Type 45 – Power to Command

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Synopsis

The Royal Navy's Type 45 Destroyers have been in Service since Jul 10 and have acquired a reputation for being a world class Air Defence asset with power and propulsion (P&P) fragility, that has attracted much positive and negative attention. This paper sets out how a range of circumstances combined in those early years to make the Class unique; a world leading ship not at her full potential. Many of the contributing factors have been discussed in isolation but have not been combined in one paper. The Type 45 has a modest class size of six vessels, yet each ship has the greatest capability ever installed in a Destroyer. It achieved such a punch due to the largest technology step taken in one class, 80% of the equipment on board is new to Royal Navy (RN) Service. And the ambition to use such a potent ship meant that HMS DARING deployed, worldwide, in the quickest time from build of any RN ship since WW2. Simultaneously and with huge dedication from the team, a new support solution was introduced that had the largest Industry involvement the MoD had ever contracted for a Complex Warship. These, and other circumstances created a heady mix in the early part of this decade and this paper will discuss the lessons learnt from an engineering support perspective. It will combine the experience of our predecessors with our own to give a unique perspective of the first nine years of the Class's life. It will go on to show how improvements have been identified and embodied across the class ensuring that the Type 45 remains a world beating Air Defence Destroyer at her full potential for the next two decades.

Keywords: Type 45; Destroyer; Electric Power; IFEP; Propulsion; Integration; Marine systems.

1. Introduction

The Type 45 (T45) is a versatile Anti-Air Warfare (AAW) Destroyer capable of world-wide operations, contributing to the full range of Defence and wider Government tasks. It is widely recognised as a world leading capability; respected by the UK's allies during standing operations and trusted to defend their Nuclear Aircraft Carriers and other strategic assets. Much of this success is attributable to the step change in technology adopted in T45 that realised both risk and reward early in the class' service life.

This paper seeks to discuss the factors that have influenced the T45 story so far and to inspire future engineers to innovate responsibly, in view of relative risk and reward so as to be resilient if and when risks become issues. The learning points identified through T45 are categorised into 4 key areas:

a. T45 Conception
b. In service experience
c. The Napier Programme
d. Project Vesta

2. T45's Conception

Ahead of discussing those early years of Type 45 operation, it is important to understand the background that generated the platform so that the reasons behind key decisions can be appreciated. It is well documented that decisions made in the design and build phases of a project last the lifetime of the project and this is true for T45 but this paper draws out that whilst their effects are long lasting, they do not need to be permanent.

2.1. Design Stability

1 Author's Biography
Captain John Voyce spent the last 5 years in the Type 45 Strategic Class Authority within DE&S' Warship Support, as the Platform Chief Engineer and then Team Leader. His sea career was in Frigates and Carriers, culminating in Cdr E HMS ILLUSTRIOUS; ashore has mainly been involved in Electrical Engineering projects. He is currently the Commanding Officer of HMS SULTAN.
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T45 was conceived in 1999 following the UK's withdrawal from the Common New Generation Frigate (CNGF), which became known as Project Horizon. CNGF was a programme that was started in 1993 and always envisaged an air defence ship with the integrated Principal Anti Air Missile System PAAMS weapon suite at its core. Whilst the UK withdrew from CNGF they remained committed to the PAAMS programme and continued its integration into the T45 design. Hence the weapon requirements set out in 1992 were developed over an 18-year period until the first firing occurred in HMS Dauntless in Sep 2010. However, that long term view was not true for the Power and Propulsion (P&P) system; the initial COGAL (COmbined Gas And eLectric) and Controllable Pitch Propellers was changed in 2000 to employ the Integrated Full Electric Propulsion (IFEP) architecture with Fixed Pitch Propellers as shown in Figure 1 (MoD, 2000). This occurred in order to seize the 'Electric Ship' (Hodge, Mattick, 1997) opportunity that occurred relatively late in its design.

