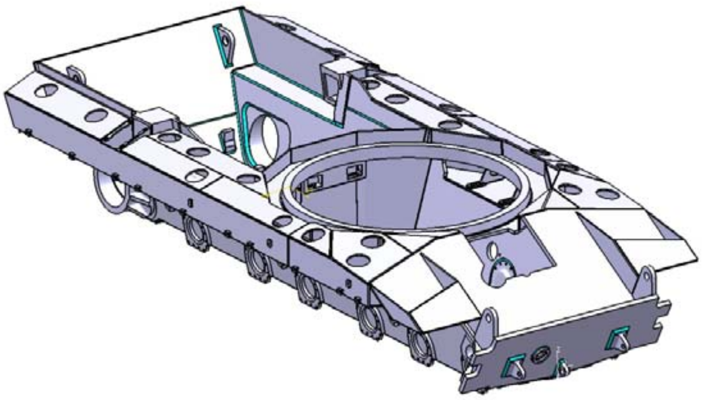
June 2010

CONFIRMATORY REPORT ON THE STRUCTURAL INTEGRITY OF CHALLENGER 2 MBT & DTT HULL

CR2 STRUCTURES

(TASK AUTHORISATION NO. FTS2/RCM/5066/024



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AMENDMENTS

Issue	Date	Comment	Approved	Authorised
Draft A	3 May 10	For CTG PT and Rmada review		
1	21 June 10	Final Report		

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ABBREVIATIONS

ACFM	Alternating Current Field Measurement
ACPD	Alternating Current Potential Difference
AD	Accidental Damage
AESP	Army Equipment Support Publication
AFV	Armoured Fighting Vehicles
ATDU	Armoured Trials & Development Unit
BAE	British Aerospace
BATUS	British Army Training Unit Suffield
BIR	Base Inspection Repair
CR2	Challenger 2
CTG PT	Combat Tracks Group Project Team
CVM	Comparative Vacuum Monitoring
DSG	Defence Support Group
DSTL	Defence Science and Technology Laboratory
DTT	Driver Training Tank
ED	Environmental Damage
FD	Fatigue Damage
FM	Failure Mode
FMECA	Failure Modes Effects & Criticality Analysis
HAS	Heavy Armour Support
HUMS	Health & Usage Monitoring Systems
IPT	Integrated Project Team
KRH	Kings Royal Hussars
MBT	Main Battle Tank
NDT	Non Destructive Testing
RCM	Reliability Centred Maintenance
RSF	Residual Section Failure
SEME	School of Electrical & Mechanical Engineering
SSI	Structurally Significant Item
STTE	Special to Type Tools & Test Equipment

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D. SEME artificer student project - CR2 inspection, 11 Aug 2009.
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F. DSTL report , Flaw growth analysis on CR2 wheelstation, dated 31 Mar 2009
G. DSTL report, Flaw analysis on CR2 – Residual Section Failure, dated 24 Aug 2009
H. Psion letter, Statement of Requirement (SOR), DSTL tasking, 15 Sept 2009.
I. DSTL report, CR2 Structural Integrity Analysis – DSTL/CR43872 V1.0, dated 7 April 2010
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EXECUTIVE SUMMARY

This report documents the deliverable under DE&S task FTS2/RCM/5066/024, which concludes the work reported earlier in Reference C. The main objective of the task was to develop a process that would enable the structural integrity of both CR2 MBT and DTT to be determined at unit level. This would enable programme managers, equipment support managers and vehicle commanders to be able to make an assessment as to whether their vehicles are both safe to operate and fit for role. The process also challenges the current method of returning vehicles to Level 4 based on a combination of time and usage, and instead return vehicles based on their condition. The process developed during this study involves establishing the structural significant items (SSIs) for both hulls. These are areas or components of the hull which if they were to fail or become weakened would result in a loss of a function and/or have safety/environmental consequences.

This process starts by collecting and analysing Level 4 BIR inspection and repair data. This data showed that the number and size of cracks in the hull is not proportional to the vehicle usage or age. 3 vehicles entered BIR with no cracks found, 9 vehicles had only one crack and 11 had only 2 cracks per vehicle. All of these cracks are considered to be only minor i.e. non critical defects. Vehicles entered BIR with an average of 7,514km. Eighty five percent of vehicles entered BIR below the 12,000 km entry criterion.

To identify fatigue related failures that may occur in the future, finite element analysis modelling had been previously conducted. A Reliability Centred Maintenance (RCM) study had also been previously carried out with equipment stakeholders to identify and agree all of the SSIs and their effects on personnel, equipment and support costs. The outcome of the RCM study was a failure management strategy which aimed to manage the risk/consequences of hull related failures (reference A).

In order to determine the condition of a hull at unit it was necessary to conduct further assessments on access requirements. Where access was possible further assessments were undertaken to detect and measure the flaws. This involved investigating and trialling several non destructive testing equipments. Where access was not possible, the SSIs became candidates for the application of sensors (Health and Monitoring Usage Systems, or HUMs) to monitor the affected area.

Condemnation criteria had to be established for all of the SSIs so that an inspector could decide whether flaws were acceptable. Part of this process involved determining the significance of the flaws and their effects on the structure under both normal operating loading and blast conditions. As there is no existing process for this particular application, DSTL were tasked with developing a fracture analysis to indicate whether any of the nominated cracks could lead to catastrophic failure (i.e. sudden) under certain loading conditions (DSTL report reference I). Through a process which involved reviewing the hull design, together with other supporting information from the RCM study a total of 6 SSIs were down selected from a total of 40 as candidates for residual section failure analysis (RSF).

These SSIs were:

- The wheelstation outer/inner and underside casting welds,
- final drive
- HTT and
- Top roller mounts.

The RSF analysis was undertaken using a finite element software ABAQUS in conjunction with fracture software Zencrack which was embedded into the FE code. Before this work could be started it was necessary for DSTL to build a full 3D model of the hull using information from 2D production drawings. The results of the RSF analysis showed that the stress intensity values at the tip of the cracks were in the order of 9 to 10 times less than the critical values for the material and so were not

going to fail catastrophically under normal usage conditions. However, the analysis also found for the wheelstation inner and outer welds that it was possible for flaws to grow to a size that, under the correct loading conditions could result in plastic collapse or even to reduced elastic stiffness.

After further consideration, 3 of the 6 SSis (wheelstation outer, inner and final drive) were chosen for blast analysis which was conducted using the numerical simulation software LS DYNA. The analysis was first conducted on a non cracked SSI to establish a baseline comparator and then flaws were added in a similar fashion to the RSF method. The standard numerical explosive test used in the analysis was an explosive mass of 10 kg of TNT at an offset distance of 1m. Further testing was carried out with an explosive mass of 20kg. The results of this work illustrated that for blast loads of 10kg, none of the flaws currently being observed on the three SSIs would have an impact on the structural integrity of the hull. However, applying a blast loads of 20kg at a distance of 0.25m under the inner wheelstation (crack size: 500mm long at 68% depth) resulted in the plastic strain reaching 50%, which is close to the 80% threshold that is regarded as a safe limit flaw size for this blast magnitude.

The results of the hull inspection assessment found that for the MBT 42.5% of the hull was easily accessible at unit level, 25% involved removing some minor assemblies, 30% required removal of one or more major assemblies and 2.5% (inner wheelstation welds) could not be accessed. To resolve the problem with the latter sensors which are able to both detect and measure crack growth (length & depth) were fitted to the rear of wheelstation No. 5 at ATDU Bovington as part of a trial fit. The detection and measurement of hull flaws for the remaining SSIs would be aided by three specialist non destructive testing equipments which were tested during the course of the study. The resulting inspection schedule is made up of a total of 26 scheduled and 14 non scheduled tasks, of which 17 and 11 respectively are mandatory i.e. safety related. The scheduled tasks are based on either time or usage intervals, with the majority being at 6 month, 12 month or 6000 km. A full inspection will take 2 qualified and suitably experienced men, approx 2 man days to complete (excludes pre-cleaning) and will require the removal of the track and top rollers on both sides of the vehicle. In terms of facilities, the minimum requirement is a 1st line REME workshop or equivalent.

It is recommended that DE&S implement the findings of this report by adopting a condition based maintenance programme to replace the current scheduled base overhaul interval of 12,000kms/2 med man tours. This will improve equipment safety, optimise equipment availability and reduce support costs.

The RCM process includes a risk assessment for each of the failure modes. The assessment uses a different risk classification matrix to the one used by the CR2 safety panel (i.e. DEF STAN 02-45 vs. 00-56). To address this, the author of this report has drafted a tailored criticality matrix so that the RCM values can be expressed in terms of DEF STAN 00-56. It is recommended that the CR2 safety panel review the tailored matrix, together with all of the RCM criticality values and integrate the hull into their vehicle safety case.

The process that has been developed under this task would provide DE&S with a through life management tool that pulls together all of the various facets of hull management and provide greater visibility of the day to day and key issues affecting safety, availability and support costs. The process allows management staff to assess changes in the future such as operating the equipment in a different environment, different usage patterns, modifications, changes to vehicle weight, increased threat e.g. larger IEDs. A key benefit of this approach is that it will assist the Level 4 repair manager.

It is recommended that further work is conducted on the following:

- Further investigation on the 5 new failure modes (all safety related) identified during the latter part of this study,

- Development of terrain models such as ADAMS to simulate the loads being applied to the vehicle.
- The condemnation criterion to be established for the rear underside picture frame and rear side flitch plates using fracture analysis modelling techniques,
- The HUMs sensors fitted to the wheelstation to be checked every 6 months for next 2 years.

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1 INTRODUCTION

1.1 This assessment forms part of a study which is being conducted to develop a means of establishing the structural integrity of both Challenger 2 main battle tank (MBT) and the Driver Training Tank (DTT) without the need to strip the vehicles to the bare hull. This challenges the current practice of returning vehicles to the Level 4 Base Inspection & Repair (BIR) programme, which is based on a combination of equipment usage (track mileage) and the number of times the vehicle has been deployed to BATUS. Under the proposed scheme vehicles will be inspected at the user unit against a set of pre-determined pass-fail criteria, and sentenced as either fit for operational use, fit for training use or not fit for use. In the case of the latter, it is likely that vehicles will have to be returned to a Level 4 repair facility, although some repairs may be possible at a lower level repair facility.

1.2 This approach is based on condition monitoring and has many advantages when compared to the current method of scheduled restoration. One of the key advantages is that it will enable both DE&S and front line commands to be able to determine at unit level, whether a vehicle is structurally sound and thus safe to operate either before or during use. To achieve this it has been necessary to further develop the process described in Reference A which combined the functional approach of RCM with the physically-based structures analysis of Def Stan 02-45 to identify all of the structurally significant items (also known as failure modes) within the hull and also their criticality value in terms of the probability of failure and whether the consequences would affect the function of the vehicle (operation/mission) or a pose a risk to crew/third parties or the environment. Through further analysis a failure management strategy can be developed for all failure modes to ensure that the consequences of any reasonably likely failure are reduced to a minimum.

1.3. In addition to the above it is also possible to optimise equipment availability as it not only allows defects to be managed more effectively before they become an issue (i.e. a stitch in time), but also ensures that only vehicles that require depth repair are returned to Level 4. A comprehensive list of the benefits is contained in Reference B.

1.4. This report concludes the structural integrity study on CR2 by addressing the outstanding recommendations of the earlier Interim report at Reference C (see also para. 4.8 of this report). It also includes a review of existing information in collated form. In particular this report has addressed the need to develop a method of determining the tolerable flaw sizes in the hull for both peacetime and operational use, to enable decisions to be made following an inspection of the hull. This report will also re-assess and update the results of the original RCM study.

2 AIMS & OBJECTIVES

2.1 The primary aim of this study was to establish a method of determining the condition and thus structural integrity of both CR2 MBT and DTT at unit level. This will enable both DE&S and front line commands to be able to manage their assets more effectively in terms of risk management, equipment availability and support costs.

2.2 In particular the study was to address the following:

a. Identify the additional Structurally Significant Items (SSIs) in the hull.
b. For all of the SSIs; determine the characteristics of the flaws e.g. size, location, direction, occurrence rate, surface/sub-surface.
c. Determine the criticality of failure in terms of probability and effects.
d. Determine an effective failure management strategy for each failure mode.

e. Where necessary determine access requirements to enable an inspection to be carried out.
f. Determine the most effective method/s of inspection in terms of ability to detect and measure flaws.
g. Determine maximum tolerable flaw sizes for both peacetime and operational environments.
h. Comment on the level of inspection, training requirements and facilities.
i. Comment on the inspection intervals and the time required to inspect.

3 SCOPE

3.1. This study addressed the structural integrity issues of CR2 MBT & DTT hulls. The assessment excluded the turret.

3.2 The study covers vehicles fitted for, but not with, additional armour. Assessments of vehicles fitted with extra armour will be the subject of future work and is dependent on the successful outcome of this phase of the project.

3.3 The scope of this study covers all of the failure modes (SSIs) identified at Reference A and any subsequent revisions to that list after the issue of the interim report, Reference C. The failure modes fall into three distinct categories; fatigue damage, environmental damage and accidental damage.

4 METHOD

4.1 The CR2 structures study has been put together as a number of phases and associated activities which form a complex relationship with each other so that changes in one area have an effect on one or more other areas. The following is a summary of the main activities:

Reliability Centred Maintenance

4.2 The foundation for the work is the RCM study which looked at the functions of the hull and identified all current or future failure modes, effects and consequences. Part of this process involved the collation and analysis of BIR data as well as conducting finite element analysis and inputting known static loadings to highlight areas susceptible to stress related failure. Each failure mode was given a criticality rating similar to Def Stan 00-56 which indicated the probability and consequence of the failure in terms of its effects on personnel/environment, platform/equipment functionality and operating costs. Decisions were then made based on a RCM methodology (Def-Stan 02-45) on the most applicable and effective method of managing each of these failures. Where a failure could affect safety or the environment, the RCM process emphasises prevention. A proactive task such as a scheduled inspection (termed 'on-condition') to see if there is a potential failure, or a scheduled discard, or scheduled restoration (e.g. re-paint) may be worth doing as long as it reduces the probability of the failure to a tolerable level. If a proactive task cannot be found which achieves this objective then we are dealing with a safety or environmental hazard which cannot be adequately anticipated or prevented. This means that something must be changed in order to make the system safe. This 'something' could be the asset itself, a process or an operating procedure. Where a failure mode is associated with a hidden function (i.e. the failure only matters if another failure also occurs – the combination being termed the multiple failure) and a proactive task cannot be found, then the first option is to seek a failure finding task that manages the risk of the multiple failure down to a tolerably low level. Typical hidden functions on the CR2 study include the ability to protect vehicle occupants against hostile attack (Ballistic, mine blast and NBC). The failure finding interval (FFI) is a function of the probability of the failure in the first place (M_{tive}), the probability of a hostile attack (M_{ted}) and the risk the user is prepared to tolerate that these two events coincide (M_{mf}).

$$FFI=2*M_{tive}*M_{ted}/M_{mf}$$

4.3 Default actions deal with the failed state and are chosen when it is not possible to identify an effective proactive task. Default actions include failure finding (as described above), redesign and run to failure.

4.4 Non-scheduled tasks are tasks that cannot be scheduled and are therefore carried out in combination with some other (usually related activity) e.g. inspect engine mounts for damage whenever the power pack is removed.

4.5 The RCM study identified 26 proactive (scheduled) on-condition tasks for the MBT and 20 for the DTT, although there was some commonality between the two hulls. There were also 14 non-schedulable tasks common to both hulls, 11 of which were safety related, all of which could be managed in conjunction with other similarly related tasks.

Preliminary Assessment

4.6 Following the RCM study an assessment was conducted to develop a failure management strategy using NDT equipment. The assessment was conducted at DSG Bovington on vehicle hulls that had been stripped of all bolt-on assemblies. This provided early visibility of typical defect characteristics and also highlighted areas of the hull that would benefit from the use of NDT equipments.

4.7 Two NDT equipments were selected and successfully trialled during the preliminary assessment. The first was a crack detection device based on the alternating field current measurement principles which was capable of detecting and measuring crack length/depth under painted surfaces. The second device was a hand held material thickness gauge which used ultrasound to measure the effects of abrasion on the hull plates.

