



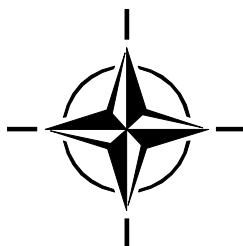
RTO TECHNICAL REPORT

TR-AVT-137

Corrosion and Maintenance Data Sharing

(Partage des données de corrosion
et de maintenance)

Final Report of Task Group AVT-137.



Published November 2011





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The Research and Technology Organisation (RTO) of NATO

RTO is the single focus in NATO for Defence Research and Technology activities. Its mission is to conduct and promote co-operative research and information exchange. The objective is to support the development and effective use of national defence research and technology and to meet the military needs of the Alliance, to maintain a technological lead, and to provide advice to NATO and national decision makers. The RTO performs its mission with the support of an extensive network of national experts. It also ensures effective co-ordination with other NATO bodies involved in R&T activities.

RTO reports both to the Military Committee of NATO and to the Conference of National Armament Directors. It comprises a Research and Technology Board (RTB) as the highest level of national representation and the Research and Technology Agency (RTA), a dedicated staff with its headquarters in Neuilly, near Paris, France. In order to facilitate contacts with the military users and other NATO activities, a small part of the RTA staff is located in NATO Headquarters in Brussels. The Brussels staff also co-ordinates RTO's co-operation with nations in Middle and Eastern Europe, to which RTO attaches particular importance especially as working together in the field of research is one of the more promising areas of co-operation.

The total spectrum of R&T activities is covered by the following 7 bodies:

- AVT Applied Vehicle Technology Panel
- HFM Human Factors and Medicine Panel
- IST Information Systems Technology Panel
- NMSG NATO Modelling and Simulation Group
- SAS System Analysis and Studies Panel
- SCI Systems Concepts and Integration Panel
- SET Sensors and Electronics Technology Panel

These bodies are made up of national representatives as well as generally recognised 'world class' scientists. They also provide a communication link to military users and other NATO bodies. RTO's scientific and technological work is carried out by Technical Teams, created for specific activities and with a specific duration. Such Technical Teams can organise workshops, symposia, field trials, lecture series and training courses. An important function of these Technical Teams is to ensure the continuity of the expert networks.

RTO builds upon earlier co-operation in defence research and technology as set-up under the Advisory Group for Aerospace Research and Development (AGARD) and the Defence Research Group (DRG). AGARD and the DRG share common roots in that they were both established at the initiative of Dr Theodore von Kármán, a leading aerospace scientist, who early on recognised the importance of scientific support for the Allied Armed Forces. RTO is capitalising on these common roots in order to provide the Alliance and the NATO nations with a strong scientific and technological basis that will guarantee a solid base for the future.

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Corrosion and Maintenance Data Sharing

(RTO-TR-AVT-137)

Executive Summary

In recent years, because of the need to keep military aircraft in service beyond their original operational life, airframe corrosion has become a critical theme in ensuring airworthiness and fleet availability. Nevertheless, since the eighties both corrosion prevention and corrosion control has overtaken design optimization and proper material selection and has played a fundamental role in managing production and deliveries of new aircraft. The same effort is still ongoing in managing aging fleets.

Corrective actions are generally seen as a national matter, with each military Air Fleet developing its own maintenance procedures even when operating common platforms. For this reason, the AVT Panel agreed that commonality and better process might be implemented more quickly if this Task Group was established.

The approved Technical Activity Proposal was aimed to carry out joint work among the NATO Nations to promote the sharing of best practices in terms of corrosion prevention and maintenance procedures used on military vehicles, as well as to establish a basis for a common and effective approach to failure analysis.

Despite a promising exploratory activity, which pointed out that many national representatives were interested in the topic, the Task Group never grew to the desired number of contributors; only three Nations produced a substantial effort, causing at first delays and – at the end – an incomplete report.

Whereas the authors feel that the goal of highlighting the best procedures for failure analysis is achievable by means of many sources including this report, and that this would be quickly available for implementation by the NATO community, however, this goal was not achieved.

Partage des données de corrosion et de maintenance (RTO-TR-AVT-137)

Synthèse

Ces dernières années, le besoin de conserver les avions militaires en service au-delà de leur durée de vie opérationnelle initiale a fait de la corrosion des cellules un thème critique pour assurer la navigabilité et la disponibilité des flottes. Néanmoins, depuis les années quatre-vingt la prévention et le contrôle de la corrosion ont dépassé l'optimisation de la conception et la sélection des matériaux adaptés et ont joué un rôle fondamental dans la gestion de la production et la livraison des nouveaux avions. Le même effort s'applique encore à la gestion des flottes vieillissantes.

Les actions correctives sont généralement considérées comme étant du domaine national, chaque flotte aérienne militaire développant ses propres procédures de maintenance, même dans l'exploitation de plateformes communes. Pour cette raison, la commission AVT a convenu que la mise en place de ce groupe de travail pourrait permettre une mise en commun et une amélioration plus rapide de ces processus.

La Proposition d'activité technique qui a été approuvée avait pour but de réaliser des travaux communs entre nations de l'OTAN pour promouvoir un partage des meilleures pratiques en termes de prévention de la corrosion et de procédures de maintenance des véhicules militaires, mais aussi d'établir une base pour une approche commune efficace d'analyse des pannes.

En dépit d'une activité exploratoire prometteuse, qui a montré que de nombreux représentants nationaux étaient intéressés par le sujet, le groupe de travail n'est jamais arrivé à atteindre le nombre de collaborateurs désiré. Trois nations seulement ont fourni un effort substantiel, ce qui a d'abord entraîné du retard puis – à la fin – un rapport incomplet.

L'objectif visant à présenter les meilleures procédures d'analyse de pannes n'a pas été atteint, bien que, dans l'esprit de ses auteurs, il ait été jugé réalisable à partir de nombreuses sources dont ce rapport, et rapidement utilisable par la communauté OTAN.

Chapter 1 – TERMS OF REFERENCE

1.1 ORIGIN

1.1.1 Background

Corrosion of military platforms or their components is an enormous matter for all NATO countries, that affects both economic and safety issues. Nevertheless prevention and corrective procedures seems too often to be designed from the single Nations, developing their own maintenance procedures even when they are operating common platforms.

In the nineties, the Tri-national (RAF, GAF and IAF) Tornado Corrosion Working Group (WG) had been operating for six years to make up and fix the lack of common management standard procedures on this fleet, up to budgetary constraints caused the ending of the WG. The results of this experience were found of a basic importance for each of the Air Forces involved in promoting the introduction of a corrosion control register based on common principles. Furthermore, these results were considered as fundamentals to assess aging effects and to support the Tornado IDS Mid Life Fatigue Package.

Taking into account the many common or very similar platforms operated by all NATO countries, an information exchange based on the experience and expertise developed along the following years in each country was considered would be useful in helping NATO Nations to gain background information on the most effective maintenance procedures.

1.1.2 Justification (Relevance for NATO)

Reduction of military budget is a general trend common to all the NATO countries that slows down the introduction of new platforms, building the need to operate increasingly aging platforms. Taking into consideration the exacerbating effect of aging on corrosion phenomena, the task of enhancing the standard of readiness and worthiness justified the creation of a NATO TG focused on the evaluation of the most adequate maintenance procedures.

A Task Group was needed to:

- 1) Evaluate case histories and maintenance data availability on the most diffused vehicles among NATO countries prone to aging;
- 2) To share the national experiences and expertise; and
- 3) To assess common approaches to failure analysis.

1.2 EXPLORATORY ACTIVITY

Exploratory Team AVT-061 ran during 2004 AVT Spring and Fall Meetings.

The participating Nations were: CAN, DEU, GBR, ITA, NLD and USA.

Each participating Nation in the Task Group gave at least one briefing on the national willing on the matter, supporting the proposal of the TG TAP and ToR.

1.3 CONGRESSIONAL ACTIVITY

A speech was given by the Chair at the 2nd World Congress on Corrosion in the military, held in Naples, Italy, on September 2007:

Title: NATO Efforts on Corrosion and Maintenance Data Sharing – *RTO AVT-137 Task Group*

Abstract: Corrosion of military platforms is a huge matter for all NATO countries that affects both economic and safety issues, especially when associated to the continuous trend in budgetary reductions that exacerbates the effects of aging. Nevertheless, prevention and corrective procedures seems too often to be designed from the single Nations, developing their own maintenance procedures even when they are operating common platforms.

In 2006 a Task Group within the Applied Vehicle Technology Panel of NATO – Research and Technology Organisation was originated in order to share, among the experts of that community, information about the policies adopted by the different countries and to promote an effective debate on the effectiveness of the solutions introduced.

Main objective of the TG, called to operate on the base of a 3 years activity, is to identify the NATO needs and develop a plan for information exchange in agreement with the general requirement for devising common approaches to corrosion prevention and maintenance procedures used on military vehicles.

In this context the TG, moving from the evaluation of case histories and maintenance data availability on the most diffused vehicles among NATO countries prone to aging, is working on tasks.

This paper presents the architecture of the activity as well as the main up-to-date achievements.

1.4 OBJECTIVES

The TG was established to identify the NATO needs and to develop a plan for information exchange in agreement with the general requirement for devising common approaches to corrosion prevention and maintenance procedures used on military vehicles.

The TG set up the following goals:

- 1) Develop a mechanism for corrosion maintenance data information exchange on selected commonly held platforms;
- 2) Measure the efficacy of the various NATO Nation procedures (including coatings, CPCs, dehumidification, etc.) and identify a common best practice approach for corrosion prevention and maintenance procedures for use on common military vehicles; and
- 3) Develop an understanding for a common failure analysis approach.

This final report has been prospecting as a review of the corrosion maintenance practices used on selected common platforms in NATO countries, containing best advice on best practice and recommending the most effective solutions to be adopted.

Chapter 2 – REPRESENTATIVE NATO CORROSION POLICIES (GERMANY)

GERMAN AIR FORCE (GAF) CORROSION POLICY

Dipl. Ing. M. Buderath
GERMANY

2.1 INTRODUCTION

To overcome Corrosion problems on aircrafts, a management working group structure was organized to support the fleet with all available expert competence.

In 1990 a national Corrosion working group within the GAF, called “AK/UAK Korrosionsschutz”, was established with additional scientific and technical support of:

- Bundeswehr Research Institute for Materials, Explosives, Fuels and Lubricants (WIWEB) at Erding;
- National support company EADS MAS; and
- Independent repair facilities (Military Aircraft Service Center at Erding, etc.) and supplier on demand.

The aim of this Corrosion working group was to provide 1993 a Corrosion Prevention and Control Program (CPCP). A concept and systematic to manage and overcome Corrosion problems of aircrafts and the implementation of a Corrosion Control Register (CCR).

2.2 DESCRIPTION OF CORROSION PREVENTION AND CONTROL PROGRAM (CPCP)

The CPCP-concept was to develop a comprehensive approach for the GAF in-service military aircrafts to:

- Support environment-friendly state-of-the-art long-term technical solutions; and
- Define activities with the aim of cost benefit and cost effective proceedings.

The following figures show firstly the schematic cycle of new activities and secondly the continuously doing of prevention and repair measures during maintenance and inspections within the different maintenance levels.

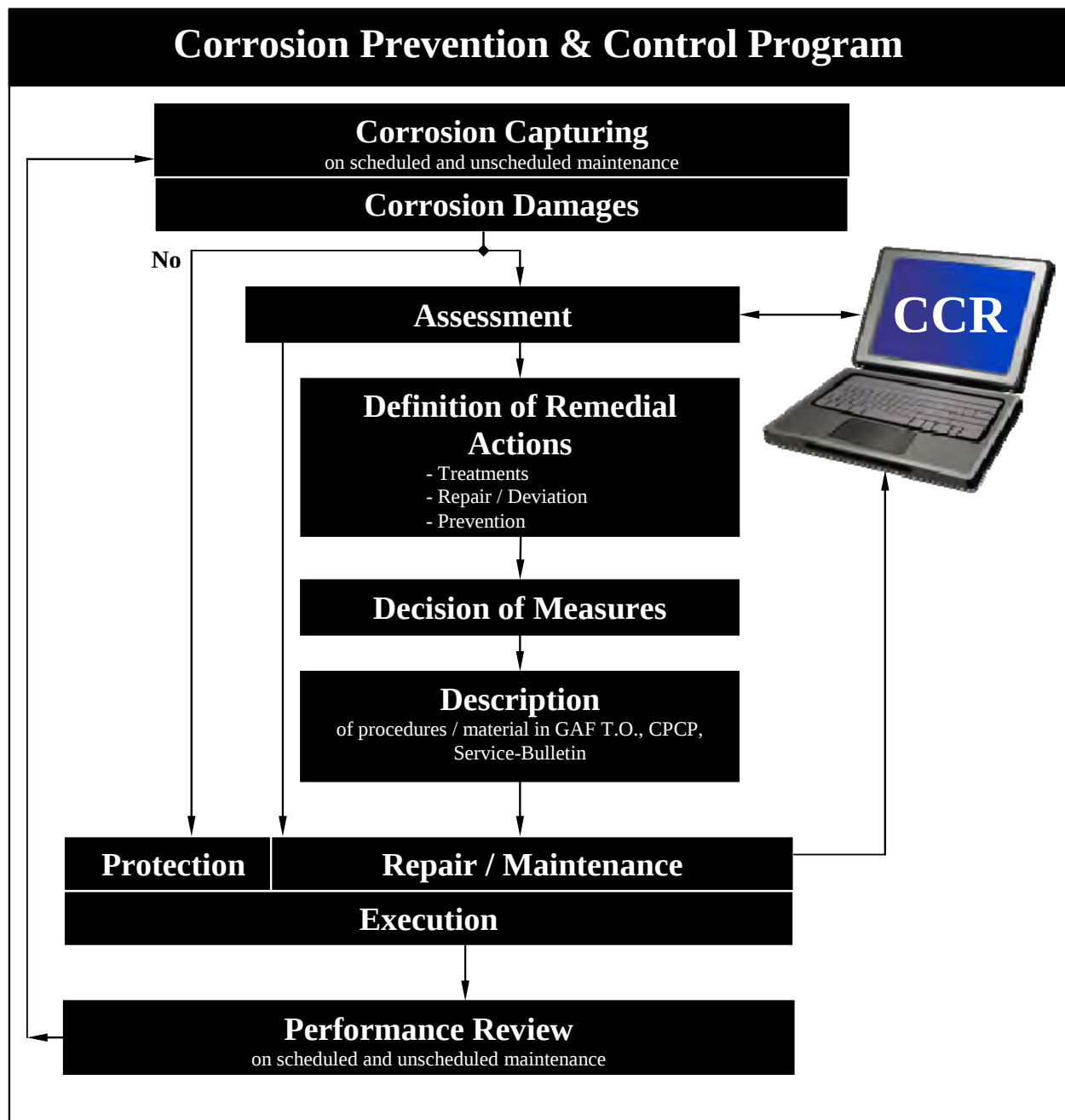


Figure 2-1: Schematic of the Corrosion Prevention and Control Program Cycle.

An example of scheduled and unscheduled maintenance measures within the CPCP program is schematically represented in the next figure.

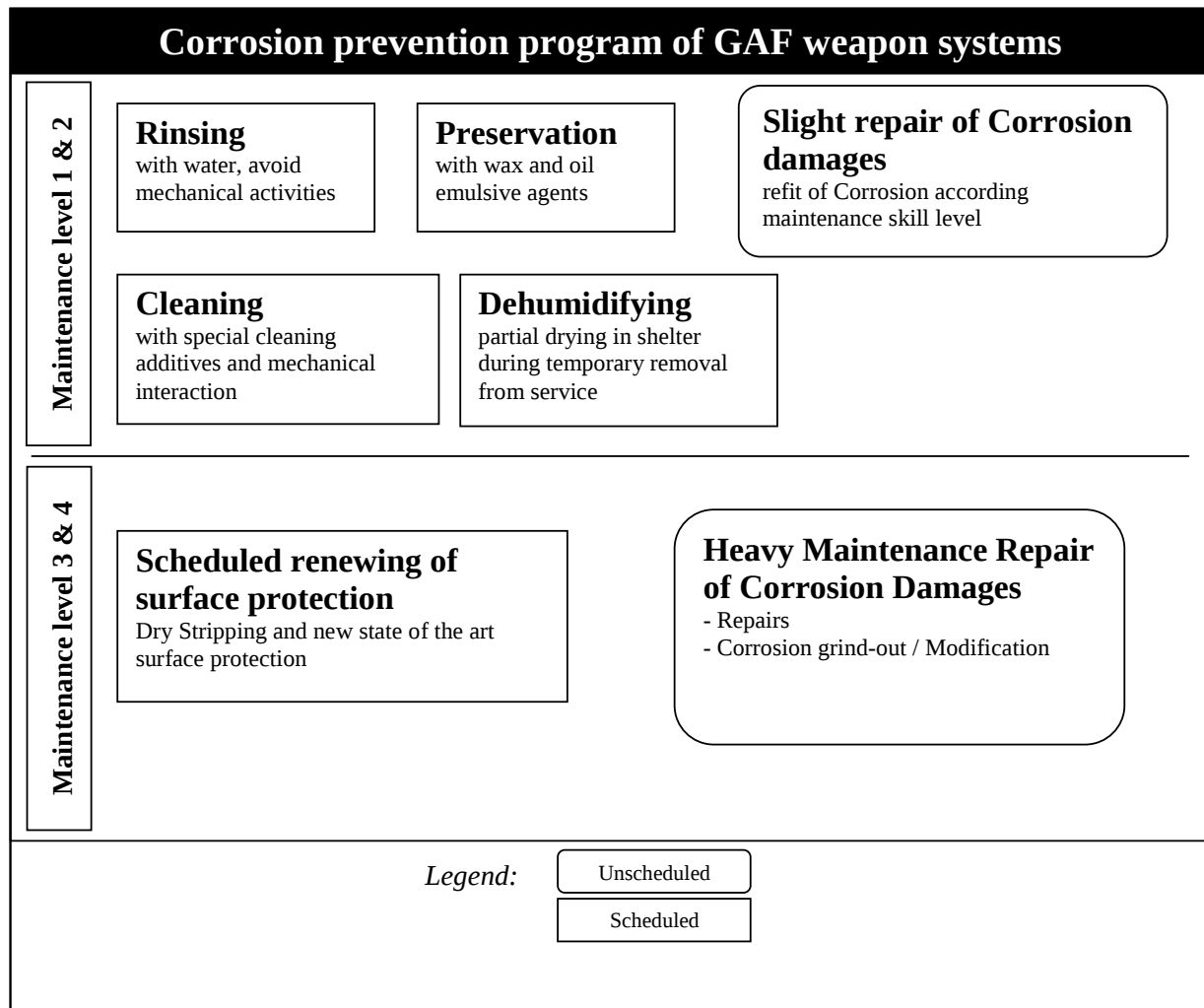


Figure 2-2: Schematic of the Continuous Prevention and Repair Measures Within the Different Maintenance Levels.