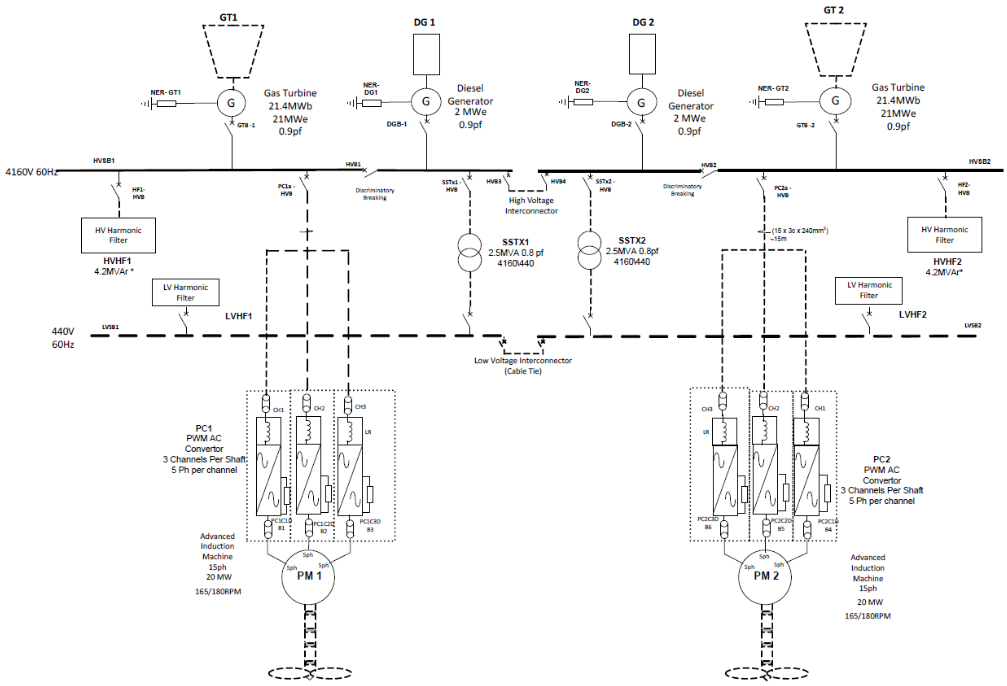

Figure 1 – T45 P&P Schematic

Also, late in the design was the clarification of the Class size. Originally, in 2000, there were to be 12 ships in the Class which, four years later, reduced to eight due to a perceived reduction in threat, revised planning assumptions and a planned improvement in network capability (e.g. Cooperative Engagement Capability (CEC)). In 2008, two and a half years before HMS DARING's In Service Date (ISD), this reduced to the six in service today. Small classes of ships need higher levels of reliability and support if they are to match larger classes ship for ship. The law of small numbers means that the non-availability of one ship out of six has a bigger effect than one out of 12, plus the economies of scale affect a small class in procurement as well as through life.

2.2. Equipment and Systems Innovation

The desire for innovation was prevalent throughout the T45 ship design with estimates suggesting that 80% of the equipment was new to service in the RN. Much of the equipment was successful, particularly the weapon systems and integrated radar suite which has helped to maintain the RN at the cutting edge of battle winning capability. However, some innovation was less successful. The P&P system was the first IFEP system in a RN complex warship and whilst electrical propulsion had been employed in many guises over the 20th century it had been either at relatively low powers, such as the Type 23 Frigate and Upholder Class Submarine, or not as integrated, such as the Auxiliary Oiler or Landing Platform Dock, when compared to the T45.

This bold move in P&P system architecture was mitigated by using the shore based Electric Ship Technology Demonstrator (ESTD), itself a significant increase in pre-build testing capability. The ESTD enabled the optimisation of T45's quality of power supplies and the measurement of the interaction between the Gas Turbine

Alternators (GTAs) and the DGs, as well as providing training for the first crews. Whilst all T45 opportunities were exploited at the ESTD, the timing wasn't ideal and with the need to hold the Class ISD, due to the lack of a phased handover with the previous class of Destroyers, the ESTD's results supported the QEC Class design better.

