Ageing Air System Programmes Working Group (AAPWG)

Paper 014

Marinisation of Air Systems – Learning From Experience
March 2016

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1. DISTRIBUTION

Task Sponsor
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2. Executive Summary

The Defence Science and Technology Laboratories (dstl), with the support of the Military Aviation Authority (MAA) through the Ageing Air System Programmes Working Group[1], initiated a research and development programme titled "Understanding Ageing Aircraft". As part of the programme, the Working Group held a Learning From Experience event entitled the Marinisation of Air Systems at Leonardo Helicopters, Yeovil, on 10th March 2016.

This paper is intended to capture a précis of the presentations held on the day and to act as a focus for Defence Equipment & Support (DE&S) staff who might be faced with similar problems of marinisation of Air Systems in the future. The presentations referenced in the paper are held by the DE&S Airworthiness Team (DAT) and by the MAA. An Aide Memoire for Desk Officers, which acts as a summary of the information, is included at the end of the paper.

The speakers at the event emphasised the need for preparation before Air Systems were embarked on ships, and it was clear that DE&S staff possessed considerable experience and knowledge that could be utilised for future marinisation tasking.

[1] The AAPWG was originally titled, the Ageing Aircraft Programmes Working Group, as a result of a change in taxonomy, the working group's title was changed to, the Ageing Air System Programmes Working Group (AAPWG).

3. AUTHORSHIP

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5. INTRODUCTION

5.1 BACKGROUND

The Defence Science and Technology Laboratories, with the support of the Military Aviation Authority (MAA) through the Ageing Air System Programmes Working Group, initiated a research and development programme titled "Understanding Ageing Aircraft". As part of the programme, the Working Group held a Learning From Experience (LFE) event entitled the Marinisation of Air Systems at Leonardo Helicopters, Yeovil, on 10th March 2016. The aim of this paper is to document the details of the LFE event and so capture lessons learned from operating military Air Systems from ships, particularly those Air Systems which might not have been originally designed to operate in a maritime environment.

The authors were especially aware of the impact of Op ELLAMY, whereby a number of helicopters were required to operate from ships within a very short notice period. This paper seeks to combine those lessons learned from the Defence Equipment & Support (DE&S) Project Teams[2] (PT), industrial Design Organisations and support teams who had knowledge of, and experience with, the topic of Marinisation of Air Systems to form best practice and guidance in one place so that PT Desk Officers could access all the relevant information easily should they require it. A précis of each presentation is contained within this paper (and each is referenced), the presentations themselves are held separately by the Military Aviation Authority (MAA) and the Defence Equipment & Support Airworthiness Team (DAT).

The subjects covered were focussed mainly on the Air System and the associated support equipment being made ready to operate from a ship. Most of the references were rotary-wing based as that is where most of the current experience lies. Fixed-wing references were either historically based from suitably experienced and qualified personnel, mostly ex-Harrier staff, or from the Lightning II PT as the Air System undertakes its current certification programme.

Finally, the paper presents an Aide Memoire which is intended to be suitable for DE&S Desk Officers who may be faced with a problem of marinising an Air System.

5.2 OBJECTIVES

This paper is a précis record of the presentations given at the LFE event. The paper does not, and the event did not, aim to cover every aspect of marinisation, but does seek to provide guidance and best practice on what to consider when marinising an Air System and its support systems either in design or in-service, and highlights some of the steps necessary to prevent problems. The paper also provides references and details of experience which may benefit DE&S Desk Officers.

This paper details current regulations and standards, referencing those extant during the LFE event (March 2016).

[2] This paper uses the term Project Team (PT) which is broadly synonymous with the current term Delivery Team (DT).

6. Regulation

6.1 Military

In 2016, the MAA promulgated new regulations which detailed the processes to be followed, and the responsibilities of those involved, to permit embarked aviation on Her Majesty's and MOD Ships:

a. RA 1029 Ship-Air Release – Roles and Responsibilities[3]

b. RA 1395 Authorisation to Permit Embarked Aviation in Her Majesty's/MOD Ships

Any questions regarding the content of the current regulations should be directed to the MAA Certification - Maritime Aviation. The regulations detail those personnel by role that have the responsibility for the safe integration of the Air System with a ship; note that ships are operated under separate Duty Holder constructs and the links are shown pictorially below. The Ship-Air Release process requires the Risk to Life associated with the activity to be understood and that the scope and boundaries of such operations are clearly defined. Equipment hazards should be reduced to at least tolerable and As Low As Reasonably Practical (ALARP) in order to support the statement that both the Air System and Ship are safe to operate together.

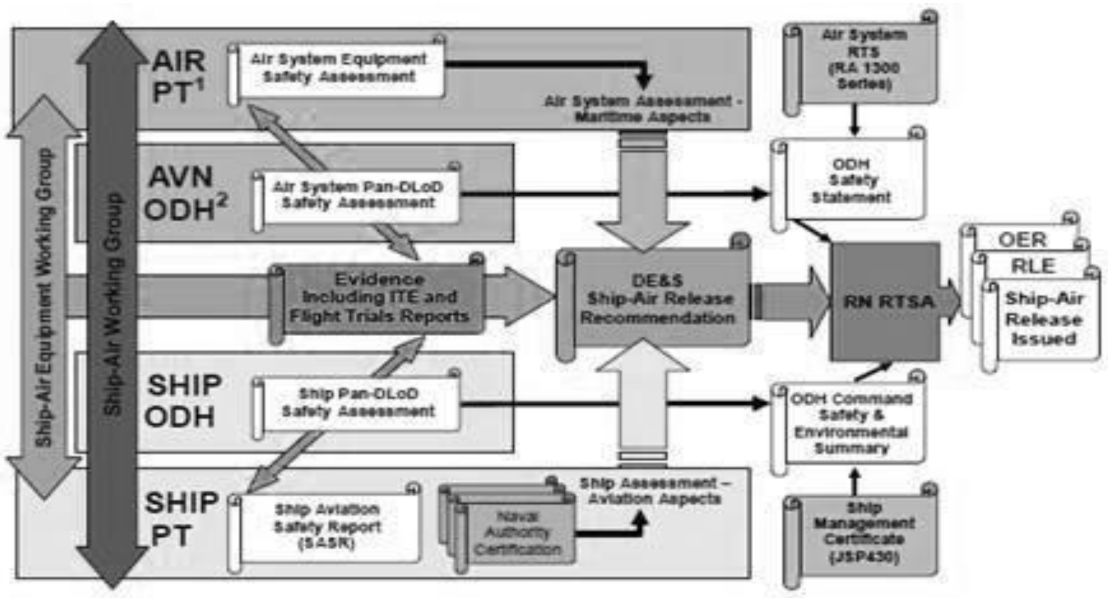

Figure 1 – Ship-Air Release Process

[3] During the marinisation event, RA1029 was titled, Ship-Air Release – Stakeholder Roles and Responsibilities. RA1029 has been revised and retitled to Ship-Air Release – Roles and Responsibilities.

