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Type 45 Destroyer
Independent Power and Propulsion System Performance Review

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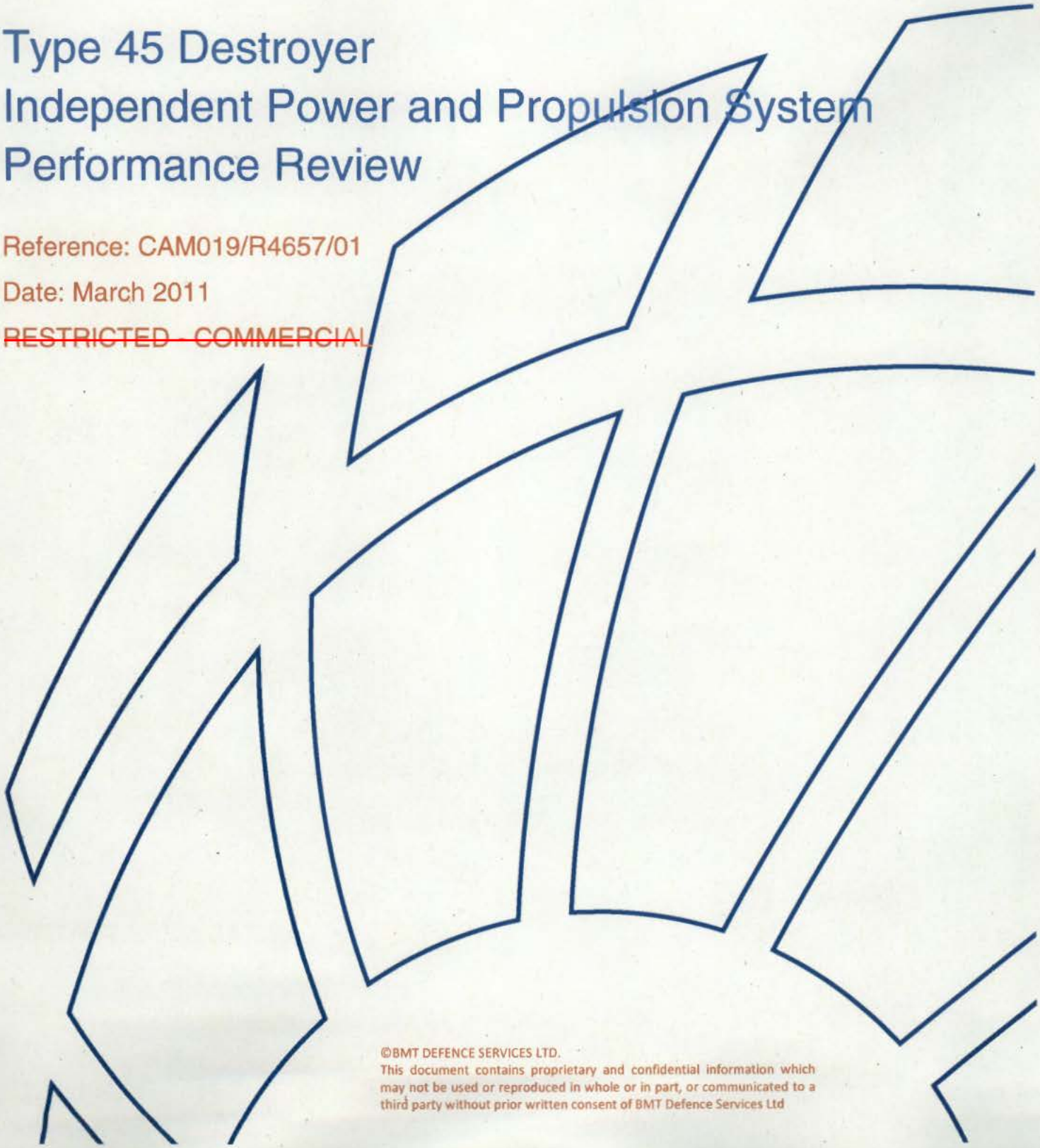

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BMT Defence Services

TYPE 45 DESTROYER
INDEPENDENT POWER AND PROPULSION SYSTEM
PERFORMANCE REVIEW

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EXECUTIVE SUMMARY

The Type 45 Class Power and Propulsion System performance has been reviewed by an independent panel constituted by the Head of the Destroyers Team in the Ministry of Defence, Equipment and Systems. The Independent Review Team found that there was no single root cause underlying the low reliability of the Type 45 Power and Propulsion System. Rather they found a large group of unconnected individual causes including, among others:

a. Manufacturing Quality Shortfalls: Xilinx chips, IGBT Heat Sinks.

b. Operating Procedures: [redacted] ships staff awareness of electrical propulsion system sensitivities.

c. Design Robustness: [redacted] WR-21 EEC Watch Dog Timer.

The principal action recommended by the Independent Review Team is to improve [redacted], which is not considered sufficiently robust in its current form. The improvements should be based on a fundamental requirements capture exercise which takes into account the needs of design intent, operations and maintenance.