One of the key areas of P&P innovation was the selection of the WR21 Gas Turbine. This engine is the prime mover for the Class and must deliver very high levels of availability if the selected IFEP design is to robust enough for a warship. In the early years this was found not to be the case, but it is worth revisiting the technical reasons why the engine was so attractive:

- Longevity & reliability – the core engine is the Rolls Royce RB211 and Trent engine technology.
- Low IR signature – recovering waste heat reduces gas plume temperatures.
- Low fuel burn compared to a simple cycle GT which increases endurance or decreases running costs.
- Operating profile – the WR21 is ideally suited for a power generation plant configuration as per IFEP thus avoiding the cruise/boost arrangement.

There is clear merit in these objectives and the decision to select the WR21 was understandable and forward-looking. However, whilst some of the anticipated benefits were achieved, a number of issues with reliability, sustainability and availability were encountered. Combined with other P&P issues, this led to several high-profile incidents which exposed a lack of system redundancy and equipment reliability.

2.3. Equipment Pull Through for Future Platforms

From the start, the T45 was identified as a Class that could develop and 'pull-through' equipment and systems for QEC and Type 26 (or CVF/FSC as they were known at the time). The combat system architecture, combat system equipment and propulsion system were all identified as possible candidates. This pull through was successful in many instances, with similar combat systems being in QEC and T45. Certain technologies (such as fuel filtration and WR21) were not taken forward by learning from T45. In such cases the T45 was a successful de-risking/path finder for future platforms given QNLZ's successful entry into service; a point often not understood when the in-Service performance of T45 is assessed.

2.4. SMART Acquisition in T45

The Type 45 was designed and built in a period that followed the 1998 Strategic Defence Review which introduced widespread procurement reform and acquisition reorganization encapsulated in the SMART Procurement initiative. It was against this backdrop that a Prime Contractor, BAE Systems, was instructed to be the Design Authority and, for the first time in RN ship building, undertook much of the equipment design and selection. It also led to a novel Contracted Logistics Support (CLS) solution for the Class which moved to a Contract for Availability (CFA). Whilst CLS and CFA is relatively common for civilian shipping this was innovative for warships. It meant that the equipment and system analysis required to achieve the availability target within the CFA was undertaken by the contractor, and not the MoD, and so results from that analysis, such as a Failure Mode Effect Criticality Analysis (FMECA), Reliability Centered Maintenance (RCM) analysis or Level of Repair Analysis (LORA) were not available to the MoD. This provided a saving and meant the scaling of stores, documentation, training, etc was the responsibility of the CFA which created some unique circumstances:

- Less detail in training for RN maintainers. The RN only undertook Operate and Maintain tasks and the CFA undertook Diagnosis and Repair. (OMDR)
- The ship could be leaner manned given there was no requirement for Diagnose and Repair.
- Maintenance manuals only needed to reflect Original Equipment Manufacturer (OEM) handbooks rather than MoD technical publications because the CFA would undertake deeper, Cat B, maintenance and Ship's Staff would undertake routine Cat A maintenance.
- Sparing was set by the CFA and Prime Contractor.
- Fewer spares required NATO codification because they were encompassed in the CFA.
- With only maintenance spares required on board, normal Illustrated Parts Catalogues (IPC) for equipment were not available for planned maintenance or defect rectification.

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Thus, the T45 was introduced to service with innovation high on the agenda. It was the first to implement an industry led support solution using CFAs and the first to bring circa 80% of new-to-service equipment into the Fleet in one step. The challenge had been set.

3. In Service experience

It is well documented that the initial years of the T45 were challenging and soon the class developed a reputation in the UK press for underperformance. What was less well reported was how well they performed on operations; ill news travels fast (Dickens, 1839). That said, it was a testing time. Bath tub failures were higher than expected and unanticipated issues kept the Class busy, particularly with respect to P&P. This paper will not detail specific failures but will instead draw out two important themes.