The Release To Service Authority (RTSA) is responsible for the authorisation and issue of the initial release and subsequent upkeep of the documentation. The RTSA should be consulted at the start of the process to ensure the process is followed correctly.

Consideration should also be given to increased maintenance schedule inspections and the impact that being in a very damp, salt laden, moving, space-restricted environment will have upon the integrity management of the Air System. The following documents contain more information on integrity management:

a. RA 5726 Integrity Management[4]
b. Manual of Air System Integrity Management (MASIM)[5]

6.2 ROTORCRAFT – REGULATORY FRAMEWORK

The rotorcraft regulatory framework is intended to promote safety and formalise requirements on manufacturers and operators. Three categories of rotorcraft regulations are:

a. Military
b. Commercial
c. Private – Non-commercial.

The design requirements for Naval Helicopters are laid down in Military Specifications including:

a. DEF STAN 00-970 Part 7. Certification Specifications for Airworthiness. Part 7: ROTORCRAFT[6]
b. AR-56 - US Navy Requirement – Structural Design Requirements, Helicopters
c. MIL-T-81259B. Military Specification – Tie Downs
d. Maximum Operating Capability
e. Operate to specific Ship Helicopter Operating Limits (SHOLS)
f. Deck Limits defined in terms of pitch/roll angle and wind speed.

6.3 MILITARY OPERATIONS - LITTORAL

Military helicopters operating in a littoral environment may be specified to lower requirements (but still detailed within Def Stan 00-970 etc.). Although the specifications may be more benign, helicopters which operate on and off ships will still need to operate within specified SHOLS which will include limits in ship pitch/roll angle and wind speed.

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[4] During the marinisation event, Integrity Management (IM) was prescribed within 3 RAs: RA5720 Structural Integrity, RA5721 Systems Integrity, and RA5722 Propulsion Integrity. In 2019 RA5726 was published, combining the separate IM disciplines in to one RA.

[5] The MASIM was not published until 2019, after the marinisation event. The reference to the MASIM has been included, as the MASIM should be read in conjunction with RA5726.

[6] In 2016, the applicable UK Military specifications were titled Def Stan 00-970 Part 7. Design and Airworthiness requirements for Service Aircraft – Rotorcraft.

6.4 COMMERCIAL OFFSHORE OPERATIONS

Commercial offshore helicopters should be designed to JAR/FAR/CS29 regulations. Authorisation of helidecks is in accordance with JAR-OPS3 “Commercial Air Transport Regulations”. The UK also imposes CAP437, and CAA Paper 2008/03 requirements and Operational Limitations are usually set by the Operator in collaboration with the designer from the Original Equipment Manufacturer (OEM).

Helicopter Limitations List (HLL) contains limits in terms of:

a. Pitch and roll angle
b. Maximum inclination
c. Maximum heave rate.

These limits vary only according to:

a. Helicopter categorisation (A or B)
b. Deck categorisation (1 to 3).

The limits are generic and SHOLS generally do not apply.

7. PROJECT TEAM EXPERIENCE

7.1 OVERVIEW

The Apache and Chinook PTs, as the 2 PTs with most recent experience of supporting Air System operations at sea were asked to provide evidence of best practice on the Marinisation of their Air Systems. Two presentations were given: *Lessons from AH Embarked Operations* by Apache PT Eng Mech 4 and *Chinook Marinisation Issues* by ChPT Mk 3 Contractor.

7.2 APACHE EMBARKED OPS CASE STUDY

During Op ELLAMY the main issues experienced were:

a. Corrosion (15)
b. Damage (10)
c. Avionics (8)
d. Weapons (15)
e. Rotor Brake (3)
f. Premature Wear (7)

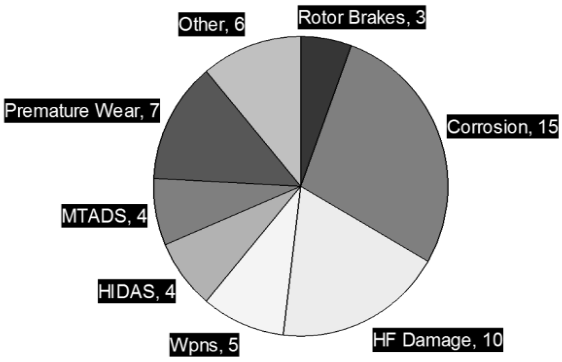


Figure 2: Embarked Apache Problems

7.2.1 CORROSION

Corrosion was by far the biggest issue on board. Damage was found on the Air System in many areas, typically in the Port Improved Extended Forward Avionics Bay.

Maintenance corrosion issues which were found were often the result of either the lack of correct Corrosion Prevention Compounds/Treatments or the poor quality of their application. Daily wash procedures were necessary to prevent corrosion, and protective covers were required to prevent the ingress of both salt and water into the Air System which would affect the “Rockhard” surface finish.

7.2.2 OTHER LESSONS

Other issues encountered on board were:

a. The time for moves between hangar and deck, to then spread/fold the rotor blades and prepare for general flight deck operations was about **1 hour** minimum. This time was significantly longer than the preparation time when at a land Main Operating Base (MOB).

b. Ship operations are an unfamiliar environment for most aircrew and technicians and were fraught with inherent dangers eg dark, rolling decks, the need to tie down everything that could move and, as such, additional training and familiarisation were required.

c. There is limited space for living/working and manoeuvring as the ship cannot take an entire Squadron of maintainers, aircrew, etc. Therefore, a selection process needed to take place prior to embarkation to ensure that only the minimum number of appropriate personnel were deployed.

d. There was minimal stores support – the Detached Stores Package (DSP) is not usually scaled to support enduring embarked operations. Help was sought from DES SEOC SCP-SCA (who have a modelling team that can help with accurate scaling of shipboard DSPs for Air Systems).

e. Stores routes to the ship were protracted and subject to customs clearances, Air Transport (AT) availability, etc. Good logistic planning and liaison with the ship ahead was essential.

f. Hangar facilities on board were excellent, with no problems reported.

g. Tool husbandry requirements increased significantly due to corrosion.

h. The Multi FAGE General Support Equipment (GSE) corroded when used on deck and could not be used in the hangar; it was also very heavy.

i. Air System wash facilities were unsuitable, but the temporary solution was to use the Pavehawk kit. In general, liaison with Navy Command Equipment Support Team well in advance of the deployment paid great dividends.

j. Blade fold kits were easily damaged. Consequently, and subsequent to Op ELLAMY, the Apache PT is procuring a new blade fold kit to mitigate against this problem.

k. Operation over water caused unforeseen problems: the Apache Cockpit Survival Device would harm aircrew if used under water, ie if the Air System crashed into the sea and inverted. The Air System's battery life was very short which meant a short safe flight time over water in case of electrical failures. Both of these problems were mitigated with use of 'Overwatch' Air Systems.

l. The Apache is not a sealed Air System and, as such, it does not float and this necessitated different crew drills and procedures.

m. Ship-Air Integration – Apache is a complex weapons platform; integration will always require a clear understanding of the environment in which it operates.