2.3 DOCUMENTATION AND CONTROL OF CORROSION

This CPCP program details the basic principle of Corrosion detection, assessment, documentation and control. With assistance of the ADP-supported Corrosion Control Register (CCR) the structure and attaching parts have to be captured from each weapon system.

Subject of the CCR is:

- To capture, control and classify Corrosion damages;
- To find out Corrosion emphases in due time;
- To define effective repair schemes; and
- The determination of efficiency to protective treatments and preventive actions.

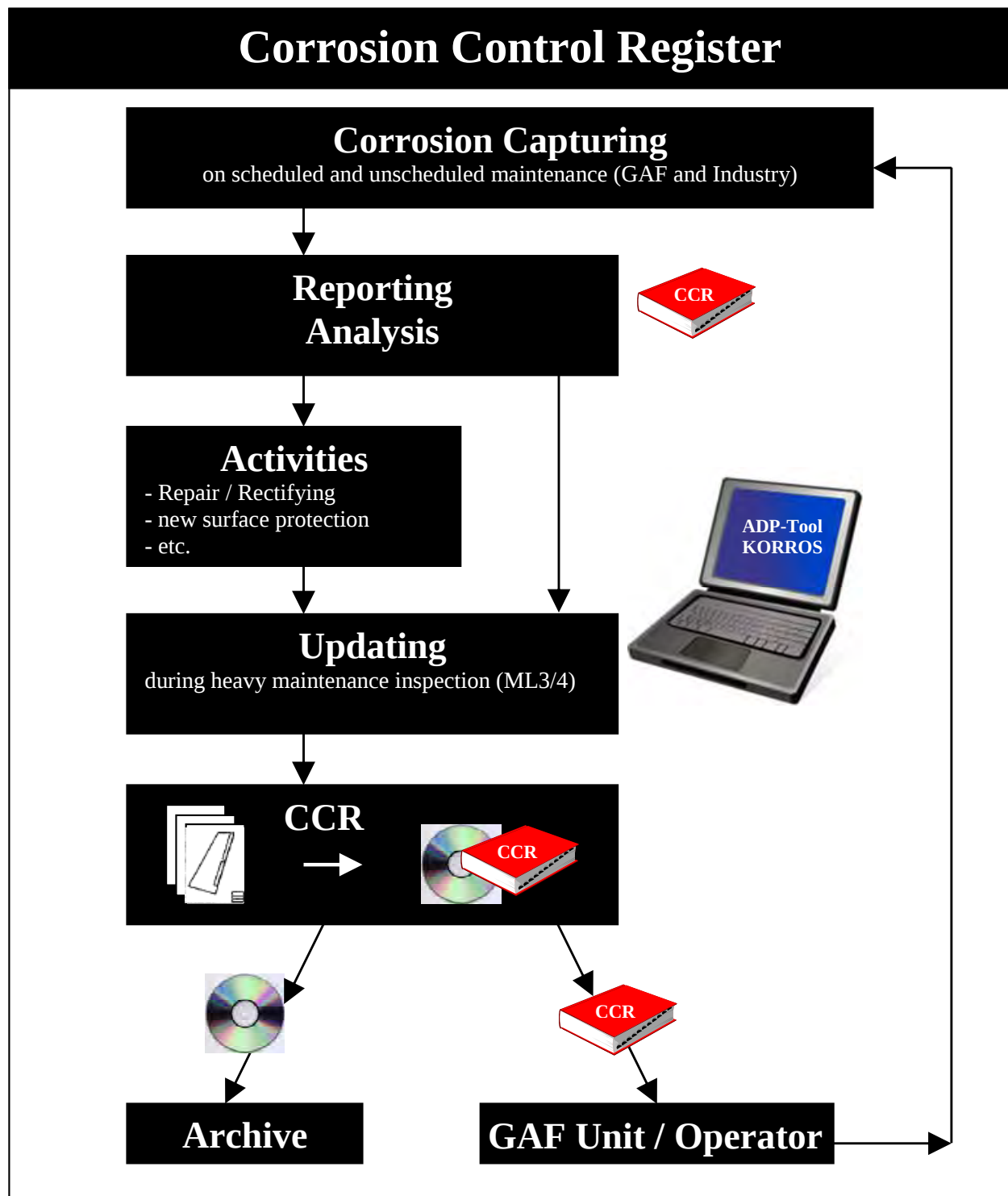


Figure 2-3: Example of CCR Documentation Concept.

The detailed position and frequency of captured Corrosion damages are registered and evaluated within the ADP system. The following picture shows an example of corresponding skin panel evaluation plots CCR-generated.

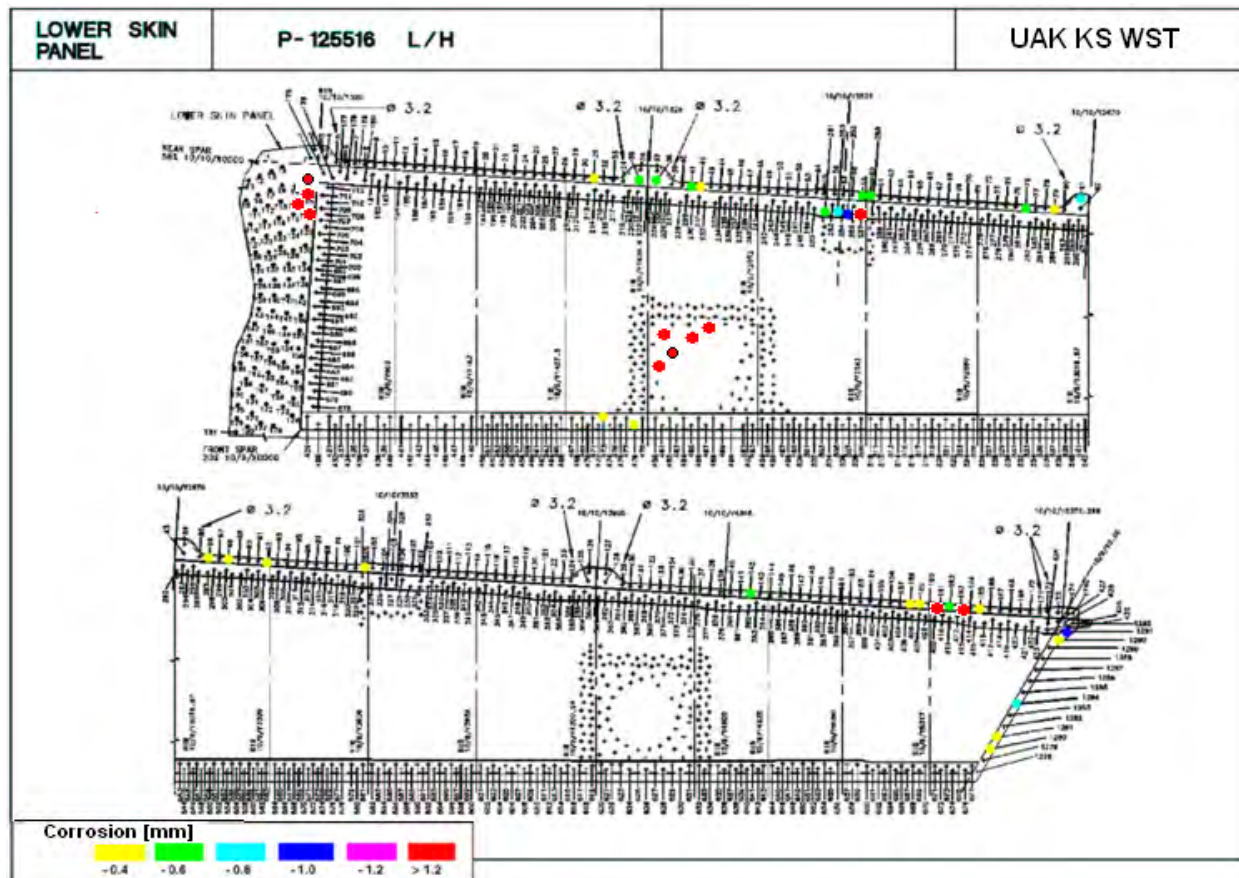


Figure 2-4: CCR Generated Evaluation Plot on Example Component.

Subject of the evaluation with the help of the CCR is to emphasise components and zones particularly concerned in order to point out statistically representative Corrosion concentration and supplies investigations of corroded areas with fatigue critical areas for example.

Beyond that further aircraft factors, like:

- flight hours,
- age in years,
- inspection dates,
- parts/serial numbers,
- dimension of corrosion grind-out and position, and
- the increase of corrosion

are represented from the aircraft/fleet over the total life cycle.

It is important that the capturing (ADP) of the Corrosion data inclusive the NDT test equipment is already available with the delivery of the aircraft.

2.4 COLLECTION DATA REQUIREMENTS

Corrosion Data capturing and collection is one of the most important parts of setting up a proper model. Without a systematic data capturing the best analysis model supplies unrealistic and wrong results. For the integrated assessment, monitoring and prediction model a considerable amount of data is needed. To facilitate data capturing and collection, the development of a support data user interface Tool is mandatory to be available from aircraft in-service date.

Beyond that unique data capturing and assessment stringent support corrective actions with a so called portable support system [PSS], which serves as the support frame for ground personnel damage documentation, during the production stage, pre and post and depot-level inspection.

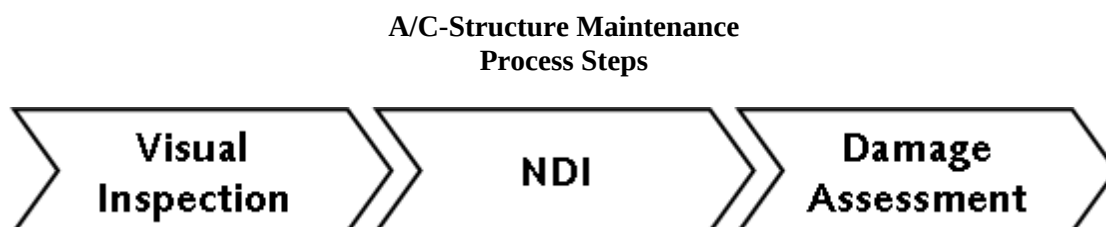


Figure 2-5: Example PSS – Concept of Operation.

2.4.1 Visual Inspection Module of PSS

- Checklists are available as paper-based documents.
- Electronic checklists on mobile devices:
 - Integration into existing distribution proc; and
 - Automatic updates.
- Automatic links to reference information.
- Structured data acquisition via electronic form:
 - System breakdown can be searched, e.g. by part number;
 - Facilitates pre-population of electronic form;
 - Only incident specific data needs to be entered manually; and
 - Possibility of automatic completeness and plausibility checks.

2.4.2 Non-Destructive Inspection (NDI) Module of PSS

- Structured data acquisition using mobile NDI Systems at the A/C:
 - Data storage in NDI database; and
 - On-demand generation of NDI Report.
- Electronic attachments enable remote diagnosis for out-of-area deployments.

- Links to information systems, e.g. 2D and 3D construction data available at the A/C.
- Guided damage classification.

2.4.3 Damage Assessment Module of PSS

- Damage categories and corresponding standard repair procedures approved by OEM (Best Practices).
- Damage database provides decision support for handling damages, which do not map to categories.

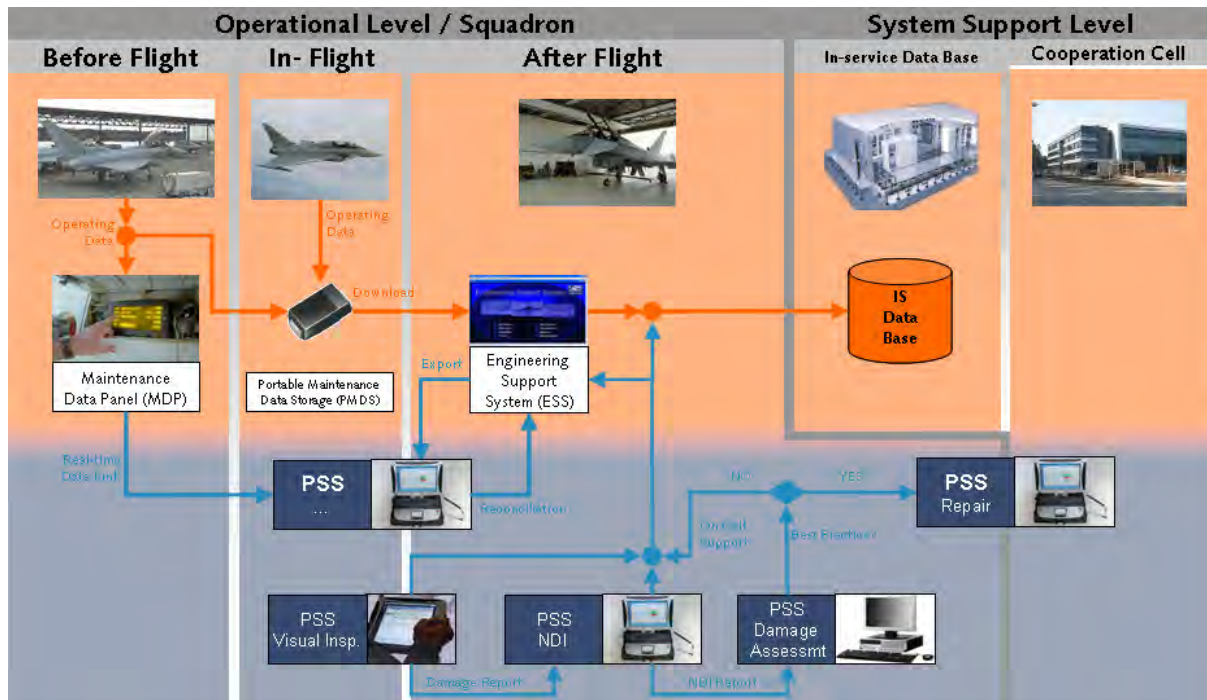


Figure 2-6: PSS Concept of Operation Example.

2.5 SYSTEMATIC CAPTURE OF CORROSION ARISING

2.5.1 Service History

Capturing of data for assessment of:

- Usage life/extension;
- Identification of corrosion concentration / hot spots;
- Remedial activities;
- Preventive activities;
- Change and shortfall of changeable items;
- Maintenance planning; and
- Highlights for new constructions.

2.5.1.1 Maintenance Data

2.5.1.1.1 From Scheduled Maintenance

- **Maintenance Level 1 and 2 (ML 1&2)**

The primary objective of this maintenance is to provide safe, mission-capable aircraft to satisfy all mission requirements. In peacetime, the primary mission is training for combat. In many instances, peacetime training requirements for aircraft are almost as stringent as battle requirements. The maintenance manager must realize the significance of aircraft availability if the unit is to accomplish its mission in both battle and peace.

It is preformed at the lowest level consistent with the tactical situation, skill, time, repair parts, tools, and NDT-test equipments.

The proper use of specified and identified report forms is mandatory and must be managed.

- **Maintenance Level 3 and 4 (ML 3&4)**

This method is for aircraft undergoing extensive repairs or lengthy inspections. It uses a fixed maintenance dock. The dock could be a location in a hangar or shop, a parking spot on the flight line, or any prearranged location. The aircraft normally remains in the maintenance dock until all maintenance is complete. Maintenance crews or teams rotate to and from the aircraft.

The proper use of specified and identified report forms is mandatory and must be managed for the depth and skill of heavy maintenance and availability of appropriate repair parts, tools and NDT-test equipments.

2.5.1.1.2 From Unscheduled Maintenance

Those unpredictable maintenance requirements that had not been previously planned or programmed but require prompt attention and must be added to, integrated with, or substituted for previously scheduled workloads.

Unscheduled maintenance activities have to be viewed and reported under the skill and depth of repair of ML 1&2.

2.5.1.1.3 From Deferred Maintenance

Minor faults noted during daily inspections that do not affect mission readiness or the safe operation of the aircraft may be deferred until the next scheduled maintenance/inspection.

The proper use of specified and identified report forms is mandatory and must be managed due to direct influencing the backlog and delay when the aircraft receives scheduled maintenance.

2.5.1.2 Environment of Aircraft Operation

- **Peace Time Maintenance/Repair**

Peace time activities follow the directives and specified maintenance shown above.

Operating experience in varying geographical areas, in particular maritime mission, special attention concerning corrosion monitoring must be implemented.

- **Battlefield Maintenance/Repair**

Battlefield damage maintenance must be divided into two separate but mutually supporting functions – battlefield damage assessment and battle damage repair.

This concept requires the full range of newest technology elements for monitoring, prognostic, diagnostic and remote communication to allow specialist assessment with the best endeavor to get the situational awareness.

This kind of maintenance/repair involves inspecting the damaged aircraft system to determine the extent of damage, classifying the equipment according to the type of repairs required, and developing a plan of action with qualified support.

2.5.1.3 Categorization of Corrosion Damages

The categorization of the individual corrosion damages is necessary to obtain the range of corrosion damages for the system. Primary considering those flight safety referred components.

Differentiation is required according

- **Category 1**

- Damage without further measures than the simple repair.
- Corrosion damages of low extent, not exceeding permissible grind-out depth as per specification.

- **Category 2**

- Damage with no further additional measures required, but intensive monitoring.
- Corrosion damages of medium extent, exceeding permissible grind-out depth, but still no flight safety-critical state and consequential damages are expected.

- **Category 3**

- Damage of serious extension, which requires immediate measures beyond the repair of the aircraft system.
- Corrosion damages over the permissible grind-out depth and flight safety-restrictive measures; high economic risk available and thus immediate measures are necessary.
- With the help of categorization it is reached that in future only investigations are authorized which effecting damages of the whole aircraft fleet.