3.1. An exquisite engineering project

Following the build phase there was a build up of engineering interventions that were required to be implemented early in the ships' life but, with a lack of handover with T42s, there was also a clear demand to deliver on operations. Hence a juxtaposition for T45 was created; either undertake sufficient maintenance to achieve the next exercise/operation or remain alongside to embody operationally enhancing engineering change. This required an intelligent balance between investing in the future and delivering on operations which tested many in the support and planning domains. Such a balance was made more difficult by premature component failures early in the class' life. The range of issues experienced prompted the first Independent Review into the class (Hodge,C.G 2011) with recommendations feeding through to the support authorities and CFA for action. Improvements were made but the challenge was significant and further changes were required; T45 was in danger of becoming an 'exquisite engineering project'. This situation brought the best out of 'UK Engineering PLC' because a joint Industry and MoD team set about resolving issues.

3.2. Not operated as designed

The high operational tempo did not reduce despite the engineering challenges experienced and it was soon found that the platforms were operating equipment more than originally assumed. The actual usage rate of the ships' gas turbines was almost double that originally assumed and diesel hours were four times greater. This was in part due to the operational demand but mainly due to the RN coming to terms with a power plant that did not have the inherent redundancy they were accustomed to. Single generator operation was a central aim of the T45s 'power station' concept but that mode of operation was difficult due to the reliability issues experienced. It was not uncommon for Commanding Officers to run multiple prime movers to establish confidence through redundancy. A combination of a lack of P&P availability and redundancy combined with a lack of ILS products to support the engineers onboard to rectify defects at sea resulted in a reduction in command confidence in T45.

4. The Napier Programme

A lack of resilience in the T45 P&P system has undermined T45's operability, negatively impacted the RN's reputation, and attracted political interest at home and abroad. The Napier programme was initiated in 2014 to urgently address these issues and restore command confidence in the class. The Napier programme comprises two discrete but highly integrated projects; the Equipment Improvement Plan (EIP) provides system reliability by targeting individual failure modes observed since entry to service. The Power Improvement Project (PIP) will provide system redundancy by replacing and installing additional power generation sources. Together the Napier programme will deliver a reliable P&P system architecture with redundancy that matches the resilience demands of the RN. It will address the shortfall in command confidence and enable the T45 class to reach its full potential. Key events from a Napier perspective are presented at figure 2.

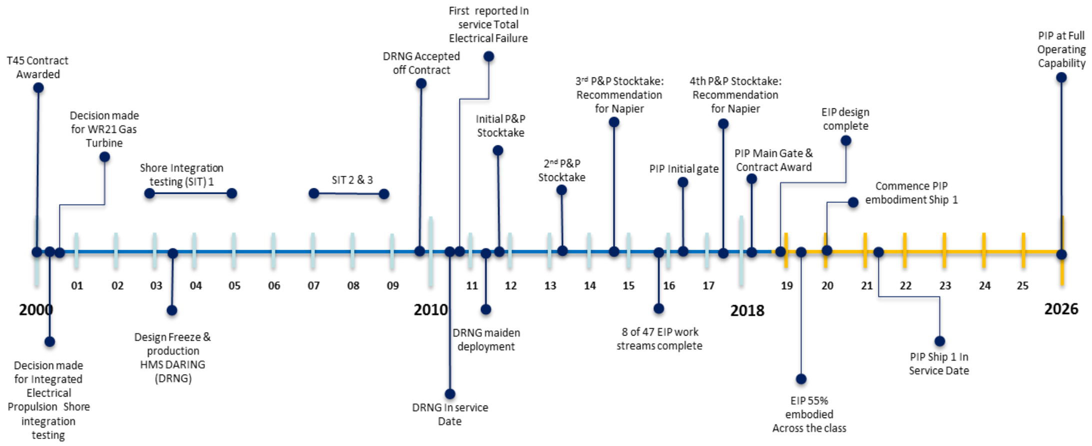

Figure 2 – T45 P&P timeline

4.1. Equipment Improvement Plan

The EIP is implementing design changes and supportability measures to enhance reliability and availability at an equipment and system level. It was initiated in 2014 following a chain of independent reviews concluding that there was no single cause underlying the low reliability of the P&P system and that a targeted approach was needed to address an array of unrelated failure modes. EIP stood up as a DE&S led programme of work with BAE systems, and key OEMs working together. It is important to recognise the urgency surrounding T45 P&P during this early phase as well as the political and reputational drivers of the time. The desire to just 'get on and fix it' needed to be tempered to ensure a credible systematic approach; an approach where second and third order effects were clearly understood for this highly integrated system. The EIP adopted 'quick wins' to address failure modes with interim solutions where prudent to do so. In parallel, a product life cycle approach was taken to determine the feasibility of technical solutions prior to completing the design[2] and installation into each vessel. There are 47 individual upgrade projects within EIP with embodiment across the fleet now standing at 55%.

