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From UMS to Full Autonomy; Experience from a Complex Warship Programme

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SUMMARY

The UK's Type 31 Frigate, an ARROWHEAD-140 variant, has been designed to reduce the number of personnel required in the Ship's Company, delivering the required operational capability whilst ensuring personnel safety and supporting personnel retention. The design adopts the latest high technology readiness level (TRL) solutions, such as the first use of the UMS notation in a Royal Navy Frigate and capable equipment with reduced maintenance requirements.

The paper will explore critical design features observed during the development of a lean crewing solution in a delivery programme, providing insight in future design effort and the adoption of technology solutions that enable trade-offs between cost, functionality and complexity on the path to increasing levels of platform autonomy.

NOMENCLATURE

1SL	First Sea Lord	RCS	Radar Cross Section
AESA	Active Electronically Scanned Array	RDN	Royal Danish Navy
AH-140	ARROWHEAD-140	RN	Royal Navy
CIWS	Close In Weapon System	RoE	Rules of Engagement
CMS	Combat Management System	SCC	Ship Control Centre
DEW	Directed Energy Weapon	TDL	Tactical Data Link
EO/IR	Electro Optic / Infra-Red	TRL	Technology Readiness Level
FOST	Fleet Operational Standards & Training	UMS	Unattended Machinery Space
GaN	Gallium Nitride	URN	Underwater Radiated Noise
HADR	Humanitarian Aid & Disaster Relief	UUV	Uncrewed Underwater Vehicle
LCS	Littoral Combat Ship	UxV	Uncrewed Vehicle
RAN	Royal Australian Navy	VLS	Vertical Launch Silo

1. INTRODUCTION

Many navies are experiencing difficulty in generating and retaining the required number of trained and experienced personnel to operate their warships. Data available confirms the number of personnel has reduced over recent years due to a combination of outflow from the service and a diminished recruit intake. This is the situation that both the Royal Navy (RN) and the Irish Naval Service, amongst others, are currently experiencing as shown in Figures 1 and 2. The availability of trained and experienced personnel is an issue that the Naval Service has been working to resolve for several years, as this quote from the RN First Sea Lord (1SL) in 2002 attests:

> *"A manning structure that is struggling in 2002 will certainly not meet the challenges of 2015. The status quo is therefore not an option and the need to change for the better is pressing"*
>
> Admiral Sir Nigel Essenhigh GCB, DL, First Sea Lord; January 2002 [1]

As has been widely reported, the navies included in the Figures below have recently withdrawn platforms from service, struggled to re-generate platforms from upkeep periods or kept platforms uncrewed alongside as a result of the reduced numbers of trained personnel available. This situation is not unique to the RN and Irish Naval Service, with many others such as the Royal Australian Navy (RAN) also grappling with similar issues. With navies still required to deliver outputs and operations as directed by government policy, this situation is not sustainable in the long term.

Warships have traditionally been reliant on large numbers of personnel, with RN battleships from the Second World War requiring a war complement of almost 2,000 crew and even the ~2,500 tonne RN LEANDER Class Frigates operating in the early 1990s with ~260 personnel. Against a background of reduced numbers of personnel available, a desire to remove personnel from the hazards of combat operations where possible and in order to take advantage of reduced in-service personnel-related costs there is a concerted drive by many navies to reduce the complement required by future warships as part of the overall solution. In order to deliver a feasible solution a number of considerations should be taken into account, with a selection of these discussed within this paper.

The Type 31 Frigate is a case study into the development of a lean complement solution that remains realistic for a class of General Purpose Frigates that are currently in build for the RN, matured over a number of years. This paper includes example aspects and systems fitted in the Type 31 platform that were key in the development of this complement solution, together with a comparison to the 'parent' IVER HUITFELDT class design solution. All of the

Type 31 Frigate features and attributes discussed that deliver a lean complement solution for the RN are also inherent in Babcock's ARROWHEAD-140 (AH-140) product, to support other navies experiencing similar constraints on personnel.

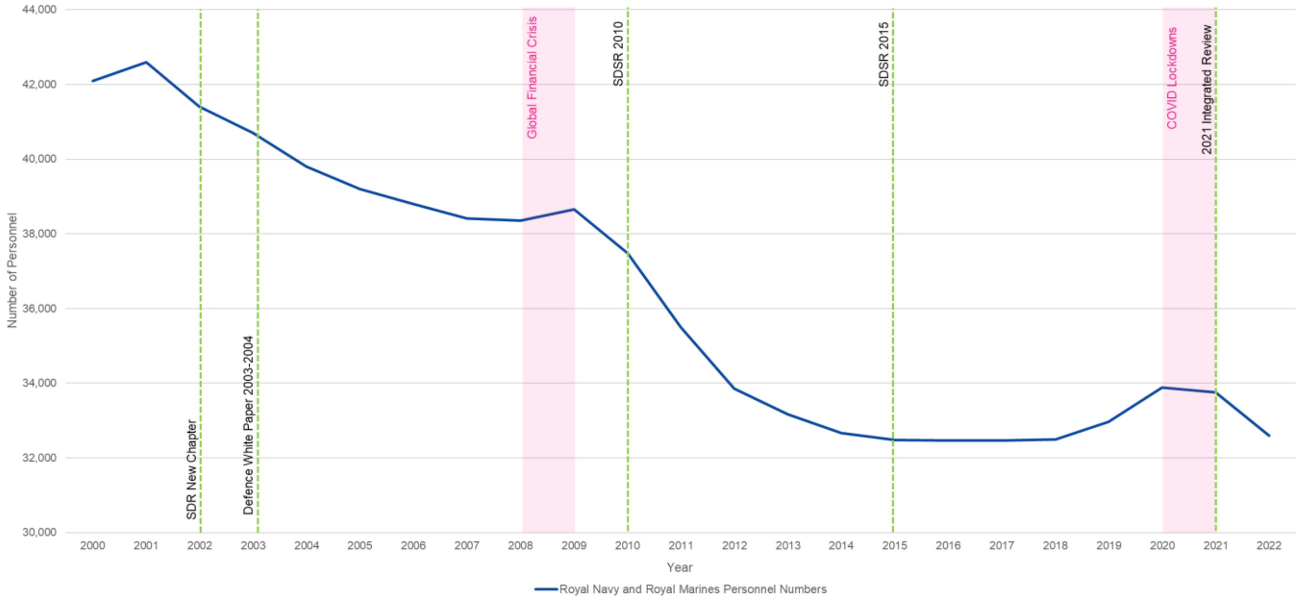

Figure 1. Royal Navy and Royal Marines Personnel Numbers 2000-2022 (data extracted from [2]).