Interim Assessment

4.8 The Interim Assessment (reference C) addressed the application of non destructive testing and also the access requirements on fully built hulls (i.e. non stripped). The assessment was conducted at SEME Bordon and DSG Bovington over the period Dec 2008 to Mar 2009.

4.9 The emphasis of the Interim Assessment was to determine whether it was possible to gain access to the flaws (defects/SSIs) without having to remove significant amounts of equipment from the hull. The Interim Assessment reported on which flaws could be seen without visual aids, those that could only be detected and measured with visual aids (NDT equipment) and flaws where no access could be made. The latter were candidates for HUMs. The report also recommended that further work should be carried out, including: blast/fracture modelling, HUMs fitment trial, review of the inspection schedule, and investigate removal or strengthening of the DTT counterbalance weight mountings.

Confirmatory Assessment (this report)

4.10 This report addresses the recommendations from the interim report, at reference C, as well as reporting on the fracture and blast modelling, risk classification, failure data management, HUMS trial, and providing an update on all of the other study aspects, as follows:

Condemnation Criteria

4.10.1 A tasking requirement was produced by Rmada for a pilot study/ proof of concept study to be undertaken by the Physical Sciences dept at DSTL. The aim of the study was to develop a method of analysis to determine the critical flaw size for a given set of loading conditions on a selected area of the hull. This initial study analysed two flaws (wheel station casting welds and top roller mounting bosses) using the finite element software ABAQUS together with a flaw analysis software, Zencrack. The results showed that neither flaw would be susceptible to catastrophic failure (meaning it would be a gradual failure), Reference F.

4.10.2 Further analysis was conducted by DSTL to determine a method of determining the tolerable flaw size based on residual section failure (RSF). The residual section is the region between the crack tip and the closest external boundaries. As the crack grows there is reduced material to bear the load in that region and consequently higher stresses develop. A failure criterion was nominated such that if the stress in the material in the residual section reached a specific level associated with the yield point, the condition is violated and considered to have failed. The initial flaws analysed were based on the largest flaws that had been reported by DSG during BIR.

Review and Analysis of Inspection/Failure Data

4.10.3 An in-depth review of the failure data recorded during the BIR programme was conducted by compiling data from BIR inspection reports and through numerous meeting with DSG staff. The information was then used to carry out a review of the RCM study FMECA through the RCM Toolkit and also provide details of typical flaws, including the following characteristics: location, frequency, size and shape. This information was then used during subsequent meetings with DSTL to develop a selection process and strategy for conducting further fracture and blast analysis. A summary of this failure data has been presented as a flaw website and is included as a deliverable with this report.

4.10.4 The Level 4 BIR inspection data shows that of the 105 vehicles that passed through BIR between 2001-2008, three vehicles entered BIR with no cracks found, 9 had only one crack per vehicle and 11 vehicles had only 2 cracks per vehicle (or 22% with 2 or less cracks). All of these cracks are considered to be only minor i.e. non critical defects. The data also showed that the number and size of cracks in the hull is not proportional to the vehicle usage or age. Another interesting fact is that although the entry criterion was 12,000 kms, vehicles entered BIR with an average of 7,514 kms.

3D Geometry Hull Model

4.10.5 A 3D hull model representing the hull production geometry was required as part of the process being developed for the fracture and blast analysis. This would enable individual areas of the hull to be meshed and used by ABAQUS and Zencrack software models to observe the behaviour of nominated flaws. The model was produced by DSTL with input from Rmada, who assisted with the procurement of the necessary production drawings and provided the tasking requirements. The model which runs in e-drawing is available to CTG PT for reference.

Candidate Items List for Residual Section Failure and Blast Modelling

4.10.6 The process of putting together the candidate items list for residual section failure and blast analysis was one of the most complex tasks of the entire study. It involved an in-depth review of the failure data and RCM study as well as a detailed look at the hull design using the 2D and 3D geometries. The initial outcome of this work resulted in the identification of 9 SSIs recommended for residual section failure analysis and 9 for blast analysis, although they were not all the same SSIs in each list. The candidate items list formed part of the tasking requirement (SOR) for DSTL, Reference H.

4.10.7. Following numerous meetings throughout the modelling stage, the initial list of candidate items was changed as more detailed information about the vehicle design was known. As an example: weld cracking to the front section of the sideplate to underside pannier welds is listed in the RCM study as a hidden safety related failure, which in the event of a mine blast could injure the crew. After closer inspection of the hull design it can be seen that the sidewall in this area is higher to provide the additional protection required and it is now considered that cracking in these welds is very unlikely to affect the structural integrity.

4.10.8 Ideally all of the SSIs (flaws) would require corresponding condemnation criteria to enable decisions to be made during a vehicle inspection, and in many cases fracture and blast modelling is the most appropriate means of establishing this. However for reasons of limited time and cost it was necessary, and more appropriate in some cases, to assign failure criteria as 'no flaws tolerated'. Examples of this are the driver's controls and the lifting and towing eyes. For a number of other SSIs that are related to the effects of abrasion e.g. rear underside picture frame and wear plate, it is considered acceptable to adopt the condemnation criteria agreed on the RCM study e.g. to allow up to 10mm of wear before repair action is required.

Vehicle Loading Values, Direction of Loads

4.10.9 It has been difficult to clearly identify the vehicle design loads due to the reluctance of the design authority, BAES, to share this information with the MoD because of commercial sensitivities. Despite this it has been possible to estimate appropriate loading values based on information already available e.g. max design loads, finite element analysis loading data provided during the RCM study and other sources of information. The direction of the loads has been determined through a combination of activities such as design review, failure data analysis and vector analysis. The use of terrain models such as ADAMs should be considered as an alternative for future projects or when assessing the effects on the structures due to changes.

Residual Section Failure Modelling

4.10.10 RSF analysis was conducted on a number of SSIs (Para 5.6.3 refers) that were known to exhibit flaws and that had the potential to compromise the structural integrity of the hull. The analysis was used to look at the effects of applying a range of flaws, in terms of length and depth, which would encompass all of the possible range of flaws that may be experienced in practice and then loading each of the flaws to a level that will exceed any practical loading (i.e. represent worst case). The method was to apply the loading in a finite number of steps (typically 10), for crack lengths in three sizes up to the maximum recorded, and at depths of 35%, 50%, 65% and 85% of the material, resulting in 12 simulations per loading. At each loading step, the stress intensity factor, K, along the crack tip is monitored to indicate if there is a likelihood of catastrophic failure (i.e. fast fracture as opposed to gradual softening of the material). In addition the zone between the crack tip and the nearest external surfaces is examined to see if there is violation of a failure criterion based on exceeding the materials elastic limit. By determining the limiting load, i.e. the maximum tolerable applied load without violating the failure criterion, for the full range of flaw depth and length combinations, it is possible to construct a tolerable flaw size curve as illustrated in charts 1 & 2 to this report. For full details of the method employed see DSTL report at Reference I.

Blast Modelling

4.10.11 The analysis was conducted using the numerical simulation software LS DYNA. As in the normal usage analysis, described above, the flaws were introduced into the vehicle in positions where flaws are experienced in practice. The standard numerical explosive test used in the analysis was an explosive mass of 10 kg of TNT at an offset distance of 1m. This is approximately the same explosive mass as a 155 artillery shell that may be used as an IED. In some of the analyses increased explosive masses (20 kg) have been investigated. The failure criterion for the blast loading analysis is based on failure strain rather than the yield criteria used in the normal usage analysis. Uni-axial stress failure strain for RHA has previously been determined by DSTL; based on this, the proposed failure criterion is nominated as 80 % of the tensile failure strain, i.e. the material in the zone affected by the presence of a flaw will be deemed to have failed if it exhibits a strain of this value. For full details of the method used, see DSTL report at Reference I.

Review of SSIs (update RCM Toolkit)

4.10.12 The RCM FMECA has been updated to reflect the work being conducted on this study. The changes affect some risk classifications, inspection intervals, accessibility ratings, inspection techniques (i.e. visual/NDT/HUMS). The significant changes are detailed in section 5 of this report.

Inspection Intervals

4.10.13 The inspection intervals were derived during the RCM study by the study group members. The resulting intervals are a mixture of time (months) and usage (km). The method of calculation depends on whether the failures are normally evident (eventually) or hidden to the crew. For hidden failures the method is the failure finding interval (FFI) which is based on probability of failures and is described in Para 4.2 above. For evident failures it depends on whether there is a specific age where most items fail (and the elapsed time up to this point is known as the useful life) or alternatively there is no known wear out period and the failures are random i.e. it is not known when they occur. The method of determining the on-condition inspection period is based on the P-F interval, where p is the potential failure (i.e. when we first detect a flaw) and F is some time (or usage) later when there is functional failure. The P-F interval can range from a split second to several years. If we want to detect the potential failure before it becomes a functional failure, the interval between checks must be less than the P-F interval. If the inspection is done at intervals which are longer than P-F interval then there is a chance we will miss the failure altogether, so in practice it is usually sufficient to select the inspection frequency equal to half the P-F interval.

Risk Classification

4.10.14 Risk assessment consists of three elements. The first asks what could happen if the event under consideration did occur. The second asks how likely it is for the event to occur at all. The combination of these two elements provides a measure of the degree of risk. The third – and often the most contentious element – asks whether this risk is tolerable. The RCM study considered each failure mode using the Def Stan 02-45 risk classification matrix which indicates the consequences as a roman numeral I to IV and the probability as A to E as shown in table 1. As an example a risk that would result in severe injury ('Critical') and was considered 'probable', would equate to IIB.

4.10.15 In order for CTG PT to be able to manage these risks as part of their Safety case it would be helpful if these risks were expressed in terms of Def Stan 00-56 values (see also Reference J). The Def Stan 00-56 criticality matrix differs from the Def Stan 02-45 matrix in that it uses a single letter A-D to represent probability vs. consequences. It also has an additional consequence 'Incredible' and the default probability values increase by a factor of 10^2, compared to a factor of only 10 for Def Stan 02-45. There is also a difference in the definitions for the consequences for personnel.

Probability / Consequence	Frequent (A) > 1 per 1000 hrs	Probable (B) < 1 per 1000hrs > 1 per 10,000hrs	Occasional (C) <1 per 10,000hrs >1 per 100,000hrs	Remote (D) <1 per 100,000hrs > 1 per 1,000,000hrs	Improbable (E) < 1 per 1,000,000hrs
Catastrophic (I) Death, loss of platform Costs >£500,000	1 High	2 High	4 High	5 High	8 High
Critical (II) Severe injury Loss of mission Costs >£200,000	3 High	6 High	7 Medium	9 Medium	14 Low
Marginal (III) Injury (loss >3 days work) Reduced system availability Costs >£10,000	10 Medium	11 Medium	12 Medium	15 Low	18 May be Tolerable
Negligible (IV) No more than first aid treatment. Minimal risk to system Costs <£10,000	13 Medium	16 Low	17 Low	19 May be Tolerable	20 May be Tolerable

Table 1. Def Stan 02-45 Criticalities Matrix (values used on RCM study)

Consequences / Probability	Catastrophic Multiple Death, *loss of platform Costs>£500,000*	Critical Single Death *Loss of mission Costs>£200,000*	Marginal Severe Injury &/or multiple minor injuries. *Reduced system availability Costs>£10,000*	Negligible Single minor injury. *Minimal risk to system Costs <£10,000*
Frequent > 1 per 100 hrs	A	A	A	B
Probable < 1 per 100hrs >1 per 10,000hrs	A	A	B	C
Occasional <1 per 10,000hrs >1 per 1,000,000hrs	A	B	C	C
Remote <1 per 1,000,000hrs > 1 per 100,000,000hrs	B	C	C	D
Improbable < 1 per 100,000,000hrs > 1 per 10,000,000,000	C	C	D	D
Incredible < 1 per 1E-12	C	D	D	D

Table 2 - Def Stan 00-56 Criticalities Matrix (default values)

4.10.16 As Def Stan 00-56 allows for tailoring of the values for both the probability and consequences to suit the equipment and operating context, it is recommended that the default values in the Def Stan 00-56 matrix are changed so that they align with Def Stan 02-45 values where possible. This will of course have to be agreed by the CTG Project safety committee as it may conflict with the committee's current criticality matrix. It is recommended that the standard definitions for the effects (consequences) to personnel in Def Stan 00-56 are retained but all of the values for probability, effects on system/mission and costs are adopted from Def Stan 02-45. This would mean that 'Incredible' would not be applicable. The result of these changes can be seen in Table 3.

Consequences / Probability	Catastrophic Multiple Death, loss of platform Costs>£500,000	Critical Single Death Loss of mission Costs>£200,000	Marginal Severe Injury &/or multiple minor injuries Reduced system availability Costs>£10,000	Negligible Single minor injury Minimal risk to system Costs <£10,000
Frequent > 1 per 1000 hrs	A	A	A	B
Probable < 1 per 1000hrs > 1 per 10,000hrs	A	A	B	C
Occasional <1 per 10,000hrs >1 per 100,000, hrs	A	B	C	C
Remote <1 per 100,000hrs > 1 per 1,000,000hrs	B	C	C	D
Improbable < 1 per 1,000,000	C	C	D	D

Table 3 - Def Standard 00-56 Criticality Matrix (tailored values)

4.10.17 To illustrate the use of the tables above: a risk that has been assessed using the Def Stan 02-45 criticality matrix values as being a safety related failure 'Severe Injury' (Critical) and 'Occasional' would be a 'IIC'. If the same risk was assessed using the tailored Def Stan 00-56 criticality matrix values then it would be classed as a 'Severe Injury' (Marginal) and 'Occasional' so would be risk class 'C'.

4.10.18 It should be noted that the criticality values assigned by the RCM process, which have been recorded in the RCM Toolkit and also at Annex A, represent the risk assessment prior to any mitigation. It is recommended that the safety panel review all of the criticality values listed in Annex A for each of the failure modes in order to agree a strategy to reduce all of the risks to ALARP.

5 FINDINGS (SEE ALSO ANNEX A)

5.1 There are 26 scheduled inspection tasks for the MBT, 9 of which can be managed by visual inspection, 16 require the use of specialist non destructive test equipment and one requires monitoring with HUMS sensors (inner wheelstation casting welds). 17 are mandatory tasks (i.e. safety related). All but one of the SSIs can be accessed.

5.2 For the DTT there are 20 scheduled inspection tasks, 5 of which can be managed by a visual inspection, 14 require the use of specialist non destructive test equipment and one requires monitoring with HUMS sensors (inner wheelstation casting welds). All but one of the SSIs can be accessed. 11 are mandatory tasks.

5.3 In addition to the above, there are 14 non-scheduled tasks (11 of which are mandatory) that are common to both the MBT and DTT and which can be carried out in combination with other related tasks in the form of procedural redesigns. All 14 failure modes (tasks) can be managed by an initial visual inspection but the use of NDT may be called for, as part of the diagnosis.

Vehicle variant	Visual inspections	NDT inspections	HUMS inspection	Total Tasks
MBT	9 (34.6%)	16 (61.4%)	1 (4%)	26
DTT	5 (25%)	14 (70%)	1 (5%)	20

Table 4a: Inspection method (Scheduled inspections)

Vehicle variant	Visual inspection	NDT inspections	HUMS inspection	Total Tasks
MBT/DTT	14 (100%)	0 (0%)*	0 (0%)	14

*Note: NDT may be required following visual inspection.

Table 4b: Inspection method (Non-scheduled inspections)

5.4 The Interim Assessment highlighted 2 failure modes where a proactive management task could not be found, but injury to personnel was possible if the failure modes were to occur and another 2 failure modes where injury is possible in the event of a ballistic incident. Management of these failure modes has now been resolved, as follows:

5.4.1 MBT only (ballistic integrity):

- Cracking of the driver's armoured bulkhead to sideplate welds (FM3A2). This was a candidate for the fitment of HUM sensors to monitor the condition of the welds and a recommendation that DSTL conduct blast modelling to determine whether the welds would yield in the event of a charge bin explosion. DSTL have now advised that blast modelling would not be necessary as the bulkhead offers little protection in the event of a charge bin explosion due to presence of the gap between the two bulkhead plates. It would appear that the purpose of the bulkhead is to provide a means of mounting equipments such as the charge bins and also strengthen the hull (to reduce hull distortion) by bridging the front left and right hand sides. This failure mode has been changed to non plausible.
- Cracking in the side plate to underside pannier plate welds (FM3A5) - towards the front section. This failure mode was also a candidate for the fitment of HUMs sensors to monitor the condition of the welds but also that DSTL conduct blast modelling to determine the effects of a blast. After a lot of consideration, including a review of both the vehicle design and failure data and meetings with DSG and DSTL, it is now considered to be non plausible for the following reasons: there is no failure data to support cracking under the front section of the flitchplate as the weld is hidden. The design of the front section of the side plate is higher in this area so even if there were cracking present it is highly unlikely to pose a threat to the driver.