2.5.2 Corrosion and Failure Analysis Data

The production of a detailed corrosion analysis and assessment can only be established on fundamental corrosion and failure analysis data fleetwide captured. Special attention must be focused on the world wide aging aircraft fleet and the long enduring capture and collection of corrosion damage and repair data. Combined with new inspection techniques and highly sophisticated sensor applications the corrosion data capturing and monitoring requires great efforts to meet the challenge solving complex corrosion problems.

With the help of adequate capturing and monitoring tools the subsequent corrosion and failure analysis data are required.

REPRESENTATIVE NATO CORROSION POLICIES (GERMANY)

Table 2-1: Form Used for Corrosion Data Capturing and Monitoring.

Aircraft Type / Equipment	
Aircraft Serial Number	
Datum Aircraft Delivery	Aircraft handover in-service
Aircraft Unit Code	Base of operation for minimum 6 month in the past
Part Number	PN
Serial Number	SN
NATO Stock Number	NSN
System/Work Unit Code	or higher component
Corrosion Location/Position	[mm]
Original Material Thickness	[mm]
Allowed Material Thickness	[mm] according Techn. Directive
Damage Grind-Out	• Depth [mm] • Area [ø mm] or plot • Perimeter [1/8 partition]
Corrosion Appearance Code	1 – Smooth corrosion abrasion 2 – Pitting corrosion 3 – Exfoliation corrosion 4 – Crevice corrosion
Corrosion Initiation Code	1 – From fastener 2 – From drill hole / countersink 3 – From overlap/edge 4 – Free surface 5 – Others
Corrosion Extension Code	Category 1 “simple repair” Category 2 “intensive monitoring” Category 3 “immediate measures”
Corrosion Activity Code	1 – New surface protection 2 – Grind-out of corrosion 3 – Cavity conservation 4 – Compilation of deviation 5 – Repair scheme 6 – Exchange of component 7 – Deferred repair to the next scheduled maintenance
Map of Corrosion Area	History mapping with support tools proposed (3D mapping)
Total Flight Hours	Flight hours up to the time of capturing the corrosion damage
Flight Hours Since Inspection	Flight hours since last inspection
NDT Sensor Signal available	NDT Report as attachment or detailed description under Notes
Datum	Datum up to the time of capturing the corrosion damage
Initials	Initials of person performing the corrosion check
Notes	Additional information from corrosion damage capturing

2.6 COLLECTING SYSTEM

The corrosion data collection system must be a process oriented and ADP-support centered system with interactive edits. Included in the system are several integrated terminals that are used to update or enter additional information.

The purpose of data collection is to obtain information, to keep on record, to make decisions about important issues and to pass information on to others.

The formal data capture and collection process is necessary as it ensures that data gathered is both defined and accurate and that subsequent decisions based on arguments represented in the findings are valid to maximize their usefulness in compliance with state of the art engineering reporting requirements.

Furthermore the management of critical corrosion locations must be monitored, harmonized and assessed with other structural integrity issues, e.g. fatigue. Therefore the systematic usage of a data capture and collection system is significant in solving safety critical aspects of aircraft systems everywhere on maintenance and operation bases.

Therefore to support the ability for a reliable assessment and maintenance/repair performance an adequate on-site mobile ADP Support System is prerequisite. Beyond that the integration of existing processes and diagnostic systems must be supported to:

- Interface with additional Information sources;
- Analyse reliable situational awareness;
- Provide decision support;
- Realize maintenance/repair and on-the-job training; and
- Show and trace the digital collaborative workflow.

2.6.1 Data Log

For the management and assessment of different capture and collection data from data sources and data sharing across functional areas the following Data Logs are proposed.

MWO Ident No.

Key Text	Description
Ident No.	This number is to identify a MWO (Maint. Work Order) uniquely. This section can be filled in also from another source. The number must make possible a unique allocation of the work order definition – otherwise the date has to be integrated here.
Mandatory Field	Yes.

Working Hours

Man Minutes	The working hours for the complete work are indicated. This section is added for data capturing and can be filled in also from another sources.
Mandatory Field	No.

REPRESENTATIVE NATO CORROSION POLICIES (GERMANY)

Checker

Worker Because of partly working several persons under MWO, it cannot be indicated who must register itself here uniquely. Therefore this section serves rather in order to call a negotiating partner for questions concerning the damage.

Mandatory Field No.

When Found Code

When Found Code The When Found code indicates on which activity the damage was found (e.g. GAF T.O. -06); for example during a depot level inspection or unscheduled maintenance inspection, etc.

Mandatory Field Yes.

When Found Date

When Found Date This date indicates when the damage was found (dd.mm.yyyy). This section is added for data retrieval and can be filled in also from other sources.

Mandatory Field Yes.

Event Code

Event Code The indication on which process the damage was captured (according GAF T.O. -06 e.g.) e.g. maintenance, depot level inspection, special inspection, etc.

Mandatory Field Yes.

Repair Date

Repair Date This date indicates the beginning of repair. This section is added for data retrieval and can be filled in also from other sources.

Mandatory Field Yes.

Notations

Note All information are recorded which cannot be expressed by codes.

Mandatory Field No.

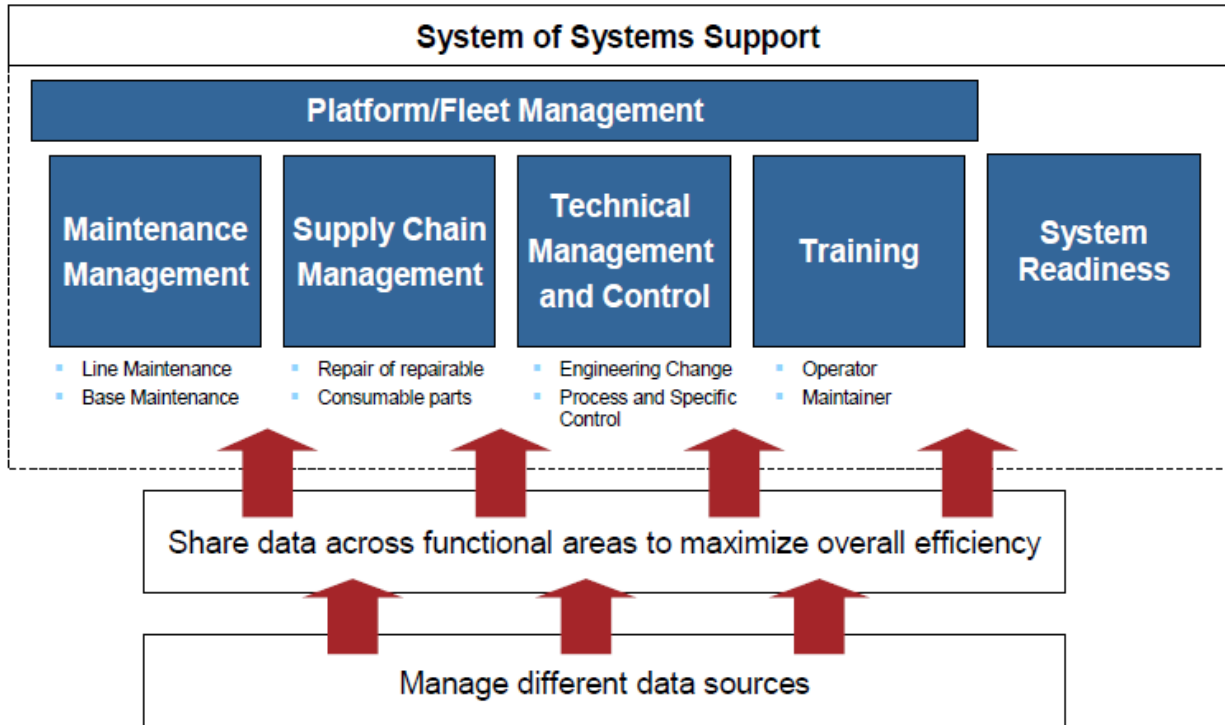


Figure 2-7: The Complexity of System Shared Data Support.

2.6.2 Analysis of Data

Data basis for the following evaluations is a corrosion data base of a combat aircraft. This data base is internationally almost singular to its extent; in the meantime other Nations use likewise corrosion data bases.

Already shortly after the aircraft delivery into service corrosion damage collection was started. It is very important to start the systematic damage capturing directly after the aircraft in-service date with a well structured and harmonized ADP data base tool.

The data capturing takes a major part of the total aircraft repair time and is mainly applied during Depot-level Inspection (DI). In this phase the aircraft is stripped and high dismantled for detailed damage investigations. Apart from the DI check several smaller inspection intervals accomplish additional capturing data just as well during aircraft operation at Main Operation Base (MOB).

Whereas the not availability of special inspection equipment and skills for more detailed damage investigation at MOB prevents accuracy of corrosion data capturing. In cases of urgency a specialist team is requested.

Nevertheless, in order to make sure a trustful data capturing validity checks are mandatory in combination with excellent skilled inspection staff.

Corrosion occurs in a wide variety of the aircraft structure and if ignored, it will threaten aircraft structural integrity, shorten fatigue lives and become a major cost driver. Therefore the corrosion reporting and analysis of data is of highly importance.

With an actively monitoring of corrosion arisings, the analysis of aircraft areas of concern (corrosion hot spots) will be possible at an early stage.

2.6.2.1 Analysis of Captured Corrosion Fleet-Wide

Basis of these analysis examples are the data specified under Section 3.1.

Distribution of Corrosion Grind-Out Depth

The figure shows the probability (y-axes) of grind-out depth exceedance (x-axes) reported from the aircraft fleet in a logarithmic scale. The average grind-out depth, according to the 50% line, reflects about 0.4 mm. “Count” general defines one corrosion data base entry.

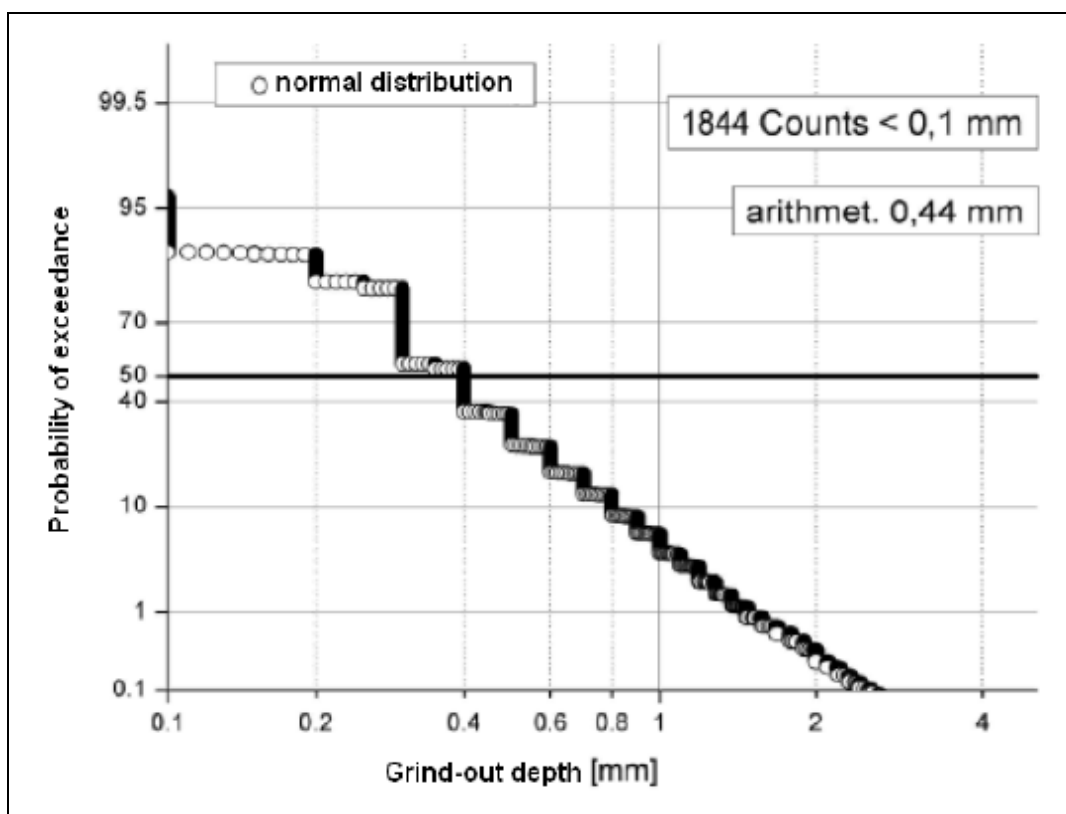


Figure 2-8: Grind-Out Depth of Complete Aircraft Fleet.

The bar chart displays corrosion counts for an allocated aircraft fleet. The y-axis, labeled 'Corrosion counts', ranges from 0 to 20,000 in increments of 2,000. The x-axis, labeled 'allocated aircraft fleet', shows a sequence of fleets from 'Fleet 1' to 'Fleet n'. The corrosion counts start very low for Fleet 1 and increase steadily across the fleet, reaching approximately 17,000 for Fleet n.

Fleet	Corrosion counts (approx.)
Fleet 1	0
Fleet 2	0
Fleet 3	0
Fleet 4	0
Fleet 5	0
Fleet 6	0
Fleet 7	0
Fleet 8	0
Fleet 9	0
Fleet 10	0
Fleet 11	0
Fleet 12	0
Fleet 13	0
Fleet 14	0
Fleet 15	0
Fleet 16	0
Fleet 17	0
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Fleet 149	0
Fleet 150	0
Fleet 151	0
Fleet 152	0
Fleet 153	0
Fleet 154	0
Fleet 155	0
Fleet 156	0
Fleet 157	0
Fleet 158	0
Fleet 159	

2.6.2.2 Detailed Analysis Example of Aircraft Corrosion

For example some parameters are analysed according data base counts.

REPRESENTATIVE NATO CORROSION POLICIES (GERMANY)

Table 2-2: Example of Analysis Centered on Data Base Counts.

Parameter	Definition	Counts acc. Data Base
Corrosion activity Code	1 – new surface protection	19
	2 – grind-out of corrosion	28971
	3 – cavity conservation	7
	4 – compilation of deviation	1464
	5 – repair scheme	3085
	6 – exchange of component	345
	7 – deferred repair to the next scheduled maintenance	1

Parameter	Definition	Counts acc. Data Base
Corrosion Appearance Code	1 - smooth corrosion abrasion	654
	2 - pitting corrosion	1545
	3 - exfoliation corrosion	31693
	4 - crevice corrosion	0
Corrosion Initiation Code	1 – from fastener	221
	2 – from drill hole / countersink	32220
	3 – from overlap / edge	681
	4 – free surface	770
	5 – others	0
Corrosion Extension Code	Category 1 "simple repair"	23412
	Category 2 "intensive monitoring"	2651
	Category 3 "immediate measures"	7829

A selection of the most important parameters from the chart is graphically represented as follows.

Analysis Example According Corrosion Appearance

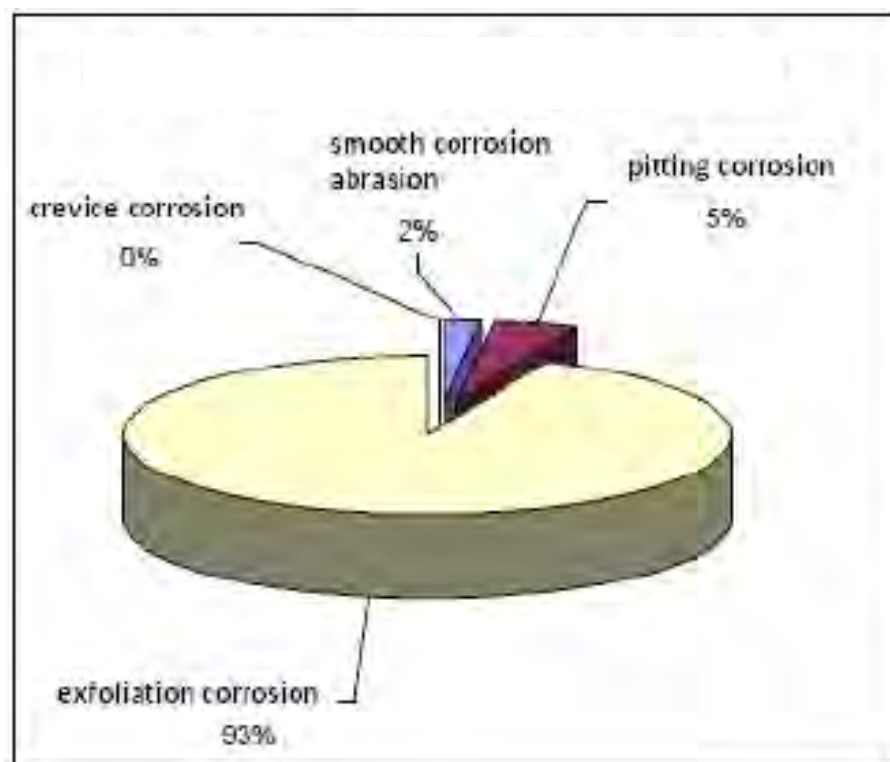


Figure 2-10: Distribution of Corrosion Appearance.

With this chart distribution of corrosion appearance becomes very clear – over 90% of the counts are subject to exfoliation corrosion.

Analysis Example of Counts per Corrosion Initiation

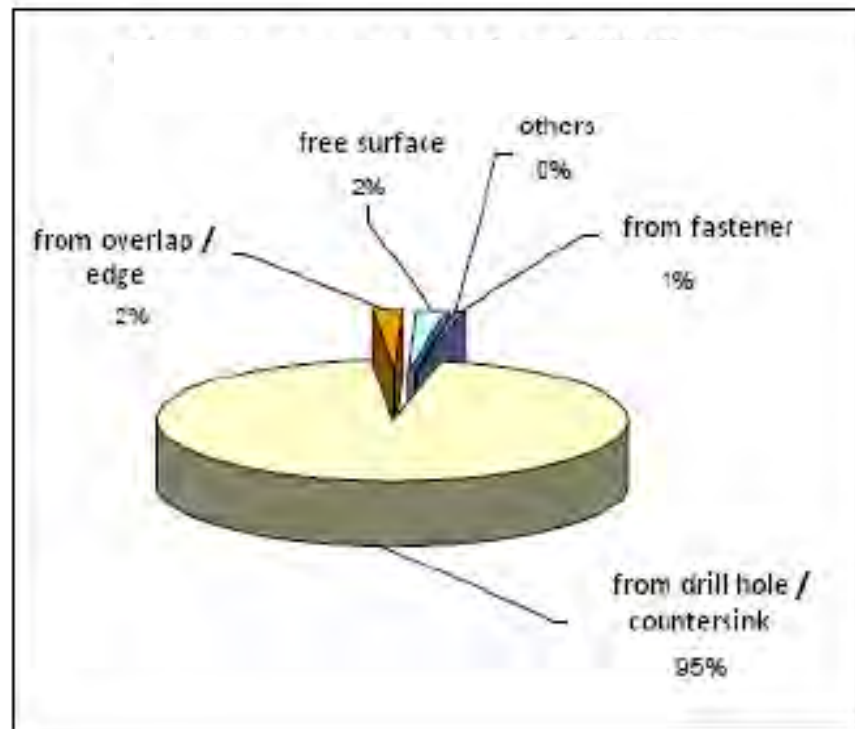


Figure 2-11: Counts per Corrosion Initiation.

