incurs a substantial training burden. As such, this product driven methodology is becoming increasingly outdated and thought leadership in this area is approaching the problem in a different way.

The United States Unmanned Maritime Common Control initiative (David B Larter , 2019) looks to create a common framework structure, with a common user interface and components to enable integration and testing across all platforms. Ultimately this approach seeks a future state in which an open software architecture supports evolving requirements and scale in an agile manner.

The Royal Navy has taken significant steps towards open interfaces with programs such as Maritime Autonomous Platform Exploitation, and proven this military owned system in operational experimentation exercises such as Robotic Experimentation and Prototyping Maritime Unmanned Systems 21. These demonstrations have demonstrated multi domain interoperability of multiple NATO assets, and exemplifies how essential this requirement is for future Mission Taking and C2 systems.

4.2. Modular Autonomy & Payloads

4.2.1. Artificial Intelligence

Inclusion of Artificial Intelligence (AI) to automate some or all operations of a UAS enables them to become more than just remote control vehicles. It also is key to facilitating operators to direct desired effect instead of determining actions to produce effects. AI enables the development of intelligent systems with increasingly capable mission related behaviours, including potentially swarming, moving beyond the 'Dull, Dirty and Dangerous' tasks uncrewed vehicles are already tasked with.

The scope and the scale of intelligence system required is dependent on the use case and hosting AV. Longer endurance, higher value AV which are conducting persistent ISR operations will require a different approach to Suppression of Enemy Air Defence swarms.

4.2.2. Flexible Payload Integration

The integration and testing of new payloads is key to maintaining technological advantage. To facilitate this rapid test and evaluation, inclusion of a flexible payload bay into the AV with a defined space envelope, power supply, interfaces and data protocols is essential. Sharing the details of this payload envelope with small and medium sized enterprises, academia and traditional defence primes would enable them to develop demonstration devices that can be tested as Minimum Viable Products or de risk components of a larger system.

4.3. Communication Systems

Secure, resilient and coherent communication architecture across multiple channels is required to support uncrewed systems operations. These channels are;

- Vehicle Control
- Payload Control
- Task Group level data exploration network

Existing messaging infrastructure i.e. Link 16, Link 22 must be utilised to enable data gathered to be disseminated across the nodes. The proliferation of this data allows commanders to make decisions in near real time and effectively outthink the enemy. Increasing the number of nodes that can receive and contribute within a network proportionally increases that networks value according to Metcalfe's Law (Metcalfe's Law, 2019).