The Independent Review Team concluded that the current Type 45 Class Power and Propulsion System performance is a combination of both "design shortfall" and "reliability growth". Many of the issues that initially beset the Type 45 Class Power and Propulsion System are now resolved, if not implemented.

It is the view of the Independent Review Team that Integrated Full Electric Propulsion remains a sound choice for the propulsion of the Type 45 Class and that acceptable reliability will be achieved once the issues identified in this report have been satisfactorily resolved.

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1. INTRODUCTION

1.1 The Type 45 Class represents a dramatic advance in surface warship capability for the United Kingdom and is arguably the world's most capable anti-air platform. Apart from her many advances in weapon systems the Type 45 Class also has a highly innovative Integrated Full Electric Propulsion (IFEP) System. The build of the Type 45 Class is now well advanced with three units (HMS DARING, HMS DAUNTLESS and HMS DIAMOND) effectively in service (if not operational), with the build of the fourth (HMS DRAGON) nearing completion and soon to be followed by HMS DEFENDER and HMS DUNCAN.

1.2 Early experience of operating HMS DARING exposed high unreliability of the Power and Propulsion (P&P) Plant with many failures of both the electrical power system and its integrated electrical propulsion system eroding Command confidence in continuity of power and Navy Command confidence in the ability to deploy the Ships. Although there has been some evidence of the follow on ships having better reliability than the first of class the improvement has not been sufficient to provide assurance that all will be well without specific action being taken.

1.3 As a result the Head of the MoD Defence Equipment and Support (DE&S) Destroyers Team initiated an Independent Review of the performance of the Type 45 Class P&P System.

2. SCOPE OF REVIEW

2.1 At its simplest the scope of the review was to assess the performance of the Type 45 Class P&P System. In a sense the review was asked to determine whether the current performance has arisen from isolated design shortfalls or as part of the normal "reliability growth" that is an inherent part of the introduction of any new technology.

3. INDEPENDENT TYPE 45 P&P REVIEW TEAM

3.1 The Independent Type 45 Power and Propulsion (Type 45 P&P) Review Team appointed by the Head of the DE&S Destroyers Team was as constituted follows:

Team Leader

[redacted]

Team Members

[redacted]

Team Secretary

[redacted]

4. AREAS OF INVESTIGATION

4.1 Drawing from the original tasking of the Head of the DE&S Destroyers Team the following areas of investigation formed the focus of the Independent Review Team's work:

a. Component reliability;

b. Reliability of the integrated P&P system;

c. Root cause of defects;

d. Continuity of power to the Command;

e. System operation;

f. Diagnostics;

g. Training;

h. Documentation.

5. TIMESCALE

5.1 The Type 45 P&P Review commenced with the following top level milestones:

a. Commence mid December 2010;

b. Interim Report mid February 2011;

c. Final Report end March 2011.

6. REPORT STRUCTURE

6.1 This main report is, by design, brief and contains only the most salient points, recommended actions and the conclusion. There are two associated Annexes:

- Annex A: The complete record of the discussion and commentary of the Independent Review Team;
- Annex B: Transcripts of the contemporaneous interview notes recorded by the Independent Review Team (limited distribution).

7. CONTEXT

7.1 The context of the review was immediately acknowledged to be important and the key aspects of the general Type 45 P&P environment were: novelty, accumulation of disparate defects and the trend of the defect rates with time and individual ship. These are fully discussed at Annex A.

8. HISTORY

8.1 The Independent Review Team identified many legacy defects within the Type 45 Class P&P system which could be further categorised into those that were resolved (albeit not necessarily fully rectified across the class) and those that were understood but not yet fully resolved. These are listed below and discussed in full at Annex A.

8.1.1 Resolved Legacy Issues:

a. GTA / Propulsion Motor Coolers;

b. Xilinx Memory Chips;

c. VDM25000 Condensation;

d. HV Harmonic Filter – Capacitor Drain Wire.

8.1.2 Understood Legacy Issues:

a. WR-21 Fuel Controller Watch-Dog Timer;

b. IGBT Bridge Arm Heat Sink QA;

c. UPS converters and filters;

d. VDM 25000 and [redacted]

e. Cross Flow Fuel Filtration.

9. KEY SYSTEM ASPECTS

9.1 The Type 45 Class P&P System is undoubtedly novel and this novelty brings with it new operating imperatives and new sensitivities. In the case of the Type 45 Class this is associated with the IFEP system [redacted]

9.2 [redacted]

10. ASSESSMENT OUTPUT

10.1 The following is a shortened version of the full output given at Annex A but it contains all of the most important aspects.

