Addressing Fleet Management Needs With EWIS Risk Assessment Technologies

Lectromec – January 2012

SUMMARY: This document provides a brief overview of Lectromec's process for addressing the maintenance and life extension needs of aircraft fleet managers. The comprehensive process combines arc damage analysis, wire insulation degradation research, and risk assessment methodologies into a single, turnkey process. The outcome from an aircraft risk assessment provides a quantitative basis for business decisions on EWIS related preventative actions.

Contact Lectromec to find out how our turn-key process can be customized to address your fleet and budget needs.

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1 Introduction

Having a regular, predicable functioning aircraft is critical for both commercial and military purposes. When aircraft fail to operate as designed, they place additional workload on the flight crew and may require emergency landing. Aircraft age, and when they do, the components degrade. They become more susceptible to wear-out and random failures reducing the aircraft availability.

In the course of planning for an aircraft's life extension program, eventually it becomes necessary to considering the wire system health. Like all other system components, wires (particularly the wire insulation) degrade over time and reduce the aircraft safety margins. Heat, mechanical strain, and fluids affect the wire insulation and can make the wire more susceptible to failure.

Although there has been significant improvement in wire system awareness over the last decade, latent risks can still exist. Lectromec's process identifies these throughout the aircraft.

An EWIS evaluation is not reasonable in all cases. The following is a list of common reasons to help determine if an EWIS evaluation should be considered as part of a life extension program:

#	Yes	No	Question
1	○	○	Are the maintenance logs starting to show an increase of wire related problems?
2	○	○	Is the aircraft nearing the end of the certified life?
3	○	○	Are the aircraft operating in climates with elevated heat and/or humidity?
4	○	○	Is the aircraft more than 15 years since the last major rewiring program?
5	○	○	Is the aircraft more than 20 years old?
6	○	○	Is there a need to reduce the number of harnesses to be replaced at the next maintenance cycle?
7	○	○	Is there a need for reduce the cost of harness replacement?
8	○	○	Is there a concern that wire degradation led to a loss of another aircraft in the fleet?

Answering 'yes' to none of these questions means that you are probably in a good position and not in an immediate need for wire degradation analysis services. Answering 'yes' to one or more questions indicates that an EWIS risk assessment to support your life extension program could provide valuable insights.

The EWIS risk assessment goal is to determine the additional susceptibility to failure based on aircraft wiring degradation. This is accomplished through methodical evaluation of the wiring system and determining the risk escalation. In particular, a wire system life extension program must answer all of the following questions:

Why not just maintenance logs?
Maintenance logs provide information as to what has happened. Relying only on these creates a reactive maintenance environment. The benefit of Lectromec's processes is that it is a *predictive technology* providing information that can help with business justification of preventative maintenance actions.

1. What is the condition of the existing wiring system? Has the wiring been stressed beyond its design limitation or has it operated in benign conditions?
2. What wiring system components need to be replaced now? What is the reason for the replacement?
3. If not replaced now, how much longer can the wiring be considered reliable? Is it possible to make it to the next depot level maintenance without a significant impact on airworthiness?

With answers to the above questions, it is possible, based on sound engineering judgment, proven risk assessment techniques, and years of polymer degradation research to determine the best course of action for your EWIS. This is the result of Lectromec's EWIS risk assessment services. The comprehensive services are an economical turnkey process applicable to any fleet or single aircraft.

1.1 Defining EWIS Risk

Risk is often a misapplied term. When applied to an engineering process or assessment of a system, risk can be simplified to being a combination of failure probability and failure severity.

Probability of Failure
The probability of failure is a numeric quantity based on field data or laboratory analysis that component determines the degradation over the wire life. The acceptable level for combined

probability and severity is dependent upon the actual use. A low value system may have a high failure probability may not need to be addressed, whereas a high-value/mission-critical system must have a much lower threshold. It is the analysis of these two factors that is central to an EWIS assessment for an aging aircraft.