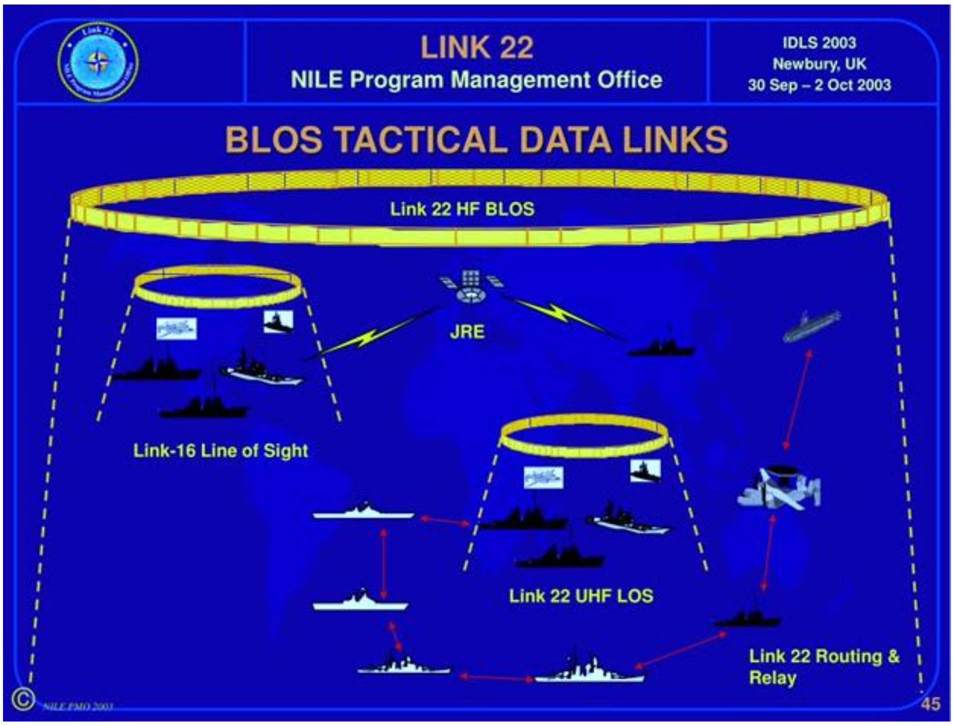

Figure 3 Visual representation of Link 16 & Link 22. *Image NILE Program Management Office*

Within a system of systems, bandwidth availability will always be limited therefore relying on centralised data centres has inherent limitations for the system. Payloads producing high volumes of data i.e. electro optics or synthetic aperture radars must effectively use the available communication networks whilst prioritising which data is essential for transmission to the operator.

Naval Strike Network (NSN) looks to deliver a pan-navy solution for information architecture, enabling uncrewed vehicle operations alongside major warships with an increasingly distributed and disaggregated fleet.

Operations within denied environments is a challenge for UAS which currently rely on continuous control. A combination of the mission planning tools and collaborative autonomy to overcome this lack of communications enables completion of certain use cases, however direct operator interaction is still currently required to deliver lethal effect according to established rules of engagement.

5. Use cases

A number of use cases for maritime UAS have been proposed and developed in recent years (Brien Alkire, James G.Kallimani, Peter A.Wilson, Louis R.Moore, 2010), and these use cases are being increasingly proven within operational theatres. As operators get their hands on these vehicles, so more, increasingly novel use cases are developed through action. Many of these use cases cannot be devised by use case development based on tradition crewed systems. The systems architecture must have sufficient flexibility in its design and employment to facilitate these new use cases or have some facility to accommodate new features, many of which haven't been conceived yet.

5.1.1. Threat Representation & Training

This is by far the most developed use case, especially for the Jet80+ system and has been conducted within MOD ranges for over 30 years. The ability to conduct operator training against an uncrewed target system with a representative payload, and also complete live fire exercises end to end weapons system tests is essential to operational readiness of a platform. Large live fire exercises like Formidable Shield 21 (AT SEA DEMO / FORMIDABLE SHIELD 21, 2021) have utilized a range of aerial vehicles to deliver operational training to the Royal Navy and partner Navies.

The ability to deliver live operator training for the Royal Navy has been delivered by No. 736 Naval Air Squadron operating the Hawk T1 aircraft. This capability has been retired in early 2022 with no replacement, which opens the window for an uncrewed platform to provide a cost effective alternative.