[redacted]

10.2 Training

10.2.1 The Type 45 Class steady state training system is not yet fully in place, with some deliverables running up to 2 years late. The main concern is the Simulator for the Type 45 Class SCC (and outstations) which is still awaited by HMS SULTAN. Hence OEM training courses originally set up for First of Class (FOC) Ship's Staff have been used for longer than anticipated. All T45 training courses have been developed for intakes of Petty Officer Engineering Technicians (POETs) and only cover T45 specific equipment and systems. However most trainees have been legacy artificers and mechanics with a quite different previous training history and in order to provide continual training, synthetic training has been designed to work on board Ship as well as in the traditional shore training environment. However this capability has yet to be achieved. As a result a culture has developed of promoting personnel within their Ships to retain their SQEP, but this cannot be sustained indefinitely.

10.2.2 The introduction of the Type 45 Class with its novel series connected PWM based converter brought with it new equipment sensitivities that appear not to have been immediately recognised by Ships' Staff and the support community. The main areas are: fibre optic communications and [redacted]

10.3 Fuel Consumption

10.3.1 The Type 45 Class is designed to be operated with a single prime mover when electrical load and operational circumstances permit. However, the early low reliability of the Type 45 P&P System has eroded Command confidence in the ability to operate in this way and increased fuel consumption has resulted. Effective Fired Hours (EFH) have exacerbated this as two prime movers are being run to maintain engine load below a sharp rise in EFH. Effectively trading fuel consumption for engine life; what is not clear is whether this is an appropriate or desirable strategy.

10.4 Command System Guidance

10.4.1 There was some assertion[2] that the Command Guidance for the P&P System was not sufficiently detailed and did not make clear what the operating philosophy for the whole plant was. Therefore, it is felt that better guidance is needed for systems line up, the use of redundancy and [redacted]

10.5 [redacted]

10.5.1 [redacted]

[2] Although not made by the Commanding Officers themselves.

[redacted]

WAC Trip Valve

10.5.2 The WAC system has an isolating valve on each converter channel which automatically shuts on receipt of a leak detection signal from its respective converter channel. However, there have been some incidents where the leak detection signal has not automatically shut the valve. There is some evidence that this behaviour has happened relatively frequently during setting the converters to work, but on one occasion it contributed to a major water ingress to a converter when the valve remained open despite being in receipt of a valid leak detection signal. The Independent Review Team recommend that the valve and its control circuits and logic structure should be subjected to a formal review.

10.6 [redacted]

10.6.1 [redacted]

10.6.2 [redacted]

10.7 [redacted]

10.7.1 The Type 45 Class has a 4.16 kV power generation and distribution system. [redacted]

10.8 [redacted]

10.8.1 [redacted]

10.9 Condensation

10.9.1 There were early rectifier bridge module failures caused by accumulation of condensation inside the VDM 25000 Converters. A modification to the rectifier bridge modules has resolved this problem but accumulation of condensation on other VDM25000 components is suspected to be a potential source of propulsion unreliability and therefore remains cause for concern.

10.9.2 The accumulation of significant condensation in the VDM25000 converters is a continuing cause for concern. The Independent Review Team recommend that Converteam's procedure for converter start up, both normal and rapid, should be applied. The Independent Review Team also recommends that the converter air cooling circuit should be reviewed to ensure that any make up air enters the enclosure at the optimum point and minimises the ingress of condensation. The HVAC system also makes a significant contribution to equipment cooling and compartment environmental conditions, the Independent Review Team found that there is some evidence that the air flow in some compartments is inadequate and that this should be reviewed.

10.10 PMS Overload

10.10.1 The Type 45 Platform Management System (PMS) has a propensity to indicate alarms and trips that, at times, is almost overwhelming to operators. Some form of analysis of cause to identify the top level initiating event and then to filter alarms to provide more clarity to the operator is within the capacity of the PMS. The Independent Review Team recommends that this capability should be investigated and appropriately implemented.

10.11 IGBT Batch QA Problem

10.11.1 The manufacturing process for the IGBT heat sink was changed and a delay in introducing a necessary change to the layer of thermal compound created a batch of sub-quality IGBTs. Many of these remain in service (3 in HMS DARING, 1 in HMS DIAMOND, 99 in HMS DAUNTLESS). The Independent Review Team recommends that these defective modules are replaced as soon as possible.

10.12 Documentation

10.12.1 The Type 45 Class uses Interactive Electronic Technical Manuals (IETMS) and this certainly offers a capability beyond that offered by traditional documentation methods. However, there has been little feedback of errors or omissions from Ship's Staff back to the DDA. As a result, consistency has suffered with local amendments appearing in individual ships but with no class wide rationalisation occurring. The Independent Review Team recommends that:

a. Ships Staff are encouraged to provide feedback on documentation to the DDA and;

b. Documentation across all ships of the Daring Class is reviewed by all stakeholders, DDA, COM, OEMs and MDH.

10.13 Design Reputation

10.13.1 During the investigation the Independent Review Team heard several views that conflated system design and technology attributes. Examples are:

"IFEP is not appropriate for a warship ..."

"HV is not appropriate for a warship ..."

"The Type 45 is too noisy ..."

"A step too far ..."