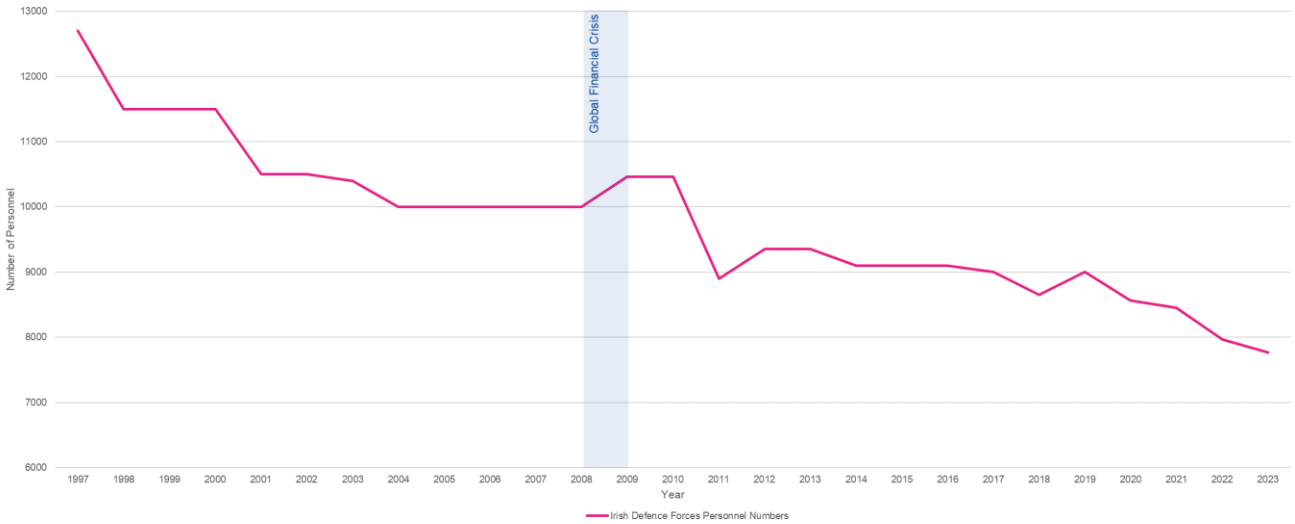

Figure 2. Irish Defence Forces Personnel Numbers 1997-2023 (data extracted from [3]).

2. PERSONNEL CONSIDERATIONS

Warships are sent to sea to deliver operational capability against a series of defence outputs that are defined by government policy. The capability of a warship itself comprises of a number of elements or 'abilities', each as critical as the others, and are currently influenced or enabled by the number of personnel onboard. Some examples of these elements, and how they relate to the number of personnel, are described in the section below.

- Susceptibility. This covers a range of aspects that include the number and configuration of hardkill effectors (missiles such as Sea Ceptor or SM-2, Close In Weapon Systems (CIWS), Turrets or Directed Energy Weapons (DEW)), softkill effectors such as decoys, and sensors such as radars and sonars. Susceptibility also covers the signatures of the platform, or reducing the ability of an enemy to detect and target the ship; this includes radar cross section (RCS) and underwater radiated noise (URN). Personnel are currently required to deliver this element of capability; as operators scrutinising the picture provided by the sensors or targeting the weapon systems, or maintaining those same weapons, sensors and the supporting infrastructure so that they are available when they are needed.

- Survivability. This covers the ability of a warship to mitigate the effects of being hit by enemy weapons, in order to carry on functioning while also preserving life onboard as far as possible. It is naive to believe that the hardkill and softkill effectors fitted will mean a platform is invulnerable to damage from enemy action, and key design effort is placed on providing aspects such as blast, shock and armour protection, and increasing the resilience of systems onboard so that they continue to function if parts of the system are destroyed.

- Recoverability. This covers the ability of the warship to react to the damage sustained and restore capability to remain in action or to counter follow-on attacks. This includes measures in the platform to mitigate the spread and effect of damage, such as fire-fighting and flood repair actions. This element of a warship's capability currently draws heavily on personnel, with these actions requiring large numbers of people to successfully prosecute.

- Lethality / Mission Capability. Covering the systems fitted to launch land strike cruise missiles, anti-ship cruise missiles or the operation of offboard vehicles as examples, this element of capability delivers the wider operational effect of the warship. Facilitated by the installation of equipment such as the Mk41 Strike Length Vertical Launch Silo (VLS) and launch & recovery systems for boarding craft this enables the warship to carry out maritime interdiction operations, combat operations at sea and influence events ashore, as examples.

A true warship requires a balance across all elements within the bounds of platform margins available; this generally favours a larger warship due to the expanded inherent margins. Unfortunately 'capability analysis' has a tendency to descend into a lone comparison of the weapon and sensors fit, to the neglect of the other critical aspects. All aspects must be considered when examining both the true capability of a warship and the number of personnel onboard in the effort to reduce this number or remove them completely.

When it comes to warship design, globally deployed navies like the RN place significant emphasis on features to support survivability and recoverability of the platform. Experience of and lessons learned from both combat in the missile era, including the Falklands Conflict (Figure 3), and peacetime incidents, such as the grounding of HMS NOTTINGHAM and flooding of HMS ENDURANCE, all drive requirements into the design. These requirements are largely met through overall design considerations and fixed systems, the nature of which means that they are configured or installed in build and not fitted whilst the platform is in-service. It is significantly easier to add sensors and effectors to a ship that is already built to be survivable and recoverable to increase lethality than it is to somehow increase survivability and recoverability in a ship already built to commercial standards that has a bristling topside full of weapons. The installation of the Mk41 Strike Length VLS in Type 31 is a good example of this type of upgrade in a warship built for survivability and recoverability, employing the dedicated margins to introduce additional lethality via a spiral development philosophy. The following sections examine personnel considerations related to some of these aspects in more detail.

Figure 3. RN Frigates and Destroyers lost during the Falklands Conflict (clockwise from top left: HMS SHEFFIELD, HMS ARDENT, HMS ANTELOPE and HMS COVENTRY). The hard-won lessons and experience from these platforms, amongst others during the conflict, spurred 40 years of UK development in survivability and recoverability aspects that are now incorporated into the latest RN warships like Type 31 and influence personnel numbers.