7.3 CHINOOK MARITIME OPERATIONS CASE STUDY

The Chinook fleet consists of 52 standard range (Mk4/Mk6/Mk6A) and 8 long range (Mk5) Air Systems. All Air Systems have been upgraded to have “Glass” cockpits and Digital Automatic Flight Control System (DAFCS).[7]

7.3.1 WET ASSEMBLY ISSUE

Current in-service Chinook Air Systems are dry-assembled, therefore, they are not suitably sealed for maritime operations. At present, they do not conform to the UK maritime design standards.

Regulations require that an Air System should have design features or specific modifications to enable sustained operations from naval platforms. The Air System and its weapons must be: capable of movement and safe stowage on deck during inclement conditions and operations by day and night in mainly benign conditions; issued with appropriate maintenance procedures to counter corrosion, and be sufficiently hardened against the effects of electromagnetic radiation. Alternatively, the Air System will have to operate with severe restrictions.

Def Stan 00-970[8] requires that:

a. where appropriate, all sealants shall be applied to the mating surfaces so as to completely fill any crevice and produce at the edge of the joint a specific fillet which shall not be subsequently removed. Where fasteners form part of the assembly, the sealant shall be present down the shank and under the head and tail.

b. where appropriate, jointing compounds shall be applied to the mating surfaces so as to completely fill any crevice, but excess material at the edge of the joint should be largely removed by wiping prior to painting. Where fasteners form part of the assembly, compounds shall be applied to the hole and/or the shank and thread so that in the assembled joint the compound completely fills any space under the head and tail of the fastener.

c. the aircraft shall have a method of construction (component or structure) in which jointing compound/sealant is used. It should be noted that UK and US definitions of "wet assembly" differ:

1. UK - jointing compound is applied to faying surfaces before joining

[7] At the time of the marinisation event, the Chinook fleet were in the process of ‘Glass’ cockpit and DAFCS modification and upgrade. At the time of publication of this paper, the entire fleet have ‘Glass’ cockpits and DAFCS.

[8] At the time of the marinisation event, Def Stan 00-970 Part 7 contained design guidance and certification criteria. The design guidance covered instances when sealants should not be used (Part 7, Section 2, Supplement 4, Sub Part D, Issue 6, Para 23.4) and reference to general guidance on engineering practices such as “wet assembly”. The current Part 7 (Issue 10) does not feature this guidance and focuses solely on Air System certification. Def Stan 00-970 Part 7 no longer contains a definition of “wet assembly”; however, it is important to understand the different methods of “wet assembly”, which is why the details at 7.3.1. c have been retained.

2. US - joints are sealed with sealant after joining (ie no sealant is present between faying surfaces).

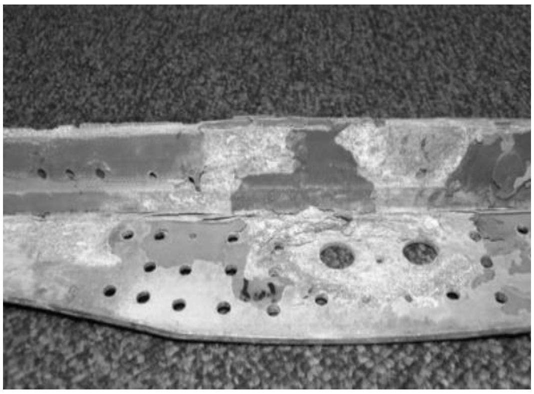
3. For future Chinook purchases, the Chinook DT will base their Certification Strategy on Def Stan 00-970.

7.3.2 MAIN CORROSION ISSUES

Typical examples of corrosion found on the Air System whilst embarked on maritime operations are:

a. Ramp and belly skins were found to be susceptible
b. All under floor areas were problematic before the introduction of Corban 35[9].
c. Antenna skin interfaces were problematic
d. Undercarriage assembly, specifically aft, was found to suffer
e. APU area and assembly.

Figure 3 Chinook Ramp Stringer



7.3.3 LESSONS LEARNED

Evaluating the issues found has resulted in the Chinook PT working with Boeing Defence UK to develop a jointly agreed Environmental Damage Prevention and Control (EDPC) plan. This plan will be managed under the current Chinook EDPC policy and will describe the measures to be taken to control environmental damage, the most significant form of which is corrosion.

[9] Previously AV 15.

8. MILITARY AIR SYSTEM SUPPORT

Two papers were presented in this part of the proceedings: 1710NAS-MATLS Corrosion : *The Practicalities of Operating Aircraft on Ships (What Designers and Operators need to know!)* and NC Eqt Spt Team C2: *Support Equipment Marinisation Problem Areas.*

8.1 1710 NAS (NAVAL AIR SQUADRON) – SPECIALIST SCIENTIFIC AND TECHNICAL SUPPORT TO THE MOD

8.1.1 THE CHALLENGE OF SHIP'S MOVEMENT

The first and most obvious issue is that a ship rarely stops moving: it pitches, rolls, heaves whilst at sea and even when it is alongside a jetty it is often at an angle, which can change. This movement brings many problems and issues, particularly the requirement that all equipment, including the Air System, has to be tied down to stop it moving.

Jacking an Air System at sea is a major evolution. The jacks themselves must be chained to the deck, and the Air System must be lashed, usually with nylon lashings, which can be adjusted as the Air System is raised. Jack operators and the safety team must all be fully briefed and co-ordinated. Finally, before jacking commences, it is necessary to call the ship's bridge and tell them that jacking is about to commence.

Jacking can reduce the effective wheelbase of the Air System and makes it more unstable, for example, when a Sea King air System is raised on jacks, it reduces its wheelbase width by around 2 metres.