10.13.2 All these – and certainly the first three – were offered as reasons why the whole concept of integrated full electric propulsion was flawed at a very fundamental level. In fact the claims made all relate to the aspects of the systems design rather than the fundamental characteristics of electric propulsion.

10.13.3 It is the view of the Independent Review Team that IFEP remains a sound choice for the propulsion of the Type 45 Class and that acceptable reliability will be achieved once the issues referred to in this report have been satisfactorily sentenced.

10.14 Test and Acceptance

10.14.1 The Type 45 Class testing and acceptance process departed from the normal prescriptive and hard edged policy of earlier warship classes. The result was a much more flexible approach termed "measure and decide". The Independent Review Team understood that it is unlikely that such a process will be used again for future classes and this will only be beneficial.

11. ACTIONS

11.1.1 The following actions are recommended to be undertaken as a matter of priority. All need resolution in the near term.

11.2 [redacted]

11.3 **Converters**

[redacted]

Maintenance:

a. Converters should only be opened when absolutely necessary and then moisture ingress should be minimised as far as is practicable.

11.4 Bridge Arm Replacement

11.4.1 The replacement of the bridge arms known to contain the following faults should be expedited:

a. Heat Sink QA Batch Problem;

b. Fibre Optic Signal Strength;

c. Xilinx Memory Chips.

11.5 Converter Air Circulation

11.5.1 The converter air circulation should be reviewed to establish the optimum make up air point.

11.6 Fibre Optics

11.6.1 The need for care when handling fibre optics should be reinforced. (Noting that the best practice may be with the Weapon Engineering Branch.)

11.7 [redacted]

11.7.1 [redacted]

11.8 HVAC

11.8.1 Reinforce the requirement to condition the HV Switchboard compartments before energising the VDM25000 converters.

11.9 [redacted]

11.9.1 [redacted]

[redacted]

11.9.2 [redacted]

11.10 Documentation

11.10.1 The complete Type 45 Class documentation should be checked for correctness and consistency across the Daring Class, DDA, COM, OEMs and MDH.

11.11 Training

11.11.1 T45 awareness, context and [redacted] should be inserted into training courses.

12. CONCLUSION

12.1 The current performance of the Type 45 Class Power and Propulsion Systems is a combination of both "Design Shortfall" [redacted] and "Reliability Growth" (QA, SQEP, Operation to Design Intent). Many of the unconnected defect and reliability problems that initially beset the Type 45 Class are now resolved, if not implemented, but the following necessary action areas remain:

[redacted]

b. VDM 25000 Converter;

c. HVAC;

[redacted]

e. Type 45 Class Documentation;

f. Type 45 Class Training.

It is the view of the Independent Review Team that Integrated Full Electric Propulsion remains a sound choice for the propulsion of the Type 45 Class and that acceptable reliability will be achieved once the issues identified in this report have been satisfactorily resolved.

ANNEX A

Detailed Commentary and Discussion

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A1. INTRODUCTION

A1.1 This Annex records the full commentary and discussion of the issues raised during the Type 45 P&P Performance Review that the Independent Review Team feel merit formal record but does not need to be absorbed by every reader.

A2. CONTEXT

A2.1 The context of the review was immediately acknowledged to be important and the key aspects of the general Type 45 P&P environment were:

a. Novelty;

b. Accumulation of disparate defects;

c. Overall trend of the defect rate with time and individual ship.

A2.2 These are now discussed in turn.

A3. NOVELTY

A3.1 As has already been mentioned, the Type 45 Class has significant novelty throughout its design and intended operational policy. With respect to the P&P System these may be further categorised with respect to Equipment Novelty and Operational Novelty.

A4. EQUIPMENT NOVELTY

A4.1 Converters: The main propulsion converters – Converteam's VDM 25000 units – contain two levels of novelty with respect to Royal Navy electrical propulsion. The converters use medium voltage (MV) series connected Integrated Gate Bi-Polar Transistors (IGBTs) to achieve force commutated Pulse Width Modulated (PWM) voltage source inversion[1].

A4.2 Series Connected IGBTs: the use of series connection to achieve overall higher voltage levels than can be achieved by a single IGBT is inevitable when designing a converter to the level of power required by the IFEP system of the Type 45 Class. [redacted]

A4.3 Pulse Width Modulation: PWM offers much tighter control of output voltage waveform than is possible with a synchroconverter.[2] This is because PWM can switch at a much higher frequency than a naturally commutated synchroconverter where switching is dictated by the frequency of the output waveform.[3] [redacted]

[1] As opposed to naturally commutated thyristors in synchroconverters.
[2] Synchroconverters are used in LPD and AO for propulsion.
[3] Arguably cycloconverters can achieve high quality voltage waveforms but recently PWM inverters have been able to be produced with smaller volume and mass.

A5. OPERATIONAL NOVELTY

Electronic Documentation

A5.1 The Type 45 Class is the first in the Royal Navy to use a full suite of electronic documentation including Interactive Electronic Technical Manuals (IETMs) Standard and Emergency Operating Procedures (SOPs and EOPs) and Sequential Action Flow Routine (SAFR) Cards.