Determining the scope of the EIP was an organic process that considered the experience of engineers both at sea and ashore. Data from which to make decisions was sparse but special reporting for Loss of Power to Command (LPC) proved pivotal in understanding the potential impact of each upgrade. The EIP used LPC and operational defect (OPDEF) recording to categorise the potential benefit for each upgrade, enabling resources to be assigned where needed the most. The proportion of events experienced by equipment is presented at figure 3.

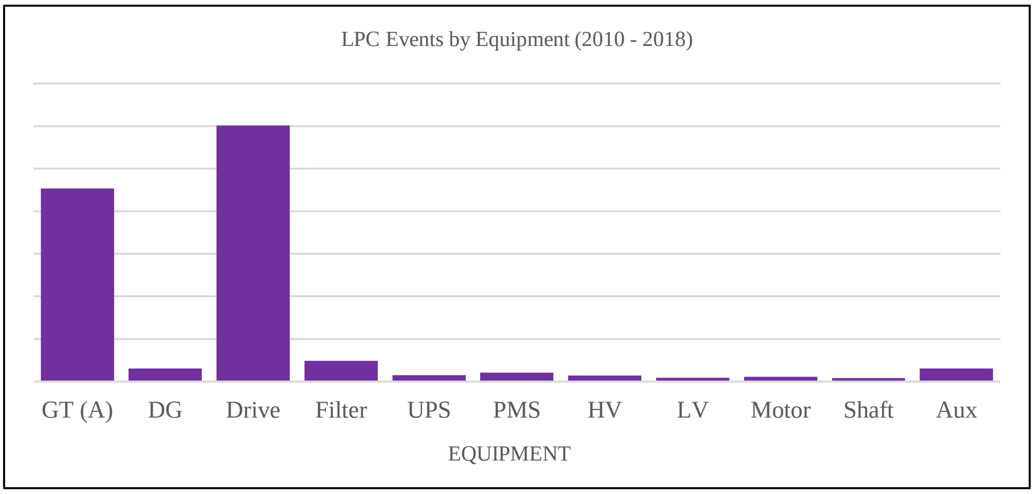

Figure 3 – T45 LPC events by equipment category

[2] Where the term 'design' refers to the technical development of embodiment solutions, as well as Integrated Logistic Support (ILS) and training to match the complexity of individual upgrades.

The relative impact of EIP is difficult to quantify as there are many factors that contribute to the availability measures used within the warship support arena. Mean time between Failure (MTBF) and Mean Time to repair (MTTR) are both effective lagging indicators, but the preventative nature of EIP proves hard to forecast and measure in practice. The most reliable insight as to the contribution of the EIP is the reduction in LPC events over time. Figure 4 outlines the number of LPC events per sea day since 2010, indicating that there has been a circa 90%[3] reduction over this period.