Suppose only the probability of failure were examined for the wiring on the aircraft. There would certainly be benefits from this:

- The worst harnesses would be identified for replacement.
- Good harnesses would be identified thus reducing the overall cost of harness replacement
- Projections could be made as to future failure probabilities

These metrics can be useful in making determinations for wire harness replacement if a full risk assessment is not deemed necessary. However, there are weaknesses of only examining the failure probability. Some of these shortcomings include:

- The failure impact is not identified: Harnesses which contain mission critical system wires may not be identified (the acceptable failure probability on these is much lower).
- Harnesses that carry a large number of power wires may cause more damage in an arcing event. The nearby systems are also likely to be damaged are not identified.
- Collocation of systems is not identified.

In some cases, it may be tempting to focus on a single aspect of the risk assessment, namely, the failure probability. If all of the poor quality harnesses are replaced, then will not the aircraft be in like-new condition? True, but there are disadvantages to this:

- It may be cost prohibitive to replace so many harnesses.
- The down time is too long.
- Maintenance efforts cannot be directed to monitor the most critical systems

Failure Severity

As identified earlier, determining the failure severity is important to the overall EWIS risk assessment process. In particular, it seeks to determine where failures can have the greatest impact on the aircraft airworthiness. It is necessary to both consider the aircraft level functional impacts (which systems are affected by a failure) and the physical impacts (what may be damaged may be caused from a wire failure) when defining the severity failure.

Alone, the failure severity does provide valuable insights:

- System collocations.
- Critical systems.
- Identifying areas for directed maintenance.
- Identifying areas for routine visual inspections.

Combining failure severity with failure probability provides a clear, cohesive picture of the current aircraft EWIS health that can be directed to focus on what matters most: a fully functional airworthy aircraft that can be maintained in a cost effective manner.

1.2 Preface to Process

The EWIS risk assessment process combines information from various parts of the aircraft. Information from the maintenance logs must be combined with physical routing information. Circuit information must be combined with failure severity information. It is through the combination and analysis of these individual components that an EWIS risk assessment is possible.

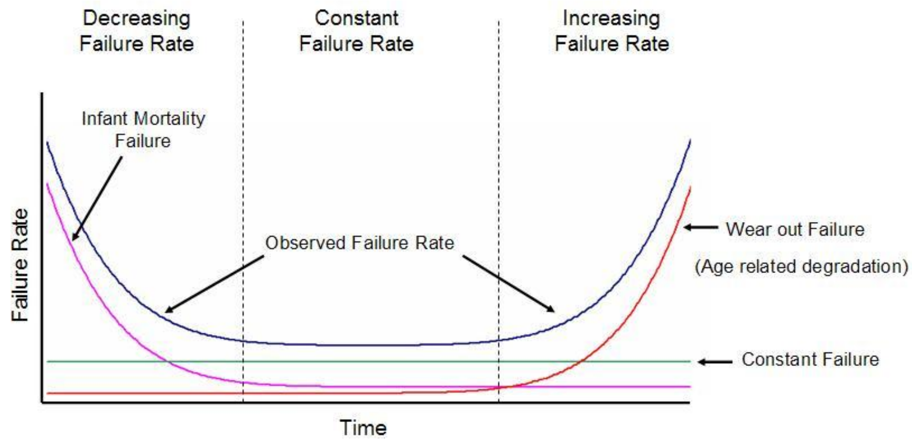
Because the available aircraft data of two different platforms are not going to be the same, no two risk assessments are the same. The key to the success of any risk assessment process is data and process flexibility. This means having mechanisms to supplement or replace unavailable data or tasks that are not applicable.

The process described here is flexible and designed to meet the unique needs of each maintainer. It is expected that there will be gaps in the available data. Lectromec has developed statistical techniques, logical inferences, and algorithms to compensate or generate ‘missing’ segments of data. This allows for imperfect data to be used to generate useful results.

While additional data will improve the reliability of the results, keep in mind that *not all of the data points are necessary for a risk assessment* that can provide positive impact on your fleet maintenance and life extension efforts.