2.1 SUSCEPTIBILITY

In legacy platforms typically the sensors integrated into the combat system feed data to the displays of the picture compilers working in the air, sub-surface and surface domains. They interpret the information presented, including altitude, speed and Identification Friend / Foe (IFF) codes (as air-domain examples) before deciding how to classify the track. They may also contact the Bridge for the watchkeepers there to make a visual identification using binoculars before classifying the track. This compiled picture is scrutinised by Picture Supervisors, augmented by Tactical Data Link (TDL) operators feeding in and correlating the 'Link Tracks' from allied units, and overseen by the most experienced personnel. This picture is further augmented by a separate team feeding the Electronic Warfare sensor data into the 'recognised picture'. Each weapon has an operator traditionally sat behind a specialist console who will carry out targeting and engagement of threats.

A large number of highly trained and specialist personnel is therefore required in legacy ships to enable the Operations Room (or Combat Information Centre (CIC)) to deliver the required operational outputs. In enduring operations and higher threat areas this number has to be further expanded to meet the constant operational tempo; operators need frequent breaks and role rotation to ensure everyone remains alert and at the top of their game to detect and counter threats without excessive fatigue. Much operator time is spent in undertaking low-difficulty and repetitive tasks often with poorly designed user interfaces. Modern, integrated combat management systems (CMS) seek to remove this operating burden from operators through automatically undertaking the routine picture compilation and tracking functions allowing the operators to concentrate on unexpected or anomalous events. This is designed to enable a reduction in the number of personnel required on watch, without compromising the output of the Operations Room or overwhelming the operators.

2.2 RECOVERABILITY

Recoverability of a warship is a key consideration that drives the number of personnel in a platform. Efforts to contain damage from enemy action or peacetime accident draw on relatively large numbers to react to the dynamic situation, to stabilise incidents and then attempt to recover and restore equipment back to a state in which it can be used. Aspects of modern warship design have alleviated this activity; of note are fixed firefighting systems that reduce the need to send fire parties into a space to extinguish large fires, structural fire insulation that reduces the need to 'boundary cool' the external bulkheads around the fire-affected compartments to prevent the fire from spreading further through the ship, and smoke containment features that were a crucial lesson learnt by the RN from experience in HMS SHEFFIELD and other platforms.

Redundancy in system routing, such as High Pressure Sea Water (HPSW), power distribution and data networks of a modern warship reduces the need for personnel to manually re-route cables or hoses to bypass damaged sections in order to restore capability.

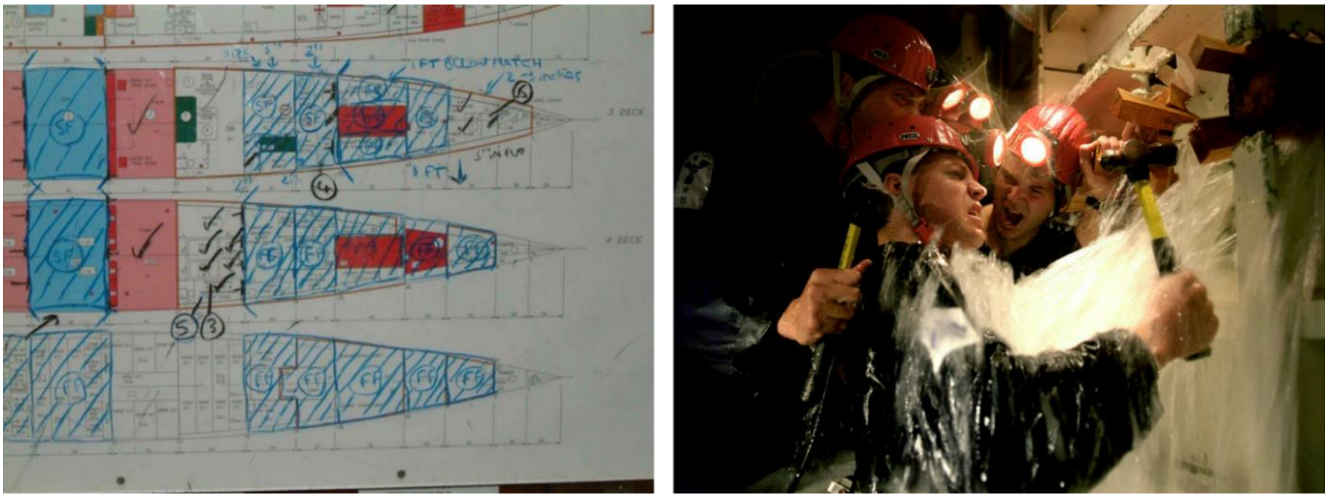

Figure 4. (image left) HMS NOTTINGHAM Incident Board in 2002, blue hatched 'FF' indicates a free-flooding section; (image right) RN Damage Repair Instructional Unit (DRIU) flood control / leak stopping training.

Beyond these features in modern warship design, damage that penetrates the hull causing extensive flooding is still difficult to counter and typically requires a large number of people to contain and manage. The incident in 2002 where HMS NOTTINGHAM suffered extensive flooding from accidental grounding required a considerable number of personnel to contain the extents of the incident in order to save the ship; an image of the incident board used during this event is included in Figure 4 above showing the breadth of this damage. This damage could occur anywhere onboard, with trained personnel able to react to the situation in order to use the correct equipment, build shoring to stem the flow (in many situations creating some inventive shoring solutions), or deploy portable pumps in the correct areas.

There has not yet been a robot demonstrated that can replicate the full flexible and adaptable capability that a trained sailor will provide in regard to damage control, able to carry out the targeted application of firefighting medium where compartment-level sprays would cause more damage than a minor fire or leak stopping in hard to reach areas, with this aspect a significant constraint to the reduction of personnel onboard.

2.3 MAINTENANCE

Without the output of the engineering and logistics departments a ship would not leave its home port. The marine environment is tough on all equipment, and the heavy use of a warship in dynamic operational scenarios exacerbates the wear on the complex systems fitted. There are two forms of maintenance that have to be accounted for; preventative and corrective. Preventative maintenance can be defined and planned in a schedule, split over activities that take place at sea, activities that take place in supported maintenance periods alongside or in a full refit. Understanding and optimising the levels of preventative maintenance of all systems is critical in the design of a warship, and this is a driving factor on the number of engineers required onboard. Corrective maintenance should be minimised, especially in new platforms, however it will inevitably grow as a burden over time as systems become worn. Allowance has to be made in the number of trained personnel onboard for this activity, enabled by automated diagnostic services, spares, tools and knowledge of the systems, in order to prevent an unmanageable workload developing and a resulting issue in retention of key engineering personnel.