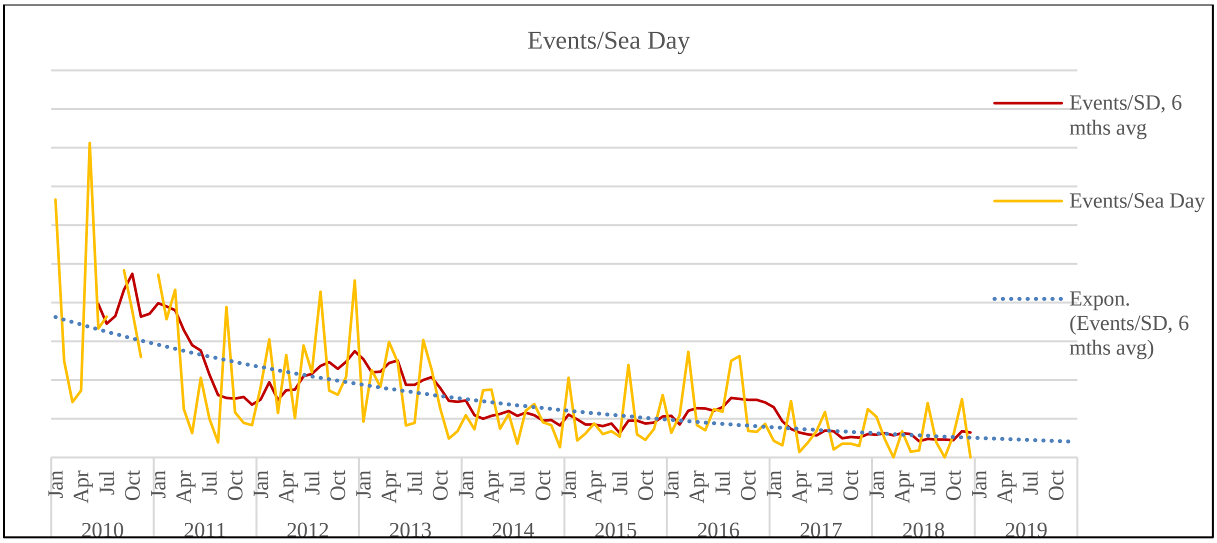

Figure 4 – T45 LPC events per sea day

Whilst figure 3 demonstrates the scale of improvement at a system/platform level it does not reflect the contribution that EIP is making at an equipment level. The graph at figure 5 describes the reduction in LPC events attributed to the propulsion drives, and the correlation between the roll out of two EIP upgrades. Plots such as this exist across various equipment indicating the trend downwards as EIP rolls out across the class.

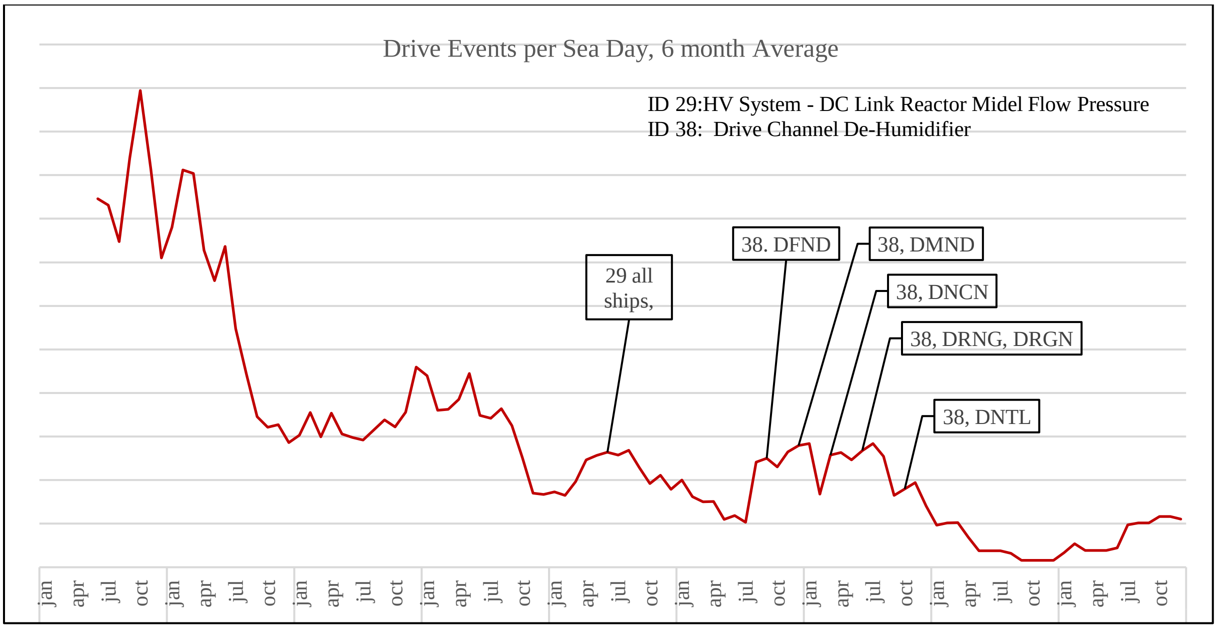

Figure 5 – T45 LPC events on Main Propulsion drives

[3] When considered against the 6 monthly rolling average of 0.95/sea day in 2010, vs 0.1/sea day in 2018.