5.4.2 For the MBT and DTT:

- Battery vent failure (FM18A1). Although this is considered unlikely, it could lead to battery rupture or explosion and cause injury to the driver. This has been recommended for further investigation by CTG PT, in both References A and C.

5.4.3 DTT only:

- Failure of the balance weight mounting welds (FM2A4). This failure mode can now be removed from the RCM toolkit as CTG PT has decided to remove the balance weight to remove the risk of injury to crew.

5.5 Failure modes

5.5.1 New failure modes

5.5.1.1 Five new failure modes (SSIs) have been identified (see also Annex A), one of which is currently being analysed by DSTL to establish the condemnation criteria for fatigue and blast. The remaining 4 SSIs have been added to the RCM Toolkit with a recommendation that further investigation is required. The following is a summary of these SSIs:

- Wheelstation casting to side plate - inner welds (FM1A45 & 1A51). For MBT and DTT respectively. Cracks have been reported in the toe edge of the welds (nearest the parent metal side) at the rear of the wheelstations. There have been 12% instances of cracking reported during the BIR of 105 vehicles, which equates to a 'probable' failure with safety consequences (similar to the outer weld FM1A11). An on-condition task to check for signs of cracking is recommended every 6000 km, however as it is not possible to get access to all of the wheelstations; HUMS sensors have been fitted as part of a trial (see Para. 5.11.5 below).
- Underside of panniers (mid section) FM3A11. DSG have reported that cracks occasionally occur along the weld that secures the underside filler plate to the adjoining plates, although it does not appear that any occurrences have been formally documented during the BIR. The location of a flaw in this area could have safety implications in the event of a blast incident, as the area above the plate is the crew compartment. Further investigation is recommended.
- Garbage hatch above LH Wheelstation No. 3 FM3A8. Cracking to the hinge plate securing the external hatch. In the event of an incident (blast) which is directly below the inner edge of the track, there is a possibility that the hatch door becomes detached resulting in blast injury to the crew. No reported failures, but recommend further investigation.
- Security of the driver's fire extinguisher - FM3A12. This relates to the function to protect the vehicle occupants from hostile attack. In the event that the extinguisher bracket is not secure and there is a blast incident then the extinguisher could become a secondary projectile. Recommend this is investigated further.
- Security of driver's seat on TES vehicles (FM not allocated). This relates to the securing arrangement of driver's seat for 24 TES vehicles, where the seat is mounted off the floor and secured to the driver's bulkhead. Recommend this is investigated.

5.5.2 Failure modes – general

5.5.2.1 Failure mode 16A1 – (Check all lifting eyes for signs of damage before a lift is carried out). Each lifting eye is designed to take the full vehicle weight (original design weight), however it is unlikely that a vehicle would be lifted in service, the normal practice is to push or pull the vehicle onto a tank transporter using the towing eyes. DSG use the lifting eyes in the Base Inspection Repair (BIR) process but at a much reduced weight i.e. the bare hull is only 15 tonnes. It is recommended that this failure mode is managed by a visual inspection to look for obvious signs of damage before lifting. If damage is found then the crack detection equipment should be used to determine whether the weld is cracked. The condemnation criterion is no cracking tolerated.

5.5.2.2 Failure mode 1A40 – (Visually inspect steering pivot boss for signs of cracking). The current position and securing arrangements of the boss is the subject of a design review, following blast trials conducted by DSTL. In the meantime it is recommended that this failure mode is managed by incorporating it into the 6 monthly scheduled 12A unit inspections. Access is at the rear of the seat after removing 4 bolts that secure a cover plate. The condemnation criterion is no cracking tolerated.

5.5.2.3 Inspections around the driver's controls - (Steering tiller mountings FM1A34, accelerator pedal FM1A32 and brake pedal FM1A33) are non scheduled Level 2 tasks that can be done whenever any servicing is carried out in the area. As there have been very few reported cases of cracking at the welds, it is recommended that these areas are managed by a visual inspection and if cracking is suspected then this should be confirmed with the aid of NDT equipment. The condemnation criterion is no cracking tolerated.

5.5.2.4 Failure mode 1A37 – (Check driver's seat for security). The RCM study recorded this as a mandatory redesign and that it should be managed by a before use check. Access to the mountings is very restricted and would ideally require the seat to be removed. As this is not practical and the probability of all of the mounts becoming detached without the driver noticing there was something wrong (excessive movement, increased vibration etc.) is remote, it is recommended that the inspection is limited to a physical check to ensure there is no excessive movement of the seat on its mounts. In addition to this it is recommended that an inspection of the mounts is carried out in conjunction with FM1A40 (visually inspect steering pivot boss) or whenever the seat is removed for any other reason. Following a design review which involved DSTL investigating the effects of blast under the driver's compartment, 24 TES vehicles have now been modified so that the seat is suspended off the floor and the mountings secured to the drivers bulkhead. Para 5.5.1.1 refers.

5.5.2.5 Failure mode 3A1 – Inspect front tow plate to side plate welds for cracking. This failure mode was identified during the RCM study when DSG reported that cracks can occur in the subject welds. After reviewing the vehicle design on a 3D model and failure data it is unlikely that DSG would have been aware of any cracks because the weld is hidden behind the Hydraulic Track Tensioner (HTT) block which is itself welded in place. The HTT mounting block would provide the necessary structural strength in this area (FM1A23) so this failure mode has been changed to non plausible (NP) and retained in the RCM Toolkit for reference.

5.6 Condemnation Criteria

5.6.1 Condemnation criteria have been established for all of the SSIs (See Annex A). Some of these have been determined by scientific means i.e. through residual section failure analysis/blast modelling (see below), while others have been determined through engineering judgement such as recommending that no crack should be tolerated. For the SSIs that are related to loss of material (abrasion), the failure criteria that were agreed on in the RCM study have been used. There are a number of SSIs where it would not be appropriate to use a scientific approach because the cost and time involved would outweigh the benefits. Examples are the turret turntable mounts, the side armour fixing points, steering boss, engine mounts, APU mounts, and turret support mounts. In these cases engineering judgment has been used (e.g. no flaws tolerated on 2 of 4 mounts).

5.6.2 There are 3 SSIs that would still benefit from residual section failure and blast analysis, but due to difficulties developing the various models it was decided to concentrate all of the remaining available time and funds on the higher priority candidates (i.e. safety related SSIs). In lieu of any future modelling on these SSIs, condemnation criteria have been based on engineering judgement as follows:

- Rear underside picture frame welds (FM3B4) – Operational. The failure criterion is cracking the full length of two or more sides of the picture frame.

- Rear side plate to underside pannier welds, to rear plate (FM3B3) – Operational. The failure criterion is cracking within the gap of the rear flitchplate and the rear corner and accompanied by any crack along the weld securing the rear flitchplate. (This would indicate a crack 1.8m long).
- FM3A7 – All external metal plates (see items listed in Annex A) – Safety. As there is no data to support cracking to any of the areas listed under this failure mode, it is recommended that any cracks are reported to CTG PT for further consideration.

5.6.3 Candidate Items List for Residual Section Failure and Blast Modelling

5.6.3.1 Table 5 is the candidate items list for residual section failure analysis (stage 2) and blast analysis (stage 3). The decision as to which of the SSIs would require stage 2 and/or stage 3 analysis was changed on a number of occasions and reflected the complexity during this phase of the project.

FM Ref (MBT)	Safety or Operational	SSI description	Fracture Mechanics			Priority 1a: Safety Crew/driver. 1b: Safety third party.(loss of control) 2: Operational	Comments
			Catastrophic (Stage 1)	Residual Section Failure (Stage 2)	Blast (Stage 3)		
1A11	S	Wheelstation Casting (outer)	Completed	Completed	Completed	1a	
1A14	S	Wheelstation casting (underside)	*Completed	Completed	Not required	1a	
1A20	S	Final Drive (outer casting)	*Completed	Completed	Completed	1b	
1A26	S	Top Roller Bosses	*Completed	Completed Completed	Not required	1b	Bottom LH Bottom RH
1A7	S	HTT mounting	*Completed	Completed	Not required	1a	
1A45	S	Wheelstation casting (inner)	*Completed	Completed	Completed	1a	

*Completed as part of stage 2 analysis

Table 5: Residual section failure and blast analysis agreed candidate items list

5.6.4 Results of the Residual Section Failure (RSF) Analysis

5.6.4.1 Wheelstation casting (outer weld) – See DSTL report Reference G. The results of the RSF analysis on the outer face of the wheelstation casting welds indicated that a circumferential flaw up to 500 mm in length with an average depth of 13 mm could be tolerated. The analysis also determined the stress intensity at the crack tip for each of the flaws. Even though the flaws studied were much larger than those considered in the previous study (Reference F), it was determined that the stress intensities were significantly below critical values and hence were not going to fail catastrophically. However it is possible that the flaws could grow to a size that, under the correct loading conditions, the remaining material between the crack tip and the closest boundary may experience significantly increased stress, which could result in a failure mode such as plastic collapse or even reduced elastic stiffness.

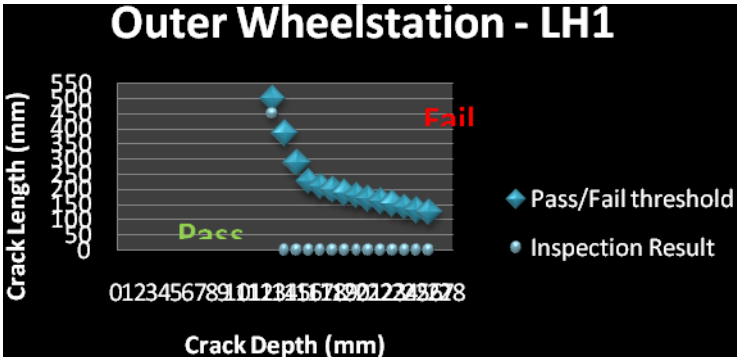


Chart 1: RSF Pass/fail criteria for cracks on wheelstation (outer face)

5.6.4.2 Wheelstation casting (inner weld) – See DSTL report Reference I. The results of the RSF analysis for the inner casting weld found that circumferential flaws up to 500mm in length with an average depth of 17mm could be tolerated. The stress intensity values for maximum flaw and load were significantly below critical values, indicating that the flaw would not fail catastrophically under normal usage loads.

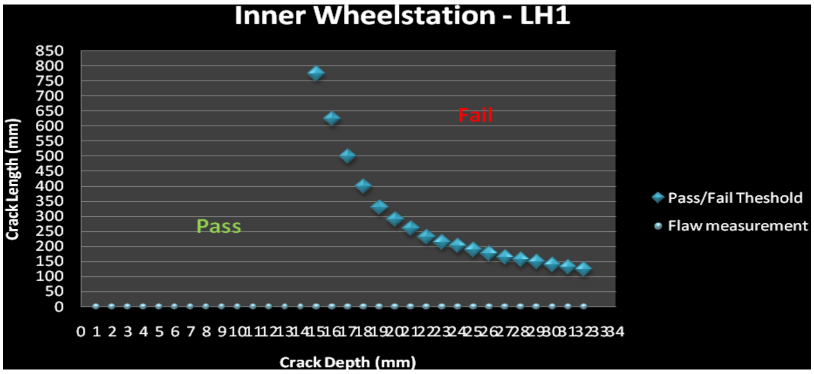


Chart 2: RSF Pass/fail criteria for cracks on wheelstation (inner face)

5.6.4.3 Final Drive – See DSTL report Reference I. The results of the RSF analysis for the final drive casting welds found that for the maximum flaw observed the stress intensity was below critical values and was therefore not going to fail catastrophically under normal usage loading. None of the combinations of flaw size violated the RSF failure criterion even at the maximum (100%) applied load and so it was concluded that it was unlikely that flaws in this location were going to affect the structural integrity of vehicle under normal usage conditions.

5.6.4.4 Top Roller Mounting Bosses – See DSTL report Reference I. The results of the RSF analysis for the top roller mounting bosses found that for the maximum flaws observed (bottom two bosses) the stress intensity was significantly below critical values and was therefore not going to fail catastrophically under normal usage loading. None of the combinations of flaw size violated the RSF failure criterion even at the maximum (100%) applied load, so it was concluded that it was unlikely that flaws in this location were going to affect the structural integrity of vehicle significantly under normal usage conditions.

5.6.4.5 HTT mounting block – See DSTL report Reference I. RSF analysis was not applicable for this case as the applied force was trying to separate the fillet welds from the parent plate, rather than propagating into the parent plate. For the flaws applied (top weld and front weld removed) the result of the analysis found that even at the maximum working load of the hydraulic ram (250 kN) the general stress in the welds is typically less than 300 MPa.

It was unlikely that the block would fail (i.e. drop off) under normal usage, even with the untypically large flaw that was used in the analysis.

5.6.4.6 Wheelstation Casting Weld (underside) – See DSTL report Reference I. The analysis found that for the highest applicable loads applied to the maximum sized flaw, the stresses in the region of the crack ligament (between the tip and the wall surface) were well within the elastic limit and did not violate the RSF criterion. Similarly the stress intensity level was well below the critical level and therefore the flaw would not constitute a risk of catastrophic failure under normal usage conditions.

5.6.5 Results of the Blast Modelling

5.6.5.1 Final Drive – See DSTL report Reference I. For the largest size flaw length of 721 mm, subjected to the 10 kg of TNT blast at 1m distance away, there is a momentary opening of the flaw for both the crack depths (47% and 89%). There is a small amount of plastic strain which is less than 1% and it is very localised. Because the effects of this loading were so small, further analysis was done with 20kg of TNT at 1 m. This resulted in an almost 10-fold increase in plastic strain, however the peak strain at ~ 10% is still significantly less than the 80% strain nominated failure criterion. It was concluded that it was unlikely the standard blast analysed (10 kg), or the larger 20 kg blast would cause the largest flaw analysed (721 mm long and 89% wall thickness depth) to compromise the structural integrity in this area.

5.6.5.2 Wheelstation casting welds (inner face) – See DSTL report Reference I. The results of the analysis found that for a blast load of 10 kg TNT equivalent applied at a distance of 1 m just below the level of the belly plate, aligned with the centre of the wheel casting, it was observed that the flaws (500 mm, 250 mm at 37% & 68% depth) were in the opening mode for the entirety of the critical part of the blast and close at 3.5 ms. For a 20kg blast, the flaw does not close once opened. Further tests were conducted with a blast of 20kg at a distance of 0.5m and 0.25m for the 500mm crack at 68% depth. The results showed that at 0.25m the plastic strain reached 50%, which is close to the 80% threshold that is regarded as a safe limit flaw size for this blast magnitude.

5.6.5.3 Wheelstation casting (outer face) – See DSTL report Reference I. The results of an initial analysis for a flaw 500 mm long at a depth of 37%, which was subjected to a 10 kg blast load at 1 m distance applied, showed that the crack was trying to close throughout the significant section of the blast loading. For this reason it was realised that this flaw was even less likely to fail than the inner flaw on the wheel station discussed previously and would therefore not reach the critical plastic strain threshold.

	Wheelstation Casting (outer weld)	Wheelstation Casting (outer weld	Final Drive	Wheelstation (underside)	TopRoller Bosses	Hydraulic Track Tensioner
Catastrophic Failure	No	No	No	No	No	N/A
Residual section failure	Possible	Possible	No	No	No	No
Tolerable flaw	Yes	Yes	-	-	-	-
10kg blast at 1m	No	No	No	-	-	-
20kg blast at 1m	No	No	No	-	-	-

Table 6: Summary of the results of ‘normal usage’ and ‘blast’ analysis.