8.1.2 EMBARKED OPERATIONS

There are a number of scenarios of embarked operations:

a. **Containerised transit.** Air Systems which are stored and transported in containers are often moved on cargo ships. This method is effective and relatively low risk to the Air System if salt water can be kept out and humidity kept low. However, it is necessary to check that the containers are still secure during transit and it may be necessary to regularly open the containers to check for breaches or deterioration, but without putting the Air System at greater risk by breaching the container.

b. **Deck transit,** where the Air System is flown or craned onto a ship and left exposed on the deck with covers and blanks fitted, carries more risks to the integrity of the Air System; this was how Chinooks were repatriated from the first Gulf war. The risks are far greater as it is almost impossible to keep moisture, and hence salt, out of the Air System. The US Military favoured shrink wrapping their Air Systems for a while, but then found that any breach in the wrapping would introduce contaminants.

The wrappings would then cause an increase in corrosion rates by trapping water inside and providing a pressure cooker-like corrosive atmosphere inside.

c. **Deck parked operations** pose significant risk to Air Systems. This technique is used for Air Systems like Chinook which cannot easily be stored in a ship's hangar or when the whole ship's complement of aircraft cannot be accommodated in the hangar. The risks are similar to deck transit but at least the Air Systems are operated during transit and on station and can be rotated with other Air Systems so that their exposure time is limited.

d. **'Lilly pad' operations** are those where Air Systems use a ship as a temporary airfield to refuel and re-arm between sorties or in transit to theatre; this has a relatively low risk but still exposes Air Systems to all the risks of operating on a ship, albeit for limited periods of time.

e. **Hangar operations** are the 'norm', and, in principle, they involve putting Air Systems in a protected sealed hangar when not in use. However, the levels of airborne salt in a ship's hangar are very high, as is the relative humidity. The hangar of a ship is not hermetically sealed: in a storm, water (both salt water and rainwater) pours into the hangar from around the sides of the lifts. If the Air System is parked next to the lift, it is likely to get soaked with salty water, but actually anywhere in the hangar will be exposed to very high levels of salt-laden and extremely high humidity atmosphere.

The type of sorties being operated have a significant effect on exposure of the Air System to damaging atmospheres: low level maritime sorties such as Search and Rescue, Antisubmarine Warfare and littoral operations such as the Sierra Leone beach landing (see below) during the May 2000 evacuation of British Nationals will be far more damaging than high level airborne early warning or inland sorties.

Due to the high levels of salt-laden moisture which the Air System will have encountered during its embarked operations, an immediate post-deployment recovery plan will be needed to reduce the long-term effects of salt corrosion. However, in reality, fully recovering an Air System to the pre-exposure condition is virtually impossible. Any Air System that has been to sea is at far greater risk of deterioration from the effects of the exposure to the marine environment for the remainder of its service life.

8.1.3 WATER INGRESS AND ENTRAPMENT

The simplest and most effective line of defence for Air Systems that are exposed on deck, is to shut all doors and openings and fit blanks and covers made specifically for the Air

System before the salt environment can penetrate the Air System. However, putting covers over an Air System that is already salt-laden creates a ‘pressure cooker’ effect which can increase the amount of damage done by the salt. Consequently, when the weather and sea conditions allow, covers should be removed and both the Air System and the covers should be cleaned and dried.

Where leaks and puddles are found inside the Air System covers, it is essential that these are mopped and dried as soon as possible. Where authorised, dewatering compounds such as PX24 can be used to drive water from seams and joints. Often water is present not from leaks but from condensation that has precipitated out. Condensation is often present around fuel tanks where the remaining fuel acts as a cold sink, especially for fixed wing aircraft, which may fly much higher than rotary wing aircraft.

The position in which an Air System is parked on deck can have a significant effect on the amount of exposure to contaminants. On a ‘carrier’ the lee of the ‘island’ will be afforded some protection and usually Air Systems that are not required for immediate flight are parked close to the side or rear of the island. However, ships rarely point in the same direction for very long and very quickly the previously protected area can become broadside to the sea and prevailing wind. Exhausts from ships engines or auxiliary power units can also provide sources of significant contamination.

Dehumidification can have a huge positive effect on the reliability of avionic equipment, and it will reduce time of wetness inside Air Systems and hence reduce the corrosive effects of embarked operations. All Lynx and maritime Wildcat Air Systems are always dehumidified when embarked, as are Merlin Mk2. Where dehumidification is not available on the ships, it has to be taken on board by the detaching unit; all Air Systems that are embarked should be dehumidified.

Composites pose a significant problem with regard to water ingress and any damage to coatings must be repaired as soon as it is spotted. Also, damage to the composite itself can be very difficult to detect but can provide a route for water ingress which can have a significant effect on the composite mechanical strength and integrity.

8.1.4 SALT

Salt is a perennial problem when operating on or near the sea and airborne marine salt can be detected up to 50 miles inland. In practice, the levels of salt that can be measured at the shoreline drop by a factor of 10 for every mile inland so that at 2 miles from the coast there is just 1% of the airborne salt that can be measured at the sea’s edge.

The effect of salt on metals is to increase the level of corrosion by speeding up the flow of ions and, when mixed with water, salt is a very effective electrolyte. Salt water or salt crystals left on the Air System can breakdown protective systems and, once breached, corrosion can progress rapidly and cause catastrophic damage. However, salt is relatively easy to remove with plain water.

The general rule for salt removal is that any Air System that has been outside the shelter of the hangar should be washed with fresh water at the end of each period of exposure.

Any support equipment should be fresh water rinsed daily and all embarked Air Systems should be foam/industrial washed every week. In practice, the industrial (foam) wash is often deferred whilst at sea, however, fresh water washing on a daily basis, providing weather conditions and the ship's water supply permit, is essential.

Engines require a similar wash programme. Salt accretion can severely affect the efficiency of gas turbine compressors and so the fresh water and industrial washes for engines should always be performed. As an example of salt accretion in engines, in 2007 a Lockheed WP-3D was flying a meteorological sortie 500 miles from land over the northern Atlantic. The majority of the sortie was conducted at an altitude of between 3,000 and 5,000 feet and during a 10-minute period 2 hours into the flight, 3 of its 4 engines stalled and shut down due to salt ingress. The Air System was unable to maintain height on one engine but at just under 2000 feet the Air System flew through a rainstorm and the aircrew were able to restart a second engine and limp back to base.

After fresh water washing, paint is used as a key protection against salt-water damage. Most metallic Air System materials degrade in a salt-water environment. Magnesium still presents huge problems in the marine environment but the introduction of Rockhard© coatings and paint systems[10] has gone a long way to alleviate this issue.

The increasing use of composites will alleviate some of the risks of corrosion, but composites are very susceptible to water ingress and coatings must be kept in good order. It can be very difficult to detect physical damage in composites, particularly with the limited resources available on a ship. It can be equally difficult to effect repairs on a ship for the same reasons.