Levels of Integration

A5.2 The Type 45 Class P&P system has a highly integrated design whose complex multi-layered nature extends far beyond the propulsion systems. Undoubtedly a good principle, high levels of integration require deeper understanding from operators, maintainers and places higher demands on the design itself.

Single Generator Operation

A5.3 In order to maximise fuel economy, the Type 45 Class operational philosophy includes reducing to a single prime mover when connected load, in conjunction with operational and navigational circumstances, permit.

Redundancy

A5.4 Type 45 Class was designed with high levels of redundancy and a policy that individual failure would not always result in an immediate requirement for rectification.

Contract For Availability

A5.5 A large element of the support strategy for the Type 45 Class uses Contract For Availability (CFA) whereby Original Equipment Manufacturers (OEMs) are incentivised through availability targets.

A6. ACCUMULATION OF NUMEROUS DEFECTS

A6.1 The early experience of the T45 Class revealed a variety of defects with no immediately apparent single root cause.

A7. TREND

A7.1 The improvement in availability of follow on ships (FOS) was recognised albeit that this was small and did not detract from the need for the Independent Review of the Type 45 Class P&P performance.

A8. HISTORY

A8.1 An immediate result of the work of the Independent Review Team identified many legacy defects within the Type 45 Class P&P system which could be further categorised into those that were resolved (albeit not necessarily fully rectified across the class) and those that were understood but not yet fully resolved.

A9. RESOLVED LEGACY ISSUES

GTA / Propulsion Motor Coolers

A9.1 The coolers associated with the Gas Turbine Alternators and Propulsion Motors suffered severe erosion due to the locally increased flow rates, turbulence and vorticity created by substantial material debris entering the cooler sea water headers. This was resolved by employing better filtration and changing the cooler material to Cu-Ni 70-30 from Cu-Ni 90-10.

Xilinx Memory Chips

A9.2 The original Xilinx memory chips used in the bridge modules had exhibited electrical charge loss leading to corruption of the software and resulting in a stop fault of the channel.

VDM25000 Condensation

A9.3 Condensation, after accumulation on components, has been an enduring issue with the VDM 25000 in the T45 Class. This initially exposed a design weakness on the rectifier bridge modules which were failing due to condensation, this has been ameliorated by a design change. However, it is yet to be determined if accumulation of condensation remains an issue with the machine bridge modules.

HV Harmonic Filter – Capacitor Drain Wire

A9.4 A simple and otherwise inexplicable design oversight resulted in a drain wire within the HV Harmonic Filter which had insulation of too low a voltage rating and caused earth faults in the HV filter. This has now been fully rectified across the Class.

A10. UNDERSTOOD LEGACY ISSUES

WR-21 Fuel Controller Watch-Dog Timer

A10.1 The timer in the WR-21 fuel controller, part of the electronic engine controller (EEC), uses a 16 bit counter which "rolls" over after a certain period of the controller being energised (not necessarily the engine being run – hence the defect appears randomly). The OEM has provided a solution, using a 32 bit counter, as part of the R3.2 software update of the EEC although this has yet to be fully installed across the Class.

IGBT Bridge Arm Heat Sink QA

A10.2 A change to the manufacturing process of the IGBT module base changed the surface finish. Although still within specification the new surface finish was not matched with an appropriate depth of thermal compound (it was not changed).

UPS converters and filters

A10.3 Early reliability issues with the Uninterruptible Power Supplies (UPSs) for converters and filters auxiliary supplies caused significant system failures (exacerbated by the high levels of inter-system integration).

[redacted]

A10.4 [redacted]

Cross Flow Fuel Filtration

A10.5 The design of the Cross Flow Fuel Filtration System has proved problematic with the ship installation not performing as the shore development systems indicated. Alternative in line filtration has been installed and the Cross Flow System has been developed further and is now reliable but only as a pre-production prototype and with a flow rate less than the original specification.

A11. ASSESSMENT OUTPUT

A11.1 The following is a record of the discussion and conclusions reached in each of the subordinate topic areas.

A12. TRAINING

A12.1 It is generally accepted that T45 steady state training is not fully in place, with some deliverables running up to 2 years late. The main concern is the T45 Simulator for the SCC and outstations in HMS SULTAN. This is a key component to many of the core training courses. Hence, OEM training courses originally set up for FOC Ship's Staff have been used for longer than anticipated. This situation has led to concerns over the following areas:

A12.2 Training Pipeline

A12.2.1 All T45 training courses have been tailored for the Petty Officer Engineering Technician (POET) and only cover T45 specific equipment and systems which are not covered in the core training courses. Unfortunately, the training pipeline is only just producing it's first POETs, which has meant that the T45 training courses have been used to retrain personnel from the legacy Branches. Because the pipeline is yet to receive its design intake, it is hard to identify shortfalls in course content.