The data suggests that EIP is delivering increased reliability and performance today at 55% complete, but this is only part of the story. There are considerable efforts across the Defence Lines of Development (DLODs) to improve the way we deliver RN capability and Improvements in our people, training and in-service experience operating T45 has all contributed to the improvements observed. As important is the lived experience of our men and women at sea who when surveyed offered their view on the EIP contribution:

> *"…the de-humidifier fit for the Drive Channels has been the single biggest improvement seen across T45 propulsion. I was a maintainer pre and post the fit on Defender. The number of defects we sustained on the drives was reduced drastically..."* HMS DRAGON, Feb 19.

> *"[The fuel centrifuge EIP A&A] has improved fuel system hygiene and fuel quality, reduced maintainer workload and increased the rate at which fuel can be transferred to service tanks." HMS DEFENDER, Mar 19.*

4.2. Power Improvement Project

Whilst EIP is focussed on reducing the frequency of events through greater reliability, the PIP is focussed on reducing their severity should issues occur. Approved at Main Gate in March 18 the PIP is being delivered by DE&S under contract with BAE Systems and alliance partners BMT Defence and Cammell Laird. It is best categorised as a Ship conversion project focussed on providing additional P&P redundancy in the form of three new (3MW) propulsion capable Diesel Generators (DGs). In doing so, the PIP will remove the two existing (2MW) black start DGs and convert the T45 from a two prime-mover ship, to a five prime mover ship. Taken together with EIP this additional redundancy will reduce the risk[4] associated with P&P by vastly improving the resilience of the P&P system and restore confidence in the class. The single statement of user need for the Napier programme is:

> *"To restore **Command Confidence** and ensure greater **platform availability** to the Operational Commander by increasing the **reliability, redundancy** and overall **resilience** of the T45 Power & Propulsion System.".*

The PIP is more than just new DGs however, the intrusive nature of the embodiment brings about some significant challenges within an existing 'brown field' ship design. This manifests spatially with significant changes to main machinery spaces, through-ship systems and ship structure to enable integration of new equipment. From a functional design perspective, the PIP affects nearly all Marine Engineering (ME) systems aboard the vessel, with minor impacts identified on platform and aspects of combat system equipment. Not surprising therefore that much of the design effort has been to ensure interface design requirements are properly considered and de-risked through sea trials, digital modelling and functional integration testing for software enabled systems. These measures will deliver an updated P&P system architecture that meets the performance requirements,[5] having also considered the through life aspects such as training and Integrated Logistic Support (ILS).

PIP is a significant change that will influence how the RN configure their vessels across a range of operational scenarios. There has been much focus to ensure the benefits of the IFEP system are not lost, and that the flexibility it affords is fully exploited. Economy and efficiency are amongst these benefits which are at their peak when configured for single generator operation[6]. The post PIP operating philosophy defines nine standard system configurations that enable HV resilient, LV resilient and high efficiency modes to command. The proportion of time spent with a single generator connected is in part dependent on the success of Napier in restoring command confidence.

5. Project VESTA

Even after EIP and PIP have delivered, and both will be delivered with improved ILS packages, it was clear that the lack of ILS products from build, which curtailed Ships' staff ability to organically rectify defects, would not be resolved. Availability would plateau if spares, technical documents, specialist tools or training were not addressed. An overarching strategy to better align with DefStan 00-60[7] was needed. Two strands of work were

4 Aligning with the risk analogy – EIP reduced the frequency of defect/event, PIP reduces the severity should issues occur

5 Defined within the PIP System Requirement Document (SRD) and T45 In-service SRD.

6 One prime mover (WR21) delivering all propulsion and domestic services for the vessel

7 Integrated Logistic Support.

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required: one to resolve the obsolescence issue that had built up since build and the second to target the intelligent application of the DefStan to remove any shortfalls. This works scope is delivered through Project VESTA.