The picture above is of the hangar of HMS Dauntless with 2 Mk 8 Lynx; note the gantries overhead and there is less than a metre between the rotor blades of the 2 Air Systems. Also

[10] Refer to www.indestructiblepaint.com

note the chain and nylon lashings securing the Air Systems. What is not visible in this picture is the dehumidification rig which is strapped down with a nylon lashing.

8.1.5 Sealants, Coatings and Repairs

It is generally not possible to hermetically seal an Air System. Some MoD Air Systems have been built with no sealant in the joints and even those that are sealed often have voids within the joints. Access doors and removable panels pose additional problems as they cannot be sealed and there is a higher danger of water ingress through these points.

Designers need to understand and cater for repeated access to compartments and the consequent wear and tear on seals and gaskets. Equally, operators need to be aware of how to replace or repair any seals that are showing signs of wear or failure.

Many of the components and equipment installed in Air Systems need to have electrical continuity between them and this can provide the possibility of creating small voids into which liquids will readily wick through capillary action. However, this problem can be alleviated with the use of modern conductive gel gaskets and seals.

Helicopters and fixed wing aircraft skins are subject to high levels of vibration and fatigue which can cause sealants and paints to crack. Even the micro-cracking of coatings caused by tightening of securing bolts on a gearbox has been found to provide a pathway for water and cause the rapid onset of corrosion.

Aerial seals have been a huge problem and before gel gaskets were introduced; Chinook used to have to replace large areas of its airframe at every depth maintenance cycle because the aerials were so difficult to seal and water would get in and cause severe corrosion.

8.1.6 Paint

Whilst it is essential to repair coatings on both metals and composites as soon as breaches occur, all RN ships now only carry very small amounts of paint, which is for emergency use only, to reduce the incidence of fire on board (until the mid-1980s 40% of all fires on ships involved paint). Even if paints are approved to be used, they must be used carefully as any venting of the fumes can cause a hazard.

Pre-treatments, such as Alocrom, can be very difficult to acquire, handle, store, mix, use and dispose of on a ship as most contain noxious substances such as chromates. Used materials, as well as being toxic and carcinogenic, can also spontaneously combust.

Touch-up repairs can be effected with small epoxy repair kits which can give up to about one square foot of coverage using a relatively safe paint type. But epoxy has its disadvantages, and in hot climates it tends to turn to a consistency like cottage cheese within a few minutes of mixing, and whilst this can be alleviated by the addition of thinners, thinners are most unlikely to be found on a ship due to fire risk.

The Fleet Air Arm has used anti-corrosion kits for many years and, following redesign in 2002, the kits are now authorised to hold all the ready use pre-treatments, paints, chemicals, and equipment used in treating corrosion and restoring coatings. These kits have also been issued to Chinook and Puma operators.

8.1.7 ROHS (RESTRICTION OF THE USE OF CERTAIN HAZARDOUS SUBSTANCES)

In electrical and electronic equipment, the Restriction of the Use of Certain Hazardous Substances (RoHS) affects the use of materials such as lead, cadmium, mercury, chromium 6 compounds, PBB and PBDE.

Chromates based on chromium trioxide form the basis for most of the commonly-used corrosion inhibiting packages utilised for Air System coatings, many sealants and some adhesives; dichromates, which are also restricted, are used as catalysts which is why PR 1422 disappeared. The RoHS legislation also bans chromic acid anodising and a number of other plating processes which use chromic acid as a passivizing solution.

More recently a number of plasticisers and UV absorbers have also been added to the list of restricted (often indeed banned) chemicals and these substances are used in coatings, sealants and seals to give required mechanical properties. The loss of chromates and phthalate plasticisers could have a profound effect on the MOD's ability to protect and preserve its Air Systems, particularly those operating in the harsh maritime environment.

The MOD has already stopped using a number of products, eg PR1422 and JC11, and a significant number have been reformulated, such as Ardrox 6092 aircraft wash fluid (which was reformulated without the knowledge of MOD staffs). MOD personnel therefore should be careful when using alternative materials as they may be less effective than the originals.

8.1.8 ADAPTABILITY

Getting Air System spares to the ship can be a major problem. A general guide is to take as many spares and as much support equipment as can be accommodated in the ship, accepting the fact that space is at an absolute premium on board. Wherever possible, common spares, including bolts, seals and washers should be used. Air Publications should always be up to date and as complete as possible. The Air System maintainers and operators need to be fully trained, experienced, capable, and authorised to work without constant supervision, and often without any off-ship support at all.

8.1.9 FIXED WING OPERATIONS

The last time UK fixed wing aircraft embarked was in 2006[11] and the UK has not used catapults or arrester gear since the Queen's Silver Jubilee year in 1977, except for those who have trained on USS Wasp.

[11] Since the marinization event, UK F-35 Air Systems have embarked on the Queen Elizabeth Class-carriers as part of the UK Carrier Strike Group 21 (CSG21).

Problems caused by jet efflux, on-aircraft oxygen systems, air weapons and ejector seats are but a few of the key issues to be faced. Particularly of note for the F-35 is the repair of the stealth coatings on the Air System and its panels.

8.2 NC EST (NAVY COMMAND EQUIPMENT SUPPORT TEAM)

The Navy Command Equipment Support Team (NC EST) are located at RNAS Yeovilton, the team is made up of military and civilian staff who are the subject matter experts on a varied and large amount of generic Air System Ground Support Equipment (GSE).

NC EST also ranges and scales all Naval Aviation units, including shore stations, embarked platforms including RFA Aviation platforms and lodger units within the Navy Command Domain, and now includes Army Air Corps (Wildcat) regiments located at Yeovilton.

NC EST is designed to act as a focal point for all technical queries, including spares issues, OPDEF requests and technical advice to units embarking for the first time, i.e. Chinook, Apache, and occasionally other Air Systems from NATO countries. NC EST has contact with the various equipment PTs, all the users and, importantly, industry, particularly the equipment manufacturers, who can assist with a technical resolution if required.

NC EST is an invaluable source of information for desk officers and units faced with embarked operations.