Secondary duties for personnel onboard typically include the maintenance of cleanliness of spaces from bathrooms to the overheads in passageways. Dedicated effort is also required on the upperdeck to keep fixtures and fittings in working order against the harsh saltwater environment. Design features in the platform itself and examining the method of delivering this activity can alleviate the impact on personnel so that these aspects do not become unmanageable in a lean complement.

2.4 RECONFIGURABILITY

Modular and autonomous offboard systems are not miraculously maintenance free, and in a number of cases also require operators to process data and pilot vehicles remotely. Like the Flight personnel that embark with an aircraft in current platforms, these modular and autonomous systems are assumed to embark with their own teams and specific-to-capability spares in the short term at least. While these personnel are not counted as part of the core complement of a platform, they will still draw on a Ship's 'life support' including catering personnel, systems such as fresh water production and stores / victuals holdings, which would therefore have to be scaled accordingly in the design of the platform and themselves accommodated or maintained onboard. Until this maintenance and operating burden inherent in employing offboard systems can be reduced or removed, personnel will still be required at the uncrewed system's forward operating position and in turn drive personnel numbers in the core complement to support them.

2.5 DYNAMIC OPERATIONS

A warship will be required to react to unforeseen situations at short notice, in support of government direction and objectives. Following a tsunami in east Asia, a hurricane in the Caribbean or an Icelandic volcano eruption that disrupts air travel the initial government response has frequently involved deploying naval assets to carry out initial actions to assist. Beyond humanitarian scenarios, fast moving geopolitical situations also require the rapid deployment of naval assets; for example the short notice deployment of HMS DIAMOND to the Red Sea in December 2023 due to attacks on civilian shipping in the area. In order to be available to be deployed in these situations a sufficient number of personnel onboard have to be available and trained to deal with the dynamic circumstances safely.

With a reduction in the number of personnel onboard in a core Ship's Company, these kind of short-notice operations at the direction of government could be a challenge in a Ship with a lean complement. Disaster Relief operations typically rely on large numbers of personnel to distribute equipment and supplies, or to carry out initial actions to assist a civilian populace in order to provide an effective response. An option to enable the rapid augmentation of the core complement may provide a number of personnel that makes a meaningful contribution to the event. This augmentation could be supported by fly-away teams that join the Ship in order to then deploy to the scene of the incident, however the ability to hold a number of trained personnel ashore at readiness purely for contingent tasking such as this may be a challenge for a lean Navy, and instead might potentially be enabled by working with personnel from the RN Reserves or civilian organisations such as REACT [4].

In many ways this is more complicated in a short notice combat operation. A fly-away mission/combat augmentation team who are unfamiliar with the particular Ship may not be able to carry out this type of combat operation effectively or safely without significant prior continuation training on the platform and its systems and a period of integration with the core Ship's Company. This kind of 'modular' complement solution formed part of the intended philosophy behind the US Navy's Littoral Combat Ship (LCS), with the reality of this philosophy in operations now well documented [5].

3. TYPE 31 FRIGATE METHOD - ROUTE TO A LEAN COMPLEMENT

3.1 TYPE 31 INTRODUCTION

Type 31 comprises a class of five General Purpose Frigates currently under construction in Rosyth, Scotland, for the RN. Based on Babcock's ARROWHEAD-140 product line, and designed against Lloyd's Register Naval Ship Rules, ANEP-77 and a significant number of UK Defence Standards (DefStans), Type 31 possesses capabilities, levels of survivability and features not found in previous escort classes such as the Type 23 and Type 45, themselves designed against previous generations of standards. A full introduction to the Type 31 Frigate, including the novel procurement strategy and inherent capabilities, is available in a previous paper [6].

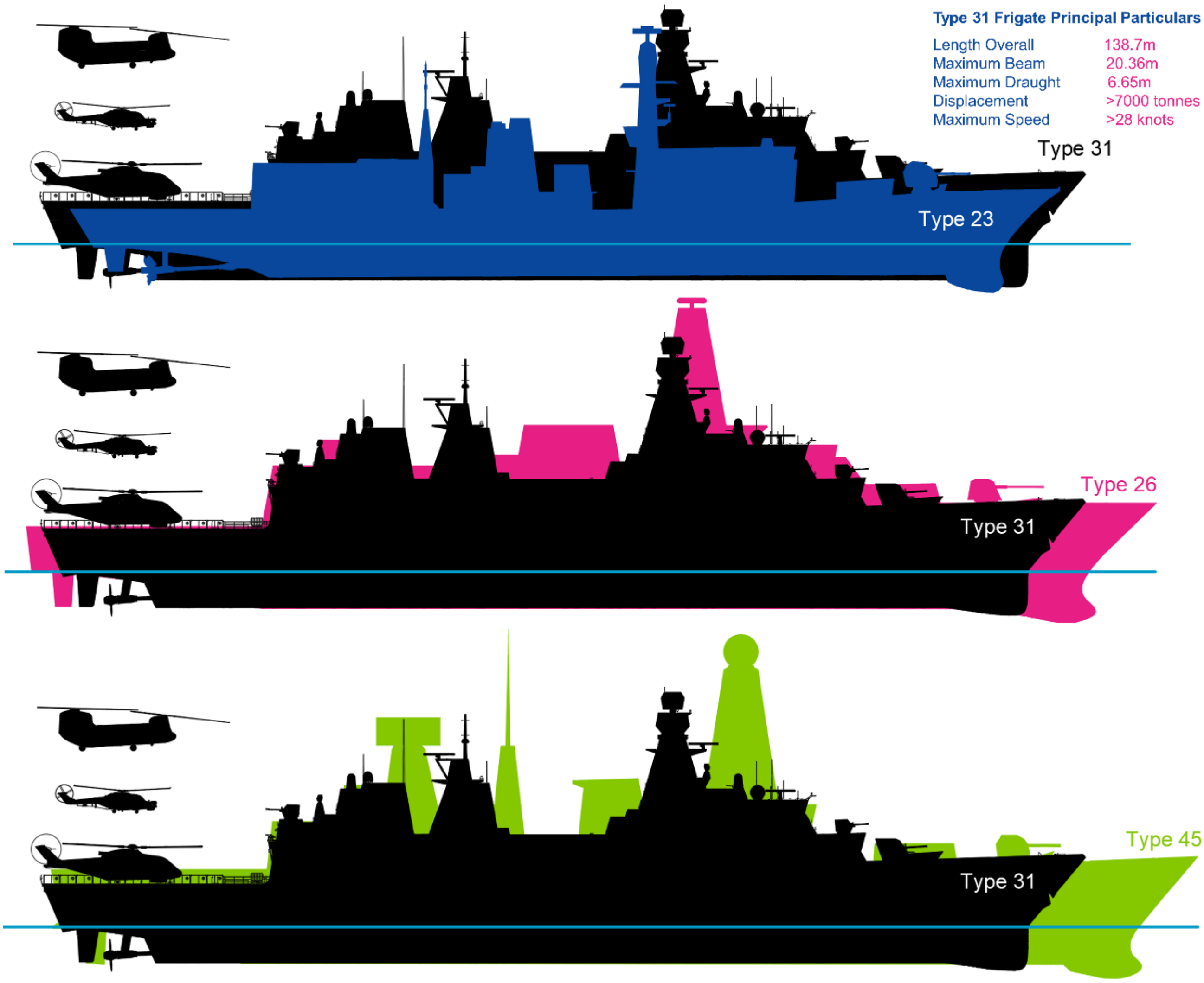

Figure 5. Type 31 Frigate size in comparison to contemporary Royal Navy escorts for context within this paper.