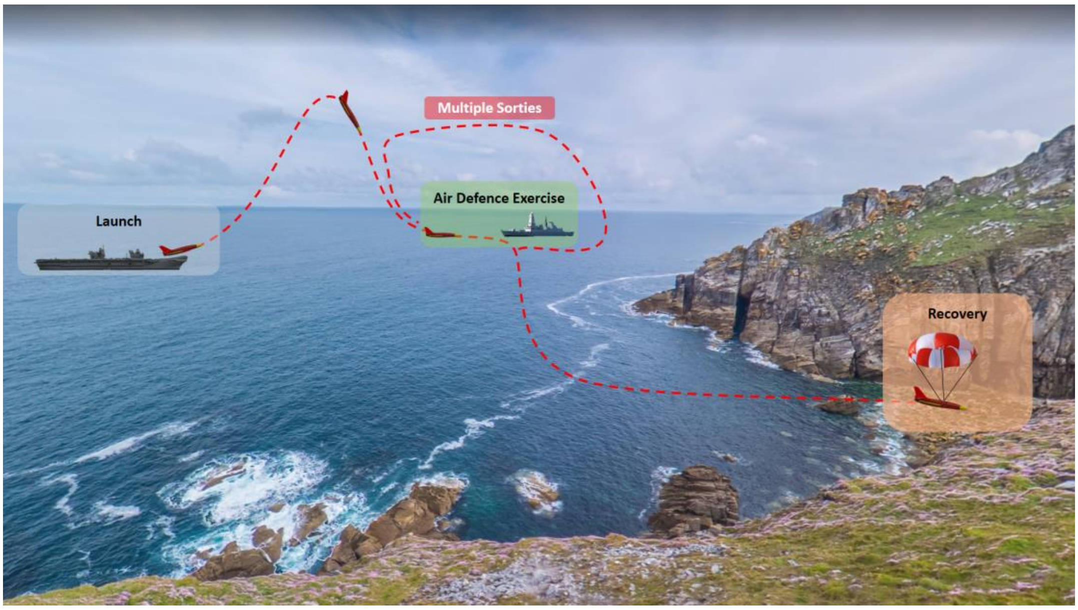

Figure 4 Use case ADEX with recovery to land

Currently this use case relies on the ability to recover the AV to land which means training locations are limited to ranges. The capability to conduct live training outside of the bounds of a fixed range would provide flexibility whilst forward deployed and conduct training against representative threats in areas of operation. This facility will enable rapid Tactics Development through adapting threat profiles or emulation based on intelligence gathered whilst deployed.

5.1.2. Counter Offensive/SEAD

The ability to deploy UAS that can provide seduction or Electronic Warfare has been recently proven through the Rapid Capability Office (RCO) of the Royal Air Force (RAF) (Joseph Trevithick , 2020). This basic principle of making a low value asset look like a high value asset which can be achieved through simple passive Radar Cross Section (RCS) augmentation. This basic deception is ideally suited to uncrewed systems that are expendable and can be launched in swarms.

It could be conceived that a counter offensive AV could act as a quick reaction medium range interceptor for incoming threats when the carrier is operating in higher readiness states. AV loaded onto the launcher and prepped with RPIC closed up at the GCS, ready to launch to deliver visual confirmation, seduction and interception as required.

5.1.3. Offensive

Recent conflicts have been a clear demonstration of the effectiveness of loitering munitions and low cost attritable AV (Brennan Deveraux, 2022). The ability to provide flexibility to commanders on the ground with loitering munitions has been invaluable. Although not a replacement for traditional cruise missile systems, the attritable UAS gives the ability to conduct precision strike missions, especially against targets with limited duration visibility e.g. when intermittent radar is used. The UAS can loiter in an approximate area of interest until target is detectable before engaging.

5.1.4. Co-operative ISTAR Support

Airborne Intelligence, Surveillance, Target Acquisition and Reconnaissance (ISTAR) is a key military capability which has changed significantly in delivery over the past decade. UAS now conduct the majority of ISTAR missions, however this is currently land based.

Delivering this capability from a sea launched AV enables radar contacts to be quickly classified without deploying crewed assets, thereby enabling the crewed assets to be utilised elsewhere in support of the operation. The ability to conduct airborne early warning is a persistent operation that could be achieve by UAS, then tasking additional UAS swarms to interrogate and return information for command to make a decision.

The ability to deliver distributed sensing through swarming drones enables single points of failure to be removed.