5.7 Level of Inspection

5.7.1 The majority of the tasks (80%) can be carried out by trained/experienced and competent inspectors at Level 2 (Unit), with 20% recommended as crew tasks. Crew tasks do not require the use of special to type tools and test equipment (STTE), but will require some familiarisation training on the inspection requirements. In some cases it may be necessary for the user to request Level 2 support with NDT equipment, in order to help diagnose failures. In an independent review of the level of inspection requirements for this study, which was conducted by SEME (Reference D), it was recommended that a civilian contractor, rather than REME, should carry out the inspection. The reason was that a civilian contractor would be able to interpret weld results to a higher level of accuracy due to continued use of the equipment. The inspection time will also be reduced due to the contractor's knowledge, experience and continued use of the NDT equipment.

5.8 Special to Type Tools and Test equipment (STTE)

5.8.1 This is the STTE that has been identified during the course of this study and refers to the NDT equipments, rather than any special tools that are already available to the current repair organisation at unit level. Where STTE is required to facilitate an inspection this has been included next to the relevant inspection task in Annex A. Without NDT it would not be possible to detect many of the flaws, as they are often hidden beneath layers of paint. For cracks in particular, it would not be possible to determine the length or depth of the cracks without resorting to the removal of the surrounding assemblies, removal of paint, grinding out the affected areas, re-welding, re-painting, and re-assembling.

STTE	Type	Application	Manufacturer/supplier
ACFM	Alternating Current Frequency Measurement	Crack detection, measurement (length & Depth)	TSC Inspections Ltd
*ACPD (fixed)	Alternating Current Potential drop	HUMS: Crack detection, measurement (length & Depth).	TSC Inspections Ltd
Audit 107	Ultrasonic	Material thickness	Baugh & Weedon Ltd

* Under review

Table 7: STTE requirements for CR2 hull inspection

5.8.2 Crack Detection (Annex B)

5.8.2.1 The alternating current field monitoring (ACFM) equipment has the ability to detect and measure the length and depth of cracks (in excess of 25mm), beneath protective coatings such as the painted surfaces of the hull.

5.8.2.2 The standard probe supplied with the ACFM equipment was suitable for all but one of the inspection areas; the weld area between the No. 1 wheel station and the HTT casting failure mode 1A17. However, a narrow probe can be supplied by the manufacturer.

5.8.2.3 The ACFM equipment is relatively straight forward to set and operate, however it does take a trained and experienced operator to be able to interpret the complex waveforms representing the injected electro-magnetic field. For the CR2 inspection, 2 operators are required to conduct the inspection.

5.8.3 Hull Abrasion (Annex B)

5.8.3.1 The Audit 107 ultrasound plate thickness tester has proved very effective in determining the thickness of the various underbelly hull plates. It is quick and easy to use and does not require any specialist training. It is currently used by DSG Bovington as part of the inspection on the BIR programme. To access the underside of the hull at unit level, it is recommended that either a vehicle crawling board is used or the vehicle is driven over an inspection pit.

5.8.4 Crack Detection Using Fixed Sensors (Annex B)

5.8.4.1 Details of the ACPD crack detection and measurement equipment, can be found under the header 'HUMS' at para 5.11 and Annex B.

5.9 Vehicle Preparation

5.9.1 The following statements quantify the cleanliness requirements prior to carrying out a vehicle inspection:

5.9.2 The vehicle should be clean, dry and free from all loose foreign matter such as sand, mud and oil deposits that may have accumulated around the areas to be inspected. As a minimum it is recommended that the vehicle is put through the wash down facility.

5.9.3 Inspections in any of the areas around the engine compartment should be cleaned degreased as appropriate.

5.9.4 Where there is loose or flaking paint this should be removed prior to inspection and ideally repainted afterwards, using the approved patch paint repair.

5.9.5 Where corrosion is found, it should still be possible to conduct an effective NDT inspection. If necessary the affected area should be rubbed down with an appropriate abrasive and repainted after inspection.

5.9.6 Prior to an inspection of the running gear components it is recommended that the equipment user unit is requested to remove the track guards, track, and top roller arms from one side of the vehicle to facilitate access for the inspection. When the inspection on that side of the vehicle is complete the assemblies should be re-fitted before doing the same for the other side of the vehicle.

5.9.7 Appropriate notice should be given to the operating unit prior to the inspection.

5.10 Accessibility

5.10.1 A colour code indicating the ease of access has been applied to each of the inspection tasks listed in Annex A, as a quick reference. In general, areas marked as green do not require assemblies to be removed to gain access. Areas in yellow are more difficult to gain access and may require the removal of one or two smaller assemblies e.g. remove mud flaps, side skirts or lift engine decks. Areas coloured amber would require the removal of one or more larger assemblies to facilitate access and would ideally require workshop facilities, examples are removal of track and top roller brackets, removal of power pack. Areas in red are not considered accessible without Level 4 facilities.

5.10.2 Table 8 is a summary of the results of the accessibility assessment:

Vehicle variant	Good access (Green)	Restricted access (Yellow)	Very restricted (Amber)	No access (Red)
*MBT	42.5%	25%	30%	2.5%
*DTT	44%	20.5%	32.5%	3%

*Applicable to scheduled & non-scheduled tasks

Table 8: Hull access rating

5.10.3 Gaining sufficient access to all of the areas around the running gear (suspension, track tensioner, HTT and final drive) was a significant problem, so it is recommended that in most cases the track guards are removed, along with the track and track support top roller assembly. As these assemblies are removed as part of the 12 month (12B) unit inspections and to a lesser degree on the 6 month/1000 km (12A) unit inspection, it is recommended that the inspection tasks that are scheduled at these intervals are carried out at the same time (see Annex A for details of relevant inspection periods). For structural integrity tasks that are scheduled to take place at 6000 km, it is recommended that some of these tasks are also carried out in conjunction with either the 12A and 12B inspections, where possible.

5.10.4 Even with the track removed, it is still only possible to get access to approx 60% of the weld around the HTT unless the hydraulic ram is removed. Despite this, it is not recommended that the ram is removed, as this is a difficult and time consuming task and the inspection of the accessible welds should provide a good indication of the condition of the supporting arrangements.

5.11 Health and Usage Monitoring (HUMS)

5.11.1 Areas of the hull where access is not possible and safety related failures where the failure pattern is random or unknown are candidates for the application of HUMs as a means of managing them. The interim report highlighted a number of failure modes that would benefit from the application of HUMs sensors to monitor the condition of the flaws. Following further investigation this list has now been amended with the following comments:

- **MBT FM 2B1**: Underside turret race ring supports - Criticality rating IIID (marginal/remote). This is an 'operational' failure with no access for inspection (without removal of the turret). After review it was found that the affected areas are accessible by rotating the turret over the side of the vehicle, therefore these flaws can be monitored with the ACFM NDT equipment and the access rating has now been changed from 'Red' to 'Green'.
- **MBT FM 3A2**: Either driver's armoured bulkhead to side plate fails - Criticality rating IIE (Critical/improbable). This is a random, hidden, safety related failure, with no access for inspection. DSTL have now advised that the presence of cracks in the subject welds would have no effect on the safety of the driver in the event of a crew compartment charge bin explosion. This is because the driver's bulkhead offers minimal protection even with intact welds. This failure mode has now been changed in the RCM toolkit as Non plausible (NP) but retained for audit purposes.
- **MBT FM3A5**: Either sideplate and pannier weld fails – criticality IIC (critical/occasional). Random, hidden, safety related failure, with no access for inspection. After further investigation this failure mode has now been recorded as non plausible.
- **DTT FM2A4**: Any balance weight weld fails IIC (Critical/occasional). Random, safety related failure. CTG PT is in the process of having the balance weights removed. This failure mode has now been recorded as non plausible.

5.11.2 The interim report recommended that the weld that secures the rear of the wheelstation castings to the side plates should be monitored with HUMs sensors as cracks have been reported by DSG and most of the welds are inaccessible for inspection. At present the risk of a wheelstation becoming loose or detached is based only on the results of the exterior inspection.

5.11.3 Two HUMs equipments were down selected as being the most suitable:

- Comparative vacuum monitoring (CVM) – SMS Ltd
- Alternating current potential drop (ACPD) – TSC Inspections Ltd

5.11.4 CVM - After further investigation the CVM crack detection equipment has now been discounted as it cannot provide information on the depth of the crack. If a relationship between crack length and depth can be established in the future, ideally through measurements taken from actual cracks, then it is recommended that CVM is re-considered as a means of monitoring the inner wheelstation casting welds.

5.11.5 ACPD - The ACPD fixed sensing equipment is capable of detecting and measuring fatigue cracks (length & depth) either continuously or periodically. It requires electrodes to be welded to the area to be monitored which needs to be prepared beforehand (removal of all protective materials/dirt/grease etc). The electrodes are wired to a test connector which allows connection to the instrumentation. The output is displayed on a windows-based ruggedized laptop and shows the crack profile in a very easy to interpret format. ACPD was recently fitted to the rear of a wheelstation casting weld (LHS No.5) as part of an ongoing trial to assess its potential. The method and initial results of this trial fitment are at Annex B.

5.12 Manpower

5.12.1 A vehicle inspection using the ACFM test equipment requires two personnel. For health and safety reasons this is also the minimum number of trained operators who should conduct the inspection. For tasks that require the track and side skirt to be removed, this will require the vehicle crew. A vehicle mechanic is also required for removal of the top rollers.

5.13 Training

5.13.1 Inspectors would be required to have attended and passed the TWI (formerly The Welding Institute) course on the use of the ACFM test equipment. An engineering background, experience of heavy armoured fighting vehicles and use of non destructive testing would also be an advantage.

5.13.2 The ACPD HUMS monitoring equipment requires formal training through TSC Inspections Ltd.

5.13.3 There is no formal training required on the use of the Audit 107 ultrasonic hand held NDT test equipment.

5.13.4 It is assumed that vehicle preparation will be conducted by the vehicle crew and that they will have received the necessary training.

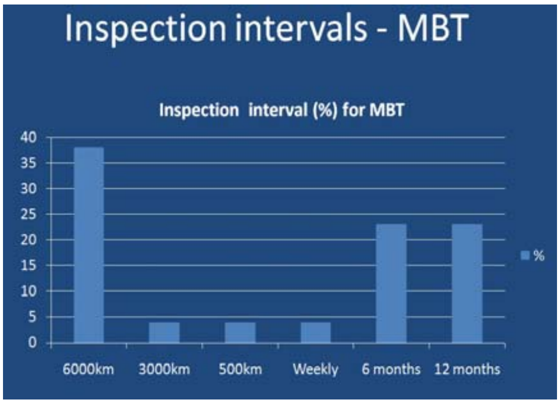
5.14 Facilities

5.14.1 Minimum requirement is 1st Line REME workshop facility or equivalent with sufficient hard standing, equipped with adequate lighting and 240v ac power supply to power the ACFM test equipment. The ACFM equipment can operate from its own internal rechargeable batteries (AMIGO and Laptop) for several hours if necessary. A crawling board or a vehicle inspection pit is also highly desirable, to facilitate underside inspection. The inspectors should liaise with the unit before an inspection to ensure the facilities are available.

5.15 Inspection time

5.15.1 The time taken to conduct individual tasks varies from a couple of minutes to several hours. Many are influenced by factors such as: the amount of preparation required beforehand, problems removing assemblies (e.g. seized components/damaged threads), and whether a crack has been detected or not.

5.15 .2 Assuming no unforeseen problems, a full 'scheduled' inspection on an MBT as per the tasks listed in Annex A, which includes the removal of track guards, tracks and top roller brackets, would take a minimum of 4 man day's effort (2 men, 2 days). This excludes pre-cleaning activities.



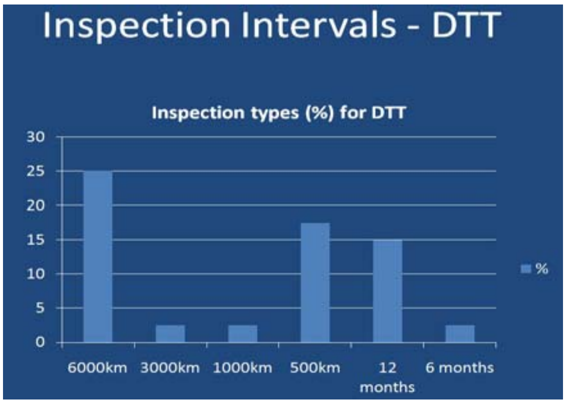


Chart 3 – MBT and DTT Inspection Intervals

6 CONCLUSIONS

6.1 The CR2 structural Integrity study has successfully demonstrated a viable alternative to the current practice of managing armoured vehicle fleets by returning individual vehicles for scheduled restoration at Level 4, based on time and usage. Analysis of the Level 4 hull inspection data has shown there is no link between vehicle age or usage and the size of flaws. Twenty three percent of vehicles that passed through the BIR programme, between the period 2001-2008, had two or less cracks reported in the hull and all of these are considered to be only minor i.e. non critical. Eighty five percent of vehicles entered BIR below the 12,000 km entry criteria, with vehicles averaging only 7,514 km.

6.2 Vehicles can be assessed for 'fit for role' at the operating unit, against a set of pre-determined pass-fail criteria that take account of the operating environment and intended use. This will enable programme managers, equipment support managers and vehicle commanders to be able to make an assessment as to whether their vehicle/s are both safe and operational. The process will also determine and provide justification as to which vehicles require Level 4 repair.

6.3 The process that has been developed addresses all aspects of hull safety and provides a means of identifying and managing risks as an integral part of the vehicle safety case. It also provides a full audit trail to all of the information recorded, making it easier to review.

6.4 Vehicle availability is optimised as vehicles will no longer be required to be backloaded to Level 4 to determine their condition, but instead only when they actually require repair. This in turn will optimise vehicle support costs because not all vehicles will require repair, compared to the current practice of repairing all flaws.

6.5 One of the outputs of the study is a hull defect (flaws) database which is in the form of a website. This is possibly the only such database for the CR2 hull and should prove to be a very useful source of information.

6.6 One of the most challenging aspects of the study was to determine maximum tolerable flaw sizes (also known as condemnation criteria). This was achieved through a combination of developing scientific methods (fracture analysis and blast modelling), engineering judgement and by adopting previous criteria used by the repair organisation.

6.7 The study identified 6 high risk areas (final drive, wheelstation inner/outer & underside castings welds, HTT, and top roller mounts) within the hull which exhibited flaws and had the potential to compromise hull integrity. All 6 areas were modelled by DSTL to show the effects of applying extreme normal usage loading to each of the nominated areas with a combination of flaw sizes (up to maximum values reported at Level 4). The results show that none of the areas are prone to catastrophic failure (i.e. sudden). This is because the stress intensities were found to be significantly below the critical values for the material type. However the study did find that it is possible that two of these areas could fail in a more graceful way through fatigue. These were the interior and exterior welds securing the wheelstation castings.

6.8 Of the 6 high risk areas of the hull that were assessed under extreme normal usage loading, 3 of these were selected to analyse the effects of blast (final drive, wheelstation inner & outer casting welds). The results show that for the method employed (10 kg at 1m and 20 kg at 1m), none showed signs of compromising the structural integrity of the hull. Under further analysis of the wheelstation inner casting weld with a maximum observed crack (500 mm at 68% depth) and a blast load of 20 kg at 0.25 m, the plastic strain reached 50%, which is close to the 80% threshold which is regarded as the safe limit flaw size for this blast magnitude.

6.9 The recommended hull inspection regime is made up of scheduled and non-scheduled inspection tasks. The scheduled tasks are broken down into usage-based intervals and calendar (or time) based intervals. The most common intervals are 6000 km and 6 and 12 months and were derived during the RCM study using information from a number of expert stakeholders, including DSG, BAE Land and the IPT. An electronic vehicle inspection sheet has been produced which will indicate a pass or fail result for flaw sizes input against individual SSIs.

6.10 One of the key outputs of the CR2 study is that it could provide a 'through life' management tool for DE&S that not only addresses hull repair requirements but also determine in advance the effects of changes in the future (i.e. safety, operational, availability, and support costs). Examples of such changes are: operating in different environments, different usage patterns, modifications, changes to vehicle weight, increased threat e.g. larger IEDs etc. The tool would consist of the flaw website, RCM toolkit (database) & associated equipment operating context, 3D hull model, finite element models using ABAQUS and Zencrack software, interactive inspection schedule, and any future modelling techniques such as ADAMS. The flaw website could be modified to provide a front end user interface to all of the relevant information and could be accessed by different stakeholders over a secure network. This approach would provide significant benefits, in terms of efficiency savings on hull management, such as: quicker and easier access to relevant information, improved decision making process based on reliable and current information, information based on shared ownership with full audit trail for all decisions made.