8.2.1 NEW, ADDITIONAL AND REPLACEMENT GROUND SUPPORT EQUIPMENT

When discussions take place between stakeholders regarding new, additional or replacement GSE, NC EST should be consulted as it can offer good advice. Typical issues to be resolved for embarked operations include:

a. Does the GSE have lashing/tie-down points?
b. Can the GSE be easily of moved and stored when embarked?
c. Is the GSE diesel or electrically operated? Is it suitable for ship's voltage etc., (note that no 2 ships are the same), are the equipment/hanger plugs/sockets compatible?
d. Can the GSE's compartments be sealed to prevent salt water/moisture ingress?
e. The electrical connections must be protected, especially those connections or connectors that are "open" to the elements.
f. Does the equipment have its own instrument lighting?
g. Is the external paint work good enough to withstand harsh environments presented by salt water, desert heat and arctic cold?
h. Is the GSE suitable for a tactical environment, eg not painted bright yellow?
i. Is the GSE suitably sized for the ship? Even on larger ships, due to hangar space constraints, there are requirements for some GSE, eg tractors, JCB cranes etc., to remain on deck. Consequently, the GSE is more likely to be subjected internal and external corrosion and thus requiring more maintenance.
j. What are the limitations on the use of the equipment in varying sea states?
k. Is the GSE cleared to be used within the RADHAZ area on the deck?
l. Is the GSE Zone 2 capable or does it have any other specific military requirement?
m. Can the GSE be air freighted easily, can it be moved by road as a towed item?

8.2.2 TRIALS AND TESTING OF AIR SYSTEM SUPPORT EQUIPMENT

There should be a robust trials programme to ascertain the suitability of the Air System GSE selected for the maritime environment.

8.2.3 SPECIAL TO TYPE EQUIPMENT

The STT (Special to Type) equipment supplied via the platform PT or the Design Organisation has to be designed to suit the environment for which it is intended. Early discussions between the Users and the Design Organisation are important to capture the full spectrum of requirements within the System and User Requirements Documents.

9. DESIGN CHALLENGES

9.1 AW159 WILDCAT CORROSION PROTECTION STRATEGY

Two papers were presented in this section: T Neville (Fin-H - Helicopter System Design – Marinisation): *Marinisation of Helicopters* and M Rees (Fin-H - Deputy Chief Project Engineer Wildcat): *Wildcat Corrosion Protection Strategy.*

The Wildcat corrosion protection strategy is in accordance with AgustaWestland's (AW) design and in-service experience gained over time from all of AW's naval platforms. The design aim being to satisfy the requirements of DEF STAN 00-970, Part 7, CS29.609 and UK29.609a-d "Protection of Structure"[12]. The design aim was predominantly addressed through 2 aspects: by "**Design**" and through "**Husbandry**".

9.1.2 DESIGN

The AW design process DI No.ISO.4.3.10660 and its Appendix includes consideration of the operating environment of the product, identifying risk areas and implementation of resulting mitigations by design or scheduled maintenance (including use of MSG3 logic for Wildcat) such as:

a. Selection of appropriate materials to minimise susceptibility to corrosion
b. Selection of appropriate protective treatments and finishes to minimise the risk of corrosion
c. Provision of suitable drains and elimination of water traps to minimise exposure
d. Adoption of assembly methods to minimise exposure to environment e.g. airframe wet-assembly.

The Wildcat design process included the capture of legacy Lynx in-service corrosion related issues (captured as part of the set of Stakeholder requirements for the System Readiness Requirements key gate review, see DOORS Database of In-Service Design Requirements: DRS-L-C-05-0003). Corrosion related issues identified were:

a. Water ingress due to ineffective sealing (various locations – particularly doors, windows and removable panels)
b. Cabin floor and cargo tie-down fittings (which acted as moisture traps)
c. Fuel bay structure
d. 420A bulkhead
e. Sponson structure
f. Magnesium gear cases

[12] Previously Def Stan 00-970, Part 7, Section 2, Supplement 4 – Design and Construction (Subpart D), Issue 6, Leaflet 407.

9.1.1 WILDCAT DESIGN SOLUTIONS

The design of effective seals proved problematical due to the requirement to provide both environmental and Electromagnetic Compatibility (EMC) sealing. The standard EMC seals available are not ideal as environmental seals and so design changes were required to obtain an acceptable level of environmental sealing.

The adoption of monolithic aluminium machinings for the airframe and floor structures reduced the parts count (reductions of between 30:1 and 100:1 achieved) and, together with wet assembly, significantly reduced the number of potential corrosion sites.

Adoption of floor seat rails rather than pan fittings and with an associated new design Sea Tray eliminated water trap sites.

Although it was not practicable under the contract to eliminate the use of magnesium gear cases, an improved, durable epoxy varnish (Rockhard© varnish) protective treatment was introduced for the magnesium gear cases to reduce the risk of corrosion.

9.1.2 HUSBANDRY

The Compound Interactive Electronic Technical Publications (CIETP) identified scheduled maintenance activities and standard practices to ensure any signs of corrosion were identified and eliminated before the product becomes excessively damaged and unusable, for example:

a. Scheduled Zonal Inspections to identify any signs of corrosion with subsequent removal and reinstatement of protective treatment and finishes
b. Air System cleaning (fresh water and foam wash)
c. Maintenance action to reinstate corrosion protection compounds
d. Use of De-Humidifiers in tropical environments
e. Standard airframe and electrical husbandry practices which have been incorporated into the following datasets:

    1. Wildcat CIETP DESC C12-22-00-00-018A-A Zonal inspections - Introduction
    2. Wildcat CIETP PROC C20-20-00-09-259A-A Application of protective treatments - Other procedures to protect surfaces
    3. Wildcat CIETP DESC C20-30-04-00-010A-A Radio frequency bonding - General data
    4. Wildcat CIETP PROC C12-31-00-01-260A-A Cold weather conditions - Remove and prevent ice and remove contamination
    5. Wildcat CIETP PROC C12-21-03-00-250A-A Husbandry procedures - Aircraft antennas, clean and apply surface protection

No additional husbandry activities for embarked operations are specified

The Wildcat CIETP DESC C05-00-02-00-010A-A Master Maintenance List - Maintenance Table identifies all of the scheduled maintenance activities and periodicities. Some activities do identify an increased frequency for embarked operations, though not specifically for corrosion prevention. The MOD, however, may undertake more frequent maintenance activities when embarked e.g. aircraft washing.

9.2 HELICOPTER MARINISATION

Enabling a helicopter and its support system to operate in a maritime environment requires a clear definition of the requirements and AW defined a maritime environment as an environment that has/is:

a. Motion
b. Spray
c. Limited space
d. Hostile "terrain" (limited options in the event of an emergency)
e. Salt laden atmosphere

Helicopter benefits are many: they are able to land in a small area, the pilot can wait and elect to land during "quiescent period" and a helicopter can act as a generic part of the ship's system. However, ships make for difficult airfields and landing can be one of the most demanding situations a helicopter pilot may encounter; the designer must therefore make suitable allowances.

9.2.1 LANDING AND TAKE-OFF CONSIDERATIONS

The deck must be "within limits" for a given helicopter type (or category). Clearance to land must be authorised by the ship's command and must recognise issues such as:

a. Unpredictable deck motion
b. Spray/glare
c. Lighting
d. Ship's air wake – local flow conditions
e. Landing gear loads – vertical/lateral/fore/aft (brakes on)
f. Air System stability on touchdown
g. Restraint system.