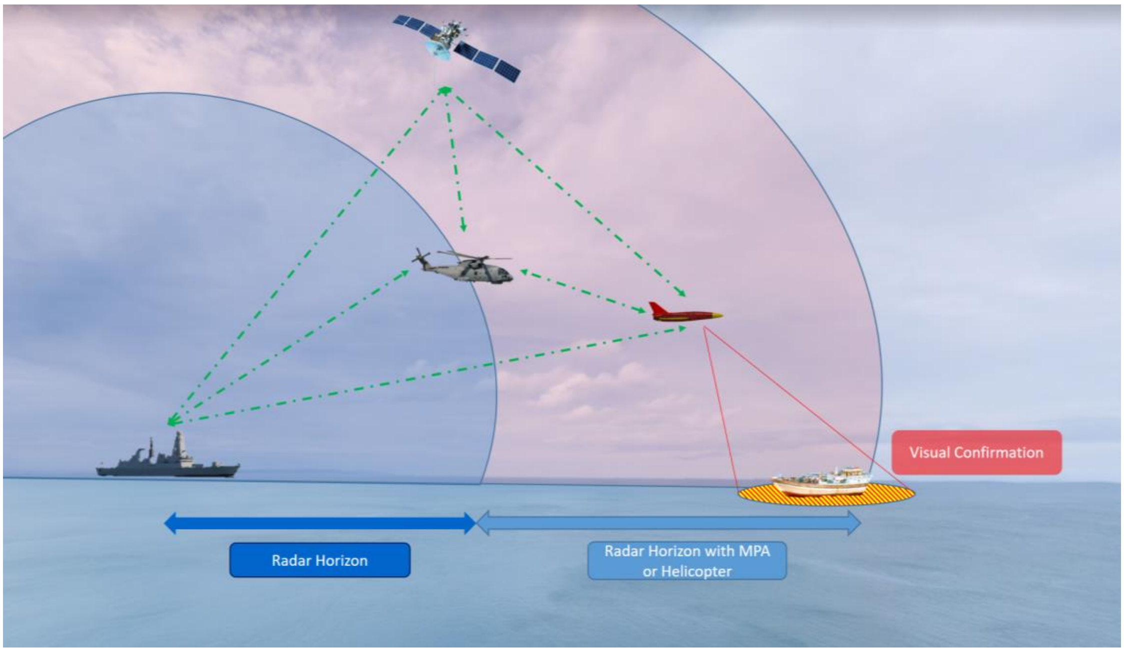

Figure 5. UAS launched from vessel and handed over to air asset to provide visual confirmation of radar contact

Up threat metrological data gathering to inform radar range prediction software is essential to maintian a range advantage for surface vessels. UAS offer the ability to gather this data at significant range without utalising crewed assests.

6. Podded Solution

The FMAF vision extends beyond the carriers and the RN has ambitions around UAS capability across the whole fleet, As such modular deployment of UAS is highly attractive, The Persistent Operational Deployment Systems (PODS) announced at DSEI21 (Richard Scott , 2021) recognised this clear drive for modular capability development. This ability to rapidly add UAS capability to a common platform, such as Type 31, Type 32 and Type 26 is a core principle of the Banshee based solution.

Figure 6. Banshee Jet80+ fuselage shipping container racking system

During Project Vampire, the capability demonstration was delivered from four 20ft shipping containers. These containers are easily transportable by civilian contractor and military logistics teams alike. One container was modified for use as the UAS control centre but the remaining three were standard.

To make PODS a genuine capability enabler the systems need to ‘Plug and Play’ with a host vessels Mission Planning & C2 systems with little or no integration time required. This ability will enable the PODS capability to be deployed rapidly and embarked to deliver one or all of the use cases identified in section 5.

7. The Development Roadmap

The multi-faceted nature of maritime UAS means road mapping development is complex and a systems of systems approach is necessary. Experimentation and demonstration to provide feedback throughout the development spirals is essential. In addition to addressing C2, modular autonomy and payloads and communications, the Banshee roadmap is also exploring the following areas which are seen as key challenges.

7.1. Ship Integration

The contract for the delivery of the Queen Elizabeth Class (QEC) Carriers was announced in 2007, and the first deployment of UAS under project Vampire was 14 years later. During that period of time significant steps forward have been made with UAS technology, but the QEC Carrier has been focused on becoming operationally ready for and delivering traditional crewed operations. Deck operations and the process for approving launch are two particular examples of challenges exposed during project Vampire.