With similar dominance this chart shows the focus of corrosion with 95% resulting from drill holes and countersinks.

Therewith a corrosion focus and area of concern was found. For this example high attention must be directed component-dependently to drill holes and countersinks with preventive activities against exfoliation corrosion.

2.6.2.3 Position Oriented Evaluation with Regard to Superimposition

From the previous analysis results the corrosion concentration on components becomes apparent of corrosion appearance and initiation.

In order to receive exactly allocations of the corrosion impact on components, the documentation form must be specified in due time. Due to new technologies (e.g. 3D-Viewer on PSS) in future digital views shall be preferred beside sketches as shown to realize superimposition.

For further evaluation of the corrosion regarding of measures and superimposition more analysis are necessary on data base as follows.

Analysis Example of Multiple Counts per Position

Multiple counts defines corrosion occurrence, which was grinded several times at an aircraft at the same position on a focused component.

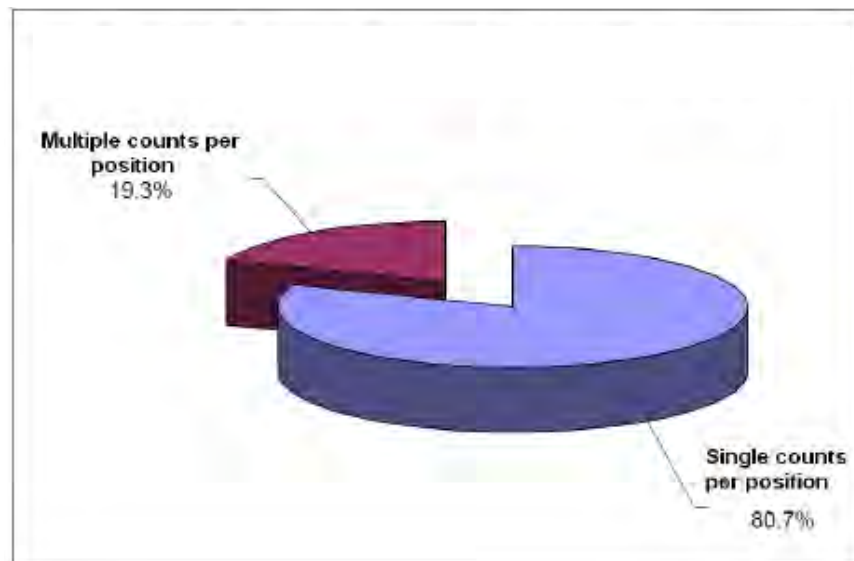


Figure 2-12: Share of All Captured Counts on Example Component.

Analysis of Grind-Out Depth Distribution on an Example Component

The chart illustrates the grind-out depth distribution of all captured counts on the example component. The average grind-out depth shows 0.4 mm.

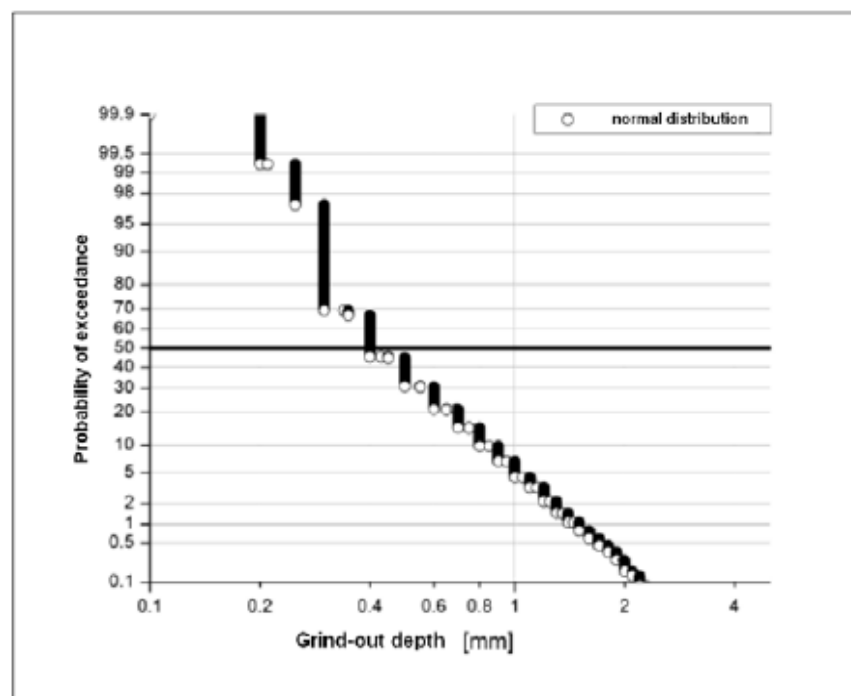


Figure 2-13: Grind-Out Depth Distribution on Example Component.

REPRESENTATIVE NATO CORROSION POLICIES (GERMANY)

Analysis of Occurrence and Depth Distribution on Example Component

The analysis is based on documented positions on data base and allows to focus all corrosion appearances in a graphical layout (sketch or 3D-view) for the selected components.



Figure 2-14: Occurrence and Depth Distribution on Example Component.

Analysis of Corrosion and Fatigue Superimposition on Example Component

A final example is given for a component. An evaluation of the corrosion database revealed a number of arisings related to corrosion. The review of the qualification evidence of the wing concludes that a number of arisings are located within the fatigue critical areas of the wing see figure below.

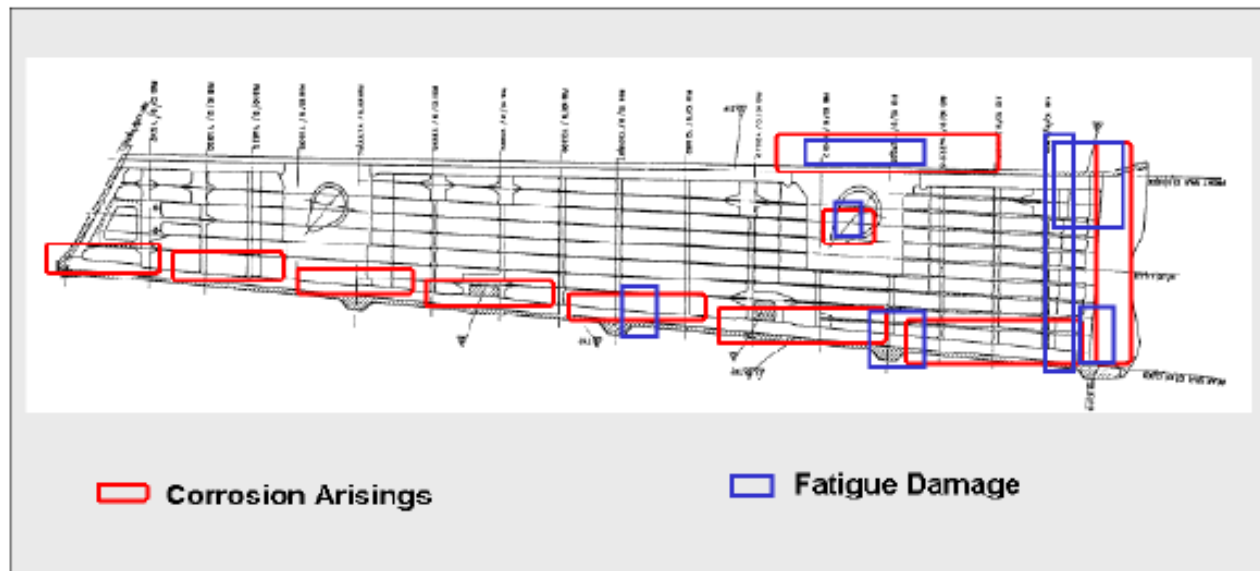


Figure 2-15: Corrosion and Fatigue Superimposition on Example Component.

In order to recognise relevant points of intersection between corrosion arisings and fatigue, a graphic comparison is used as decision criterion.

It is obvious that load monitoring alone cannot manage the structural integrity. Therefore, addition directed inspections and sampling programmes should be performed.

2.6.3 Assessment

On the basis of the database of an example aircraft evaluations were made over the corrosion arisings in the fleet. The arising frequency as well as the corrosion depth were evaluated. With advanced age of a fleet the maintenance expenditure continues to increase.

Measures are developed in order to hold the further effort under control. In the work frame of an investigation of components the focus of corrosion was selected with support of the mentioned data base. At these focus an analysis of the residual lifetime will be accomplished with additional engineering supported effort later.

Nevertheless, there is a requirement to actively monitor corrosion arisings and identify new areas of concern at an early stage with reasonable data base support – for example with Portable Support Systems (PSS).



Chapter 3 – REPRESENTATIVE NATO CORROSION POLICIES (UNITED KINGDOM)

UK MILITARY AIRCRAFT CORROSION DATA GATHERING AND EXPLOITATION

Matt Mishon

UK MOD TES-MIG

Corrosion Control And Aircraft Husbandry

TES Technical
Enabling Services

DPA DLO
Working together to deliver capability

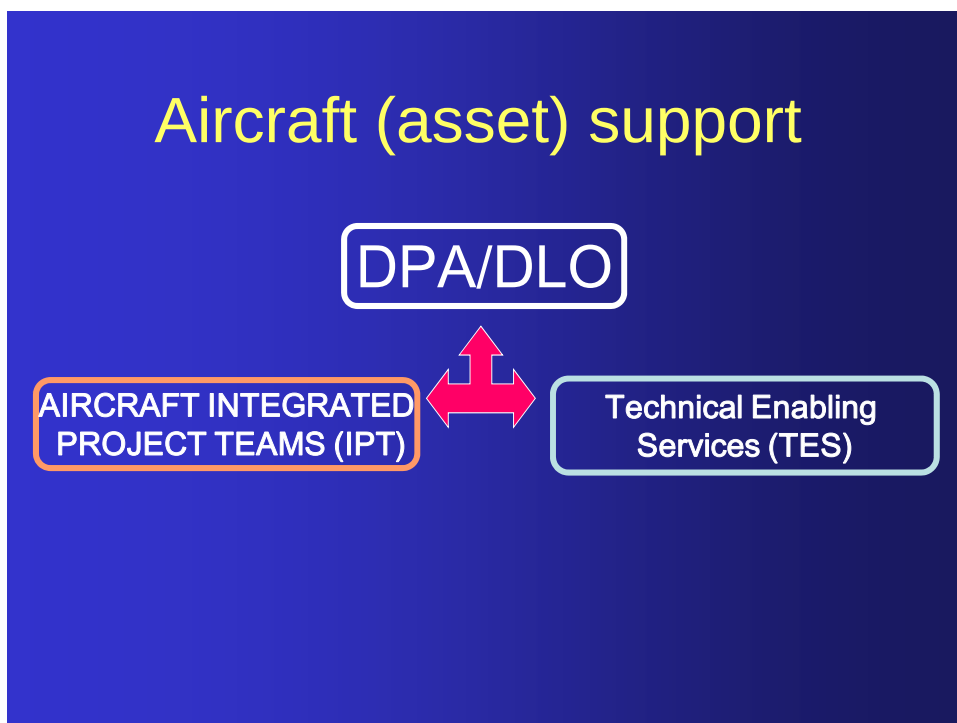
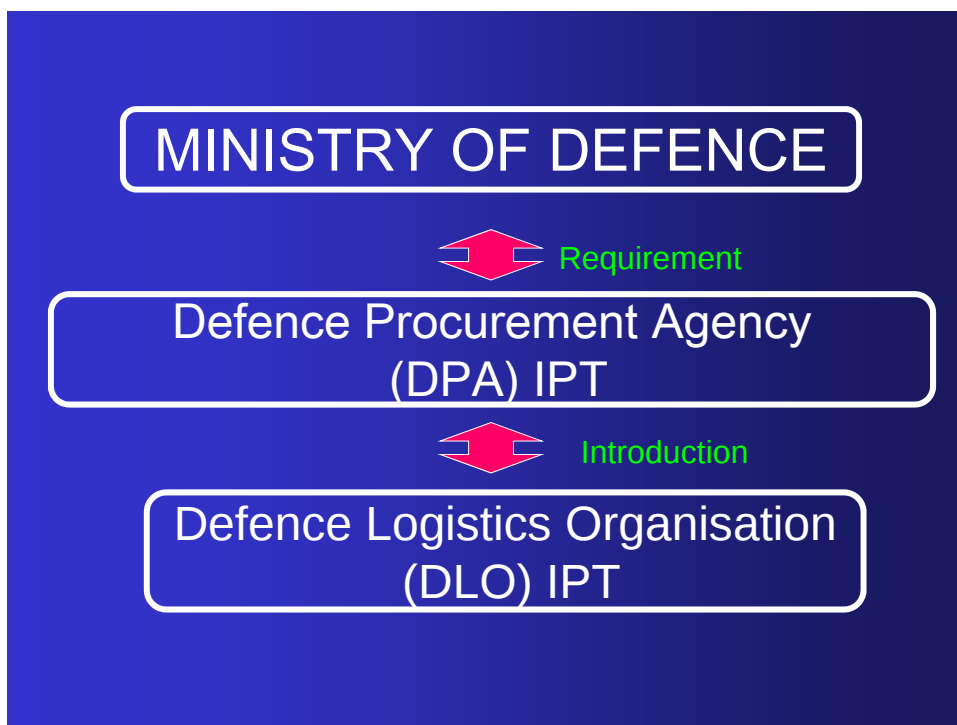
OBJECTIVE

- To present an perspective of data gathering for corrosion incidents on UK military aircraft and the methods used to exploit this data to reduce the incidents on aircraft fleets.

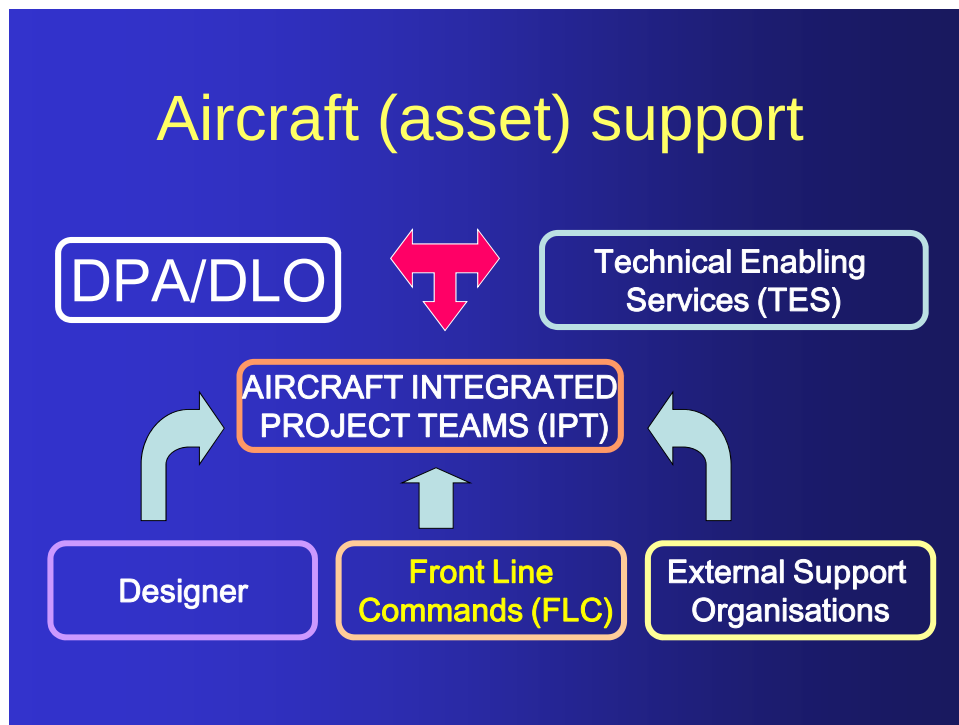
Contents

- Structure of MOD asset support
- Data collection
- The review processes
- Policy
- Summary
- Future Issues

Structure of UK MOD Asset Support



Aircraft (asset) support



MOD structure

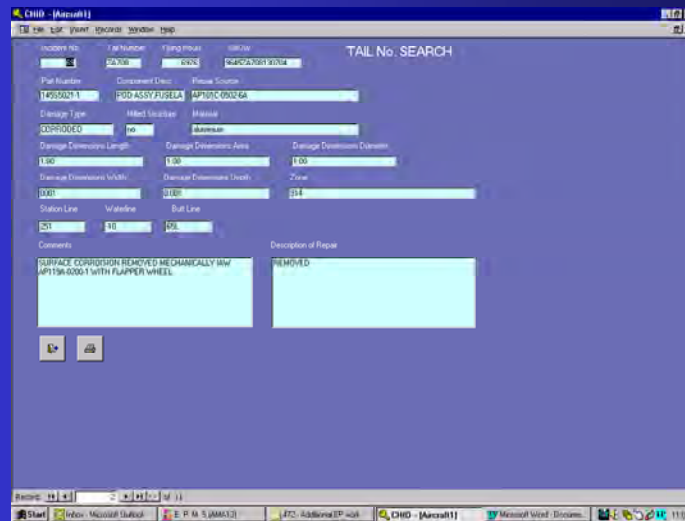
- IPTs/Owners
- TES/advice & policy
- FLCs/Operators
- Extrenal Advice (and Depth Organisations)

Data Collection

How UK MOD/RAF collect

- Job cards
- Aircraft Maintenance Records

How can be searched

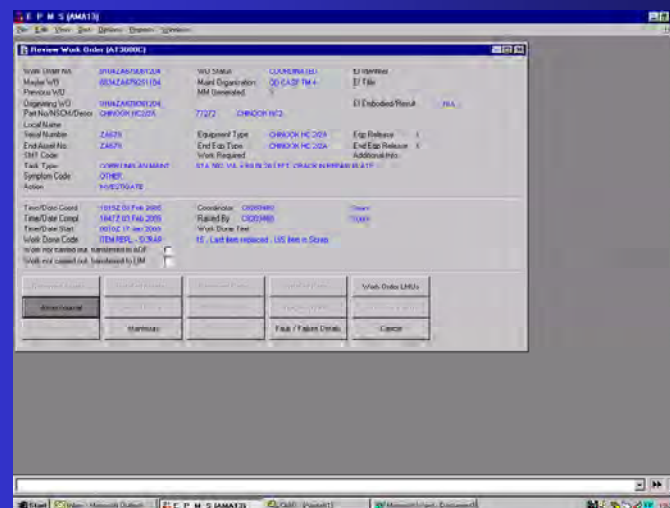


The screenshot shows a software window titled "CHOD - (Access)11". It contains a search form with the following fields and values:

- Incident No.: 14950001
- Part Number: 14950001
- Component Desc: 14950001
- Damage Type: CORROSION
- Material: 14950001
- Damage Dimensions Length: 1.00
- Damage Dimensions Area: 1.00
- Damage Dimensions Volume: 1.00
- Damage Dimensions Width: 1.00
- Damage Dimensions Depth: 1.00
- Station Line: 1.00
- Butt Line: 1.00
- Comments: SURFACE CORROSION REMOVED MECHANICALLY WITH FLAPPER WHEEL
- Description of Repair: REMOVED

The form also includes a "TAIL No. SEARCH" field and a "Description of Repair" field.