Other aspects to consider are:

a. Blade fold.
b. Maintenance on board
c. Effects of spray/corrosion
d. Electromagnetic Environment
e. Navigation system performance
f. Visual references (day/night etc.).

10. MLSP (MERLIN LIFE SUSTAINMENT PROGRAMME)

10.1 OVERVIEW

Merlin Life Sustainment Programme (MLSP) was a 2-phase programme with 2 main objectives: The obsolescence mitigation to support an Out of Service Date (OSD) of 2030, and the Ship Optimisation for Littoral Manoeuvre operations to replace Sea King Mk4. One paper was presented in this section: C Massey (Fin-H - Chief Project Engineer EH101*): Configuration Changes for Merlin Mk3 to Mk4 Conversion.*

The sustainment programme consists of:

a. **Phase 1 –** Initial Capability to temporarily fill Sea King Mk4 gap. Interim Ship Optimisation capability only via Merlin Mk3 modifications.
   - On 7 'interim' Merlin Mk3 aircraft

b. **Phase 2 –** Full Capability
   - Cockpit & Avionics Upgrade
   - Full Ship Optimisation

The programme was based upon a 25 Air System Programme: 19 Merlin Mk3 being converted to Mk4 and 6 Merlin Mk3a being converted to Mk4a. It was assessed as a low technical risk, building on previous studies and programmes (Merlin Mk2 and AW159 Wildcat).

10.1.1 PHASE 1

Phase 1 design focuses around providing a ship clearance and role specific functionality. The configuration changes to the Air System as part of the MSLP were:

a. Folding main rotor head
b. I Band transponder system
c. Naval lashing rings and deck lashing scheme
d. Updated twin wheel undercarriage for ship operations
e. Gagging valves
f. Heavy duty gas heads
g. Fast roping capability
h. Special Forces radio fit
i. Blade restraint
j. No changes to Air System cockpit
k. Ship operations limited to 14,600kg and Sea State 4
l. Some modifications will remain on Phase 2.

10.1.2 PHASE 2

The second phase primarily addressed: full obsolescence mitigation; the introduction of Merlin common cockpit; an increase in cleared operating mass of the Air System; full ship operating limits to Sea State 6; conversion of Mk3a aircraft included in this phase; Phase 1 Air System modified to Mk4 standard and a commonality between Mk4 and Mk4a.

The key design features of the upgrade were:

a. Fully automated folding head and tail
b. New rear fuselage to provide fold capability and reinforced for ship landings
c. Increased undercarriage operating pressure for deck operations above 14,600kg
d. Upgraded cockpit, maximising commonality with Merlin Mk2
e. Introduction of AW159 Wildcat-based Tactical Processor
f. Introduction of a new DAS Controller
g. Change of 15,600kg Alternative Gross Weight (AGW) to All Up Mass (AUM)
h. Replacement Rotor Ice Protection Unit
i. Common egress methodology between Mk4 and Mk4a.

10.1.3 SUMMARY

MLSP Air Systems will fulfil a number of key UK roles in operation with the Royal Navy. The MLSP conversion substantially improves the ship operating capability of the Air System. The ship optimisation features of the conversion are largely read across from other Merlin/EH101 variants. There is a low technical risk, and it provides a commonality with Merlin Mk2, but, most importantly, the programme mitigates obsolescence on the Mk3 and Mk3a.

11. DESK OFFICERS' AIDE MEMOIRE

11.1 DESK OFFICERS' MARINISATION OF AIR SYSTEMS AIDE MEMOIRE

Introduction

1. The aim of this document is to provide guidance and best practice on what to consider when marinising an Air System, either in design or subsequently in service. The information has been collated from the Ageing Air Systems Programme's Working Group Marinisation event; note that any references made to military or civilian regulation and standards were those which were force in March 2015. For convenience, this Aide Memoire contains the key points organised into a "TEPIDOIL" format.

Training

2. Additional competencies will be required for all crew members for maritime operations:

a. The ship's company will need to complete basic familiarisation training to confirm awareness of the additional hazards associated with the specific Air System on-board and immediate actions in case of emergencies.

b. The Air System's aircrew and maintainers will need to undertake more rigorous training to confirm they will be competent to operate in an unfamiliar sea-based environment with the inherent dangers on-board a ship e.g. a moving deck and limited space.

Equipment

3. When operating on-board ship, the biggest threat to structural and system integrity is corrosion. Minimising the risk of corrosion due to the maritime environment is key for embarked operations. It is impossible to hermetically seal an Air System or the GSE required to operate it, therefore, the following should be considered to protect against/delay the onset of corrosion:

a. **Wet Assembly.** Def Stan 00-970 details the requirement for all static joints to be wet assembled with an approved sealant or an approved jointing compound.[13]

b. **Surface Finish.** It is essential that any degradation to the Air System's surface finish is reported, documented, and repaired. When operating on-board ship the original surface finish product may not be permitted due to safety regulations. Prior to embarking it is essential to ensure the surface finish integrity can be maintained either through the use of the original specified product (if possible) or a suitable temporary alternative.

[13] At the time of the marinization event, UK and US definitions of "wet assembly" differed. The UK definition stated that the jointing compound is to be applied to faying surfaces **PRIOR** to joining, whereas the US definition states that joints are sealed with sealant **AFTER** joining, with no sealant present between faying surfaces. Current regulation does not contain a definition of "wet assembly".

c. **Minimising ingress of contaminants**. Ensuring Air System panels are correctly sealed, closed, and secured post use is basic but of paramount importance. The provision of Air System covers to protect from the weather, sand and salt should be given high priority by TAAs, CAMOs and Maintenance Organisations; suitable SOPs should include their use when embarked

d. **Maintenance Schedule**. Prior to deployment, a review of the Master Maintenance Schedule by Reliability-Centred Maintenance (RCM) trained staff should be instigated by the TAA as normal, land-based, maintenance inspection regimes are unlikely to be sufficient for embarked operations in salt-laden environments. Typically, more flexible maintenance packages may be required and certain activities, for instance Air System and engine washing and NDT inspections, may require reduced periodicities.

e. **Dehumidification**. Whilst the benefits of dehumidification are well known, the necessity for dehumidification is even more important at sea and existing land-based equipment may be unsuitable for the task. Consequently, equipment should be checked and advice sought from experts at Naval Systems Command and 1710 NAS.

f. **GSE & Tooling**. Commanders should consider the requirement for additional GSE and tool inspections/maintenance (including clean water washing) to counteract the adverse maritime operating environment. Typical examples of potential problems that were encountered during Op ELLAMY are shown in this paper.