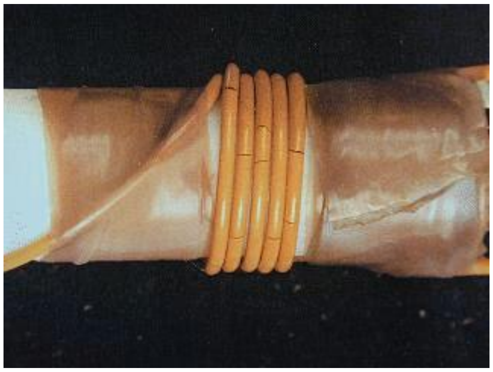
2 Assessing the Wire Condition

Like all devices, a wire is subject to the three standard portions of a device life cycle which include: infant mortality, random failure, and wear-out. Infant mortality of wires is associated with manufacturing or installation flaws; these are typically detected early and are replaced. The majority of a device's life is in the random failure period. Here, device failures are associated with random occurrences such as damage during maintenance actions. The final portion of the device life cycle is the wear-out: parts begin to have reduced performance and eventually stop working as designed.



To determine where a wire is in the life-cycle, the natural first step in assessing the wiring system is to perform a physically examination. Visual examinations can identify obvious wire damage such as chaffing, pinched wires in clamps, and exposure to possible corrosive fluids. While these are important to identify and resolve, ***wire insulation degradation is not always visible***. Micro-cracks in the insulation or heat damage caused by electrical overloads are difficult to see in individual wires and becomes more difficult in large bundles.

Below is an example of topcoat cracks in wire insulation. These are easy to see when the wire is wrapped around a mandrel, but incredibly difficult to find if straight and in the middle of a wire bundle.



During the Intrusive Inspections performed by the FAA in 2000, a trained team visually inspected wire bundles with the goal of reporting breaches or damage to wires. One bundle selected for *thorough visual examination found two wire breaches*. This same bundle was then selected for additional testing (DelTest™) to be performed by Lectromec. *Lectromec's testing found 60 insulation breaches* that exposed the wire conductor (all insulation breaches were independently verified). Alone, unaided visual examinations are not sufficient to determine the wire condition.

It is impossible to have test data for the random failure rates for all aircraft environments. However, it is possible to perform a comparative analysis of certain aircraft environments and project the importance of key variables. Lectromec has performed the research and developed a random failure rate function representing more than 1million aircraft environment conditions.

To further complicate the work of visual examination, there are wide differences in insulation chemical compositions. Different insulation types have different failure modes which present under different chemical, mechanical, or thermal stresses. Each wire insulation type has its specific strengths and weaknesses. Some do well under one set of stresses (e.g. fluid emersion) while fail under other stresses (e.g. repeated mechanical strain). These different environments affect the degradation of the wire insulation.

To address the differences in the environments and how they impact the airworthiness, it is necessary to understand the wire degradation rate. The rate of degradation is dependent on the thermal, mechanical, and environmental strains to which the wire is subjected. Reducing the severity from anyone one of these factors will likely increase the wire longevity.

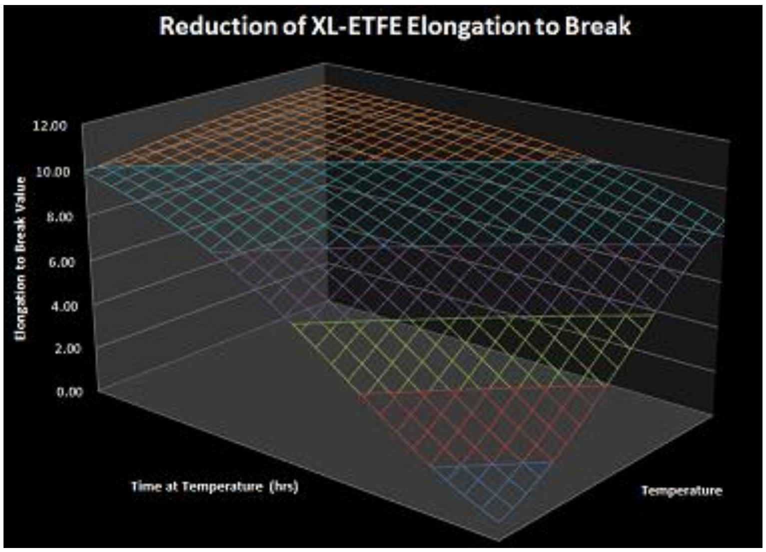
Regardless of insulation type, as the wire ages, it becomes more susceptible to failure. Cracks and tears are more easily formed during maintenance actions and the insulation is more easily worn down from chaffing or being pinched at a clamp. Over time, cracks in multiple wires will occur in close proximity to one another allowing for crosstalk or power conduction.