So, in the main:



The screenshot shows a software window titled "E P M S (AMM13)". It displays a detailed view of a corrosion incident with the following information:

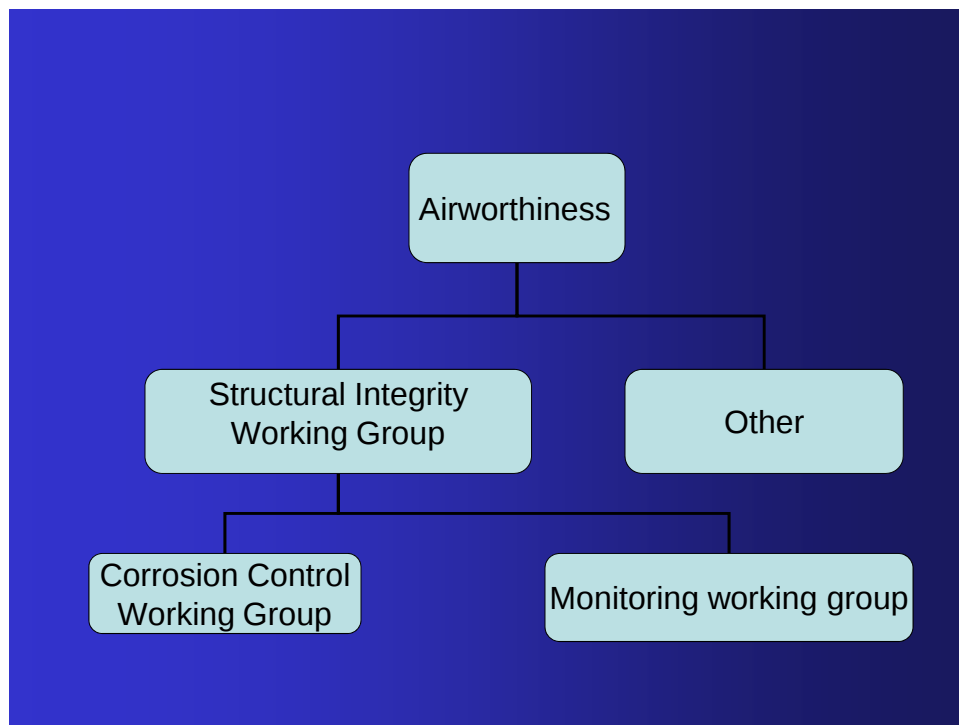
- System: 14950001
- Module: 14950001
- Part Number: 14950001
- Component Desc: 14950001
- Local Name: 14950001
- End Date: 14950001
- Task Code: 14950001
- Symptom Code: 14950001
- Action: 14950001
- Equipment Type: 14950001
- End Date: 14950001
- Work Request: 14950001
- Work Done: 14950001
- Work Done Code: 14950001
- Work Done Date: 14950001
- Work Done Time: 14950001
- Work Done Location: 14950001
- Work Done Status: 14950001
- Work Done Comments: 14950001
- Work Done Date: 14950001
- Work Done Time: 14950001
- Work Done Location: 14950001
- Work Done Status: 14950001
- Work Done Comments: 14950001

The interface includes various buttons for navigation and data management, such as "Previous", "Next", "Find", and "Print".

The Review Process

IPT role

- Availability of asset to Front Line Command (FLC)
- Maintain effectiveness of platform
- Through life costs
- Maintain airworthiness



CCWG

- CCWG owned by IPT individuality of approach
- All:
 - TES-MIG, TES-ASI, NDT,
- Some:
 - FLC, aircraft specific training delivery organisations, Aircraft designers, other support organisations (SME), depth organisations
 - Unit corrosion control post

Exploitation mainly consists in:

Review of data and corrosion incidents leads to

- Corrosion Control Plan detailing individual components, issues and processes
- Specific Plans
 - (eg Magnesium replacement programme)
- Feedback to policy training and central support organisations
 - Pan-platform overview

Policy

Policy

JAP 100A-01

Present corrosion policy is detailed in JAP

Chapter 11.6 Aircraft Corrosion Control

“MoD policy is, therefore, to discourage the onset of corrosion in the first place and, when it does occur, to ensure that it is speedily recognised and contained.”

Policy

JAP 100A-01

Future policy following Tri-annual review

Chapter 11.6 Aircraft Environmental Damage Prevention and Control

Recognises Corrosion as the primary ED mechanism:

“MOD policy is, therefore, to discourage the onset of corrosion in the first place and, when it does occur, to ensure that it is speedily recognized and contained.”

Policy

JAP 100A-01

Chapter 11.6 Aircraft Corrosion Control

“IPTs are to establish a means of detecting and tracking trends in corrosion arising across the fleet, to support decision making for Structural Integrity (SI) and through-life management”

Future policy

JAP 100A-01

Chapter 11.6 Aircraft Environmental Damage Prevention and Control

“IPTs are to produce and maintain a Corrosion Control Plan (CCP). The CCP is a living document used by the IPT to highlight current corrosion issues, proposed solutions and details of prevention and control initiatives ”

Policy

JAP 100A-01

Chapter 11.6 Aircraft Corrosion Control

“... where IPTs consider corrosion to be a significant problem for the platform, FLCs are to direct ship/station/unit engineers of authority level K to establish a unit corrosion control post for a Senior Rate/SNCO”

Future policy

JAP 100A-01

Chapter 11.6 Aircraft Environmental Damage Prevention and Control

“... However, where IPTs consider corrosion to be a significant problem for the platform, FLCs are to establish for each Stn/Ship/Unit a corrosion control post for a Senior Rate/NCO, ”



Chapter 4 – COLLECTION OF CORROSION DATA (ITALY)

Dr. M. Colavita
ITALY

4.1 OCCURRENCE OF CORROSION IN AIRFRAMES

4.1.1 Introduction

Although aircraft corrosion is an old matter and many advances have already been made in corrosion prevention and materials selection science, it is an issue that has yet to be solved. For instance, corrosion matter, a serious problem for every high engineered system in airframes, became more and more important over the last decade when the subject of aging aircraft was promoted by many different factors, most of them afferent to economic constraints [1]. Recently, corrosion's contribution to aging aircraft-related costs has been estimated at up to 80%. On the other hand, corrosion problems also have a heavy impact on safety and about 45% of the observed component failures can be ascribed to corrosion, when both direct and initiation effects are considered.

Corrosion in airframes is mainly an electrochemical matter, where an electrically conducting solution assists the transfer of metal ions, dry corrosion being almost always limited to engine components. In spite of this limitation, a lot of different forms can be observed and one of the most useful theories that can be used to categorize them is the Structural-Electrochemical one [2]. In agreement with this theory, the presence of heterogeneity on the metal surface has to be considered as the driving force of the electrochemical corrosion process taking place. Depending on the nature and the dimension of this non-uniformity, three different categories of corrosion must be experienced:

- **Uniform Corrosion**, in presence of sub-microstructural heterogeneity from 1 to 1000 Å, comparable to the crystallographic lattice dimensions (i.e. differences in the position of atoms, thermal fluctuations of metal ions in solution).
- **Selective Corrosion**, in presence of microscopic inhomogeneities from 0.1 m to 1 mm, comparable to the size of crystallographic structures of the metal (i.e. grain boundaries, second phases in alloys).
- **Localized Corrosion**, in presence of macroscopic inhomogeneities greater than 1 mm, comparable to the size of the component (i.e. galvanic coupling differential aeration).

4.1.2 Uniform Corrosion

Here, the inhomogeneities on the metal surface interacting with an aggressive environment are so small in dimension and potential that the same area will change, continuously playing a different anodic and cathodic role. The total effect is an attack on the whole surface leading to a uniform or quasi-uniform in depth loss of the metal. Although this is a very common mechanism in many corroded systems, it is not so often observed on airframes because the chosen aeronautical materials are always less prone to it. Uniform corrosion is common for non-stainless steel and iron where it can be easily recognized by red rust. Easily detectable and forecasted uniform corrosion can't be considered a very dangerous form of corrosion. Usually general attack occurs on parts where the original protective coating has failed for any reason. The most typical case is certainly observed on cadmium plated steels after the anodic coating has been totally sacrificed (Figure 4-1).



Figure 4-1: Uniform Corrosion on a Cadmium-Plated AM-X Air Combustion Chamber.

Erosion, caused by the action of a fast moving fluid, can also lead to a uniform or quasi-uniform attack. This specific mechanism, called erosion-corrosion, becomes more severe in aircraft operating in hot desert climates, where a high humidity content, especially at night, is associated with sand: the solid particle content, furthermore rich in salt, acts as an extremely abrasive media, removing paint, surface finish and corrosion products, offering a continuously new metal surface. Aging aircraft issues exacerbate uniform corrosion problems on electrical and avionics equipment where, in order to obtain the requested performance, materials are often inferior in terms of corrosion resistance.

4.1.3 Selective Corrosion

In this category are included all the phenomena depending on the presence of heterogeneities in chemical composition. In this sense we can also talk about this electrochemical attack as caused by an intrinsic heterogeneity of the material.

4.1.3.1 Intergranular Corrosion

On airframes, intergranular corrosion (Figure 4-2) is the more often observed mechanism of this class because it is characteristic of the aluminium alloys, both the Al-Cu (2xxx) and the Al-Zn (7xxx) alloys, where the driving force for the electrochemical process is the difference in potential between the second phases (richer in copper – more noble –, or richer in zinc – less noble) and the aluminium matrix.

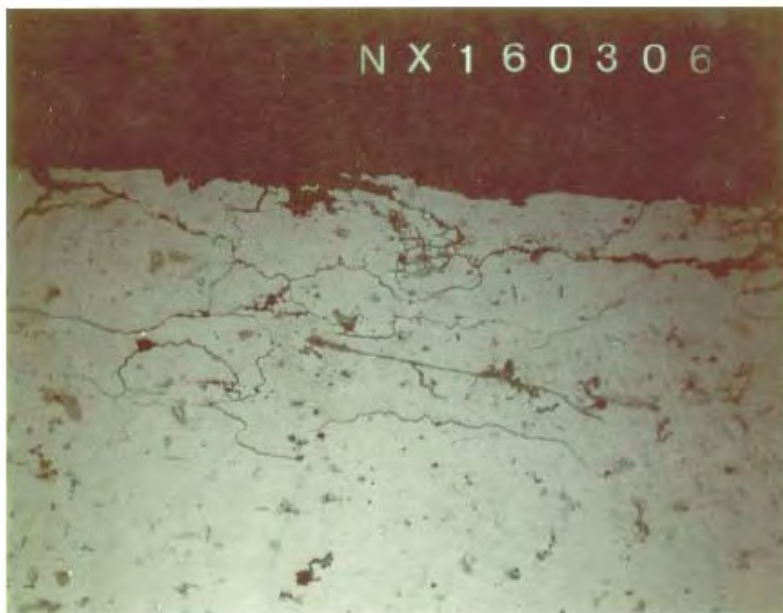


Figure 4-2: Intergranular Corrosion on AA2024 (160x).

In this case corrosion profile follows the shape of grain boundaries (Figure 4-3), where second phases are precipitated, and must be considered very dangerous because, in spite of a minimum material lost, mechanical properties fall dramatically down [3]. Furthermore, intergranular corrosion is frequently hard to detect also by means of NDE.

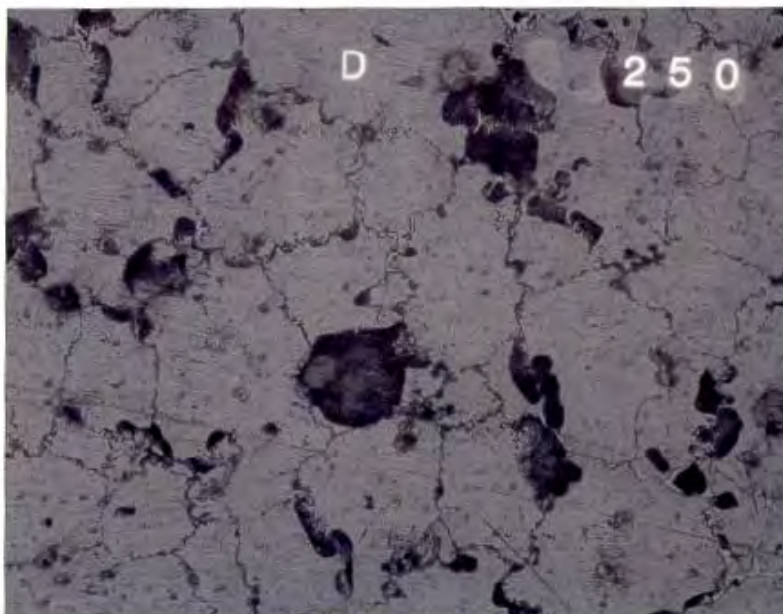


Figure 4-3: Intergranular Corrosion on Mg Alloy AZ-91C (250x).



Figure 4-4: Exfoliation on a Breguet Atlantic Br. 1150 AA2024 Spar.

Intergranular attack can also be observed on austenitic stainless steel. On these materials an incorrect cooling procedure after a heat treatment can lead to a sensitization of the part, caused by the grain boundary precipitation of chromium carbide (Cr_{23}C_6) and according to this the strong depletion in chromium content of the contiguous areas. This can be the case of wrong welding procedures (Figure 4-5).



Figure 4-5: Low Temperature Sensitization on a PH 17-7 Stainless Steel.

4.1.3.2 Crystallographic Corrosion

Although much less common on airframes, another kind of selective attack to be mentioned is the crystallographic corrosion which can be generated when whole grains or volumes are each other electrochemically different enough. This is the case of some brasses where parts richer in zinc leave the metal leading to a spongy structure.

4.1.4 Localized Corrosion

This is certainly the class where the widest number of corrosion mechanisms is observed. The common factor among the different forms of corrosion in the case of a localized attack is the presence of stable and clearly separate cathodic and anodic areas.

4.1.4.1 Pitting Corrosion

Pitting corrosion is a dangerous attack which occurs on passive materials when the protective oxide layer breaks. It is often observed on stainless steel and aluminium alloys that spontaneously form a protective film: as a result of small damages on the passive layer, the damaged areas will work as anodes immersed in a very large cathodic area and will suffer in consequence of this a very localized attack which leads to the formation of deep and narrow cavities. Pitting corrosion is particularly common on aircraft structures operating in marine environments, since the chloride ions and halide ions in general promote the local dissolution of protective oxide films. Here following (Figure 4-6 and Figure 4-7) some cases occurred in the recent past are shown.



Figure 4-6: Pitting Corrosion on a HH-3F Compressor Blade.



Figure 4-7: Pitting Corrosion on MB-326 Balance Tabs.

Some authors [4] include in pitting corrosion mechanism also those corrosion phenomena that take place on active metals, previously protected by a suitable external coating, when the protection is locally damaged. In any case pitting must be considered very insidious since it tends to accelerate its corrosion rate because of the increasing acidity and chloride content inside the cavity; furthermore, in highly loaded structures, the stress concentration at the base of a pit is often sufficient to promote fatigue or stress corrosion cracking.

4.1.4.2 Crevice Corrosion

This form of attack (Figure 4-8) is originated by the difference in the concentration of dissolved oxidant agent (usually oxygen) inside and outside a crevice. In this case the area inside the crevice will act as anodic and there a pit will develop.



Figure 4-8: Crevice Corrosion on a Tornado.

In airframes, corrosion crevice is frequently observed on lap joints or under surface deposits in presence of stagnant solution. It is usually associated with a poor performance of the sealant or sometimes can be caused by a defect of design (i.e. poor drainage conditions).

Its nature makes it dangerous because often occur on unexpected areas and can't be detected by visual inspection if not disassembling.

4.1.4.3 Galvanic Corrosion

Galvanic corrosion is the most evident form of localized attack, where anodic and cathodic areas are very clearly identified. It occurs when two metals of different electrochemical potential are in contact in a corrosive medium and the resulting damage to the less noble metal will be more severe than if it was exposed alone to the same medium. The extension of the corroded area on the anode as far as the corrosion rate will depend on the difference in the electrochemical potential between the metals and the conductivity of the aggressive medium. Anyway, the corrosion attack will be more concentrated in the part of the anodic metal closest to the cathode. In aircraft structures it is often necessary to use different metals and galvanic corrosion can't be completely avoided. In this case it is important to consider the ratio between the cathode and the anode: by increasing the ratio, the corrosion will tend to be superficial. This is the typical example of occurring at fastener holes in aluminium alloy skin when steel bolts or rivets are used. Looking at the galvanic series it's easy to realize that magnesium alloys are very susceptible to suffer galvanic attack when used in conjunction with any other metal (Figure 4-9).