A12.3 Synthetic Training

A12.3.1 All members of the Independent Review Team were very impressed by the synthetic training material and supporting information. It was deemed an acceptable way of replacing the more traditional hands on training methods which required retaining and maintaining costly pieces of equipment. This transition to synthetic training has not been seamless and will require some time to bed into the training establishments. It is important to note that synthetic training has been designed to work not only in the shore training environment but also on board Ship when it can provide additional training and refresh knowledge. Though this potential has not been fully achieved due to delays in the delivery of other DE&S programmes such as DII.

A12.4 SQEP

A12.4.1 There are no concerns about the SQEP of current Ship's Staff as the majority are experienced senior Chief Petty Officers (CPO) from legacy branches, who have attended OEM training courses and have at least 1 year working alongside OEM commissioning engineers during build. The main concern is that as the original Crew are promoted or drafted to other billets; their replacements may be less SQEP as they would be replaced by relatively new POETs, who have attended the new (and possibly incomplete) steady state training course at HMS SULTAN with little exposure to the actual equipment.

A12.4.2 This has led to a culture of promoting personnel within their Ships to retain their SQEP, but this cannot be sustained indefinitely.

A12.5 Awareness of Equipment Sensitivity

A12.5.1 The introduction of the Type 45 Class with its novel series connected PWM based converter brought with it new equipment sensitivities that appear not to have been immediately recognised by Ships' Staff and the support community.

A12.6 Fibre Optics

A12.6.1 An important element of the converter design is to transmit the IGBT gate firing signals with fibre optics in order to reduce latency, maximise isolation and ensure near simultaneous switching of the IGBTs in a single limb. Although there is a long history of the use of fibre optics in weapons equipments there is little experience of this technology within the Marine Engineering Branch. It was noted by the Independent Review Team that insufficient care was being taken with the protection of the fibre optic cable terminations during intrusive converter maintenance.

A12.7 [redacted]

A12.7.1 [redacted]

A12.7.2 [redacted]

A12.7.3 [redacted]

A13. OPERATIONS

A13.1 Fuel Consumption

A13.1.1 The Type 45 Class is designed to be operated with a single prime mover when electrical load and operational circumstances permit. This aspect is central to the design intent and underpins the capability of the platform to operate with minimised fuel consumption. However, the early low reliability of the Type 45 P&P System has eroded Command confidence in the ability to operate in single prime mover mode and this has increased fuel consumption.

A13.1.2 This situation has been exacerbated by the introduction of Effective Fired Hours (EFH) which can shorten the time between WR-21 maintenance periods as operating environmental conditions become more onerous.[4] On occasion it seems to have been decided to keep two prime movers connected (when one might be sufficient) in order to maintain engine load below a sharp rise in EFH. But this effectively trades fuel consumption for engine life. What is not clear is whether this is an appropriate or desirable strategy.

A13.2 Condensation

A13.2.1 There were early rectifier bridge module failures caused by accumulation of condensation in the VDM 25000 Converter enclosures. A modification to the rectifier bridge modules has resolved the problem but overall the build up of significant condensation within the enclosure is still a cause for concern [redacted] In addition Ship's Staff and support community should be encouraged to only open up the converters when absolutely required and to take steps to ensure, so far as is reasonably practicable, that ingress of moisture is minimised.

A13.3 Command System Guidance

A13.3.1 There was some assertion[5] that the Command Guidance for the P&P System was not sufficiently detailed and did not make clear what the operating philosophy for the overall plant was. The following areas were noted:

a. Line Up:

i. The tendency to operate in multiple prime mover line up (when single generator operation was feasible) has already been noted.

b. Redundancy:

[redacted]

[5] Although not made by the Commanding Officers themselves.

i. The overall operational philosophy of the design intent includes the acceptance of defects, using redundancy to maintain the required operational output. But understandably – and especially when overall reliability is low – Ship's Staff appear reluctant to accept defects.

[redacted]

A13.3.2 [redacted]

A13.3.3 [redacted]

A13.3.4 [redacted]

A13.3.5 [redacted]

A13.3.6 However there are larger system design and operational aspects to this issue:

a. OPSTATs: Power System Operability Statement, requires the shaft to be held stopped when at zero PCL as [redacted] due to inadequate hydrodynamic bearing lubrication. But it also notes that for extended periods the shaft brake will be applied;

b. External Shaft Bearings: Externally the shafts are supported with traditional A brackets and these bearings need a minimum rotational speed to ensure adequate sea water lubrication;

c. [redacted] were originally included in the motor's design by Converteam but were removed as a cost reduction measure. They were subsequently replaced, but only as stand alone pumps without any of the original communication with the converter control system. As a result, even though [redacted]

A13.3.7 It is recommended that the issue of bearing lubrication throughout the propulsion train is considered from a holistic perspective to identify the exact requirements limiting low shaft speed operation. Once this is done the balance of advantage from once more including the motor jacking pumps in the converter control circuits can be identified and, if justified, consideration can then be made to include inputs from the motor jacking pumps.