2.1 Identifying Wire Condition

To determine the health of the wiring itself, it becomes necessary to examine the insulation's physical and/or chemical properties. This is done by accelerated age testing and/or chemical degradation analysis. The specific process for determining the wire health is objective and material dependent. Some tests that can be performed to determine wire condition include WIDAS, Inherent Viscosity, or Wirelytics. The results of the accelerated aging and/or chemical degradation analyses are used to determine the remaining wire life.

The ‘remaining wire life’ is a concept describing where the wire is in the device life cycle. This is not to say that the remaining life is the time at which all wires will fail (a failure defined as a breach that exposes the conductor); rather, this sets an expected threshold at which the degradation related failures would begin.

For most wire types, insulation degradation is not a simple linear process. As identified earlier, numerous factors affect the degradation process. To determine the degradation evolution of wire insulation, significant research is necessary to identify the reliable life limit (the point at which the failure probabilities are expected to increase). Below is an example of research Lectromec performed on XL-ETFE insulated wires.



Lectromec has performed degradation research on nearly all modern aircraft wire types and continues to perform additional testing to better improve these proprietary analysis techniques. It is this research that Lectromec relies upon for assessing the current wire conditions and projecting the remaining wire life.

2.2 Identifying Environmental Factors

The wire degradation analysis process starts with defining the project scope to limit the necessary testing. Trouble areas are identified through examination of available maintenance data and a preliminary EWIS review. Obviously, the most severe environments for wire are experienced during aircraft operation. These operation stresses compile over time along with the degradation that occurs to the wire insulation during its time on the ground.

The first step is to gather physical conditions within the aircraft. The environment examination, broken down into individual zones, considers the severity of environmental conditions. Gathering information on the environmental conditions provides a starting point about stresses impacting wire longevity. Successful aircraft environments definition provides details for forecasting of failure areas and is used to place expected limits on the degradation analysis.

The examination starts with the aircraft being partitioned into environmental zones. The environmental zones are defined as contiguous physical areas with similar environmental characteristics. Examples of particular environmental characteristics include but are not limited to:

- Operating temperature
- Vibration level
- Exposure to fluids

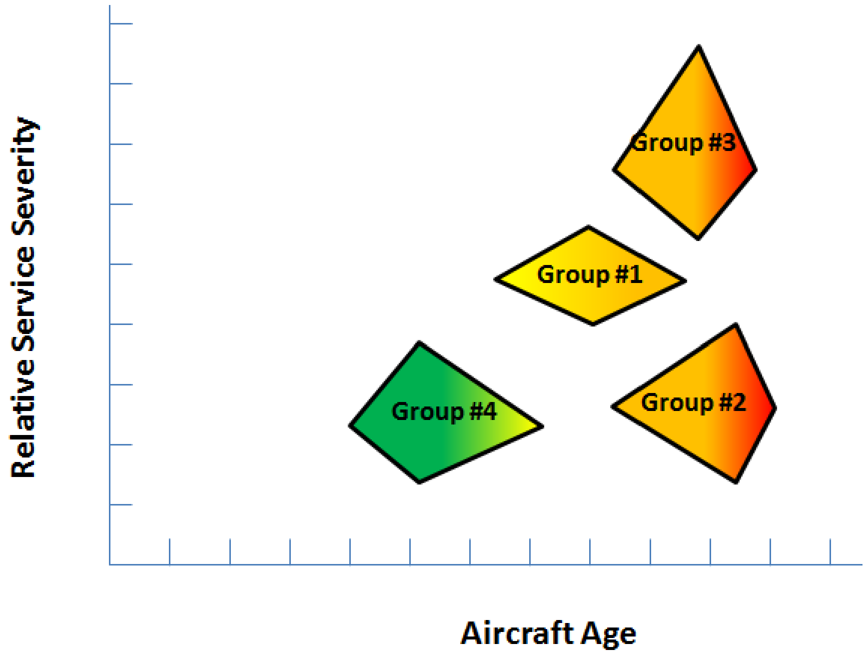
While physical examination and monitoring of the aircraft is ideal, it is not practical in all cases. This is addressed through a survey of a small group of individuals (engineers and technicians) familiar with the aircraft. This survey does a comparative analysis of each aircraft zone and elicits opinions on the environmental conditions. The survey results are evaluated and similar contiguous environmental zones are grouped together.

2.3 Fleet Partitioning

After determining the operating conditions within the aircraft, the next step is to review the aircraft from the fleet level. This fleet level assessment examines how and where the aircraft have been in use; the goal is to evaluate the fleet variability (age, service history and service locations). This is necessary as aircraft used differently will show different aging patterns.

Understanding how, where, and how long the aircraft have been used provides the prerequisite information for logical aircraft grouping. Just as grouping of aircraft zones reduced the number for testing, the logical grouping of fleet aircraft identifies the selective sampling partitions. This process ensures the validity and applicability of risk assessment results.

For example, suppose there is a fleet that has been in production for a number of years. The fleet consists of multiple squadrons with different service liv tes (and locations). Utilizing Lectromec's fleet analysis algorithm, four distinct groups are created. Within each of these groups there is some variability in terms of service severity and age, but these are not so large as to warrant partitioning into small groups.



While this analysis would traditionally be a labor intensive process, these partitions are easily determined with Lectromec's fleet analysis algorithms which generate groups to minimize intragroup variability. The algorithms have been designed such that, if a target number of groups are desired, then the relative loss of confidence interval is determined (versus the ideal group selection). This provides a huge advantage over standard manual assessments that may ignore the factors impacting fleet groupings.

After the groups have been created, the next step is to determine which aircraft within these groups should be selected for testing. The aircraft within these groups are typically those that are most available for wire removal (e.g. depot level maintenance). This typically ranges from 5-15% from each selected group.

These wires removed from the selected aircraft are tested to examine the current condition and for projections on remaining wire life. But these steps are only half of the process; the wire degradation results must be combined with the failure severity to determine the aircraft risk.

3 Failure Severity

The wire insulation assessment is a significant step forward in understanding the wire system condition. However, to achieve a full system risk assessment, the failure probability must be combined with failure severity. This requires an examination of the aircraft electrical wire interconnection system.

As with all other parts of the risk assessment process, examination of the EWIS starts with data gathering. For a new aircraft, this information is easy to gather – all of the design drawings are available and the wire routing is easy to determine. However, an in-service aircraft with upgrades and modifications can make the original engineering information obsolete. This is addressed by Lectromec's data gathering process. The process focuses on data gather in an efficient manner and is performed with the customer to ensure that all engineering data is representative of the aircraft.

EWIS RAT: Electrical Wire Interconnection System Risk Assessment Tool

The EWIS RAT was originally developed by Lectromec under the FAA to provide EWIS Risk assessment for both new and existing aircraft. The tool combines wire degradation information with failure severity.