Figure 4-9: Galvanic Corrosion on an Mg Alloy Spacer, Coupled with a Steel Beam in the MB-326 Central Section.



Figure 4-10: Galvanic Corrosion on the MB-339 between Mg Alloy Trim and Aluminum Rivets.



Figure 4-11: Galvanic Corrosion on the MB-339 Attach Fitting.

4.1.4.4 Filiform Corrosion

Filiform corrosion (Figure 4-12) can be found under organic coatings such as paints, due to penetration of moisture through the coated surface under specific temperature ($T \geq 30^{\circ}\text{C}$) and humidity conditions ($\text{Hr} \geq 85\%$).

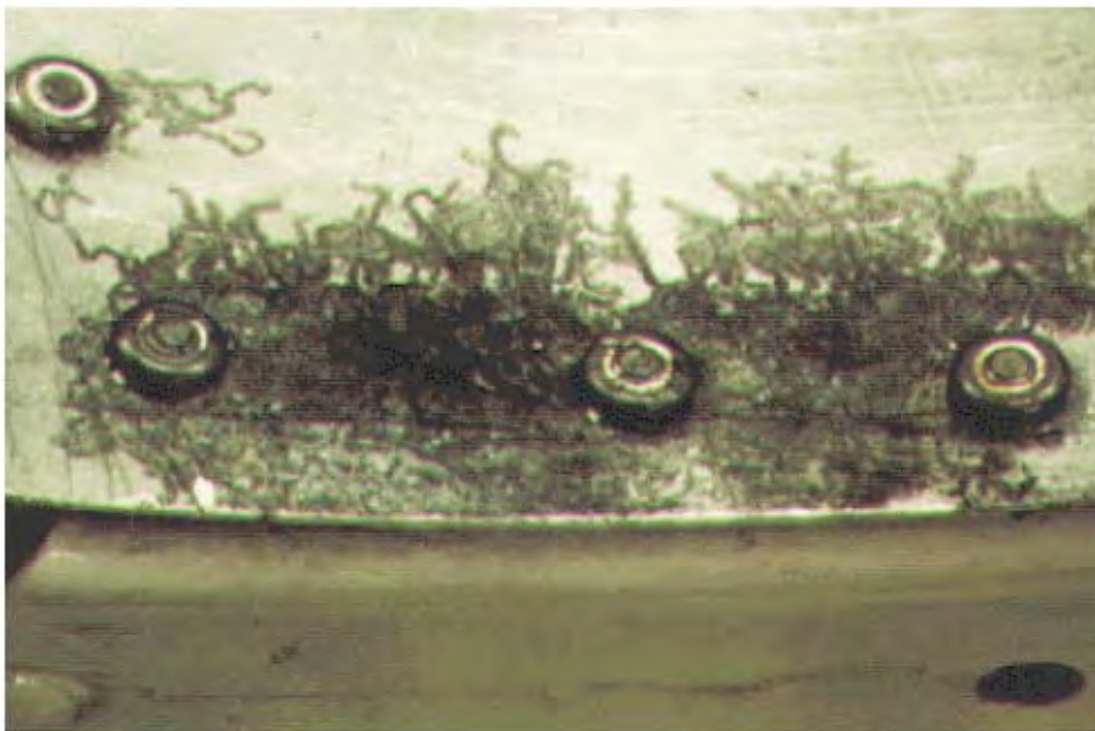


Figure 4-12: Intergranular Corrosion on Aluminum Alloy.

This mechanism is not particularly dangerous on itself since it propagates creating blistering “wires” of corrosion products on the surface of the metal, active just on the tip of each wire, but can degenerate in more serious attacks if not detected and removed at an early stage.

4.1.4.5 Stress Corrosion Cracking (SCC) and Corrosion-Fatigue

Unfortunately, these two dangerous localized corrosion mechanisms are often observed on airframes. Both produce cracks, different in shape and pattern, whose growth is caused by the synergetic action of a moderate corrosive environment and a mechanical stress: a static load (lower than the material’s yield tensile stress) in the case of SCC (Figure 4-13), or a cyclic load in the case of corrosion-fatigue (lower than the material’s fatigue limit).

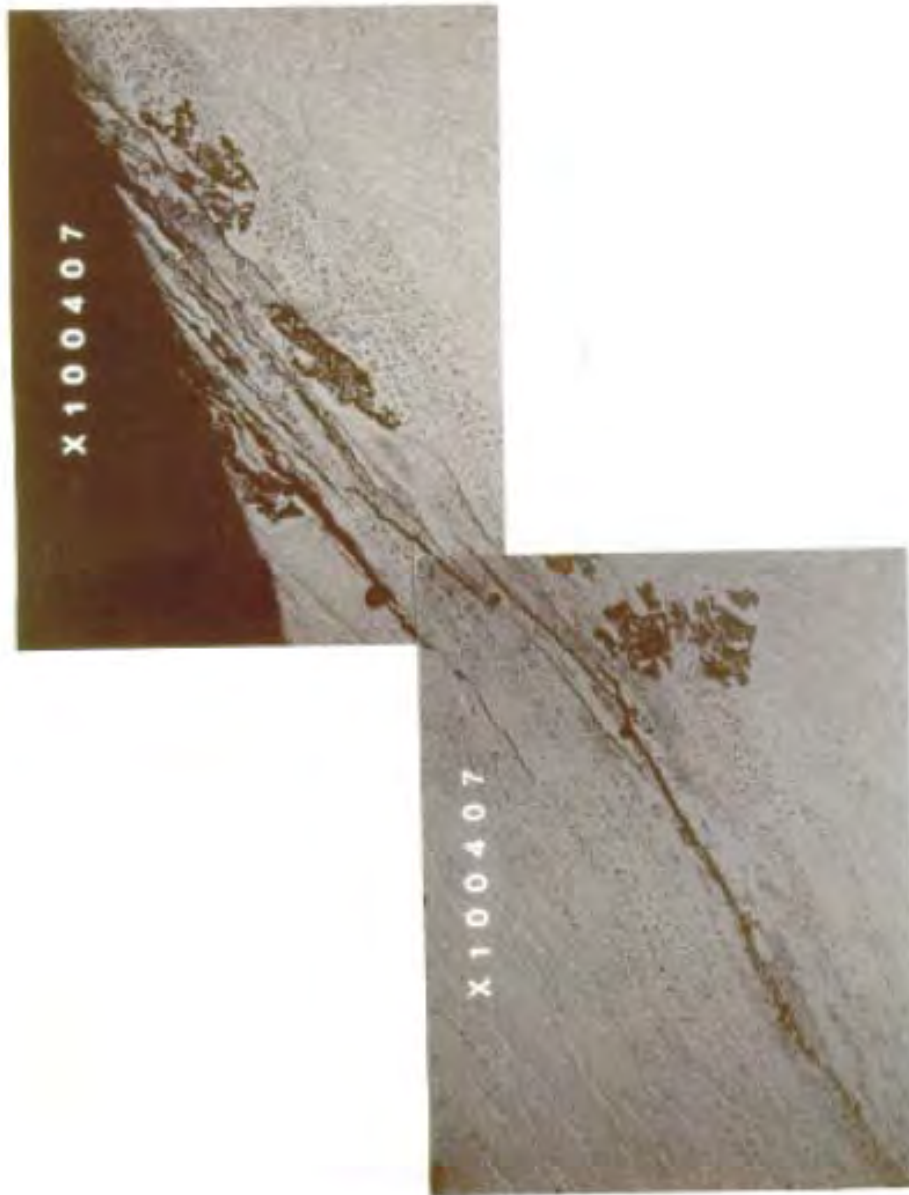


Figure 4-13: Stress Corrosion Cracking on a Br.1150 Bomb Bay Guide Rail.

Many models have been proposed [5] to explain the crack growth process for these attacks, all of them coinciding that just the crack tip is anodic while the rest of the metal (including the walls of the crack) act as cathodic. Once the crack has formed it will continue to grow, stopping only when the static (SCC) or the cyclic (corrosion-fatigue) load has fallen below the critical value, or alternatively, excluding the corrosive environment. These forms of corrosion must be considered as a major problem in aging airframe related issues, particularly corrosion-fatigue at low frequency cyclic stresses, where the time dependent corrosion process has the opportunity to explicate its action. In effect, Multiple Side Damage, a phenomenon under intensive investigation in the last ten years, can often be seen as an extension of the corrosion-fatigue mechanism.

4.1.4.6 Hydrogen Embrittlement

Hydrogen embrittlement is often considered as a special case of the more general SCC mechanism [6]. Its effect is to lower the ductility in metals when penetrated into the material [7] by means of a natural corrosion reaction or, more often, during a plating or pickling process. High strength steel and austenitic stainless steel are the most commonly affected aerospace materials, their susceptibility also depending on the metal composition [8]. Parts more often failed for hydrogen embrittlement are bolts and main landing gear items.

4.1.4.7 Fretting

Fretting is an insidious form of corrosion that occurs when the environmental action is assisted by material wear under low vibratory relative motion of parts. The abrasion of the surface finishing, and then of the corrosion products, continuously exposes new metal surfaces to the aggressive environmental attack: because of the abrasive nature of the corrosion products, this mechanism's rate increases, usually leading to hemispheric pits where fatigue marks are often found on their bottom (Figure 4-14).

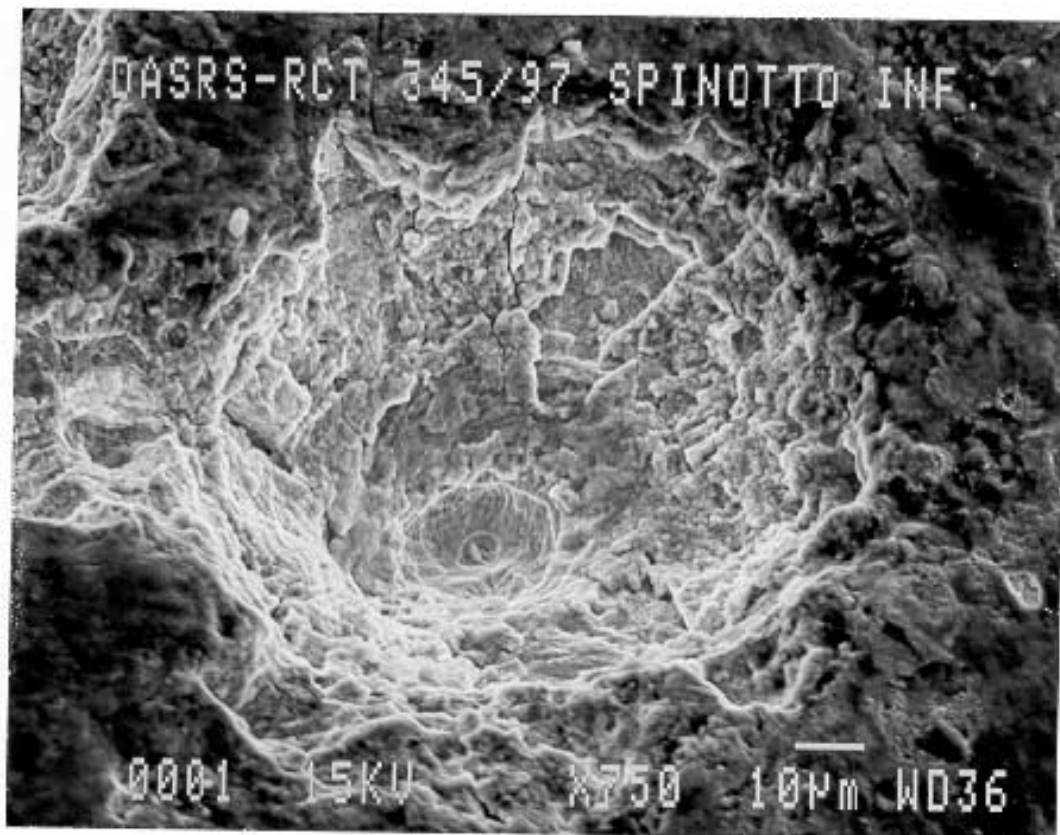


Figure 4-14: Fretting Corrosion on the MB-339 Landing Gear Spine.

4.1.5 Conclusions

The scheme followed in the presentation of the corrosion forms was derived from the Structural-Electrochemical theory, in order to clarify some aspects common to different corrosion mechanisms. An ever-increasing

knowledge of the corrosion problems, based on past experience and multi-disciplinary approaches comprehensive of design philosophy, condition based maintenance and NDE development, is essential to win the new economic and safety challenges offered by concerns of aging aircraft.

4.2 CORROSION PREVENTION AND CONTROL

4.2.1 Introduction

Control and prevention are both issues used to describe the procedures necessary to provide effective corrosion maintenance on aircraft. In effect, they must be considered as complementary because corrosion and prevention can have a synergistic effect when each one explicates its specific action. However, it is important to remember that corrosion control includes:

- Corrosion detection;
- Corrosion removal; and
- Renewing the protective systems.

On the other hand, corrosion prevention is devoted to:

- Material design;
- Surface treatments, finishes and coatings;
- Corrosion inhibitor compounds and sealants; and
- Preservation techniques.

The entire process, including all of these phases has been recently called corrosion surveillance [9], indicating the increasing interest from aircraft operators in this matter, largely due to the growing number of aging fleets. For many years, “find and fix” has been the universal maintenance philosophy but now that aircraft are being flown beyond their design life, this practice will not allow a safe and cost-effective management of the fleets [10]. So in the last decade, corrosion control and prevention both improved in many aspects where environmental constraints also played a very important role.

4.2.2 Corrosion Control

Many significant advances have been done in this field and more are expected to come in the near future. In the past, control procedures were only related to scheduled maintenance and non-destructive evaluation and repair but now, early diagnostic, condition-based maintenance and paint removal technologies are some of the most interesting areas where impressive improvements are continuously carried out.

4.2.2.1 Corrosion Detection and Monitoring

Several NDT were used for many years to detect corrosion, the most common of them being:

- Visual inspection;
- Magnetic particle flaw detection;
- X-ray;
- Ultrasonic inspection;

- Eddy current; and
- Dye penetrants.

However, increasing corrosion costs have encouraged practices that lead to early detection and reduce unnecessary inspections. Monitoring during service became the key to this new approach and as a consequence of that, different strategies were investigated. Corrosion data collection and analysis [11], carried out in order to evaluate the areas most affected, estimate the costs and plan the priority of intervention, should be considered as the first stage, followed by the development of in-situ monitoring systems. Thin film Au-Dc galvanic sensors [12] were developed and successfully installed on military aircraft for monitoring hidden corrosion or corrosivity in aircraft interiors, sealants and coatings [13]. These bimetallic sensors are kept isolated until moisture from the environment bridges the two electrodes: when it occurs, the sensors will develop a galvanic current directly proportional to the corrosivity of the trapped moisture. In harsh environments, Ni-Au sensors are recommended to provide a long-term lifespan. Promising investigations are being carried out to incorporate fluorescence-based sensors into paint coatings to provide an easy and economic means to detect corrosion [14].

At the same time, new technologies are increasingly used to reduce the time-consuming corrosion control activity. In this area, the Thermal Wave NDI [15] that uses an IR video camera to image the surface of the aircraft after the application of a short pulse of heat seems very interesting as far as the Double Pass retroflection Aircraft Inspection system (DAIS) [16]. A user-friendly probe with a high degree of accuracy and sensitivity, based on Electrochemical Impedance (EI) measurements [17], has also been developed.

4.2.2.2 Paint and Corrosion Removal

Corrosion control on aircraft often need paint removal but today chemical stripping is no longer the only way to achieve it: diffusion of composite materials, environmental regulations and health and safety considerations are eroding such a monopoly. New technologies have been investigated and some of them are widely used. Plastic Media Stripping (Figure 4-15), is a method that involves subjecting the paint surface to a high pressure stream of acrylic particles. In some cases, this method uses natural products (wheat starch) as the stripping medium instead.



Figure 4-15: IAF Tornado Stripped by Means of Plastic Media.

However, these techniques need special care and are strongly dependent on the operator's ability. Wrong swell times or stream pressure could remove the clad on aluminium parts or damage composite materials. Research is in progress to evaluate safe and cost-effective alternative solutions. At the moment, the two most attractive options are:

- Flashjet (a Xenon flashlamp with carbon dioxide pellet); and
- Hand-held laser.

Interestingly enough (at least for some components – though at an early stage of development) seems to be a photochemical process that uses only waterborne stripping media with no organic solvents [18].

Once detected, corrosion must be removed by means of a pickling operation also necessary as a surface preparation for the following treatments. Even in this field, environmental compliance needs to substitute the traditional sulpho-chromic pickling with a chromate-free alternative. In this case, a hot sulphuric-ferric acid mix [19] currently showed the most promise.

4.2.3 Corrosion Protection

Many factors have to be taken into account in order to carry out effective corrosion prevention and most of them are strongly correlated. Of course, the starting point must be the material's design that will depend not just on its corrosion behaviour, but often more than this, on its mechanical properties. Once the material is chosen, its corrosion behaviour will not be fixed unless surface treatments, finishes, coatings and operating environments are not clearly identified. Aging aircraft and environmental acceptability have deeply modified old concepts and rules, making this matter an important research and development focus for technologies [20].

4.2.3.1 Materials

With regard to the materials, if it is true that in the design of new aircraft there exists a trend towards plastics, in many cases, aging fleets require the substitution of alloys with equivalent strength but higher corrosion resistance in order to extend maintenance schedules and decrease down time. Particular attention is given to some of the most dangerous forms of corrosion such as Stress Corrosion Cracking (SCC) and Exfoliation. On aluminium alloys, the most interesting performances have been achieved by means of the new tempers (in particular the T77) that allows for better control of the size, spatial distribution and copper content of the strengthening precipitates [21] and [22]. The 7055-T77 provides a high resistance to intergranular corrosion, exfoliation and SCC, attributed to its high ratio of Zn:Mg to Cu:Mg and, as a consequence of that, an optimum microstructure at and near grain boundaries [23]. Chemical composition improvements, finalized at a lower Fe and Si content, have brought reduction to pitting initiation on aluminium alloys series 2xxx. 2024-T3 suffers from pitting corrosion attack, and this phenomenon is strongly dependent on the Fe and Si bearing second-phase constituent particles [24]. The reduction of their density and size achieved on the derivative alloy 2524-T3, resulted in a reduction of the pits nucleation that can act as potential initiation of fatigue cracks.