With the challenges of a reduced number of available trained and experienced personnel to crew RN platforms in the immediate future (as shown in Figure 1 above), against a background of contemporary platforms requiring additional personnel in order to function to their full capability, Type 31 had to be designed from the outset to be as efficient to operate as possible in terms of personnel numbers whist still able to deliver sustainable operational capability. This was a specific requirement placed on the Type 31 design by the RN to be delivered as part of the programme.

There is analysis underway by a number of organisations looking at futuristic concepts to deliver personnel reductions in future platforms, on a route to completely autonomous vessels. Type 31 required a different focus; the technology and features in the platform to deliver personnel reductions had to be available as high-TRL products and capabilities right now, in order to meet the challenging delivery schedule of the programme as the warships are currently being built in Rosyth. Overlaid with the critical safety case evidence requirements that accompany all military equipment introduced to UK service, the more futuristic ideas to reduce personnel could not be adopted. To enable some of the futuristic concepts the burden of evidence required to satisfy the mandatory safety case outside of adopting recognised standards would be prohibitive in the timelines of the Type 31 programme. The regulatory challenges encountered as part of these futuristic complement reduction concepts may benefit from prior resolution separate to the platform design phase, so the design is then able to follow a set of revised codified standards to avoid driving uncertainty, cost and delay into the warship procurement process itself.

3.2 TYPE 31 COMPLEMENT DEVELOPMENT PROCESS

The Type 31 Ship's Company is smaller than legacy RN escort platforms thanks to the latest modern technology, regulations and standards used in the design. This is shown in Figure 6 below, broken down by department. With the Type 45 Destroyers requiring a complement of 194 personnel and the Type 23 Frigates at 174 personnel [7], Type 31 represents a considerable reduction while maintaining a sustainable and effective capability.

The number of personnel in the Ship's Company for Type 31 is sufficient to operate the platform during enduring combat operations using the features of the equipment selected and fitted and the attributes of the Ship such as the Unattended Machinery Space (UMS) notation. This Ship's Company would be augmented as required by embarked forces such as those required to safely operate and maintain aircraft or offboard systems, and specialist boarding troops (Royal Marine Boarding Teams). The core complement has been deliberately configured to include the personnel needed to carry out recoverability actions in the event of damage (fires and flooding), and sufficient personnel to sustain operations without excessive fatigue through selection of latest-generation technologies.

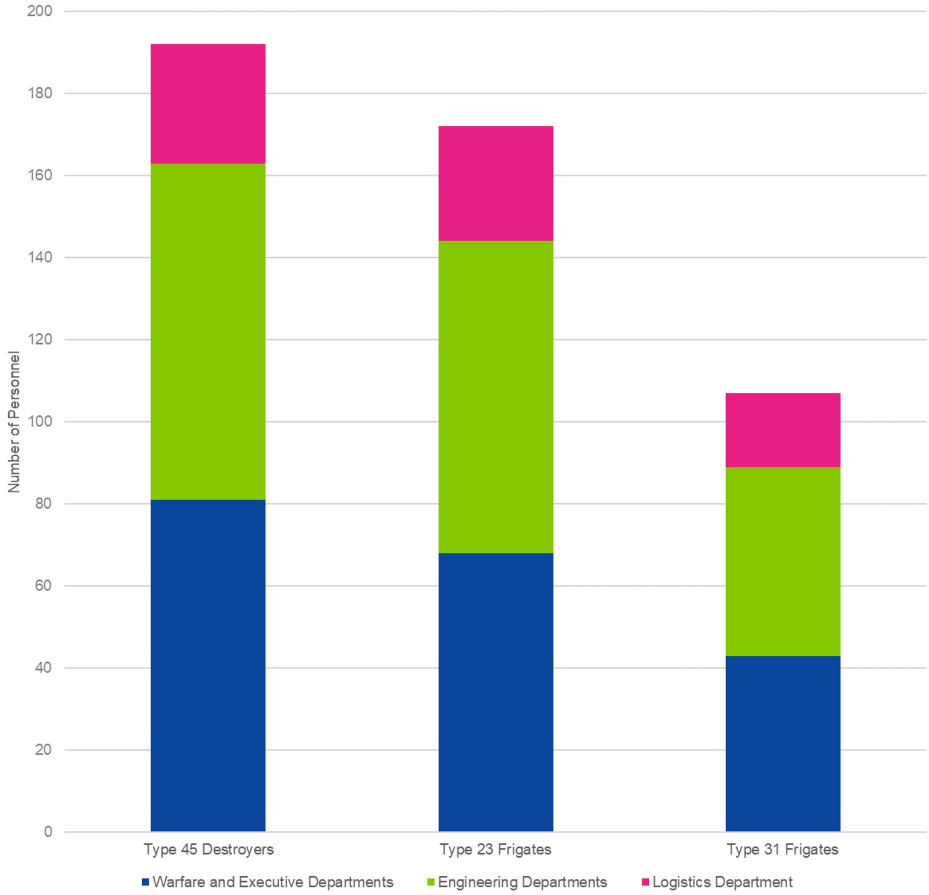

Figure 6. Comparison of the number of personnel required in the Ship's Company of contemporary Royal Navy escort platforms (data extracted from [7]).

There were no 'black box' software tools or automated databases used in the development of the Type 31 complement. A large table listed each individual by row, with states (cruising, defence watches and action) and evolutions (for example Replenishment at Sea (RAS), Boarding Operations, Humanitarian Aid & Disaster Relief (HADR) etc) listed by column. This ensured that the exact workload on individuals could be understood and tracked in each scenario, without the logic connections being lost or corrupted inside an inevitably complex software model.