A14. EQUIPMENT & SYSTEMS

A14.1 [redacted]

A14.1.1 [redacted]

Fitness for Purpose

A14.1.2 [redacted]

A14.1.3 The [redacted] has little control available to the operator, worse, it provides no indication which further limits the operator's ability to control the system.[6] Given its lack of indication and control it is understandable that the system is set to work with balanced flow rates [redacted], as a result the converter has been "over-cooled" and this has exacerbated the condensation issue.

A14.1.4 The lack of adjustability in the converter cooling system has another implication beyond that of inhibiting a match of cooling capacity to waste heat load. The expectation must be that converter channels will eventually fail – albeit at nothing like the rate being experienced – when this happens the cooling water to the failed channel is isolated. This significantly disturbs the flow to the other two channels and the motor [redacted]

A14.1.5 [redacted]

[redacted]

[redacted]

[redacted]

[6] It is intended to fit flow meters to all T45 Class.

[redacted]

A14.1.6 [redacted]

A14.1.7 [redacted]

A14.1.8 [redacted]

d. All IGBT Bridge Modules with sub optimal heat sink conductivity replaced;

e. Satisfactory P&P system operation established over a reasonable length of time.

A14.1.9 [redacted]

Converter Cooling Water System Testing Post Maintenance

A14.1.10 The hoses used for the internal converter sea water distribution are rated for pressures up to [redacted] but this is not proven routinely by Converteam. However, failure of the hoses is graceful and the in-service pressure much lower [redacted]

A14.1.11 The testing of the converter sea water hoses was originally defined by Converteam in the Service Manual to be [redacted] bar and this is achieved at the start of commissioning by blanking the converter module and filling it with fresh water pressurised by a hand pump, but this cannot be achieved easily in Ship. Hence Ship's Staff pressure test converter modules after maintenance by using the WAC system to pressure test the modules. The WAC System pressure limits are running, [redacted] bar maximum, [redacted] bar test and [redacted] bar relief and hence this technique can never match that specified in the Service Manual.

A14.1.12 Converteam documentation is being amended and will recommend test procedures for single module and mass module changes. A single module change will use a WAC system test and a mass module change will require the full blanked and hand pumped [redacted] bar test. In addition module pressure testing will become a 6 or 12 month maintenance procedure.

A14.2 Fuel System

Cross Flow Filter

A14.2.1 The Type 45 uses a newly developed cross-flow filter in its fuel system. However, although the shore based prototype was successfully tested, the ship fit system immediately experienced problems. A series of modifications were implemented on board (but not to established production standards) that worked satisfactorily until poor quality fuel was used. The revised system only provides [redacted] l/min conditions against the initial requirement of 85 to 120 l/min.

Fuel Transfer Pumps

A14.2.2 The fuel transfer system has proved difficult to operate with varying pump performance dependant on which tanks were being used.

A14.3 [redacted]

A14.3.1 [redacted]

A14.4 ABB VCB breaker control board

A14.4.1 Failures have been experienced on in the control board within the ABB Vacuum Circuit Breakers used throughout the ship (16 in total). Many of the circuit breaker states are pervasive throughout the system control. An investigation is in hand.

A14.5 VDM 25000

A14.5.1 The VDM 25000 PWM converter was a impressive design achievement offering compact high power PWM medium voltage conversion for the first time. Its reliability has suffered from various – and mainly unconnected – issues as has been discussed in the report. In addition the following areas are noteworthy.

WAC Trip Valve

A14.5.2 The WAC system has an isolating valve on each converter channel which automatically shuts on receipt of a leak detection signal from its respective converter channel. However, there have been some incidents where the leak detection signal has not automatically shut the valve. There is some evidence that this behaviour has happened relatively frequently during setting the converters to work, but on one occasion it contributed to a major water ingress to a converter when the valve remained open despite being in receipt of a valid leak detection signal. The Independent Review Team recommends that the valve and its control circuits and logic structure should be subjected to a formal review.

[redacted]

A14.5.3 [redacted]

Fibre Optic Emitter Strength

A14.5.4 There have been issues with fibre optic signal strength which, whilst not resolved, are being investigated and a satisfactory resolution is expected.

Condensation

A14.5.5 The problems with condensation in the Type 45 Class VDM 25000 Converters has been discussed previously in this report in the section on Operations and there is no need to repeat the discussion but for completeness it is worth reiterating and expanding the recommendations:

[redacted]

c. Converters should only be opened when absolutely necessary and then moisture ingress should be minimised as far as is practicable.

WAC Hoses and Clips

A14.5.6 The design uses flexible hoses and high integrity screw drive clips that have a much better technical under-pinning and justification than their appearance at first sight suggests. This has caused some concern among operators and maintainers which was not helped by the initial recommendation that hoses and clips did not need to be changed when a module was changed. Although there is no firm evidence that re-using hoses and clips has been a root cause of subsequent water leaks, Converteam are now including replacement hoses and clips in replacement module kits.