4.2.3.2 Surface Treatments, Finishes and Coatings

Chromate-based pre-treatments and chromate pigmented primers are extensively used in the corrosion protection of aluminium alloys because of their excellent performance. However, many investigations about chromate-free protection schemes have been undertaken for the past ten years and some of them (cerium salts, nickel metavanadate [25], Phosphoric Sulfuric Acid anodizing [26], etc.) have already given promising results.

A non-toxic trivalent chromium conversion coating formed by applying dilute solutions of basic chromic sulfate and hexafluorozirconate has been already successfully proposed [27]; it also appears to have promising applications for cadmium and zinc-nickel coated steels.

Either way, the cadmium plating process, able to provide an effective corrosion sacrificial protection and high lubricity on high-strength steels, will no longer be allowed even in military and aerospace applications because its main disadvantage is the toxicity of the cyanide baths. Many studies have been started and investigations are still in progress to evaluate the best alternative process (zinc-nickel or zinc-cobalt-iron electrodeposition, metallic-ceramic consisting of aluminium particles in an organic matrix spray, etc.) [28].

4.2.4 Corrosion Prevention

Corrosion Preventative Compounds (CPC) are able to explicate a really effective corrosion protection, and their use is considered essential to delay the corrosion initiation, extend the scheduled maintenance and reduce costs. These compounds explicate a combined effect: isolating the metal surface from the environment (barrier effect) by means of a water displacing action carried out by the wax base, and modifying the local environment to make it less aggressive (active effect) by means of the inhibitors included in their formulation. CPC will be consumed and as a consequence of that, the compounds must be frequently renewed, depending on the environmental aggressiveness they will be exposed to (usually every two years). Here, environmental compliance forces the R&D to look at new products that reduce the VOC content.

Sealants and jointing compounds, on the other hand, are necessary to avoid both galvanic coupling between dissimilar metals and crevice corrosion that could act as nucleation points for fatigue crack propagation.

It's important to remember that effectiveness of the protective measures both by sealants and CPC depends on a good preparation and proper application. This means that specialist training is a decisive step in corrosion prevention.

4.2.4.1 Prevention Techniques

Preservation is a broad area that includes many different actions. The most common preservation technique is washing and rinsing the aircraft after each mission. This is most important when aircraft were on a low-high mission on the sea. In this case, eliminating chloride and salts from the metal surface is a must. Usually, preservation is conceived in agreement with three different strategies, depending on the preservation time:

- Short term (0 – 90 days) preservation;
- Medium term (up to 1 year) preservation; and
- Long term (beyond 1 year) preservation.

When long-term preservation is required, dehumidification is necessary. In any case, the more time spent on preservation, the less man-hours spent on maintenance. Sometimes it is necessary to protect the aircraft or part of it for a long time from contamination and the effects of high relative humidity by means of a barrier material. This is the case for Nitrogen Purging Packaging (NPP) System [29], that uses a flexible barrier to form a cocoon around the object to be protected and the inner atmosphere is modified to achieve the desired level of relative humidity.

4.2.5 Summary

Corrosion prevention and control have been separately described in this presentation in order to deal with the most interesting concerns in their respective matters, although they represent a continuous process that can be summarized as corrosion surveillance. They cover many different areas and represent a multi-disciplinary subject strongly related to airworthiness. This paper contains a selection of the numerous studies and investigations that have been undertaken in the recent past, many of them still in progress, to ensure an effective corrosion protection and control of aging aircraft under environmental constraints.

4.3 CORROSION CONTROL REGISTER PROGRAM

Aircraft Corrosion strictly affects Safety and Economic Issues.

Corrosion Control Register (CCR) Program was started in 1994 in order to enhance the Tornado maintenance partnership with the German and the Royal Air Forces.

**Italian Air Force
conceived the CCR Program as a flexible
and useful tool to monitor corrosion on
nine different fleets.**

✈ Tornado	✈ AM-X	✈ MB.339
✈ C.130	✈ F-104	✈ Br.1150
✈ G.222	✈ HH-3F	✈ AB.212

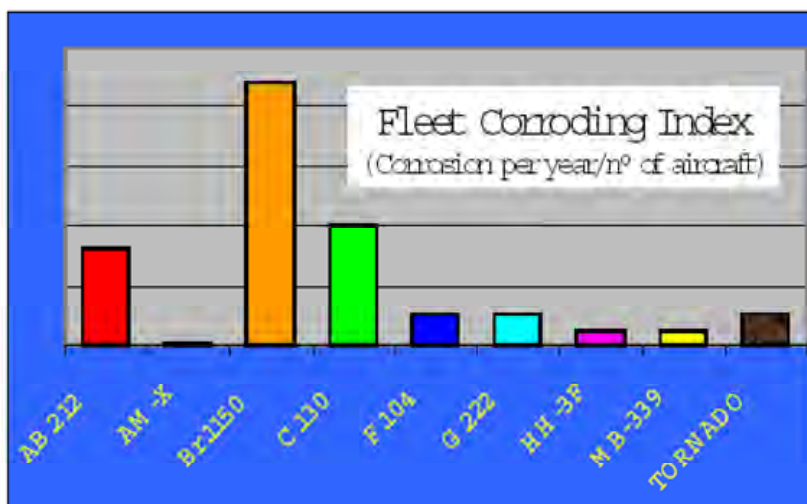
The CCR Program is managed by a Data Base where many useful information are collected.

Properly trained specialists are devoted to fill in a double sheet form each time corrosion is detected at any step of the maintenance inspection.

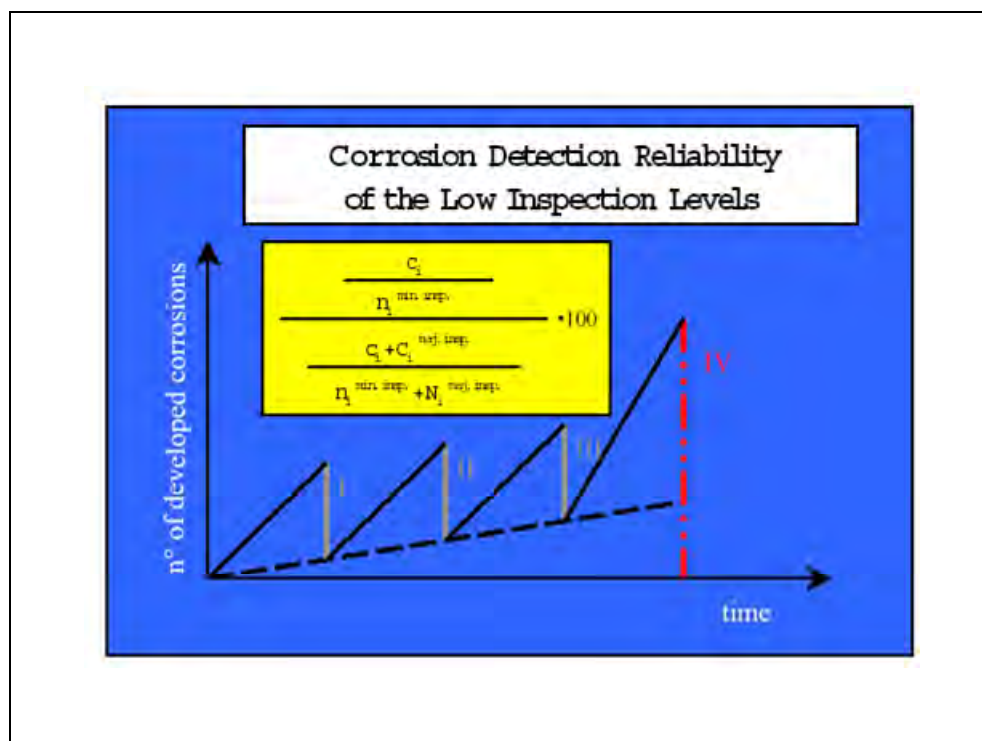
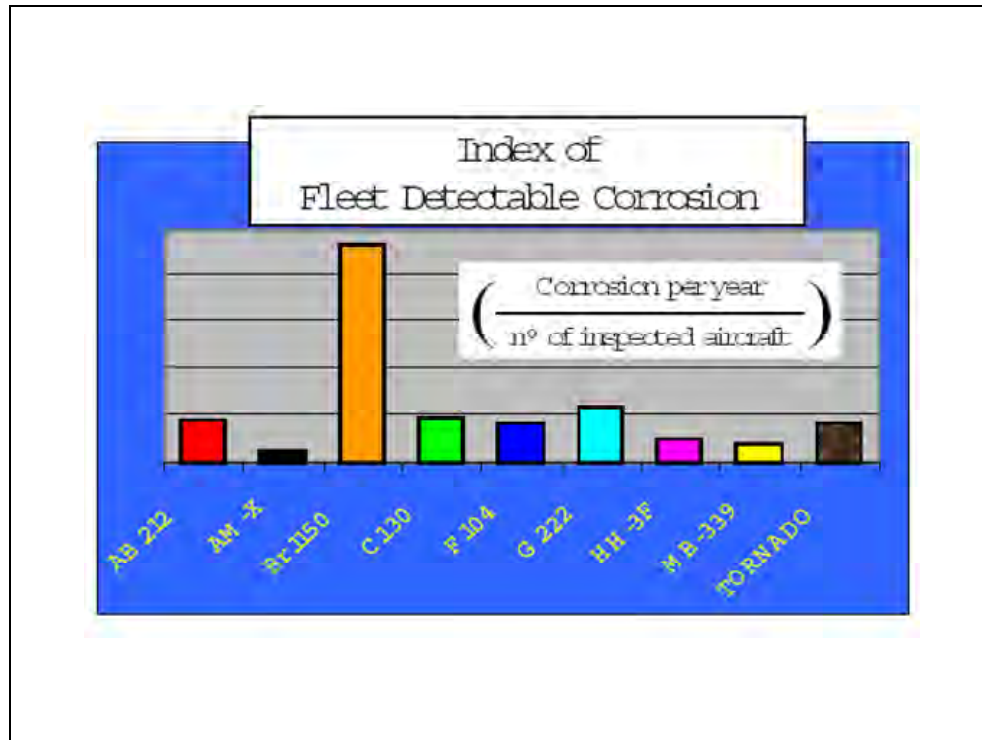
- Information about the Aircraft (Total Flight Hours, Base of Operation, Base where the A/C was more often based in the past six months, etc.)**
- Information about the Corroded Part (Identification Code, P/N, S/N, Work Unit Code, etc.)**
- Information about the Type of Corrosion**
- Maintenance done and its cost**
- A Map of the Corroded Area (Mandatory just for the parts where corrosion is already expected)**

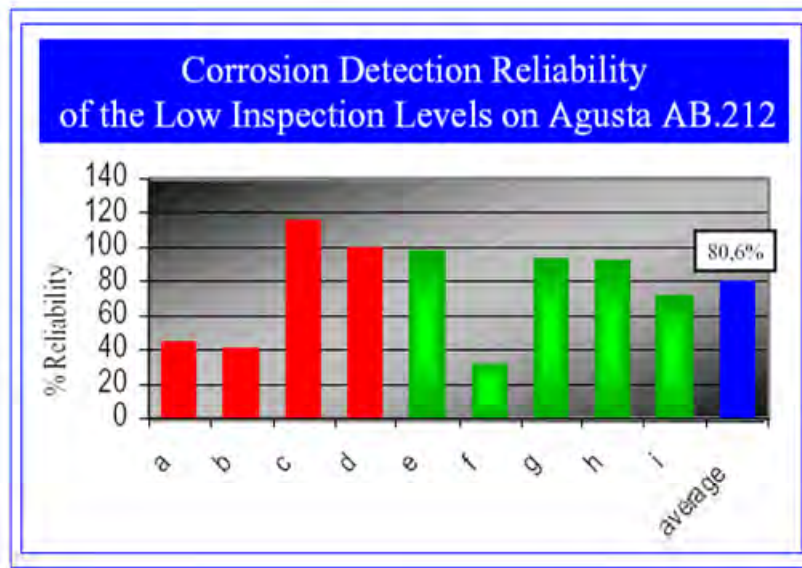
The acquired Data are then submitted to a statistical analysis.

The results are collected in an annual state of the art of the aircraft corrosion matter that provides a much more detailed scenario than in the past.



COLLECTION OF CORROSION DATA (ITALY)





**Corrosion Index
Distribution for each Squadron**

Allows to evaluate the effect of environmental and operative factors on Corrosion.

The bases operating in the South on the sea show the the highest values:

- * High Temperature;
- * High Humidity;
- * High Chloride Content.

Corrosion Index for Different Parts

On cargoes, the majority of corrosion occurs on the wings; less often on taileron and fin;

On helicopters, the most susceptible items must be considered the honeycomb structures on the floor, followed by main rotor and blades;

On fighters, corrosion is more often located on the body fuselage, the fuel cells, air intakes and landing gear;

On anti-submarines corrosion is very spread, especially on the wings and the bomb compartment.

Corrosion Index as a function of Aircraft Flight Hours

By means of this Index, corrosion susceptibility depending on the usage of the fleet has been monitored.

As a consequence of this, maintenance can be modulate to aging.

Maintenance Procedures and Costs for the different Fleets

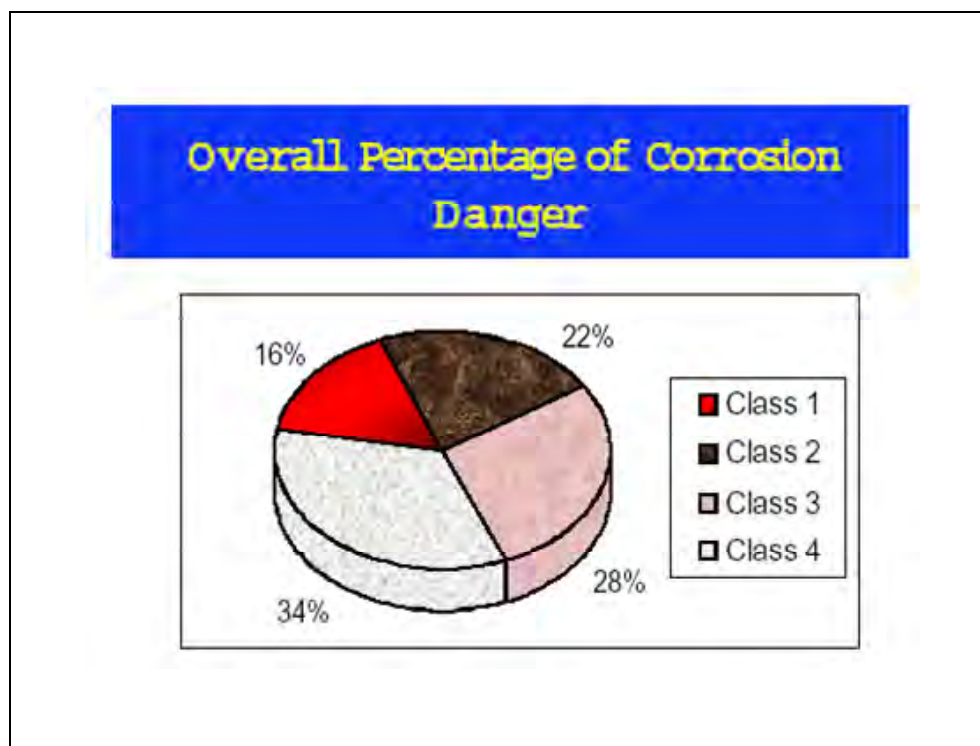
It must be considered the most important parameter in order to address the maintenance policy in agreement with efficiency needs.

At the moment only Direct Costs are shown
Man Hours Spent being the most significant of them.

Classification of Corrosion Danger for the Different Fleets

Damage Tolerance is obviously improved when the Risk Factors associated with Corrosion Danger are known.

To achieve this goal four danger classes have been individuated moving from Corrosion Morphology and Critical Level of the Corroded Component.



4.4 REFERENCES

- [1] R. Kinzie, "Cost of Corrosion Maintenance" – 2nd Joint NASA/FAA/DoD Conference on Aging Aircraft, Proceedings (Williamsburg, VA, USA, 31 August – 3 September 1998), 193-202.
- [2] N.D. Tomashov, "The Development of the Structural Electrochemical Theory of the Corrosion of Metals and Alloys" – Protective of Metals English Version, Vol. 22, No. 6 (November – December 1986), 679.
- [3] E. Lee, "Shipboard Exposure" – 2nd Intl. Aircraft Corrosion Workshop, (Solomons, MD, USA, 24-26 September 1996).
- [4] W. Wallace and D.W. Hoepfner, "AGARD Corrosion Handbook Vol. 1 – Aircraft Corrosion: Causes and Case Histories" – AGARDograph No. 278 (July 1985), 79.
- [5] A.J. McEvily, "Atlas of Stress-Corrosion and Corrosion Fatigue Curves" – ASM (1990), 17 ss.
- [6] G.E. Kerns, M.T. Wang and R.W. Stahele, "Stress Corrosion Cracking and Hydrogen Embrittlement in High Strength Steel" – Stress Corrosion Cracking and Hydrogen Embrittlement of Iron Base Alloys, NACE Publ. (June 1973), 700.
- [7] R.D. McCright, "Effect of Environmental Species and Metallurgical Structure on the Hydrogen Entry into Steel" – Stress Corrosion Cracking and Hydrogen Embrittlement of Iron Base Alloys, NACE Publ. (June 1973), 306.