5.1. T45 Obsolescence Management.

The first stream within VESTA is to provide increased platform availability through the replacement of obsolete equipment. Whilst the T45 has only been operating since 2010, many elements were procured and installed many years before. Furthermore, the predominance of electrical componentry and software enabled by an IFEP architecture meant the effect of obsolescence is felt quicker than in a mechanical equivalent.; the well documented Moore's law effect is less prevalent in mechanical systems.

VESTA established an obsolescence baseline across all 192 Master Equipment within the T45. It produced a picture of high-risk equipment and a forecast of when the rest of the equipment would become difficult to support. It is now using this baseline to develop a Master Obsolescence Management (OM) Plan for the platform that produces a costed programme to reduce obsolescence through strategic cross class planning with equipment and system delivery teams. It will allow Navy Command to deliver capability based on Through Life Management (TLM) requirements and has realised both cost avoidance and equipment savings whilst improving equipment availability.

5.2. T45 Support Improvement.

The second stream within VESTA is to provide increased platform availability though assessing ILS shortfalls in the equipment that causes the greatest loss of availability. This gap analysis then creates a targeted support improvement plan for the key equipment so that support is focused on what is required and not wasted by repeating any aspects. The equipment currently undergoing the VESTA treatment are already seeing benefits, but the true effect will not be seen for 18 months given the lagging nature of support recovery. It takes time to complete ILS artefacts, technical media or training needs analysis, and even longer until they permeate through the support solution. Work is ongoing to identify more equipment candidates to undergo this gap analysis, which is a scalable and repeatable assessment methodology. When it is complete, Ships' staff can expect to have the right spares, tools, documentation and maintenance routines to achieve the required availability, and be trained to conduct tasks across the spectrum of OMDR. This will restore the Class to the standard expected where engineers can "*maintain the platform and ensure that it is ready to fight tonight and, in the future, ensure sustainable capability at reach and in adversity, and take part in the fight.*" (BRd4487, 2018)

6. Conclusions

This paper has presented the environment surrounding the T45 when it came into service in 2010. The Class strove to innovate in many areas, equipment, system, and support solution. That innovation brought benefits; the T45 deployed worldwide quicker than any other major platform, achieved successes in operations from the Falkland Islands to the Gulf. The Class' flexibility is shown through its achievements in counter-narcotics operations in the Middle East and NATO Flagship duties in the Mediterranean; the Class continues to showcase its world class capability. All this success was not without difficulties, principally with the fragility of the P&P system which was documented by the UK press. This paper has presented the coordinated response to those issues in the form of the Napier Programme (EIP, PIP) and project VESTA.

Today the Class Availability stands at 80% and credible plans are in place to raise it higher. The worst performing equipment, in availability terms, are now 60% more available than in 2017 and Loss of Power to Command incidents have reduced by 90% since 2010. PIP is on track to deliver during 2020 and will ensure that the step change in warfighting capability inherent in a T45 is matched by increased resilience and redundancy in the Power and Propulsion Plant. Project VESTA is on track and is delivering the underpinning equipment data, documentation, and spares to better equip and train T45 engineers as well as tackling the obsolescence challenge in a manner that will inform future platforms such as QEC, T26 and beyond.

All of this has meant that T45 availability has improved to the point that achievement of the mandated readiness is becoming the norm rather than the exception. To quote Richard Branson: '*Face failure head on, don't be afraid of it, and people will support and welcome you even more*'. Whilst T45 did not fail, the Class did experience difficulties and, with the help of those in the T45 enterprise, has faced them head on. The support of 'UK Engineering PLC' has meant we were able to learn from each incident, change and improve; it was never too late to alter solutions that didn't work and we are well down the road to achieve even greater success. There may yet be stormy days ahead, but the climate is changing for the better. The future is bright for #Fighting45s.

Acknowledgements

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