This development dived down into the detail of each individual's role across the states and evolutions. For example, a junior Seaman Specialist finishing a 'Morning' watch (04:00-08:00) after weeks of an at-sea watchkeeping routine couldn't be expected to immediately become the on-call bowman for the recovery boat (called into action if a person were to fall overboard), and still be expected to remain effective at this important safety role. Another example is the load on engineering personnel; preventative maintenance tasks had to be balanced with carrying out duties as a watchkeeper for several hours every day, if this watchkeeping activity was required by the nature of the operation and the threat environment. These considerations were taken into account when generating the complement solution; statements such as 'we managed it in my day' were banished early as unhelpful contributions.

Once compiled by the Type 31 Design Authority (Babcock), this complement solution was exposed to the RN via a series of Operability Working Groups, with multiple sessions held with serving representatives from each branch (Warfare, Logistics etc) and sub-branch (Communications & Information Specialists etc). This scrutiny, applied both to the validity of the solution and the functionality of the advanced technology within Type 31 upon which the solution was based, refined the complement. For example, members of the RN Warfare branch management were exposed to the Thales TACTICOS CMS in the Operations Room simulator facility in Crawley (West Sussex) to assure the number of Operations Room personnel required in the solution.

This series of Operability Working Groups culminated in whole ship 'Fast Cruise' events, where all branches of the naval service were represented. During the 'Fast Cruises' the ship was exposed to a range of operations, incidents, emergencies and combat operations to examine if the complement solution would stand up as a coherent answer against everything that was expected of a RN Frigate; reducing the number of personnel required to operate Type 31 without placing an unmanageable workload on each person. This includes the ability for Type 31 to react to short notice events and dynamic situations such as HADR, at the direction of government policy.

This process, conducted over a number of years and through a variety of activities, culminated at a point where the first members of HMS VENTURER's (Type 31 Ship 1) Ship's Company joined in July 2023. Now that the Ship's Company have joined, their work is ongoing to further refine the complement solution to optimise the workload on individuals.

Overlaid with the work on the Type 31 complement solution itself are higher-level operating philosophy considerations, such as the 'double crewing' of platforms that are deployed as a persistent forward presence. Adopted with the deployment of Type 23 Frigates HMS MONTROSE and now HMS LANCASTER to Bahrain, a major benefit of this philosophy is that it provides more certainty to members of the Ship's Company; they are aware of which periods they will be away from home and can plan their family lives around these dates, with this certainty aimed at maintaining retention. This is allied to the operational benefits of this philosophy in avoiding long transit times to arrive at a theatre of operations, and being able to react quicker to global events in the national interest.

3.3 TYPE 31 PERSONNEL CONSIDERATIONS

3.3 (a) Technology

The next-generation technology in Type 31 plays a key part in optimising the number of operators required. As such, those developing the complement solution were trained on systems such as the TACTICOS CMS so they understood the capabilities that this system will deliver and that enable a reduction in operators whilst still enhancing overall platform capability.

For example, advanced automation in the CMS means Picture Compilers should not be required, with the system instead able to perform this role under the oversight of Picture Supervisors without these personnel becoming overwhelmed. This is further supported by the selection of the Thales NS110 Air/Surface Radar, the first 4D Dual-Axis, Multi-Beam, Active Electronically Scanned Array (AESA) Radar to be fitted to a RN Frigate. As one example against a contemporary threat; simultaneous element-level digital beamforming in both azimuth and elevation of the GaN Radar system fitted (as opposed to previous generation 3D Radars that are multi-beam capable in elevation only) enables superior detection of small drones and low-RCS missiles at considerably increased ranges, using automation to alert the operator.

The level of automation introduced in systems like TACTICOS and NS110 as key elements of the Type 31 mission system is designed to reduce the workload on the Operations Room personnel over that experienced in previous platforms. This solution alerts to the threat using equipment that does not experience the same fatigue or potential distraction as a human Picture Compiler may in enduring watchkeeping activity. Other sensors fitted such as a 360° staring Electro Optic / Infra-Red (EO/IR) surveillance system are available as an integrated resource to any operator on the CMS; with a better view than the Bridge in both day and night conditions this system enables the Operations Room to make visual classification of tracks without constant recourse to the Bridge team and expedites the process of picture validation considerably.

Other examples include the threat engagement functionality within the CMS, again employing advanced automation features to allow the platform to counter large swarms of hostile actors, using the fully integrated suite of turret and missile effectors. This system of systems delivers a capability faster than is possible with purely human operation, while simultaneously requiring a significantly reduced number of operators over legacy platforms and maintaining necessary control over weapons under the Rules of Engagement (RoE).

Beyond mission system examples, other resilient and integrated systems in Type 31 such as the centralised digital incident boards, a camera network with motion-detection capability and comprehensive sensor suites for fire, flood and equipment monitoring support recoverability actions onboard, and reduce the considerable burden of conducting damage search and system fault diagnosis activities manually.

3.3 (b) Damage Control / Recoverability

The entire Type 31 platform has been re-designed to meet Lloyd's Register Naval Ship Rules and the latest NATO / UK naval standards & regulations, which has introduced an increased capability in the redundancy and resilience of systems over legacy RN platforms including the Type 23 (the design of which pre-dates key standards such as ANEP-77) and many other contemporary Frigate designs. The impact of these standards is demonstrated in Figure 7 below, with the same location shown in the 'parent' class (designed against alternate standards and regulations) and the Type 31 detail design model; this complex system routing increases the resilience of the platform without requiring a significant increase in the number of personnel needed to carry out battle damage repair to restore systems.

The ability to carry out damage control activities required to react to both peacetime incidents and enemy action was a driving consideration. Supported by advanced monitoring systems, fixed fire suppression and containment solutions the number of personnel in the Type 31 complement was tested against various scenarios to ensure there were sufficient numbers to sustain the safety of the platform and to restore or maintain capability. This also included stress testing of the solution, in conjunction with serving members of the Fleet Operational Standards & Training (FOST) organisation and RN damage control school instructors, by removing personnel as casualties to examine whether the solution would remain effective.

Figure 7. Example of complexity introduced by alternate regulations and standards, supporting recoverability actions. (image left) 'Parent' class passageway; (image right) the equivalent location in Type 31 (extracted from the Type 31 3D detail design model).