The information gathered includes (not an all inclusive list):

- *Wire specification (cable specification determines subsequent age degradation model and impacts wire arc damage analysis.
- Gauge: Wire conductor size has a large impact on electrical arc damage.
- *Associated system: Important for collocation assessments and harness loss impact analysis.
- *Connection points: Important for wire termination points (from-to information).
- Connectors: Necessary for associating wire connections with harness end points.
- Splices: Necessary for identify electrical power propagation.
- Relays: Necessary for identify electrical power propagation.
- Electrical Devices: Necessary for determining devices affected with loss of wiring.

*Minimal data field necessary for risk assessment

Lectromec has developed software tools to streamline the process each integrating with the EWIS RAT. These tools include methods for gathering physical information about the wire routing. The physical routing throughout the aircraft is just as important as the wiring harness composition; this information cannot be gathered from wiring diagrams alone.

The physical wire routing within the harnesses is a key factor in the arc damage analysis (fully described later). The greater the power density within the wire bundle, the greater the damage potential from a wire failure. The potential arc damage is dependent on a number of factors which include (but are not limited to) distance from the generator, number of power wires in the harness, and wire insulation type. The additional information gathered from the harness examination enhances the collocation and damage potential analyses providing a more in-depth failure severity analysis.

3.1 Assessing the Severity of failure

Assessing failure severity centers on identifying the particular hazards and how they impact the aircraft airworthiness. To accomplish this, aircraft electrical system information must be combined and evaluated methodically. For any modern aircraft application, manual evaluation of these factors is close to impossible. This need for automation is addressed by Lectromec's EWIS RAT software. This software provides a quick assessment of the aircraft systems.

The following lists some of EWIS RAT assessments available for determining failure severity:

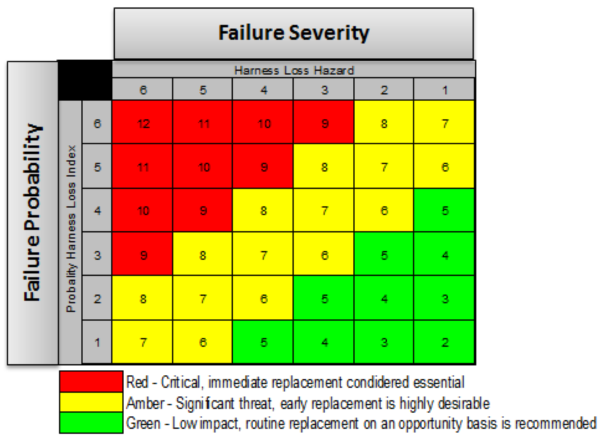
- Collocation Analysis: The design goal of any system is to make the likelihood of a hazardous or catastrophic event extremely unlikely. This can be compromised by having redundant systems routed in the same harness or in separate harnesses with limited physical separation. The collocation analysis searches for these weak points.
- Damage Analysis: Power and circuit information provide data on the flow energy through the aircraft. Combined with the wire type and routing information, this provides the details necessary for a damage potential analysis. This analysis utilizes Lectromec years of experience with experimentation and research in the field of arc damage analysis. The analysis results identify areas with the greatest arcing hazard. This analysis includes recommendations on safe separation distances from hydraulic lines and other harnesses.
- Location Hazard Analysis: This combines environmental and maintenance data with the system routing information to identify particular hazard areas and how these affect the aircraft reliability.
- Critical System Analysis: This analysis focuses on those systems identified as being critical to aircraft airworthiness (e.g. fuel quantity indicator system). Critical system analysis combines the other analysis sorted by the critical system.

Although the concept of risk assessments is relatively new to wiring systems, all processes involved in the EWIS RAT have a basis in industry risk assessment standards.

Depending on the particular needs of the life extension program, some or all of these reports may be deemed necessary. With both the failure probability and severity identified, it is now possible to combine these into a comprehensive wiring system risk assessment for a life extension program.

4 Comprehensive EWIS Risk assessment

The first item in the comprehensive risk assessment is the Risk Hazard Matrix (RHM). The RHM is the first mechanism used for quantifying the risk of the aircraft harnesses. As can be seen in the figure below, the RHM combines the failure probability (as identified by maintenance data and wire degradation assessments) with the failure severity (identified by system impact, arc damage impact, and redundancy impact) for each harnesses.