A14.6 PMS Overload

A14.6.1 The Type 45 PMS has a propensity to indicate alarms and trips that at times is almost overwhelming to the operators. Some form of analysis of cause to identify the top level initiating event and then to filter alarms to provide more clarity to the operator is within the capacity of the PMS and this should be investigated.

A14.7 HVAC

A14.7.1 [redacted]. Some compartment air flows are inadequate but it is understood that this area is already being investigated.

A15. DESIGN SILOS

A15.1 Several aspects of the issues discussed during the various interviews undertaken by the Independent Review Team led to a view that some aspects of the overall design of the Type 45 Class P&P had not taken enough account of the high level of integration in the Type 45 design intent. These issues were mainly associated with Mechanical to Electrical interfaces and are as follows.

A15.2 [redacted]

A15.2.1 [redacted]

A15.3 GTA Lubricating Oil

A15.3.1 The GTA lubricating oil is provided by a dedicated system and modifications are in hand to provide a gravity feed to maximise availability during GT trip. During the early design the sensible proposal to take GTA lubricating oil from the WR-21 system was not acceptable to Rolls-Royce. This is another example of an, at best, partial response to system integration.

A15.4 [redacted]

A15.4.1 [redacted]

A16. QUALITY

A16.1 IGBT Batch QA Problem

[redacted] The manufacturing process for the IGBT heat sink was changed and as a result the surface finish was altered although it remained within the original specification. [redacted]. By the time this shortfall was recognised [redacted] there were many bridge arm modules with these defective IGBTs in service and in storage. Although some of these have been replaced many more remain in service [redacted]

A16.2 Delivery Packaging of IGBT Bridge Modules

A16.2.1 The delivery packaging of the Bridge Machine Bridge Arm Modules was initially inadequate but Converteam have rectified this with a bespoke wooden crate, support and weather protection. Nevertheless some other problems with replacement module deliveries as the Naval Base have unpacked the module and left it unprotected on the jetty adjacent to the ship for several days.

A17. DOCUMENTATION

A17.1 The Type 45 uses Interactive Electronic Technical Manuals (IETMS) and this certainly offers a capability beyond that offered by traditional documentation. But there has been little feedback from the ships staff on IETMs or indeed on the other components of the documentation package: SAFR Cards, SOPs and EOPs. As a result consistency has suffered with local amendments appearing in individual ships but with no class wide rationalisation occurring. As a result the Independent Review Team recommend that Ship's Staff are encouraged to provide feedback on documentation to the DDA and that a complete review of the documentation across all ships of the Daring Class and the DDA, COM, OEMs and MDH should be conducted.

A18. SUPPORT

A18.1 Maintenance

A18.1.1 The Independent Review Team noted that the high defect rate associated with the Type 45 Class P&P Systems was significantly raising the support maintenance work load.

A18.2 Resource

A18.2.1 It is clear that Converteam are close to being insufficiently resourced against the workload currently being borne: Type 45 Build, Queen Elizabeth Build, Type 45 Repair.

A18.3 Industry

A18.3.1 The support contracting strategy of Contract for Availability (CFA) is a new development and will need careful control and monitoring in its early stages. There have been several incidents where the OEM – acting under the CFA – did not recognise the Command's responsibility for control of work on board the ship.

A18.4 Type 45 COM

A18.4.1 At present the Type 45 DDA is remote from the COM, but it is acknowledged that the DDA function will move South into the COM in the near future.

A18.5 Logistics

A18.5.1 It appears to the Independent Review Team that the COM remains insufficiently resourced – even after the recent significant augmentation – and in particular the resource is at its weakest with respect to logisticians and the control of stores.

A19. DESIGN REPUTATION

A19.1 Several views that conflated system design and technology attributes were expressed during the investigations of the Independent Review Team. Examples are:

"IFEP is not appropriate for a warship ..."

"HV is not appropriate for a warship ..."

"The Type 45 is too noisy ..."

"A step too far ..."

A19.2 All these – and certainly the first three – were offered as reasons why the whole concept of integrated full electric propulsion was flawed at a very fundamental level. In fact the claims made all relate to the aspects of the systems design rather than the fundamental characteristics of electric propulsion.

A19.3 It is the view of the Independent Review Team that IFEP remains a sound choice for the propulsion of the Type 45 Class and that satisfactory reliability will be achieved once the issues referred to in this report have been satisfactory sentenced.

A20. MINOR ISSUES

A20.1 COM

A20.1.1 COM seem to have a good grip on material states, but it not beyond the possible that the move of the DDA south may induce some initial communication and experience difficulties.

A20.2 Integration

A20.2.1 With highly integrated equipment but a design that (maybe) lacked sufficient integration, it was of little surprise that the HVAC system was essential to the operation of the propulsion system.

A20.3 Test and Acceptance

A20.3.1 The Type 45 Class testing and acceptance process departed from the normal prescriptive and hard edged policy of earlier warship classes. The result was a much more flexible approach termed "measure and decide". The Independent Review Team understood that its is unlikely that such a process will be used again for future classes and this will only be beneficial.