3.3 (c) Watchkeeping

Watchkeeping is a resource-intensive activity, in previous platforms requiring trained and experienced personnel to close up in locations including the Bridge, Operations Room and Ship Control Centre (SCC) to be on hand to control the Ship and react to incidents. Sufficient numbers of personnel are required to maintain a sustainable watch cycle, driving overall numbers and imposing an extensive training burden to maintain competencies. When this sufficient number of personnel isn't available and gaps appear in the watchbill this is often cited as a contributing factor in poor retention.

Employing the functionality delivered by the UMS notation, the entire capability of the SCC and machinery monitoring service is replicated on the Bridge; a feature not found in legacy RN escorts. Therefore, when the operational tasking and threat environment allow, the SCC can be closed with the systems overseen by a single engineer in the Bridge. Removed from the obligations of maintaining watches, the remaining engineers could devote more time to the preventative maintenance schedule and work a number of hours each day that are more manageable over the span of an enduring operation. CMS access is also provided on the Bridge to enable routine picture supervision activity by a smaller number of personnel in lower threat environments, which can reduce this watchkeeping burden on the remaining Operations Room specialists.

3.3 (d) Maintenance

Due to the importance of providing a sufficient number of personnel to carry out the preventative maintenance activity of all the systems fitted to the platform, a considerable amount of analysis was carried out on the maintenance burden in the development of the Type 31 complement solution. Drawing on decades-worth of maintenance data from in-service platforms that are currently supported by Babcock, and aligned with the assured data provided by the suppliers of the next generation equipment for Type 31, a detailed analysis of this preventative maintenance workload for all systems onboard was undertaken. This preventative maintenance workload was broken down by engineering department section to assess the load required to keep the ship running.

To reduce this maintenance burden Type 31 has taken advantage of the latest technology. This modern equipment, such as the BAE Systems Bofors 40mk4 shown as an example in Figure 8, places a significantly reduced workload on maintainers over alternative systems. The maintenance required by systems was a key element considered in equipment selection for the Type 31 programme, assured through evidence provided by manufacturers to substantiate claims against real-world operation, as part of the wider effort to deliver a platform that could be operated by fewer personnel whilst still increasing capability over the previous Frigate classes.

Figure 8. Type 31 annual preventative maintenance burden example (BAE Systems Bofors 40mk4), shown as a comparison to legacy RN equipment (data extracted from RN Unit Maintenance Management System (UMMS); axis scale redacted).

3.4 (e) General Activities

As an example in the area of general / whole ship activities onboard; in previous platforms the embarkation of supplies such as food and engineering parts, and discharge of waste (garbage) are handled by a 'clear lower deck' of all members of the Ship's Company passing items in a long human chain over the gangway. In a high endurance platform such as Type 31 these activities would take a significant amount of time and require a large number of people, so therefore the platform is fitted with a transverse handling system that extends over both sides from midships, that is able to pick up whole pallets of stores from the dockside and bring them into the ship, which are then processed using dedicated internal handling equipment and routes. Processed waste is offloaded using the same system. Use of this handling system minimises the burden of these traditionally personnel-intensive activities from the shipborne workload. As an additional benefit this handling system, located within the connected forward Mission bays, could also be employed in the future for the launch and recovery of uncrewed systems (UxV) such as REMUS UUVs separate to the boat handling systems.

The types of modern deck coverings selected throughout the ship can be kept clean with no polishing required, bathroom units are designed for quick cleaning and daily routines can be optimised to maintain the required levels of cleanliness onboard without imposing an excessive burden, particularly on junior members of the Ship's Company as a secondary role.

4. COMPARISON TO THE 'PARENT' DESIGN

The 'parent' design to the ARROWHEAD-140 product is the IVER HUITFELDT class in service with the Royal Danish Navy (RDN). Key amongst the inputs in the early stages of development of the Type 31 complement solution in 2018 was the Watch & Station Bill for the IVER HUITFELDT design as employed by the RDN. However the RDN operates in a different overall organisational philosophy to the RN, based more on a conscription model [8], so this could only provide guidance for the Type 31 complement rather than be used as the solution directly. The complement in Type 31 has to function within the overall philosophy of the RN personnel, branch and training structures, to fit within the overall Fleet as personnel move from ship to ship as part of the current career progression route.

This difference in organisational structure can be illustrated by looking at the Marine Engineering (ME) department of both the Type 31 and the IVER HUITFELDT class, shown in Figure 9 below. The RN use a pyramid structure where personnel are brought into the organisation at the Junior Rate level before being promoted up to Senior Rate based on experience and aptitude. The RDN structure employs a larger number of Officers, who take the leadership roles, a small number of Senior Rates who typically perform administration activities, and a large number of Junior Rates.

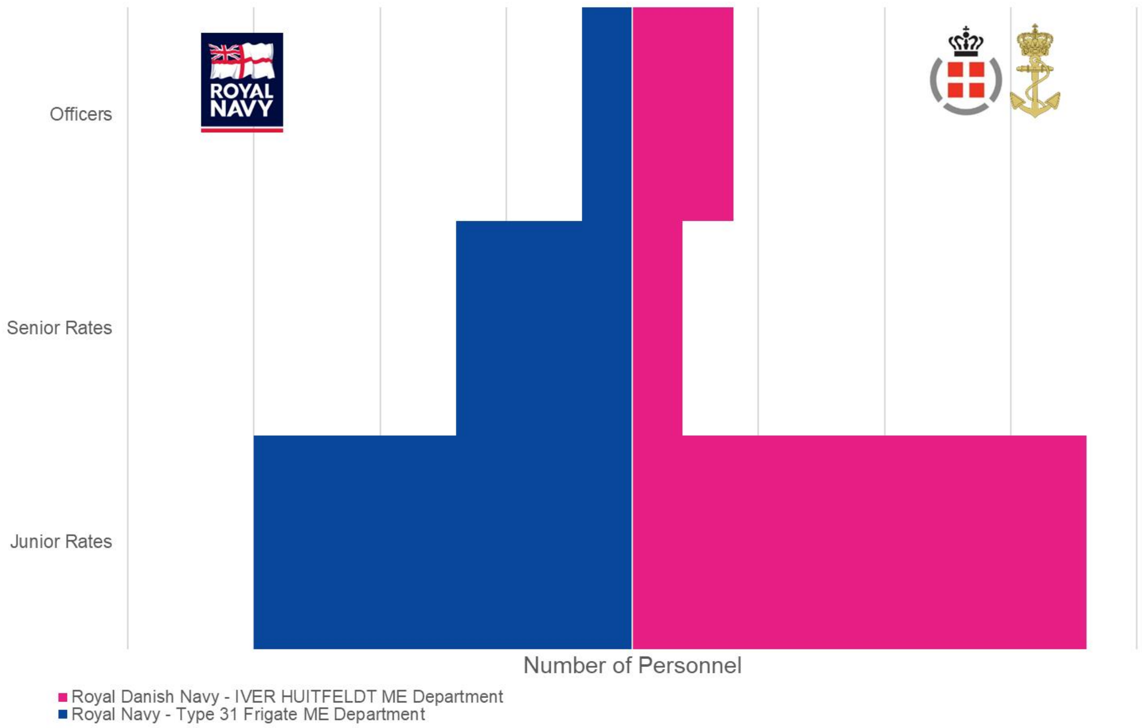

Figure 9. Comparison of the number of personnel in Marine Engineering (ME) Departments by rank / rate (axis scale redacted).