- [8] R.W. Stahele and M.G. Fontana, "Advances in Corrosion Science and Technology" – Vol. 7, Plenum Press (New York, 1980), 53-175.
- [9] M.A.A. Tullmin, P.R. Roberge, L. Gremier and M.A. Little, "Aircraft Corrosion Surveillance", Canadian Aeronautics and Space Journal, Vol. 42, No. 2 (June 1996), 72.
- [10] D. Peeler and R. Kinzie, "Managing Corrosion in the Aging Fleet: a New Approach to Corrosion Maintenance", 3rd DoD/FAA/NASA Joint Conference on Aging Aircraft (Albuquerque, NM, USA, September 1999).
- [11] M. Colavita, "Italian Air Force Corrosion Data Management", Corrosion 2000, Conference Proceedings (Orlando, FL, USA, March 2000), Paper 301.
- [12] V.S. Agarwala, "In-situ Corrosivity Monitoring of Military Hardware Environments" Corrosion '96, Conference Proceedings (USA, 1996), Paper 632.
- [13] V.S. Agarwala and A. Fabiszewski, "Thin Film Microsensors for Integrity of Coatings, Composites and Hidden Structures", Corrosion '94, Conference Proceedings (Houston, TX, USA, 1994), pp. 217-228.
- [14] R.H. Johnson, K.S. Rajan and V.S. Agarwala, "Fluorescence Based Sensors for Corrosion Detection", Microstructural Science, Vol. 25, (Seattle, WA, USA, July 1997), 65.
- [15] X. Han, L.D. Favro and R.L. Thomas, "Thermal Wave of Disbonds and Corrosion in Aircraft", 2nd Joint NASA/FAA/DoD Conference on Aging Aircraft (Williamsburg, VA, USA, 31 August – 3 September 1998), 32.
- [16] J.P. Komorowski and N.C. Bellinger, "The Influence of Corrosion Pillowing on Structural Integrity of Aircraft Lap Joint", 2nd Intl. Aircraft Corrosion Workshop (Solomons, MD, USA, 24-26 September 1996).
- [17] J. Kim, A. Gonzales and D. Hodko, "Novel NDE/I Probe for the Detection of Corrosion in Aircraft Metallic Structures Based on Electrochemical Impedance", 2nd Joint NASA/FAA/DoD Conference on Aging Aircraft (Williamsburg, VA, USA, 31 August – 3 September 1998), 95.
- [18] P. Pole, "PhotoStrip – An Environmentally Friendly Method of Removing Paint from Aircraft and its Components", 4th International Aircraft Corrosion Workshop (Solomons, MD, USA, 22-25 August 2000).
- [19] J.M. Cuntz, J.J. Budu, B. Costes, P. Michelin, D. Merchandise, F. Henriot, M. Druet, B. Day and A. Roquet, "Procédés de Protection et Environnement Problèmes et Solutions", AGARD Report 816 (Florence, Italy, 4-5 September 1996), 2.
- [20] S.J. Hartle and B.T.I. Stephens, "US Environmental Trends and Issues Affecting Aerospace Manufacturing and Maintenance Technologies", AGARD Report 816 (Florence, Italy, 4-5 September 1996), 7.
- [21] E.A. Starke and J.T. Staley, "Application of Modern Aluminum Alloys to Aircraft", Progress in Aerospace Sciences, Vol. 32 (1996), 131-172.
- [22] R.J. Bucci and C.J. Warren, "Material Substitutions for Aging Aircraft", 1st Joint NASA/FAA/DoD Conference on Aging Aircraft (Ogden, UT, USA, 8-10 July 1997).

COLLECTION OF CORROSION DATA (ITALY)

- [23] R.J. Bucci, C.J. Warren and E.A. Starke Jr., “Need for New Materials in Aging Aircraft Structures”, *Journal of Aircraft*, Vol. 37, No. 1 (January – February 2000), 122-129.
- [24] G.S. Chen, M. Gao and R.P. Wei, “Micro-Constituents Induced Pitting in a 2024-T3 Aluminum Alloy”, *Corrosion*, Vol. 52, No. 1 (1996), 217-222.
- [25] C.J.E. Smith, K.R. Baldwin, V.M. Evans, S.A. Garrett and K.S. Smith, “Research into Chromate-Free Treatments for the Protection of Aluminum Alloys”, AGARD Report 816 (Florence, Italy, 4-5 September 1996), 8.
- [26] C.W. Matz, B. Hilling, W. Kelm and E. Koch, “Phosphoric Acid Anodizing (PSA) – a Heavy Metal Free Alternative for High Quality Surface Pretreatment of Aluminum”, AGARD Report 816 (Florence, Italy, 4-5 September 1996), 11.
- [27] V.S. Agarwala, “Trivalent Chromium Solutions for Applying Chemical Conversion Coatings to Aluminum Alloys”, 2nd Intl. Aircraft Corrosion Workshop (Solomons, MD, USA, 24-26 September 1996).
- [28] G. Vaessen, F. Andrews, C. Brindle, E. Hultgren, E. Koch, D. Marchandise, W. t’Hart and C.J.E. Smith, “Cadmium Substitution on Aircraft”, AGARD Report 816 (Florence, Italy, 4-5 September 1996), 15.
- [29] J. Mercer and L. Jensen, “Long Term Aircraft Preservation Employing the Nitrogen Purging Packaging (NPP) System”, 2nd Intl. Aircraft Corrosion Workshop (Solomons, MD, USA, 24-26 September 1996).

Chapter 5 – FAILURE INVESTIGATIONS: A POSSIBLE WORK PROCEDURE

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USA

5.1 INTRODUCTION

Any failure occurring on structural materials applied on air platforms needs to be studied, in order to avoid other accidents which are going to happen on aircraft of same fleet. Though, economic and safety issues are the driving forces to develop more efficient failure analysis and investigations.

Due to the need to set up the capability to share information on failed parts, by means of the same terminology and laboratory practice, the whole community of expertises on air platforms wishes to execute investigations well reproducible and without technicians' clear mistakes and misunderstanding.

RTO AVT-137 co-operative Task Group has been working since 2005 in the framework of international cooperation between NATO countries, focusing on information exchange and sharing of maintenance data occurring on air platform fleets.

The participating countries in the Task Group are: Canada, Germany, Italy, Netherlands, United Kingdom and the United States.

Based on the experiences the author had while working at the IAF Flight Test Center through many failure Investigations, this work instruction is proposed as a setting of a general procedure to perform a failure investigation; terms and rules of the deliverable report and relative items are also discussed.

Both metallic and non-metallic materials undergo this work instruction.

5.1.1 Objective

A Failure Investigation is undertaken to determine the cause of a failure, and if possible, to identify corrective actions that should be initiated to prevent similar failures.

5.1.2 General Stages of an Analysis

The nature of the failure being investigated determines what steps and process must be employed. The following is a brief description of the typical stages of a Failure Investigation.

These are guidelines to be considered by the investigator; however, not every stage may be utilized.

5.2 PRELIMINARY DATA

Initially, the Failure Investigation should be directed towards gathering as much information relating to the failure insofar as to reconstructing its sequence of events.

This may involve obtaining materials specifications, drawings, and records as to the manufacturing, processing, and service history of the failed component or structure.

Eventually, health monitoring data regarding flight and land operations parameters could be useful during investigation.

5.3 LABORATORY STEPS

5.3.1 Photographic Records

It is important for the investigator to maintain a photographic record of the failed component (e.g. macroscopic, fractographs, micrographs, etc.) throughout the analysis to detail the characteristics of the failure.

This may initially be performed by the customer, investigator, or by an approved outside source.

5.3.2 Selection of Samples

It is critical that the investigator selects the correct components that accurately depict the failure. Sometimes, this may involve seeking other evidence of damage beyond the apparent failed component.

Also, ideally it would be beneficial to the Failure Investigation if a not failed same P/N component could be obtained for comparison.

5.3.3 Preliminary Examination of the Failed Component

Prior to cleaning, a record should be made to describe the “as-received” condition of the failed component. This is useful in determining the sequence of events leading to the failure. A thorough visual examination and record keeping are important to the Failure Investigation.

Visual inspection should be performed initially unaided and subsequently with photographic microscopes.

For fractured components, it is essential to document the entire component and then relate the fracture to the entire component.

5.3.4 Sample Handling and Operating

5.3.4.1 Preservation

The proper selection, preservation, and cleaning of fracture surfaces are critical to prevent important evidence from being destroyed or obscured. Fracture surfaces are prone to mechanical and/or chemical damage.

Surfaces of a fracture should never be touched by the fingers or be fitted together with the sections of a part. They should also be covered with a cloth or cotton during shipment and stored in a desiccator to prevent corrosion damage.

5.3.4.2 Cleaning

Fracture surfaces should only be cleaned when absolutely necessary, such as for electron microscope observation. Techniques employed are dry-air blast, ultrasonic cleaning with solvents or mild detergents, and application and stripping of plastic replicas.

For plastic materials, it is proposed to avoid organic solvents.

5.3.4.3 Sectioning

Due to the limit of size for testing and evaluation in equipment such as hardness testers and optical microscopes it may be necessary to excise a portion containing the fracture surface from the failed component. It is critical to keep an account of the sectioning with sketches or photographs. It is also important to preserve the fracture surface during cutting; application of a coolant or a secondary coating may be used.

5.3.4.4 Crack Opening

Primary cracks may need to be opened if they did not propagate to total fracture.

On the other hand, if the primary crack has been damaged or corroded such that the fracture surface has been obliterated, it is necessary to open any secondary cracks for examination and study. These cracks can provide more information since they are usually less damaged or corroded.

It is proposed to open cracks such that the two fracture surfaces move opposite to each other, normal to the fracture (crack) plane. If plausible, sometimes the use of a different fracture mechanism can be used to distinguish the secondary cracks from the primary.

It is also recommended that the crack length be measured prior to opening for fatigue fracture and strain analyses.

5.3.5 Non-Destructive Testing

Non-destructive testing can be useful in detecting surface cracks and discontinuities in a failed component.

Magnetic-particle inspection, liquid-penetrant inspection, eddy-current inspection, ultrasonic inspection, acoustic-emission inspection, and radiography are some of the commonly used techniques.

5.3.6 Mechanical Testing

Mechanical testing aids in the determination if the failed component conforms to specification or in evaluating the effects of surface conditions on mechanical properties.

5.3.6.1 Hardness

Hardness testing can be used to assist in evaluating heat treatment, providing an approximation of tensile strength, and to detect the work hardening or softening due to service/maintenance.

5.3.6.2 Tensile Strength and Toughness

Where appropriate, these tests should be performed only if sufficient material for fabrication of test specimen is available.

5.3.6.3 Dynamo-Mechanical Analysis

Where appropriate, these tests should be performed on plastic materials or polymer matrix composites only if sufficient material for fabrication of test specimen is available.

5.3.7 Chemical and Elemental Analysis

In a Failure Investigation, routine analysis is recommended to ensure that the material is one that was specified. Slight deviations in compositions are not likely responsible for failures. However, when considering failures due to corrosion or stress-corrosion, the analysis can be important in establishing the primary cause of failure.

It is worthwhile to determine elemental concentrations and to identify compounds in alloys, bulky deposits, and samples of environmental fluids, lubricants, and suspensions.

Various analytical techniques can be used in a failure investigation: emission spectroscopy, atomic absorption spectroscopy, inductively coupled plasma atomic emission spectroscopy, classical wet analytical chemistry, and spot tests. For surface constituents, compositions can be identified by energy-dispersive and wavelength-dispersive x-ray spectrometries.

Polymeric materials must be investigated for their chemical nature and both thermodynamic and kinetic parameters, by means of infrared spectroscopy, pyrolysis gas chromatography and thermal analysis.

5.3.8 Fractographic Examinations

5.3.8.1 Macroscopic Examination

The detailed examination of fracture surfaces at low magnifications (ranging from 1 to 100 X) may be done with the unaided eye, a hand lens, or a low-power optical microscope. The information obtained can give an indication of the stress system that produced the failure, the direction of crack growth and therefore the origin of the failure.

5.3.8.2 Microscopic Examination

Microscopic examination of fractured surfaces can be achieved with optical (light) and scanning electron microscopies. However, interpretation of the fractographs requires practice and an understanding of fracture mechanisms.

5.3.8.3 Microstructure Analysis

Metallographic examination of polished and polished-and-etched sections by optical microscopy and electron-optical techniques is a vital part of the failure investigation and should be conducted as a routine procedure. It provides the investigator with a good indication of the class of material involved and whether it has the desired structure. Information regarding to the method of manufacturing and heat treatment can also be obtained.

Metallurgical imperfections, i.e. inclusions and microstructural segregation in metals such as mislining of fibers and voids in polymer composites, can be detected and analyzed by microscopic examination. Other service effects such as corrosion, oxidation, and severe work hardening of surfaces, are also revealed, and their extent can be investigated.

In addition, important characteristics of the cracks can be identified, such as the mode of propagation.

5.3.9 Determination of Fracture Types

Examination of the failure region, the fracture surfaces, and metallographic sections, is necessary to identify the fracture type.

Fractures are usually classified in terms of their growth mechanism: ductile, brittle, intergranular, transgranular, and fatigue.

These mechanisms can be correlated with different modes of fracture, such as environment assisted failures (i.e. stress-corrosion cracking, melting, liquid-plastic deterioration, liquid-metal embrittlement, hydrogen embrittlement, and creep) and stress dominated ruptures (i.e. overload, wear, impact).

All these identifications aid to determine the cause of fracture.

5.3.10 Application of Simulation Tools

Finite Element Analysis (FEA) may be worthwhile in assessing how stresses act on failed part, by calculating the stress concentration factor (K_t) and residual fatigue life, either in presence or in absence of an existing crack or defect. Right material properties to be put in the calculation may be extracted both from references and mechanical tests.

5.3.11 Application of Fracture Mechanics Theories

The mechanics of fracture in metal parts and specimens under load have become increasingly important in failure investigations due to fracture and to the formulation of corrective measures that will prevent similar failures.

Fracture mechanics are useful in determining critical crack size and fracture stress (load). It can also provide a quantitative framework for evaluating structural reliability by means of NDT procedures, allowing maintenance to move to a “damage tolerant” approach of the cracked part.

5.3.12 Simulated-Service Testing

It may be necessary to conduct tests that attempt to simulate the conditions under which failure is believed to have occurred. Most of the metallurgical phenomena involved in failures can be satisfactorily reproduced on a laboratory scale, and the information derived from such experiments can be helpful to the investigator provided the limitations of the tests are fully understood. Furthermore, the simulated testing of the effects of certain selected variables encountered in service may be helpful in planning corrective action that will avoid similar failure or, at least, extend service life.

5.4 FINAL REPORT

5.4.1 Report Index

Failure Investigation final reports will include the following issues, not automatically in same sections or repeatable forms:

- Report and activity code;
- Object;

FAILURE INVESTIGATIONS: A POSSIBLE WORK PROCEDURE

- Introduction;
- Selection of failed parts;
- Preliminary examinations;
- Fractographic examinations;
- Chemical analysis;
- Mechanical analysis;
- NDT (optional);
- Application of Simulation Tools (optional);
- Simulated-Service Testing (optional);
- Discussion on experimental results;
- Application of Fracture Mechanics Theories (optional);
- Determination of Fracture Types;
- Individuation of failure cause and chronological events;
- Conclusions;
- Recommendations (optional);
- References (optional); and
- Acknowledgements (optional).

Experimental procedures, tables and figures may be present in sections containing issues from 5.3.4. to 5.3.12. These sessions should also include a brief overview of the type of analysis performed and equipment used.

Some of these items are discussed in the following sections.

5.4.2 Object

It will indicate clearly vehicle and part gone under investigation. If needed, it will refer to customer statement.

5.4.3 Introduction

Presents the Statement of Work as tasked by the customer and the reason the customer requested the tests. It also identifies the customer.

The introduction should also include a “background” discussion, which will clearly relate the sample history.

5.4.4 Discussion on Experimental Results

Discuss the significance of the experimental results. Describe how the results apply to the statement of work and how they led to conclusions.

5.4.5 Conclusions

State the overall conclusion(s) of the Failure Investigation. These can be bulletized. Answer the question, “What did analyses tell us”.

5.4.6 Recommendations (Optional)

If recommendations (such as recommendations for further tests or maintenance procedures variation) are included in the Failure Investigation Report, they may be developed in conjunction between the Italian Air Force technicians and the Customer.

5.5 ROLES AND RESPONSIBILITIES

5.5.1 Department Manager

- Empowers personnel to perform Failure Investigations.
- Supports the required Failure Investigation/Materials Investigation Training needs.
- Stimulates inter-branch team work skills.
- Has familiarity with material characterization techniques.
- Signs Final Report.
- Archives copy of Final Report and retains copy.

5.5.2 Branch Head (Program Manager)

- Takes custody of Customer-Supplied Handbooks and official documents.
- Writes the activity proposal, pointing out laboratories/experimentations/tests/man hours needs.
- Individuates the Final report author.
- Notifies Author and Laboratories Managers via e-mail, lectures, phone calls.
- Proposes a Plan of Action and consults with other Department personnel.
- Writes internal work requests with Laboratory Managers.
- Solicits author for technical reviews of Final Report drafts.
- States closure of the failure investigation.
- Signs and submits the Final Report the Department Manager for signature.

5.5.3 Primary Laboratory Manager (Author)

- Takes custody of failed and not failed parts.
- Leads and executes the big part of experimental tests.
- Obtains all relevant information from experimental results.
- Notifies Branch Head and Laboratory Managers via e-mail, voice, phone calls.
- Determines required laboratory testing.
- Proposes a Plan of Action and consults with Branch Head and Laboratory Managers.
- Contacts Customer Engineers and/or consultants.
- Performs the monitoring of Internal Work requests with Laboratory Managers.

FAILURE INVESTIGATIONS: A POSSIBLE WORK PROCEDURE

- Writes the Final Report drafts and ultimate version.
- Submits the Final Report to the Branch Head for review and signature.

5.5.4 Laboratory Managers

- Accept internal work requests from Program Manager.
- Complete laboratory experimentations.
- Generate Laboratory Reports and log-out documents to the Program Manager.
- Take custody of failed and unfailed parts during tests.
- Obtain all relevant information from experimental results.
- Notify Branch Head and Author via e-mail, voice, phone calls.

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Corrosion control	Fractographic examination	Pitting corrosion	
Corrosion policy	Fracture mechanics	Selective corrosion	
Corrosion prevention	Intergranular corrosion	Stress corrosion cracking	
Damage assessment	Localized corrosion	Uniform corrosion	
Data collection	Maintenance	Visual inspection	
Failure analysis			
14. Abstract			
The increasing average age of military platforms and greater legislative restriction of maintenance materials that has occurred in the past decade has heavily exacerbated the detrimental effects of corrosion on worthiness and maintenance costs. In order to identify the efficacy of different anti-corrosion policies and procedures adopted among the NATO countries, a number of Nations – namely Canada, Germany, Italy, Netherlands, the United Kingdom and the United States – have decided to take part in this Task Group where the exchange of information based on the expertise developed and some maintenance technology demonstrations have been carried out to provide a framework of possible best practices to be applied to maintenance procedures and the corrosion prevention of military vehicles. Furthermore, since effective maintenance and prevention often includes an in-depth analysis of the in-service observed failures, this report also provides a proposal for a common approach to the failure analysis.			





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