By combining the data sets into the RHM, it becomes apparent as to which harnesses are of the greatest risk to aircraft airworthiness. In the failure probability rankings, the wire degradation is combined with the environmental conditions to forecast the relative probability of failure for each harness. This means that if all of the wires are in good condition, then the RHM value will not show an overly conservative ranking of the failure probability (as is often the case where the results are scaled to show an even distribution).

An example RHM harnesses evaluation can be seen in the figure below. As each harness is ranked based on the loss and severity of failure values, a business case can be made as to which harnesses need replacement, additional care, or are in good condition and may not require additional actions.

Bund Sec	Harness Loss Hazard	Loss Probability	Risk Hazard Matrix Value
BS-R134	6	4	10
BS-R136	3	3	6
BS-R138	3	5	8
BS-R139	5	2	7
BS-R140	4	5	9
BS-R141	2	2	4
BS-R142	3	1	4

But the RHM alone may not provide sufficient information to make a forecast on fleet reliability. To do this, it is necessary to understand how the failure probability evolves over time (unless the vehicle is changed, the severity of failure will remain unchanged). Lectromec developed the Risk Hazard Evolution Assessment (RHEA) for forcasting this probabilty.

This is a unique assessment available from Lectromec based on extensive wire insulation degradation research. The RHEA utilizes the data gathered from the wire degradation assessment and applies it to the Lectromec wire degradation models. These models are used to identify how the EWIS risk evolves over time with the changing failure probability.

		Probability Evolution			
Bund Sec	Risk Hazard Matrix Value	Maint Cycle #1	Maint Cycle #2	Maint Cycle #3	Maint Cycle #4
BS-R134	10	11	11	11	11
BS-R136	6	6	6	7	7
BS-R138	8	9	9	9	10
BS-R139	7	8	8	9	10
BS-R140	9	9	10	10	10
BS-R141	4	4	4	4	5
BS-R142	4	4	5	5	6

In doing so, there is a clear identification of which harnesses need to be replaced and which harnesses can be addressed at another maintenance interval avoiding high upfront costs of replacing all harnesses. The harnesses can targeted for replacement at the end of a maintenance cycle before the risk to airworthiness becomes too high. By executing planned maintenance actions before the risk becomes too great, the EWIS reliability will increase and not be impacted by system degradation.

These are only a few of the reports that are generated by the EWIS RAT. There are additional reports not shown here that can help with building the business case for preventative maintenance actions.

5 Continued System Management

After the analyses have completed and the recommendations have been executed, Lectromec continues to support your process through continued system management. While the failure severity will not change for the aircraft, the wire insulation will continue to age and reduce the system reliability.

Progressive reexaminations allow for a clearer picture of the wire degradation within the fleet. The results from past examinations guide the locations for assessment and retesting. With a better understanding of the variability across the fleet and the within the individual aircraft, squadrons can be grouped and environmental zones consolidated to reduce the level of testing.

As a starting point for most systems, the minimum time interval for reexamination often recommended is 5 years. If the wiring is in good condition, the recommended reexamination interval is expanded.

In these reevaluations, Lectromec compares the latest data with those of past examinations. Areas that have had noticeable change from the expected degradation path are examined, reported, and potential investigated further if there is a significant change from the projected degradation path.

6 Getting Started Today

If you are interested in finding out more about how Lectromec can help with quantifying the EWIS risk for your fleet's life extension program, contact us today. We will get started with a brief 30 minute discussion to review your needs and how they can best be addressed by Lectromec's process.

From this meeting you will:

- Have a better understanding of your fleet needs,
- What can be done for your fleet,
- The next steps to implement an EWIS risk assessment project.

Lectromec has the knowledge and experience to deliver the results you need to make well-informed decisions for your aircraft wire maintenance.

Start to quantify the risk today.

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