The RDN Junior Rates are given responsibility for systems and equipment that resides at the Petty Officer (Senior Rate) level in the RN. Personnel either enter the RDN for a defined period via conscription, or they can repeatedly join and leave the RDN as they see fit for their careers. These Junior Rates are assigned responsibility for a system or equipment as they join a ship, such as responsibility for maintaining the main engines or the reverse-osmosis equipment. Disadvantages of this philosophy include the reduced experience of wider warship operations such as damage control and firefighting, as this is not always a transferable skill inherent in someone joining in a 'sideways entry' from a job repairing diesel truck engines for a haulage firm (as an example) and requires additional training.

This is in contrast to the RN, where any Senior Rates leaving the Service take with them knowledge and years of experience of the systems they were previously responsible for that can only be replaced by personnel coming into the system from the Junior Rate level. A reduced number of Junior Rates entering the system would also cause a 'black hole' in the system for years to come. The advantage of the RN system is in the experience built up of wider warship operations, drilled into personnel from the most junior level at the start of their careers and built upon over time.

5. FUTURE

The Type 31 Frigate complement represents an optimum solution at a point in time. Defined by the latest high-TRL technology available that can be delivered into a class of warships in build now (Figure 10), and the various naval rules and regulations against which the ship was designed, Type 31 has the smallest effective and sustainable size of Ship's Company possible for a 7,000 tonne General Purpose Frigate that is capable of global combat operations.

Figure 10. HMS VENTURER (Type 31 Frigate Ship 1) and HMS ACTIVE (Ship 2) in build in Rosyth, Scotland (photo taken April 2024).

This complement solution and philosophy has also been built into the ARROWHEAD-140 product line, drawing on the work conducted to date over years of development activity and the scrutiny applied by the RN as part of the Type 31 delivery programme. Additional separate work within Babcock has identified potential options to further reduce the Ship's Company within the ARROWHEAD-140 design, through an investigation into alternate operating philosophies.

There are also wider studies into future measures that could reduce the number of personnel to the point where there are no human operators required onboard at all. To provide a true capability as a combatant warship however, there are a number of obstacles to overcome and considerations that will have to be made.

Significant amongst this number of obstacles is the ability to conduct damage control activity, in particular flooding following either accidental damage or enemy action. Either a new philosophy in the design and construction of the hullform will have to be developed, one that can tolerate extensive flooding without intervention while retaining the speed, manoeuvrability and internal functionality of compartments expected of a Frigate or Destroyer, or the entire philosophy on the attritional nature of the platform will have to be considered.

The requirements on the number of personnel driven by damage control actions could be removed completely if it is accepted that the warship can be lost following damage. This is a controversial decision that would have to be made at senior navy and political levels; a warship represents an expensive investment of taxpayer's money, and the optics and fallout of a total loss due to the platform accidentally hitting a semi-submerged shipping container one night may be unpalatable. If a minimal crew is retained onboard for other purposes such as weapon control to satisfy Rules of Engagement, however is not sized to deal with damage control, then consideration to their safety must be made in both peacetime and in the presence of the enemy as essential moral and ethical concerns and against duty of care legislation. Where commercial ships tend to follow established shipping routes and are therefore not far from another vessel that can effect rescue, warships are deployed widely as required by the operational tasking and may therefore be extremely isolated; the incident in 2008 involving HMS ENDURANCE is an example [9]. If the crew's only available action on taking accidental or hostile damage is to abandon to the liferafts and watch as their ship goes down, many lives may then be lost to exposure or capture before they can be rescued; this philosophy also poses a possible deterrent to both recruitment and retention of personnel.

Maintenance is another consideration. As outlined above the marine environment is tough on systems, and equipment can suffer unforeseen damage particularly in heavy sea states. The ability to keep a highly complex uncrewed platform functioning at sea on enduring operations, to deliver an equivalent capability to current Frigates and Destroyers, will rely on resolving the question of how this preventative maintenance activity on its systems will be achieved.

These are two elements amongst many that have to be resolved, either through technology, policy development or an overall change in philosophy before the crew of a warship can be reduced to a point where a completely uncrewed warship is operationally feasible.

6. CONCLUSIONS

The number of trained and experienced personnel available to several Navies is reducing. Through a combination of recruitment and retention challenges, this reduced number is a significant concern against an uncertain global situation and the enduring requirement to provide safe platforms at sea in order to deliver government policy. However, as stated in JDP 0-10 a key attribute of maritime forces is their versatility to react rapidly to events in the national interest. Efforts to reduce the number of personnel required onboard warships, driven by recruitment and retention challenges, should still remain cognisant of this fundamental attribute and not degrade a Navy's overall ability to exercise maritime power.

> *"Maritime forces are uniquely versatile, easily changing their military posture, while undertaking several tasks concurrently and remaining available for rapid re-tasking. Deploying with inherently high levels of readiness, a warship can transition from a peacetime state to a combat ready one in a matter of hours."*

Joint Doctrine Publication 0-10; UK Maritime Power [10]

The process followed for Type 31 that is outlined in this paper generated a complement solution that was considered the minimum viable size for the versatile combat operations of a globally deployable General Purpose Frigate that is in build today. Taking all aspects into account this solution did not seek solely to reduce numbers at all costs; instead significant focus was also devoted to the workload on personnel to ensure the scope of tasks placed on individuals was realistic, in an effort to support retention of experienced personnel. Note that it has only been possible to provide a high-level summary of some of the considerations and solutions for Type 31 in this paper, with other critical aspects such as alongside harbour watches not discussed and comparison charts provided with redacted axes; the full capability of Type 31 is not exposed in open-source.

Type 31 represents an optimum solution that is deliverable today for a globally deployable warship. There are studies both within Babcock and in other organisations looking to reduce this number still further, ultimately seeking a viable solution to deliver a fully uncrewed warship.

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8. AUTHOR'S BIOGRAPHIES

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