6.11 The study was based on vehicles fitted for but not with additional armour protection, as directed by the customer CTG PT. The intention was to develop the baseline model/process first, and if successful, update to take account of the changes.

6.12 It has been difficult to clearly identify the vehicle design loads due to the reluctance of the design authority, BAES, to share this information with the MoD, because of commercial sensitivities. The impact of this was that assumptions had to be made for the residual section failure analysis (RSF), which could result in flawed analysis. Despite this, through a combination of calculating loads from vehicle design data, by making use of known working limits and from the RCM study finite element model, DSTL were able to determine realistic operating loads.

6.13 Crack detection and propagation monitoring sensors were fitted, as part of an ongoing trial, to the rear of a vehicle wheelstation in order to monitor the area for cracks in the weld between the casting and the side plate. Further information can be found at Annex B to this report.

6.14 The RCM study (Toolkit) has been updated to reflect changes made during the course of this assessment.

7 RECOMMENDATIONS

7.1 It is recommended that DE&S implement the findings of this report by adopting a condition-based maintenance programme to replace the current scheduled base overhaul interval of 12,000 km/2 med man tours. This will improve equipment safety, optimise equipment availability and reduce support costs. The customer should also consider adopting the same process on other armoured vehicles by conducting similar studies.

7.2 The failure management strategy detailed in this report requires that both the MBT and DTT hulls are inspected at Unit level, using the recommended NDT equipments (where appropriate) and at the intervals recorded in Annex A.

7.3 The DE&S CR2 equipment safety panel should review the tailored criticality matrix, together with all of the RCM criticality values in order to agree an effective way of managing the RCM derived hazards and reduce all of the risks to ALARP. The panel should also integrate the hull into their vehicle safety case.

7.4 Carry out a further assessment for the MBT fitted with additional armour. This would not be a major task but would be very beneficial as it would provide evidence to mitigate the risk associated with blast.

7.5 It is recommended that CR2 hulls are managed as part of a through life management process which is based on the processes developed by this study. Part of this process would require that regular reviews are conducted to ensure that risks are managed, equipment availability is optimised and support costs are reduced. Information generated in the future such as; inspection/failure data, repair information should be recorded and made available for analysis. The review process will include risk management, inspection requirements, inspection intervals, proposals for modification/repair and would require an RCM facilitator. Any changes to the current support strategy will require changes to the RCM Toolkit (database) and may require change to the safety case, hull inspection schedule, hull failure data website, 3D hull model and finite element models (for fracture analysis and blast modelling).

7.6 Provide funding to enable 6 monthly inspections (for up to 2 years) to the rear of the wheelstation casting welds using the ACPD test equipment as part of an ongoing trial to determine its suitability (Annex B refers).

7.7 A copy of the results of the Mk3 hydrogas suspension trial, which is due to take place over the next 18 months on the same vehicle, are made available to assess the impact on wheelstation welds.

7.8 In the absence of any vehicle loading data from the design authority it is recommended that consideration be given to the development of ADAMS models which can be used to provide vehicle loading data across different terrains. This information would be used as part of the through life hull management to model the effects on the structure in the future for different operating environments or changes to vehicle weight.

7.9 Investigation is carried out into a failure management strategy for failure mode 18A1 battery vent failure, as previously reported.

7.10 Conduct blast analysis to the rear underside picture frame, failure mode ref: FM3B4 and also the rear side plate to underside pannier to rear plate welds FM3B3.

7.11 As part of a through life review, conduct further investigations on a number of new failure modes that have been identified during the course of this study (listed at bottom of the table in Annex A) but have yet to be resolved. The failure modes are: cracking to the welds on the underside of the Panniers (FM3A11), cracks in the garbage hatch hinge plate (FM3A8), the fire extinguisher bracket becoming detached and under blast conditions acting as a secondary projectile (FM3A12), driver's seat mounting arrangement on 24 TES vehicles.

ANNEX A

RCM derived maintenance tasks

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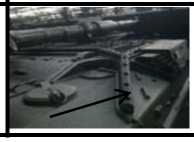
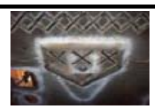
MBT or DTT	FM REF No.	SSI DESCRIPTION	INSPECT PERIOD	INSPECT LEVEL	INITIAL RISK ASSESSMENT Def Stan 02-45 Def Stan 00-56 (Brackets)	Safety vs Op	PICTURE	ADDITIONAL TASK INFORMATION	TASK REQUIREMENT	ACCESS : No access / Very Restricted / Restricted / Good access	VISUAL (V) NDT (N) HUMs (H)	SUPPORT STTE	FACILITATE ACCESS	COMMENTS	ACTION	Condemnation Criteria (Residual Section I Failure) Training use	Condemnation Criteria (Blast analysis) Ops use
Scheduled Tasks																	
MBT	1A44	Visually inspect rear hull wear protection thickness	500 km	Level 2	IIIC (C)	O		Thinning of sacrificail weld material (hard facing) to rear underside plate and picture frame	Need to measure thickness of sacrificial weld (hard facing).		N	Audit 107	Access via rear of vehicle on crawling boards or pit			1mm	1mm
MBT	3B2	Visually inspect underside sacrificial plates for thickness > 10mm	3000 km	Level 2	IIIC (C)	O		Thinning of picture frame due to abrasion. Frame is 30mm when new.	Need to measure thickness of picture frame at several points - see DSG Bov inspection Schedule. (excludes hard facing)		N	Audit 107	Access via rear of vehicle on crawling boards			10mm	10mm
MBT	1A11	Carry out a visual inspection of all wheel stations casting to side plate for signs of cracking noting and marking crack length (Exterior)	6000 km	Level 2	IIB (B)	S		Looking for surface breaking cracks on the weld toe (upper and lower edges). Often casting side. Typ 9-3 Oclock position. Travels into sideplate at approx 11 deg to sideplate	Need to be able to detect surface breaking cracks full thickness of side plate.		N	ACFM	Remove track guards and track	Qty 12. Cracks often found around top of casting moving down sides. Common on Wheelstations No. 1 & 6. Typical crack size 200-300mm long and between 2-15mm deep.		Up to 500mm long x13mm deep (see interactive inspection schedule)	As Trg use
MBT	1A14	Carry out a visual inspection of all wheel stations casting to underside plate for signs of cracking.	6000 km	Level 2	IIE (D)	S		Looking for surface breaking cracks often at the ends of the casting and less often along the back. Can crack at either casting or parent metal side of welds	Need to be able to detect surface breaking cracks to depth of weld and into floor plate		N	ACFM	Access via Crawling Boards or pit	Qty 12.		No criteria established	No criteria established
MBT	1A17	Carry out a visual inspection of both wheel station to HTT mounting welds	6000 km	Level 2	IIB (B)	S		Looking for surface breaking cracks on the middle of the weld run between the HTT and Wheelstation No.1	Need to be able to detect surface breaking cracks full thickness of side plate.		N	ACFM	Remove Track Guards and Track	Qty 2. Difficult to access with standard probe. TSC supplied thinner probe which was found to be suitable. Inspection of this will be covered by the procedure for any Wheel station outer casting.	Managed by 1A11	as per FM1A11	As per FM1A11
MBT	1A20	Carry out a visual inspection of both final drive castings welds for signs of cracking	6000 km	Level 2	IIE (D)	S		Looking for surface breaking cracking mainly at the parent metal edge of the recess. Cracks perpendicular to sideplate into parent metal. Cracking more common around top area casting10-2 oclock	Need to be able to detect surface breaking cracks full thickness of side plate.		N	ACFM	Remove track guards and track	Qty 2.		No criteria established	No criteria established
MBT	1A23	Carry out a visual inspection of welds on both HTT for signs of cracking	6000 km	Level 2	IIE (D)	S		Looking for surface breaking cracking mainly along the weld toe edges nearest the side plate, often at the top of the casting where it meets the diagonal rib and down the weld with the toeplate	Need to be able to detect surface breaking cracks down the edge of the weld to the depth of the weld		N	ACFM	Remove track guards and track. Move mudguards up.	Qty 2		No criteria established	As trg use
MBT	1A26	Carry out a visual inspection of all top roller bracket mounting boss welds for signs of cracking *(useage based)*	6000 km	Level 2	IIE (D)	S		Cracks around the weld edge nearest the side plate anti-clockwise from 9-3 and can join up between bosses (mainly the lower two) in the side plate - typ 10mm deep	Need to be able to detect surface breaking weld edge cracks down into the parent metal approx 10mm		N	ACFM	Remove track guard and track. Remove Top Roller mount arms	Qty 6 sets of 4 mounts = 24. above No.2,4,6 Wheelstations. Early vehs (Leeds) have triangular Bosses, later type (Newcastle) have round type.		No criteria established	As Trg use

MBT or DTT	FM REF No.	SSI DESCRIPTION	INSPECT PERIOD	INSPECT LEVEL	INITIAL RISK ASSESSMENT Def Stan 02-45 Def Stan 00-56 (Brackets)	Safety vs Op	PICTURE	ADDITIONAL TASK INFORMATION	TASK REQUIREMENT	ACCESS : No access / Very Restricted / Restricted / Good access	VISUAL (V) NDT (N) HUMs (H)	SUPPORT STTE	FACILITATE ACCESS	COMMENTS	ACTION	Condemnation Criteria (Residual Section Failure) Training use	Condemnation Criteria (Blast analysis) Ops use
MBT	2B1	Carry out a visual inspection of all sidewall to underside race ring support welds	6000 km	Level 2	IIIC (C)	O		Looking for surface breaking cracks mainly on weld toe on the upper part of the support and extending around the sides	Need to be able to detect surface breaking cracks extending into underside of the turret ring		N	ACFM	Traverse turret over either side of vehicle	Majority of flaws reported on both LH & RH front supports (also referred to as Sills). The turret can be traversed to a specific position to view these welds		> 4 mounting points cracked (incl 2 middle supports each side)	> 4 mounting points cracked (incl 2 middle supports each side)
MBT	3A6	Visually inspect the driver's compartment drain aperture for bung protrusion >1mm	6000 km	Level 2	IID (C)	S		Looking for loss of metal, due to abrasion, on the lower face of the inner bung.	Need to be able to measure amount of protrusion of inner bung, with ref to the lower face of the surrounding casting.		V	Depth guage	Crawling board or pit required	Incorrectly recorded as 3A9 in RCM study report (fig2.2). DSG say that an underside blast injured driver due to failure of this aperture, although no underbelly plate fitted. However as mineblast plate will be fitted in future then minimal probability that drain will fail		1mm	1mm
MBT	3B5	Visually inspect all engine compartment floor access apertures for aperture ring thickness >3mm	6000 km	Level 2	IIIC (C)	O		Looking for loss of metal, due to abrasion, on the lower face of the access plate apertures (Qty 5)	Need to be able to measure thickness of access apertures with reference to vehicle floor plates.		N	Audit 107	Crawling board or pit required	Qty 5.		3mm	3mm
MBT	10A1	Visually check all vehicle upper paintwork for condition.(relates to IR signature)	Weekly	Level 1	IIIB (B)	O	NA	Paint system is multi-layer and has several functions	As per AESP cat 512		V	-				As per AESP cat 512	As per AESP cat 512
MBT	14A1	Carry out a visual inspection of all side plate to underside pannier welds *(relates to containment of fuel in the event of a fuel bag leak)*	6 months	Level 2	IIC (B)	S		Cracking can occur along any part, although is only seen in gap of flitchplate above No. 6 Wheelstation.	Need to be able to detect surface breaking cracks in sideplate to pannier welds.		N	ACFM	Remove track guard near wheel station No. 6. Lift Engine Decks	Most of the weld is hidden behind Flitch plate. Often the only indication is when crack found in gap (above Wheelstation No. 6). Can see some of the inside weld under engine deck. Level 2 task when NDT used.		No cracking tolerated	No cracking tolerated
MBT	3C2	Carry out a functional check of NBC integrity	6 months	Level 1	IID (C)	S	N/A	Relates to any engine/fighting compartment bulkhead weld fails.			V			Crew task to carry out NBC functional check at level 1. Cracks would have to be significant to affect overpressure of NBC unit.		NBC test indicates pass or fail	NBC test indicates pass or fail
MBT	15A1	Check driver's compartment fire extinguisher bracket for security	6 months	Level 1	IIIC (C)	O		This relates to ability to extinguish fire in engine bay. Ensure the securing bracket is fixed to the hull	N/A		V		Lift and secure Drivers Hatch	A new failure mode has been generated for effects of loose bracket in the event of a blast (i.e. Secondary projectile)		No cracking tolerated.	No cracking tolerated.
MBT	19A1	Check all warning signs are legible and secure.	6 months	Level 1	IID (C)	S		Check all warning signs are legible and secure.	N/A		V					No criteria required	No criteria required
MBT	1A40 MBT	Visually inspect the steering pivot boss for signs of cracking	6 months	Level 2	IID (C)	S		Looking for cracks around the weld securing the boss	Need to be able to detect signs of weld cracking around boss		V & N	ACFM	Remove cover plate (4 bolts) behind drivers seat.	A design review has been recommended by DSTL regarding the position and securing arrangements of the steering boss, following blast trials. In the meantime it is recommended that this failure mode is managed by inspection. .		No cracking tolerated	No cracking tolerated
MBT	2A1	Visually inspect all turntable mounting, as far as possible, for signs of cracking	6 months	Level 2	IIID (C)	O		Looking for cracks in the welds securing the mountings to the floor of the hull	Need to be able to detect surface breaking cracks visually (restricted access for any NDT)		V		Limited access in crew compartment	Very few failures reported by DSG (non recorded on hull inspection reports)		>2 mounts with weld cracks	>2 mounts with weld cracks
MBT	3A1	Carry out a visual inspection of tow plate to side plate welds for signs of cracking.**(Managed by FM1A23)**	As per FM1A23	Level 2	NP	S		It is possible that cracking in the welds securing the Toeplate to sideplate could occur.	Need to be able to detect surface braking cracks full depth of weld under the HTT mounting block				Cannot get access to welds without removal of HTT casting (which is welded in place!)	On the RCM study DSG reported cracking in these welds, however after further investigation it would not be possible to see these welds as they are hidden beneath HTT mounting block.		Covered by 1A23	As per 1A23