In order to begin to integrate and operate increasingly complex UAS, the ship must adapt to accommodate these new systems and more importantly update procedures.

7.2. Launch & Recovery Systems

The potential use cases described in section 5 fundamentally rely on the ability to launch and recover the AV from a vessel.

7.2.1. Launch

The launching system used under Vampire are only suitable for vehicles upto 500kg and as weight increases the launch speed decreases proportionally. This system is ideal for the 100kg of Banshee Jet80+ but due to the range of AV planned under FMAF, a more significant system would be required. February 2021 the MOD issued a Request for Information (RFI) to industry to assess the state of electromagnetic launch and arrestor technology available for fitting to the aircraft carriers. The associated weight rating of upto 24,949kg indicates the scope and scale of UAV intended to be operated within the FMAF.

Figure 7 Banshee Jet80+ loaded onto Robonic KONTIO launching system. *Image Crown Copyright 2021*

Although launching is relatively well understood operation given the extensive understanding of airflow patterns across the deck of the QEC carriers, the permission process for releasing an UAV requires procedural definition. The RPIC will likely be below decks during the launch and therefore unable to line of sight receive permission from the FDO without a camera system.

To achieve combat mass with the AV, it is important to get multiple AV into the air simultaneously. Given the potential weight rating of the electromagnetic launch system, it would be possible to launch multiple vehicles in a single sabot which would enable this. The loading system for the rail must enable rapid transfer from ground trolley to launch rail, treating the AV more like a missile system than a traditional crewed AV.

7.2.2. Recovery

Over the history of maritime aviation there have been a number of inventive recovery ideas, but fixed wing, high speed UAS pose a particular problem due to the forces involved compared to that of a lightweight propeller driven UAS.

The risk to life of a UAS flying over open ocean is limited, but to recover the UAS it has to come into close proximity and ideally land on a crewed system i.e. the launch vessel or another vessel supporting the operation. To achieve this, the UAS has to have sufficient navigational accuracy and system redundancy to consistently achieve the recovery. Navigational accuracy and system redundancy are however two of the most expensive elements of any AV, crewed or uncrewed. The affordability of any future attritable system will have to be balanced against the requirement to recover onto a crewed vessel.

The systems used to conduct precision landings for crewed AV to ships are complexed and the decision about which of these landing aids could be used must be identified early or an alternative system proposed. UAS OEMs will be inclined to provide a proprietary system for recovery aids, but given the range of AV proposed under FMAF, a single system would be preferential.

7.2.3. Regulations

Currently within the UK the regulations for operation of UAS are lagging behind the technology. Operation requires either segregated airspace or specific pre-approved air corridors. Often overlooked, this development of regulation with the Civil Aviation Authority (CAA) and Military Aviation Authority (MAA) is critical to the development roadmap.

8. Conclusions

The Royal Navy is focused on being a leader in UAS technology, and this ambition means delivering and thinking differently. Discrete capability demonstrations are important tools to understand challenges operating new and novel systems from exiting platforms, but the AV is just an asset at the end of the operational chain, delivering effects. The fundamental challenges that require development are the C2 and communication structures that form the foundation of any capability. These systems need to be sufficiently simple to allow large numbers of operators to be trained easily and inexpensively on, and maintainable to ensure operational effectiveness.

NSN is currently in its early development as the digital backbone that will support the Royal Navy. This system of systems has the potential to provide solutions for a number of the points raised within this paper, but initial architectural design will be key.

The development roadmap for FMAF capability must be informed by enabling programs such as NSN. Focusing on capabilities rather than platforms, bringing together the best of defence to solve this complex problem which has potential to utilize UAS to deliver significant operational advantage, keeping sailors and aircrew out of harm's way.

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