4. Air Systems operating from the confines of a ship usually require specialist modifications, which can include:

a. For helicopters, the design would typically incorporate features such as a folding main rotor head and/or a folding tail unit, as were applied to the Merlin Mk4. Consequently, additional GSE such as blade fold kits, trestles and restraints may be required.

b. Due to the movement of the ship's deck, it may be necessary for designers to strengthen the undercarriage, so it can withstand the additional forces inherent with operating from a moving platform as occurred with the F-35 and the Merlin. Operating from a deck can invalidate the loads and design assumptions for a land-based Air Systems, and significant strengthening/redesign of undercarriage is often required.

c. To secure the Air Systems and GSE on deck, lashing points may need to be introduced or upgraded on the ship, Air System and GSE. Appropriate lashing schemes/patterns, and any limitations in terms of deck pitch and roll angles and wind speed and sea state will also be required.

d. Communications equipment to be considered includes the I-Band Transponder, to allow the Air System to be identified in the maritime environment by the "mother" ship, and a telebrief to allow communications when on the deck. If carrying out support for SF operations, enhanced communication systems and equipment will also need to be considered and, in this case, extra equipment may need to be fitted to the Air System or cleared for use as 'carry on' equipment.

e. GSE should be designed (or modified) to permit its use during operation on-board ship. Whilst at an MOB it may be more cost effective to produce a large multi-platform item, on-board ship a number of smaller, more mobile, items may be far more practical and potentially necessary due to weight and space constraints. An example of the inappropriate use of land-based GSE on-board ship was the Apache Multi FAGE (MFAGE) which was critical for diagnosing faults on the complex Apache equipment. However, the MFAGE was too large to be stored in a hangar and was not cleared for use in deck hangars; it also suffered from significant corrosion when stored and used on deck.

Personnel

5. With the introduction of F-35, the level of maritime experience of the aircrew, maintainers and the ship's company will need to be critically assessed. History has shown that there will be a steep learning curve for all personnel, as was evident during Ops HERRICK, ELLAMY and SHADER. Therefore, correct and comprehensive training prior to embarking personnel is vital. Not only will Air System maintainers need to understand how to operate their Air System and also support the ship, but ship's personnel will also need sufficient understanding of the needs to the Air System, aircrew, and maintenance staff.

6. Due to the limited accommodation on-board, consideration should be given to both the number of personnel and the skills of those personnel who will be embarked. Experience indicates that there is often a tendency to use the same personnel for long periods, or regularly, due to their experience, but such a policy can result in unnecessary, and potentially dangerous, fatigue.

Information

7. The following are examples of typical information resources that require consideration:

a. The Statement of Operating Intent and Usage (SOIU) will need to reflect the maritime environment, including relevant Sortie Profile Codes. Air Systems will be subject to additional loading when landing on a moving deck, they will be under different stresses during flight and they will also be at a higher risk of corrosion. There will need to be a suitable method of collating this information when operating in a maritime role. A review of the Maintenance Master Schedule, and its associated Topics, will need to be undertaken in plenty of time before deployment to ensure that any additional maintenance is correctly undertaken.

b. The Ship-Air Release (SAR), authorised by the RTSA, will clear a specified class of ship and Air System type/mark to conduct embarked aviation activity. The SAR will also include safety information and operating limitations (Ship Helicopter Operating Limits (SHOLS)).

c. Prior to embarking, the Ship Certificate of Safety Aviation (CS-A) should be checked, to ensure there are no restrictions imposed which will affect or impede the planned mission.

d. In order to maintain Air Systems correctly whilst on-board, the aircrew and maintainers will need access to hard-copy or electronic publications. Consideration should be given to the space needed for the maintainers and also for any IT support needed to ensure that updates to publications can be obtained.

Doctrine

8. Typical doctrinal documentation which should be considered includes BRD 766 Embarked Aviation Orders and the RAs which directly relate to ship-air operations, namely RA 1029 Ship-Air Release and RA 1395 Authorisation to Permit Embarked Aviation in Her Majesty's/MOD Ships.

Organisation

9. Some key organisations that can provide advice on marinisation are:

a. Navy Command and Equipment Support Team (NC EST)
b. 1710 NAS Materials Integrity Group (MIG)
c. RN RTSA including Ship-Air Release Team
d. RN Staff Aviation Officer (SAVO)
e. MAA.

Infrastructure

10. Whilst not an exhaustive list, the following are examples of infrastructure elements that should be considered:

a. The hangar facilities will generally be of a much smaller size than those at an MOB. Extra time and care will need to be afforded to ensure the correct and safe handling of Air Systems when moving to and from these facilities and whilst operating from them and within them. The levels of relative humidity and airborne salt will be extremely high as hangars are not hermetically sealed.

b. A ship cannot carry and store equipment, and spares, for every Air System and so compromises will need to be made. Prior to embarking, planning should be carried out to ensure the necessary equipment is available, whether it be the normal MOB equipment or a suitable approved alternative e.g. during Op ELLAMY there were no suitable Air System wash facilities on-board, so a temporary solution was to use the Pavehawk kit. IT connectivity back to a MOB may well be intermittent, so demanding spares or uploading latest software will have to be carefully planned and managed.

Logistics

10. It is rare for a component to fail when a ship is docked; avionic equipment is extremely complex with virtually non-existent in-situ repair solutions when embarked. Desk Officers should consider utilising the DE&S Supply Modelling Teams to optimise their DSPs before embarkation to manage the space and weight limitations on board ship.

12. REFERENCES

1710NAS-MATLS Corrosion: *The Practicalities of Operating Aircraft on Ships (What Designers and Operators need to know!)*

Apache PT Eng Mech 4: *Lessons from AH Embarked Operations*

ChPT Mk3 Contractor: *Chinook Marinisation Issues*

Massey, C (Fin-H - Chief Project Engineer EH101*): Configuration Changes for Merlin Mk3 to Mk4 Conversion*

Neville, T (Fin-H - Helicopter System Design – Marinisation): *Marinisation of Helicopters*

Rees, M (Fin-H - Deputy Chief Project Engineer Wildcat): *Wildcat Corrosion Protection Strategy*

NC Eqt Spt Team C2: *Support Equipment Marinisation Problem Areas*

13. REPORT DOCUMENTATION FORM

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This Paper contributes to the dstl “Understanding Ageing Aircraft” research and development programme. The paper provides a précis of presentations given at a March 2016 Learning From Experience event, hosted by Leonardo Helicopters and organised through the MAA. The paper provides an outline of the issues involved when preparing to operate an Air System in a maritime environment and it uses evidence from DTs, designers, and operators to provide examples of the problems faced.</td></tr>
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