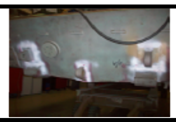
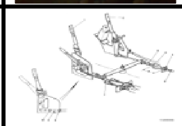
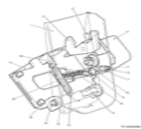
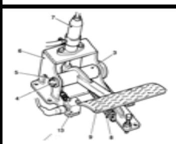
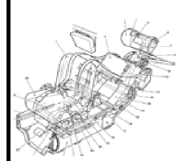
MBT or DTT	FM REF No.	SSI DESCRIPTION	INSPECT PERIOD	INSPECT LEVEL	INITIAL RISK ASSESSMENT Def Stan 02-45 Def Stan 00-56 (Brackets)	Safety vs Op	PICTURE	ADDITIONAL TASK INFORMATION	TASK REQUIREMENT	ACCESS : No access / Very Restricted / Restricted / Good access	VISUAL (V) NDT (N) HUMs (H)	SUPPORT STTE	FACILITATE ACCESS	COMMENTS	ACTION	Condemnation Criteria (Residual Section Failure) Training use	Condemnation Criteria (Blast analysis) Ops use
MBT	3B3	Carry out a visual inspection of both sideplate to rear plate to underside pannier welds	12 months	Level 2	IIIB (B)	O		Crack extends under rear flitch plate in 'J' prep joint to rear corner. Sometimes right through joint to sill in Engine Comp't	Need to be able to detect surface breaking cracks along weld in gap of flitchplate		N	ACFM	Remove rear mud flaps	Cracking starts under flitchplate due to poor production weldings (Slag trap in J prep). If crack within gap in flitchplate and rear corner then suspect full crack under rear section of flitchplate		1.8m under flitchplate + cracking along flitchplate welds	1.8m under flitchplate + cracking along flitchplate welds
MBT	3B4	Carry out an NDT inspection of the rear underside plate weld area	12 months	Level 2	IIIB (B)	O		Cracking mainly occurs to both sides of picture frame and flitchplates (Weld edge)	Need to be able to detect surface breaking cracks full depth of welds		N	ACFM	Crawling Boards or pit required.	Welders say that cracking occurs mainly on upper and lower weld toe edges.		Full length of two sides	Full length of two sides
MBT	3D1	Carry out a visual inspection of all enhanced armour fixing points	12 months	Level 2	IIE (D)	S		Looking for cracking around the welds securing the mounts to the side plates			V		Remove side plates.	As there are three fixing points per sideplate it is recommended that a visual inspection will suffice.		Any unsecure mount	Any unsecure mount
MBT	1A7	Carry out visual inspection of both track tensioner mountings for signs of cracking. **(managed by FM1A23)**	6000km	Level 2	IID (C)	S		Looking for cracks mainly in the upper and lower weld toe edges.	Need to be able to detect surface breaking cracks full depth of plates.		N	ACFM	Remove track guard, track. Remove mudflaps	All welds, except weld between wheel station and track tensioner (FM1A17). Recommend doing this check on 12B inspection. Only get access to 60% of weld area without removal of hydraulic ram. Blast unlikley to have any effect as it would push casting up into rib and sideplate, rather than away		As 1A23	as trg use
MBT	1A8	Carry out visual inspection of all top roller mountings for signs of cracking (Time based) **Manage by FM1A26**	12 months	Level 2	IIE (D)	S		Cracks around the weld edge nearest the side plate anti-clockwise from 9-3 and can join up between bosses (mainly the lower two) in the side plate - typ 10mm deep	Need to be able to detect surface breaking weld edge cracks down into the parent metal approx 10mm		N	ACFM	Remove track guard and track. Remove Top Roller mounting arms	Qty 6 sets of 4 mounts = 24. Recommend carry out on 12B inspection		As 1A26	As 1A26
MBT	3A7 MBT	Visually inspect all hull external parent metal plates for signs of cracking	12 months	Level 2	IIE (D)	S		Looking for cracks mainly in the welds securing any parent metal plate (see list in comments)	Need to be able to detect surface breaking cracks full depth of welds		N	ACFM	None	Underside floor plate, rear plate, toe plate, glacis plate, side plates (L&R), pannier plates(x6), reinforcing plate (fishtail). No failures reported.		No failures reported. Establish criteria in future	No failures reported. Establish criteria in future
MBT	8B1	Visually inspect top deck bumps stops for security	12 months	Level 2	IIIE (D)	O		Looking for cracks along the welds securing the bump stops	Need to be able to detect surface breaking cracks		V		None			No cracking tolerated	No cracking tolerated
DTT	1A44	Visually Inspect rear hull wear protection thickness >1mm	500km	Level 2	IIIC (C)	O		Thinning of sacrificial weld material (hard facing) to rear underside plate and picture frame	Need to measure thickness of sacrificial weld (hard facing).		N	Audit 107	Require Crawling boards or pit			1mm	N/A
DTT	1A48	Visually inspect rear sacrificial plate for signs of wear	1000km	Level 2	IIIC (C)	O		Relates to the sacrificial plate the picture frame is mounted on.	Need to measure thickness of sacrificial plate.		N	Audit 107	Require Crawling boards or pit	Side plate (left hand and right hand)		5mm	N/A
DTT	1A47	Visually inspect underside sacrificial plates (picture frame) for thickness >10mm	3000km	Level 2	IIIC (C)	O		Thinning of picture frame due to abrasion	Need to measure thickness of picture frame at various points.		N	Audit 107	Require Crawling boards or pit	Pannier plates (x6)		10mm	N/A

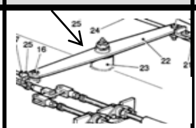
MBT or DTT	FM REF No.	SSI DESCRIPTION	INSPECT PERIOD	INSPECT LEVEL	INITIAL RISK ASSESSMENT Def Stan 02-45 Def Stan 00-56 (Brackets)	Safety vs Op	PICTURE	ADDITIONAL TASK INFORMATION	TASK REQUIREMENT	ACCESS : No access / Very Restricted / Restricted / Good access	VISUAL (V) NDT (N) HUMs (H)	SUPPORT STTE	FACILITATE ACCESS	COMMENTS	ACTION	Condemnation Criteria (Residual Section Failure) Training use	Condemnation Criteria (Blast analysis) Ops use
DTT	1A11	Carry out a visual inspection of all wheelstation casting to side plate welds for signs of cracking	6000km	Level 2	IIB (B)	S		Looking for surface breaking cracks on the weld toe (upper and lower edges). Often casting side. Typ 9-3 Oclock position. Travels into sideplate at approx 11 deg to sideplate	Need to be able to detect surface breaking cracks full thickness of side plate. (See comments)		N	ACFM	Remove Track Guards and Track	Qty 12. Typical crack is 200-300mm and 2-15mm deep		as MBT	N/A
DTT	1A14	Carry out a visual inspection of all wheel stations casting to underside plate for signs of cracking.	6000km	Level 2	IIE (D)	S		Looking for surface breaking cracks often at the ends of the casting and less often along the back. Can crack at either casting or parent metal side of welds	Need to be able to detect surface breaking cracks to depth of weld and into floor plate		N	ACFM	Access via Crawling Boards or pit	Qty 12.		as MBT	N/A
DTT	1A17	Carry out a visual inspection of both wheelstation to HTT mounting welds	6000km	Level 2	IIB (B)	S		Looking for surface breaking cracks on the middle of the weld run between HTT and Wheelstation.	Need to be able to detect surface breaking cracks full thickness of side plate.		N	ACFM	Remove Track Guards and Track	Qty 2. Difficult to access with standard probe. TSC supplied thinner probe which was found to be suitable. Inspection of this will be covered by the procedure for any Wheel station outer casting (1A11)		as MBT	N/A
DTT	1A20	Carry out visual inspection of both final drive castings welds for signs of cracking	6000km	Level 2	IIE (D)	S		Looking for surface breaking cracking mainly at the parent metal edge of the recess. Cracks perpendicular to sideplate into parent metal. Cracking more common around top area casting10-2 oclock	Need to be able to detect surface breaking cracks full thickness of side plate.		N	ACFM	Remove Track Guards and Track	Qty 2.		as MBT	N/A
DTT	1A23	Carry out a visual inspection of welds on both HTT for signs of cracking	6000 km	Level 2	IIE (D)	S		Looking for surface breaking cracking mainly along the weld toe edges nearest the side plate, often at the top of the casting where it meets the diagonal rib and down the weld with the towplate	Need to be able to detect surface breaking cracks down the edge of the weld to the depth of the weld		N	ACFM	Remove track guards and track. Move Mudguards up.	Qty 2		as MBT	N/A
DTT	1A26 DTT	Carry out a visual inspection of all top roller bracket mounting boss welds for signs of cracking	6000 km	Level 2	IIE (D)	S		Cracks around the weld edge nearest the side plate anti-clockwise from 9-3 and can join up between bosses (mainly the lower two) in the side plate - typ 10mm deep	Need to be able to detect surface breaking weld edge cracks down into the parent metal approx 10mm		N	Electro-magnetic	Remove track guard and track. Remove Top Roller mount arms	Qty 6 sets of 4 mounts = 24.		as MBT	N/A
DTT	2A1	Carry out a visual inspection of all side plate to underside race ring support welds for signs of cracking	6000km	Level 2	IIID (D)	O		Looking for surface breaking cracks mainly on the upper part of the support (weld toe)	Need to be able to detect surface breaking cracks.		V	Torch		Applicable to front & rear supports		as MBT	N/A
DTT	12A2	Visually inspect all engine compartment floor access apertures for aperture ring thickness >3mm	6000km	Level 2	IIIC (C)	O		Looking for loss of metal, due to abrasion, on the lower face of the access plate apertures (Qty 5)	Need to be able to measure thickness of access apertures with reference to vehicle floor plates.		N	Audit 107	Crawling board or pit required	Qty 5.		3mm	N/A
DTT	12A3	Visually inspect the drivers compartment drain aperture for bung protrusion >1mm	6 months	Level 2	IVD (D)	O		Looking for loss of metal, due to abrasion, on the lower face of the inner bung.	Need to be able to measure amount of protrusion of inner bung, with reference to the lower face of the surrounding casting.		V	Depth gauge	Crawling board or pit required			1mm	N/A

MBT or DTT	FM REF No.	SSI DESCRIPTION	INSPECT PERIOD	INSPECT LEVEL	INITIAL RISK ASSESSMENT Def Stan 02-45 Def Stan 00-56 (Brackets)	Safety vs Op	PICTURE	ADDITIONAL TASK INFORMATION	TASK REQUIREMENT	ACCESS : No access / Very Restricted / Restricted / Good access	VISUAL (V) NDT (N) HUMs (H)	SUPPORT STTE	FACILITATE ACCESS	COMMENTS	ACTION	Condemnation Criteria (Residual Section I Failure) Training use	Condemnation Criteria (Blast analysis) Ops use
DTT	14A1	Carry out a visual inspection of all side plate to underside pannier welds *(relates to containment of fuel)*	6 months	Level 2	IIC (C)	S		Looking for cracks in the weld in the gap between the flitch plate above Wheel station No. 6	Need to be able to detect surface breaking cracks full depth of plates		N	ACFM	Remove track guard near wheel station No. 6. Lift Engine Decks	Most of the weld is hidden behind Flitch plate. Only indication is when crack found in gap (above Wheelstation No. 6). This crack can sometimes extend behind flitchplate towards rear of vehicle. Can see some of the inside weld under engine deck - Could provide confidence.		as MBT	N/A
DTT	15A1	Check driver's compartment fire extinguisher bracket for security	6 months	Level 1	IIIC (C)	O		Ensure the securing bracket is fixed to the hull			V		Lift and secure drivers Hatch	Good access		as MBT	N/A
DTT	19A1	Check all warning signs are legible and secure	6 months	Level 1	IID (C)	S		Check all warning signs are legible and secure.			V			Good access		as MBT	N/A
DTT	1A40 MBT	Visually inspect the steering pivot boss for signs of cracking	6 months	Level 2	IID (C)	S		Looking for cracks around the weld securing the boss	Need to be able to detect surface breaking cracks around weld		V & N	ACFM	Remove cover plate (4 bolts) behind drivers seat.			as MBT	N/A
DTT	14A2	Carry out a visual inspection of both sideplates to rear plate to underside pannier welds (containment of fuel)	6 months	Level 2	IIC (B)	S		Looking for cracks mainly in the upper and lower weld toe edges.	Need to be able to detect surface breaking cracks in gap of flitdhplate and rear corner		N	ACFM	Remove mudflaps			No cracking tolerated	N/A
DTT	1A45	Carry out an NDT inspection of the rear underside plate weld area for plate thickness >5mm	12 months	Level 2	IIIC (C)	O		Relates to the sacrificial plate the picture frame is mounted on.	Need to measure thickness of sacrificial plate.		N	Audit 107	Use crawling boards or pit	I.A.W CR BIR WP1 SB9526.		5mm	N/A
DTT	1A7	Carry out a visual inspection of both track tensioner mountings for signs of cracking. **(Manage by FM1A23)**	12 months	Level 2	IID(C)			Looking for cracks mainly in the upper and lower weld toe edges.	Need to be able to detect surface breaking cracks full depth of plates.		N	Electro-magnetic	Remove track guard, track. Remove mudflaps	All welds, except weld between wheel station and track tensioner (FM1A17). Recommend doing this check on 12B inspection. Only get access to 60% of weld area without removal of hydraulic ram.		as MBT	N/A
DTT	1A8	Carry out a visual inspection of all top roller mountings for signs of cracking (FD) - time based **(Manage by FM1A26)**	12 months	Level 2	IIE (D)	S		Cracks around the weld edge nearest the side plate anti-clockwise from 9-3 and can join up between bosses (mainly the lower two) in the side plate - typ 10mm deep	Need to be able to detect surface breaking weld edge cracks down into the parent metal approx 10mm		N	ACFM	Remove track guard and track. Remove top roller mounting arms	Qty 6 sets of 4 mounts = 24. Recommend carry out on 12B inspection		as MBT	N/A

MBT or DTT	FM REF No.	SSI DESCRIPTION	INSPECT PERIOD	INSPECT LEVEL	INITIAL RISK ASSESSMENT Def Stan 02-45 Def Stan 00-56 (Brackets)	Safety vs Op	PICTURE	ADDITIONAL TASK INFORMATION	TASK REQUIREMENT	ACCESS : No access / Very Restricted / Restricted / Good access	VISUAL (V) NDT (N) HUMs (H)	SUPPORT STTE	FACILITATE ACCESS	COMMENTS	ACTION	Condemnation Criteria (Residual Section Failure) Training use	Condemnation Criteria (Blast analysis) Ops use

Non-scheduled Tasks

MBT DTT	1A39	Check main engine air cleaner mounts	Whenever Pack is lifted	Level 2	IIID (C)	O		Looking for cracks in welds mainly at top part of mount			V		Remove main engine pack and ACU			>1 mount	>1 mount
MBT DTT	1A29	Check both APU mountings.	Whenever APU removed for any reason	Level 2	IIID (C)	O		Looking for cracks in welds mainly at top part of bracket			V		Remove main engine pack and APU			>1 mount	>1 mount
MBT DTT	1C1	Check all Power Pack mountings for signs of cracking	Whenever pack is removed for other reasons	Level 2	IIID (C)	O		Looking for cracks in welds mainly at top part of bracket			V		Remove main engine pack			>1 mount	>1 mount
MBT DTT	1A28	Check security of all top rollers and mountings(AD)	Following cross-country operation	Level 1	IIE (D)	S		Looking for foreign objects that may cause damage to mountings/rollers			V					as 1A26	as 1A26
MBT DTT	5A1	Check that all insulation padding is serviceable.	Before vehicle use	Level 1	IIB (B)	S	N/A	Looking for padding that has become detached or damaged			V					As per AESP	As per AESP
MBT DTT	1A43	Check all control cable mounting pads for security	whenever the pack is removed & whenever turntable access plates are removed.	Level 2	IID (C)	S		Looking for cables that have become detached from mounts or mounts detached from hull floor.			V		Remove engine pack or turntable access plates			>1 mount	>1 mount
MBT DTT	9B1	Check all external mountings for security.	Before vehicle use.	Level 2	IID (C)	S	N/A	See FMECA for full list			V					As AESP	As AESP
MBT DTT	16A1	Check all lifting eyes for signs of damage.	Before a vehicle lift is carried out	Level 1	IID (C)	S		Looking for signs of accidental damage, eg. bent or cracked welds			V & N	ACFM	Lift engine decks	Poor access to lower part of weld (rear eyes). Vehicles rarely lifted in field - mainly at DSG. DSG look for bent eyes. Eye designed for full Veh weight but bare hull only 15 Ton, therefore lower risk.		No cracking	No cracking
MBT DTT	6A1	Check all towing eyes for signs of damage	At first parade.	Level 1	IIE (D)	S		Looking for damage to towing eye or cracks in the eye or support welds			V & N	ACFM		If signs of damage found then need to do a more thorough inspection using NDT equipment.		No cracking	No cracking
MBT DTT	1A34	Check both steering tiller mountings.	Whenever any servicing in the area is required.	Level 2	IIE (D)	S		Looking for cracks in the support bracket to floor welds			V & N	ACFM		If signs of damage found then need to do a more thorough inspection using NDT equipment.		No cracking	No cracking
MBT DTT	1A32	Check driver’s accelerator pedal mounting.	Whenever any servicing (pedal, battery etc).	Level 2	IIE (D)	S		Looking for cracks in mounting welds.			V & N	ACFM		Bolted to hull mounting bracket. If signs of cracking found then recommend use of NDT.		No cracking	No cracking
MBT DTT	1A33	Check driver’s brake pedal mounting.	Whenever any servicing in the area is required.	Level 2	IIE (D)	S		Looking for cracks in mounting welds.			V & N	ACFM		Bolted to hull mounting bracket. If signs of cracking found then recommend use of NDT.		No cracking	No cracking
MBT DTT	1A37	Check drivers seat for security	Before use	Level 1	IID (C)	S		Looking for excessive movement of the seat on its mountings			V		Access through drivers hatch	Access to mounting is very restricted and it is not practical to remove seat prior to vehicle use, therefore recommend inspection is limited to physical check to ensure there is no excessive movement of the seat on its mounts. 24 TES vehs have been modified so seat is supported by bulkhead so may be different access. (See new FM below)		No cracking	No cracking

MBT or DTT	FM REF No.	SSI DESCRIPTION	INSPECT PERIOD	INSPECT LEVEL	INITIAL RISK ASSESSMENT Def Stan 02-45 Def Stan 00-56 (Brackets)	Safety vs Op	PICTURE	ADDITIONAL TASK INFORMATION	TASK REQUIREMENT	ACCESS : No access Very Restricted Restricted Good access	VISUAL (V) NDT (N) HUMs (H)	SUPPORT STTE	FACILITATE ACCESS	COMMENTS	ACTION	Condemnation Criteria (Residual Section Failure) Training use	Condemnation Criteria (Blast analysis) Ops use
MBT DTT	1A42	Check Steering pivot Boss for weld failure (FD)	Before any road driving & following cross-country use	Level 2	IIE (D)	S					V & N	ACFM	Remove cover plate (4 bolts) behind drivers seat	The use of NDT is only required if cracking is suspected.		No cracking	No cracking

Re-design tasks

MBT	3A2	Check armoured bulkhead to side-plate welds (Drivers bulkhead)	No Life	Level 2	**Non Plausible (NP)**	S		Looking for cracks in the welds between bulkhead and side plates						A proactive management strategy (RCM) cannot be found. Redesign impractical so recommend monitoring site with sensors. FM review - DSTL say that cracks would have no effect in the event of a charge bin blast. Bulkhead offers hull rigitity but limited protection.	FMECA updated	Not required	Not required
MBT	3A5	Check side-plate to pannier welds. (Safety for front area only)	No Life	Level 2	**Non Plausible (NP)**	S		Looking for cracks in the weld hidden behind the front section flitch plate			H		Front section track guard	A proactive management strategy (RCM) cannot be found. Redesign impractical. Front flitchplate sometimes cracks and DSG suspect weld underneath cracks due to slag in bottom of weld, however they do not remove flitch to inspect (& no flaws recorded). Risk to driver very low as the sidewall is higher in this area .	FMECA updated	Not required	Not required
DTT	2A4	Check security of DTT balance weight mounting weld.	No Life	N/A	**Non Plausible (NP)**	S		Looking for cracks in the welds securing mounting			N	N/A		Mandatory re-design. CTG PT now removing balance weights from all DTT's, therefore non plausible failure mode.	FMECA updated	Not required	Not required

New tasks for consideration

MBT DTT	1A45 & 1A51	Carry out a visual inspection of all wheelstation casting to side plate welds for signs of cracking **(interia)**	6000km	Level 2	IIB (B)	S		Looking for surface breaking cracks mainly on the weld toe casting side, although can occur on both sides	Need to be able to detect surface breaking cracks up to 13 mm deep.		H	ACPD (ongoing assessment - Annex B refers))	Access to test connectors only	ACPD was fitted to the LH wheelstation No. 5 as part of a trial in April 2010.		Up to 500mm long to 17mm depth. (See interactive inspection schedule)	Same as trg use
MBT	3A11	Underside of Pannier- filler section (mid section)	FFI tba	Level 2	IIE	S		Looking for Weld edge cracks	Need to be able to detect surface breaking cracks depth of parent plate.		N	ACFM (subject to testing)	Remove track guard and track	Small cracks sometimes occur in the centre of the welds nearest the sideplate. No data available for crack lengths. Welder says cracks are perpendicular to plate and do not extend into parent plate underneath (i.e overlap joint)	Further investigation required	-	-
MBT	3A8	Garbage hatch above No. 3 WS (LHS)	FFI tba	Level 2	IIE	S		Cracks in the weld edge of the hinge plate	-		N	ACFM (subject to testing)		No cracking reported. If welds securing the aperture cover hinge are cracked then it may result in the cover becoming detached in a blast event. DSG say there is no internal cover	Further investigation required	-	-
MBT	TBA	Security of drivers seat (mounted to bulkhead)	FFI tba	Level 2	TBA	S	Pic req'd					To be investigated		New risk is security of Drivers seat where it is mounted to bulkhead (only 25 TES vehicles affected)	Further investigation required	-	-
MBT	3A12	Security of drivers fire extinguisher bracket	FFI tba	Level 2	IIE	S		This FM relates to a loose fire extinguisher becoming a secondary projectile in an incident			V				Further investigation required		No cracking

Key to abreviations:

Safety vs Op = Safety or Operational effects

S=Safety

O=Operational

NP=Non Plausible

FFI=Failure Finding Interval

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ANNEX B

Non Destructive Testing (NDT) and Health & Usage Monitoring Systems (HUMS)

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NDT & HUMS equipments

Crack Detection and measurement

Challenger 2 is typical of many heavy armoured vehicles based on welded construction using rolled homogenous steel armour, in that that they often suffer from varying degrees of cracking within their hull structure. The majority of the cracks observed on CR2 are in the welds, although there are some instances of cracking propagating into the parent metal, such as the area around the top roller mounting brackets. It is thought that the primary cause of weld cracking is related to limitations in vehicle design, weld joint design and in some cases poor weld penetration (e.g. side plate to underside pannier), but is not due to variations in the materials used. Track induced vibration and running gear will have a major effect on the fatigue life of the welds. Evidence of this can be seen on many vehicles passing through the Base Inspection Repair (BIR) programme, where cracking often occurs around wheels station No. 6 and the track support mountings, which are nearest to the final drive.

The only crack inspection process that has been conducted on CR2 was during the BIR programme and required the hull to be stripped of all of its bolt-on assemblies, including all paint, before applying dye penetrant to selected welds. One of the major challenges of conducting an effective inspection in the field is not only gaining access to the affected areas, but being able to detect cracks that are often hidden beneath layers of paint. Fortunately there are non destructive test equipments on the market that are capable of detecting cracks beneath conformal coatings, although some are better than others at achieving this, it often comes down to the requirement/application.

NDT Crack detection: Alternating Current Field Measurement (ACFM) technique.

Advantages: Crack detection and measurement (length and depth), portable, ruggedized, accurate, works on painted surfaces.
Disadvantages: Difficult to interpret results - requires specialist training and experience before use.

One of the advantages of the alternating current field measurement method of inspection is that it can detect surface breaking cracks through paint. It can also measure the depth of a crack, unlike many other electromagnetic devices, which use eddy current techniques that are more suited to aviation applications (thinner materials) where it is only necessary to measure cracks to a depth of typically 2-3mm. Another advantage of ACFM is that it does not require pre-calibration on artificial defects. TSC Inspection Systems Ltd have developed their ACFM equipment as a detection and measurement device for use on commercial oil platforms and underwater pipe installations, making it more suited to the CR2 application.

Fig 1a: ACFM - NDT equipment

Fig 1b: ACFM in use on CR2 MBT Wheelstation

The ACFM NDT equipment consists of a ruggedized instrument (known as AMIGO) and laptop (current operating System is Microsoft Windows 2000), a test plate and weld probe. There are various other probes available which have been designed to cater for particular applications and material types.

The equipment is relatively easy to set up and is powered by either the internal rechargeable batteries or via the mains powered battery charger. The equipment should ideally be operated by two personnel; one to move the probe over crack site and the other to operate the instrument and monitor the real time displays which are plotted on the laptop screen.

Due to the complex waveform patterns observed, often as a result of the uneven welds tested on the hull, it is essential that operators receive specialist training on its use and this should be followed up with regular practical experience on a platform.

Another key aspect of the inspection is that it is important to understand the nature of the defect you are looking for before starting a scan over the affected area i.e. direction of crack, is it surface breaking or not, is it in the parent metal or weld middle or toe edge? The majority of the cracks on CR2 are on the weld toe edge, rather than the middle, so this may only require two passes with the probe i.e. down each side of the weld. A useful feature of the test equipment is that it allows the user to be able to store all of the results of the inspections onto the laptop which can be accessed or exported for future reference.

HUMS - Crack detection: Alternating current potential drop (ACPD)

Advantages: Portable, quick and relatively easy to use, accurate results, measures crack length & depth, Passive.
Disadvantages: The area to be monitored has to be prepared (removal of paint) and electrodes welded in place.

The ACPD equipment consists of a ruggedized instrument, known as the Mk V ACPD crack microgauge, a laptop, and hard wired test electrodes. The laptop is used to run the specialist software that operates the test equipment and also acts as an interface for the user, displaying all of the input parameters and test results.

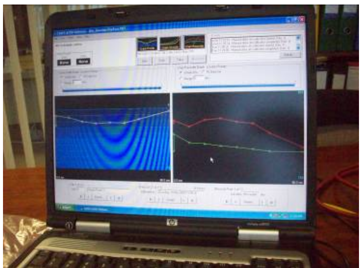


Fig 2a: Laptop Fig 2b: Microgauge instrument Fig 2c: Test piece

The equipment works by attaching a positive and negative electrical feed either side of the know crack area (shown in Fig 2c – red and blue electrodes) by attaching wires to studs welded to the parent metal. Electrodes (small pins or studs) are welded along the known crack path in groups of four; two to measure the reference voltage (Vr) and two across the crack to measure crack voltage Vc. In order to measure a crack several centimetres in length, it is necessary to add further groups of electrodes as shown in Fig 3a.

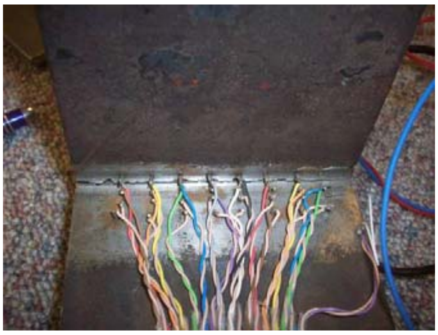


Fig 3a – Electrodes welded along crack site

The principle of operation is that an alternating current is passed down the electrodes at the side of the crack so that a reference voltage (Vr) reading can be taken. An alternating current is then passed down the electrodes over the crack area and voltage (Vc) reading is taken. If there is no crack present, the two voltage readings will be the same and the reading will be zero. However if there is a crack then this will be indicated by a higher voltage on the second reading Vc. The reason there is a higher voltage when a crack is present is that the current (€o) flowing between the two test pins has to travel further around/under the crack, which is equivalent to a higher resistance path.

If a number of readings are taken along the crack site the laptop will display the profile of the crack, clearly showing its length and depth in mm. The more readings that are taken along the crack site, the better the resolution displayed.

To calculate depth of crack ‘d’ mathematically:

(i) $V_r = \text{€}o\Delta$

(ii) $V_c = \text{€}o(\Delta+2d)$

where: Vr = Ref voltage
Δ = Distance between test pins (constant)
€o = Current flow
Vc= voltage across crack
d = depth of crack (mm)

For d:

$$\frac{V_c}{V_r} = \frac{(\Delta+2d)}{\Delta}$$

$$\frac{V_c}{V_r} = 1+\frac{2d}{\Delta}$$

$$d = \left(\frac{V_c}{V_r} - 1\right) \times \frac{\Delta}{2}$$

If no crack then $\frac{V_c}{V_r} = 1$, so d=0

Note: This formula is valid only for high aspect cracks in ferritic steel

Rmada

HUMS Trial - ACPD fitted to CR2

1. **Purpose**

1.1 The purpose of the trial is to fit on-board HUMS sensors to the rear of a CR2 wheel station casting to assess its ability to detect and monitor cracks in the affected area. The trial will also enable an assessment to be made of a number of other factors as follows:

- Electrodes: Determine suitability of material type, diameter/length, and method of attaching cables.
- Electrical cables: Determine suitability of cable size/gauge, protective coating, routing, positioning of test connector, protection, fixing
- Method and ease of fitment: Includes accessibility, preparation, welding requirements (rating/settings).
- Other materials required (e.g. protective sleeving, paint, sealants)
- Timescales for fitment (time to fit, when to fit).
- Applicability (which vehicles, which wheelstations)
- Reliability
- Durability
- Ease of test

2. **Plans**

2.1 A trials plan was produced by Psion Consulting Ltd which provided details of the scope and plan of activities, including the requirements and responsibilities (Reference E). The trial fitment was conducted at the Armoured Trials and Development Unit Bovington over a two day period 19-20th April 2010. ATDU provided an MBT and workshop facilities. They also kindly removed the main power pack to facilitate the fitment of the ACPD sensors to the rear of a wheelstation in the engine compartment.

2.2 Defence Support Group (DSG) were tasked to provide a welding operator, stud welding equipment, electrodes for welding to the area to be monitored, cable protection and advise regarding the routing of the cable and test connector.

2.3 Psion Consulting sub-contracted TSC Inspections Ltd to advise on the fitment of the electrode sensors, provide all wiring, test connectors and ACPD test equipment.

3. **Materials and equipment.**

Part	**Part Description/number**	**Quantity**
Instrument	TSC ACPD Crack Microgauge Mk IV	1
Eyelet	M4, miniature eyelet crimps.	Approx 40
Signal Wire	16/0.2 PVC insulated wire. Red/black twisted at 1 twist/cm. red for positive electrode, black for negative electrode. Approx. 2m length to suit easy access.	1 twisted pair per voltage measurement. Two twisted pairs per crack depth measurement. Two spares required Total 16 twisted pairs needed per wheel station.

0v Wire	Green 16/0.2 PTFE coated wire. Approx 2m length	1 per field input, 3 required in total.
Field Wire	16/0.2 brown/blue. Brown for positive field electrode, blue for negative electrode. Twisted at one twist/cm. Approx. 2.5m long for easy access.	1 twisted pair/Field. One spare Total 4 Twisted pairs
Mil connector	19-way mil connector socket. Signal and field wires will terminate in this socket.	3
Instrument Connection lead	19-way mil connector plug to terminations suitable for connection to ACPD Instrument.	3 off
Tape	Suitable for securing wiring in place	As required
Mastic .	Suitable for sealing wiring against environmental damage/corrosion	As required
Cable Ties	Secure cables to adjacent pipe work	
Electrodes	Studs 4mmx22mm threaded full length	40 (plus 20 spare)

Wksp equipment Type	Manufacturer	Info
Welder Alpha 850	Nelson	Electric
Stud welder attachment	Taylor 1200 DA	3mm-20mm studs

4. **Outline method**

4.1 The plan was to attach the sensors to either LH wheelstation No. 5 or 6 because both were likely to be accessible in the engine compartment with the pack removed. The decision on the day was to attach the sensors (electrodes) to No. 5 as the welds were obscured by the Fuel pump at No.6. Once the sensors had been attached the plan was to route the cables and test connectors to a protected and easily accessible place near the corner of the engine bulkhead i.e. just below the seal for the decks.

4.2 Prior to the trial a detailed plan was drawn up which provided details of the weld area that required monitoring, the number of sensors required, the spacing between sensors and type and quantity of test connects. Psion provided information regarding the dimensions of the wheel station casting, the width of the weld, details of crack type, length, depth position etc, and the area that required monitoring.

4.3 Cracks are usually found in the toe of the weld nearest to the parent metal (hull side plate) and start at the top of the casting and travel down both sides to a length of up to 500mm between the 9 to 3 o'clock positions. From residual section failure analysis conducted by DSTL the material gets close to yielding at a depth of 13mm for a maximum observed crack length of 500mm.

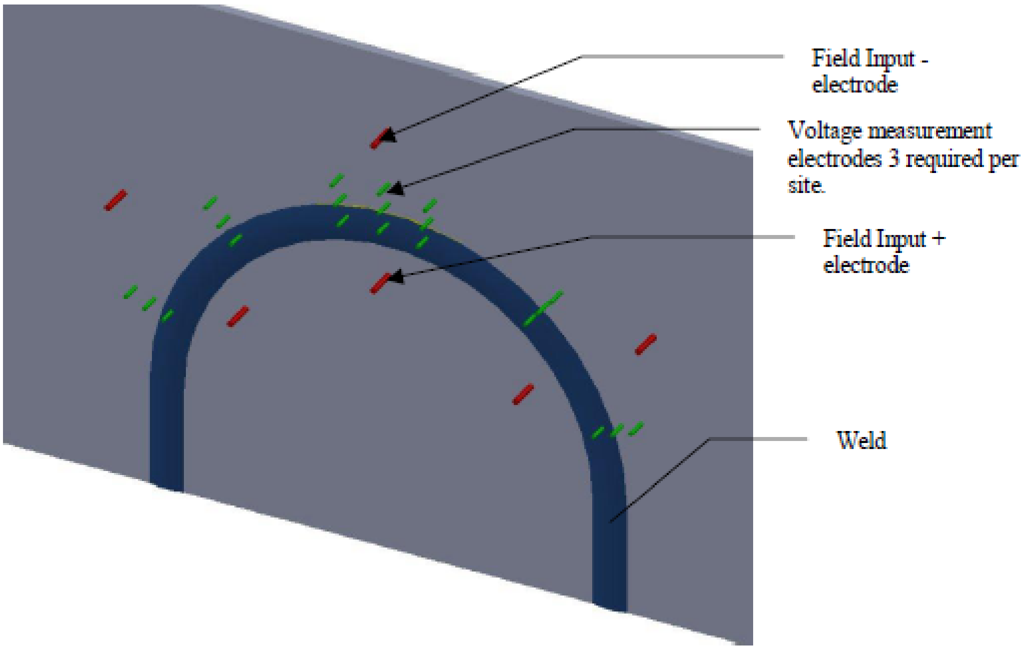


Fig 1 – Positioning of electrodes (sensors)

4.4 The illustration above shows the wheelstation weld (in dark blue) and the proposed position of the electrodes (sensors). It was proposed that seven crack measurement positions are used, three at roughly the 12 o'clock position where the crack is most likely to initiate and be the deepest. The other four are spread along the weld length as shown in Figure 1. The spacing between the voltage measurement electrodes will be 20mm. Thus a crack with10mm depth will result in a doubling of voltage reading.

4.5 Termination at the instrument end will be to 19-way mil style connectors as shown in Figure 2. In all there will be 3 connectors to suit sites at each of 3 field locations. Field 1 at 10 o'clock, field 2 at 12 o'clock and field 3 at 2 o'clock. The mil style connector can be sealed whilst not in use to maintain contact quality.

Fig 2- 19 way Mil connector

4.6 A detailed plan of the position of the electrodes is shown in Figure 3a & b.

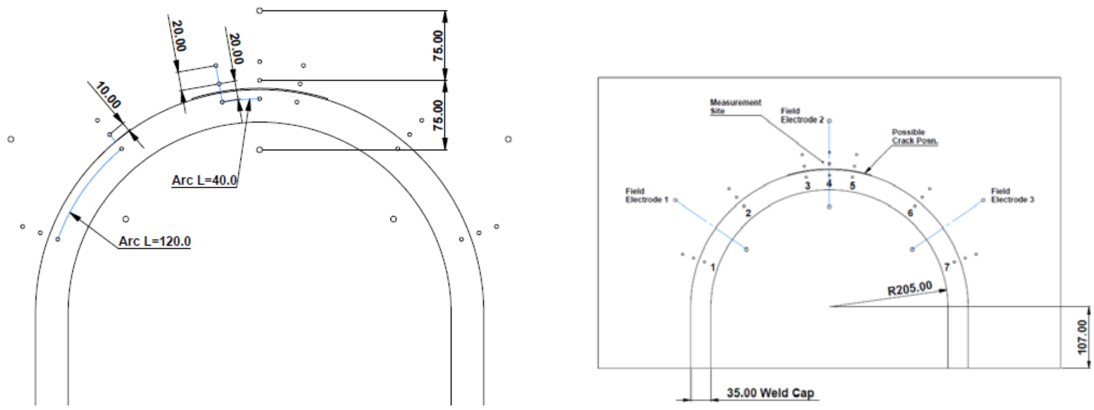


Fig 3a & 3b– Planned position of electrodes

4.7 During a meeting with DSG (Steve Batson) in the afternoon of the 19th April to discuss the plan of activities, DSG asked if ATDU could provide the welder operator as they had other commitments. Fortunately ATDU were able to agree to the request as they had an operator available. This was agreed with ATDU (WO1 Tony Longbottom). DSG provided the welder and it was agreed that ATDU would use their own stud welder, which they had recently procured, but never used.

5.0 **Results.**

5.1 ATDU removed the power pack on the morning of 19th April and a decision was made to fit the sensors to No. 5 wheelstation which required the removal of the APU to get access. All of the other wheelstations were inaccessible due to pipes other equipment. The afternoon was spent marking up the weld area so that the studs could be positioned accurately. Before this was done the areas were the electrodes (Studs) would be welded was prepared by carefully removing the paint using an angle grinder. TSC then made up a simple paper template from the measurements in fig 3 and marked the positions with a black marker pen.

Fig 4 – Pack removal at ATDU Fig 5 – Engine bay (not the cleanest seen!)

5.2 The original plan to fix 7 sets of sensors had to be reduced to 5; 3 at the top and one at the 9 and 3 o'clock positions because of the fuel pipes. This was not a major issue as we would still be able to monitoring the important part of the weld at the top and also detect when a crack had reached the maximum tolerable length. The absence of these sensors would mean that we would not be able to monitor crack propagation quite as well during the trial period. To compensate for this a little, the two sensors either side of the top 12 o'clock sensor were moved a further 10mm apart, thereby increasing the area to be monitored at the top to 100mm wide.

Fig 6-Wheelstation No. 5 marked up for sensors Fig 7- Electrodes (studs) being welded in place

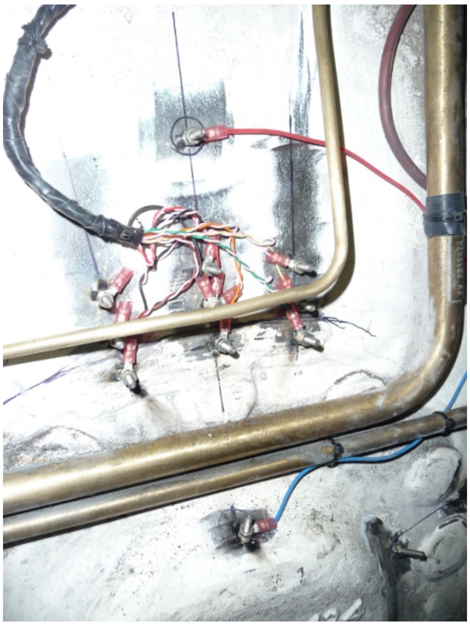
5.3 The morning of the 20th was spent practicing welding the 4mm studs to scrap metal because it was important to get the correct settings on the welder and the stud welding attachment. This part of the preparation proved problematic as there were several adjustments that had to be correct or the result was that either the stud would be damaged or there was not enough weld penetration. The stud gun was finally set so that it held the stud for a time of approx 200ms.

5.4 The afternoon was spent attaching the studs in place. This would normally be a relatively quick process; however some of the studs did not adhere in place or were damaged during the welding process. After further adjustment to the stud gun and a clean of all surfaces, the task of attaching the studs was almost complete. There was a requirement, because of the position of the fuel lines at the 3 o'clock position, to attach the last stud with the standard arc welding attachment.

5.5 There were a couple of incidents during the afternoon which caused a few problems. The ATDU welding operator accidentally damaged one of the vehicles fuel lines which resulted in a small fuel leak. This was temporarily repaired with a clamp by ATDU. The other incident resulted in the TSC engineer receiving an electric shock from the hand held part of the stud welder gun. He was not operating the stud gun welder at the time, only holding the gun while showing the welder where he wanted one of the studs attaching. After this the main welding set would not operate. Upon further investigation, where ATDU attached another (DSG) stud welding gun to determine whether it was the main welding unit or the stud welder, it was found that the problem was with the DSG main welding set. DSG were informed and their equipment was returned to them by ATDU the following day (21st April).

5.6 Once the studs were in place the TSC engineer attached all of the wiring looms. During this procedure two of the studs detached from the hull (the studs at the 9 and 3 o'clock positions). At this point none of the ATDU staff were on site as it was early evening, so the studs could not be re-attached in the absence of a qualified welder. There would not be an opportunity to complete the task the following day as the power pack was going back in. The decision was made to complete the installation with the 3 sensors.

5.7 The wire ends nearest the sensors had been terminated with M4 eyelet clamps and they were carefully secured in place by locking each one between two M4 nuts, as shown in Fig 8. It was important that none of the wire moved as this could affect the readings, so they were bonded down with silicon sealant. Cable ties were also employed to secure the cable run to the adjacent pipe work. If this fitment was ever formally implement in the future then a more appropriate method of securing and protecting the cable would be required.



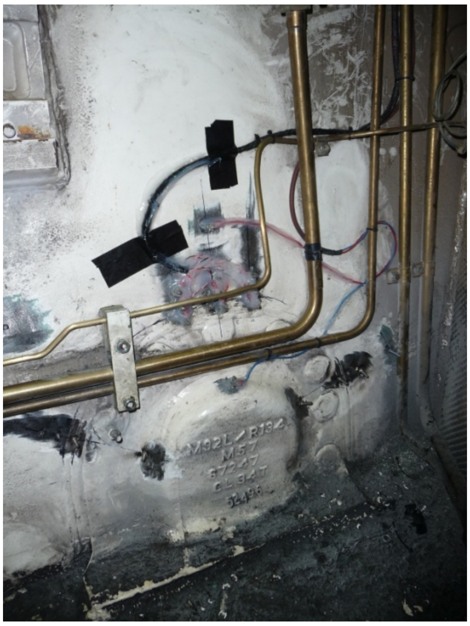
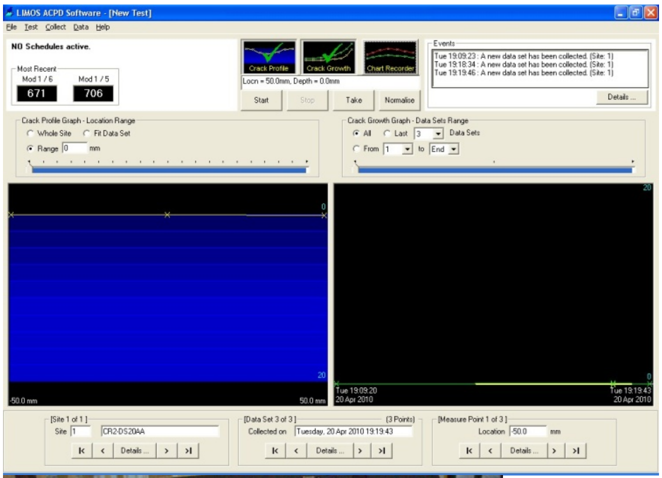


Fig 8- Shows sensors clamped to studs Fig 9- Shows installation complete

5.8 The complete installation was finally tested by TSC to ensure all of the electrical paths were good, followed by a reading of the weld on the wheelstation. Fig 8 shows the test result for the three sensors at the top of the weld casting. The plot on the left shows three points, which represent the three sensors monitoring the weld. The distance between the sensors is shown at the bottom of the graph along the ‘X’ axis i.e. -50, 0, 50. The ‘Y’ axis displays the depth of the crack. At present the trace is sitting on the zero (0mm) line. If a crack was present say between the middle sensor and the one to its right then the trace would drop down between these two points to a nominal value on the Y axis (currently set at a range of 0 to minus 20mm)



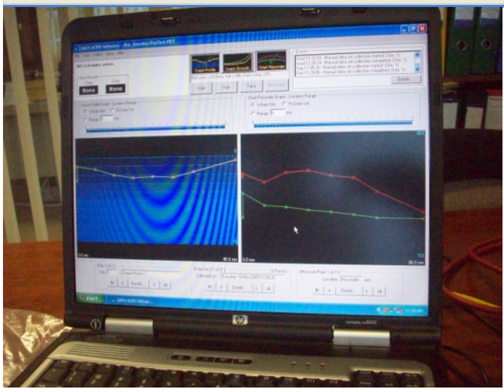


Fig 10 – LIMOS ACPD plot of rear weld on WS No. 5 Fig 11 – Illustrates a cracked sample (not CR2)

6.0 **Conclusions.**

6.1 The trial fitment of ACPD on CR2 addressed all but two of the objectives; Reliability and durability which cannot be tested until sometime in the future.

6.2 The level of planning beforehand ensured that the task was completed within projected timescales, despite a few unforeseen problems during the fitment. The engine way was not the ideal place to test this installation because of the pipe work and equipment in place; however this was the only option available at the time. The MBT provided by ATDU will also be used for the new mark III hydrogas suspension trials, so would benefit from plenty of use, which would test the reliability and durability aspects of the ACPD installation.

6.3 The main problems encountered were the method of attaching the electrode sensor studs. The size of the stud appears to be appropriate i.e. 4mm. The studs are the correct length for the application at 22mm, but any longer than this and they may contact exposed pipe work. The method of attaching them to the hull proved to be unreliable, but this was likely to be due to ATDU not being familiar with their new stud gun. If the sensors were fitted as part of a Level 4 repair programme by DSG, then the process would be more reliable because DSG are set up for this type of task.

6.4 Although only three sensors were fitted on the nominated wheelstation this does not mean that the trial was not successful. Firstly, the three sensors will be monitoring the area were all of the cracks are initiated from; it's also where they are at their deepest. The purpose of the trial installation was not to monitor the largest flaws recorded i.e. 500mm, but to prove that the equipment could be installed in place and used to detect and monitor cracks. This has been achieved because sensors have been successfully attached and the test equipment has passed the system installation check i.e. if a crack were to develop it would register on the test equipment.

6.5 The cable type, gauge and protection should be adequate for this application as advised by TSC. Advice regarding the routing of the cables for the trial fit was provided by DSG and although adequate for the trial installation, would not represent the final solution. If this was installed at Level 4 then DSG would integrate the wiring into the existing trunking which would improve reliability and durability issues (including long term accuracy of test).

6.6 Task duration - It is estimated that had this installation been conducted on a fully stripped vehicle, then all 12 wheel stations could be wired up by 2 personnel (welder and electrical fitter) in 5 days. It would take a further day to carry out testing on all of the sensors.

6.7 The installation of ACPD is applicable to both the MBT and the DTT, for all 12 wheelstations.

7. **Recommendations**

7.1 It is recommended that the application of ACPD is considered as a means of detecting and monitoring crack propagation for the inner welds around the wheelstation castings. However, further testing will be required to establish whether the installation is both reliable and durable. It is proposed that this testing is carried out every 6 months over the next 18-24 months. This is a relatively straightforward task which involves connecting the ACPD test equipment to the vehicle installation test connector and carrying out an installation (continuity) check and also taking a measurement to detect any cracking.

7.2 A copy of the results of the Mk3 hydrogas suspension trial, which is due to take place over the next 18 months on the same vehicle, are made available to assess the impact on wheelstation welds.

Measuring abrasion (NDT)

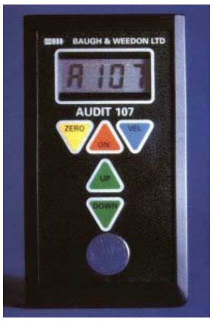
The effect of the vehicle grounding causes wear to many of the low lying components on the belly of the hull. This in time can lead to cracking of the welds and in extreme cases has resulted in one or more of the underbelly drain plugs/plates becoming detached. SEME Bordon recently highlighted a case on a driver training tank where the drain hole plate located in the rear underside picture frame had become detached, allowing great quantities of earth to enter the engine compartment and resulting in the engine being pushed up off its mounts.

At present there is no scheduled inspection, outside of the Level 4 BIR, for checking for abrasion on the underside of the hulls in the field. SEME Bordon carry out a periodic visual inspection (although they do not measure the metal thickness) at the rear underside section of their vehicles, especially the DTT's, which are more prone to this problem.

Ultrasound inspection

The recommended test equipment selected to measure the effects of abrasion and corrosion on the hulls is the Audit 107 hand held NDT instrument, which is manufactured by Baugh & Weedon Ltd and utilises ultrasound technology. It is fully calibratable to measure the thickness of a wide range of materials from 1.2mm to 199.9mm with a resolution of 0.1mm and accuracy of +/- 0.1mm.

This instrument is currently used by DSG Bovington as part of their vehicle in-inspection procedure to check for wear on the underside of the hulls. Training on its use was provided by DSG, prior to the assessment.



Audit 107 Instrument
(hand held)

Audit 107 and accessories