

Chapter 7: Conclusions and Recommendations

The working group was tasked to determine the adequacy of visual inspection. Chapter 5 addressed this issue and produced the following conclusions.

- Visual inspection is an effective tool in the management of wires subject to heat damage, burning, and chafing. In high-risk situations (where less than 100% detection is inadequate), visual inspection must be combined with other means of preventing or mitigating failure.
- Visual inspection could probably not be relied upon to detect degraded repair, cracking, arcing, or delamination. Where these conditions may occur, and where the consequence of wire failure is unacceptable, other means for prevention and mitigation must be used.

Though some specific degenerative conditions cannot be directly observed, correlation of other findings with the existence of these conditions is, in some cases, possible. The subject aircraft, DC-9-2, illustrates this point well. Though most specific instances of cracking in the tail cone were not located during the on-board visual inspection, the number of other finds in this zone, and the general assessment of the inspectors of this zone, seemed to correspond well with the number of cracks eventually found by other more sensitive examination and testing.

The working group was also tasked with assessing the state of wire in aged aircraft and determining the consequence of wire degradation to aircraft safety. The first aspect of this objective was addressed in Chapter 6. Determination of the safety hazards associated with the assessed state of wiring requires additional analysis presented below.

Development Approach to Specific Recommendations

According to SAE ARP 4761 the basis for a System Safety Assessment requires knowledge of three parameters:

- Failure Condition Severity
- Failure Condition Effect
- Probability of Occurrence

In the design phase, sophisticated analysis techniques and expert judgment must be used to estimate the probability of occurrence. For well-defined systems the failure condition severity and effects are calculated in an often lengthy but conceptually simple analysis.

For our analysis the probability of occurrence is relatively easy to assess from the frequency of the findings.¹ On the other hand, because our conclusions pertain to generic systems and because our findings are often latent flaws or flaw precursors, the failure condition and effects are harder to assess. As such the Working Group used a modified FHA referred to here as General Threat Analysis (GTA).

In the GTA *conditions* (not flaws) are assessed for severity given *plausible, hypothetical situations*². Hypothetical situations involve systems characterized, not by function and design, but by a set of factors, which would aggravate the degeneration of conditions into hazardous failures. The GTA begins with the development of two lists:

- A listing of the significant degenerative wire conditions from Table 5-2 or Table 5-3.

¹ Assuming, of course, that our findings on six aircraft can be considered representative of the fleet of aged revenue-service aircraft. There is no assurance that this assumption is necessarily valid.

² Plausible hypothetical situations will be those situations supported by the existence of data for that or a similar situation and/or the expert opinion that such situations could reasonably be expected to occur in the life of an aircraft.

- A listing of all generic conditions, which may aggravate – in any plausible situation – a failure associated with terminal condition of any observed degenerative condition. Note that this list does not necessarily include factors, which may have lead to or may yet advance the condition; only those factors that could make some presumed subsequent failure more or less severe.

These two lists (with expanded definitions) are presented in Table 7-1 and 7-2.

Deteriorated Repair	A currently dysfunctional wire splice assumed to have met requirements when established (e.g. a splice originally established to be environmentally sealed but no longer so). Does not include inappropriate or unacceptable repair practice. ³
Heat Damage or burnt wire	Thermal damage to insulation resulting from the presence of elevated temperature due to internal or external heating.
Vibration Damage/Chafing	Insulation wear (material loss) resulting from the repeated application of a force which if applied only once would not result in noticeable damage.
Cracked Insulation	A breach in the wire insulation that does not include breaches resulting from the direct physical contact or traumatic force (e.g. knife cut, or tears).
Arcing	One or more instantaneous electrical discharges evidenced by burnt spot on one or more wires and melted conductors
Delamination	The unraveling of a tape-wrapped insulation. The separation of layers of insulation in a multilayered construction.

Table 7-1: age-related wire conditions

Benign Environment	Low humidity, nonflammable environment. Few or no critical system wires in bundle. Uncontaminated and secured well.
Explosive Environment	An environment where there is a reasonable expectation of the presence of an explosive combination of gases during some phase of operation.
Flammable Materials	Surrounding materials that can sustain combustion. Includes the wire insulation itself (e.g. PVC but not polyimide.).
Other critical systems	The wire in question is bundled with other wires, at least one of which supplies current or signals to systems required for safe flight.
Moisture	Normal relative humidity in excess of 90% during some phase of flight (landing, takeoff, climb, cruise, decent, approach, landing), resulting in enhanced likelihood of shorting.
Vibration	Sufficient relative motion between wires or between wires and structure to cause or accentuate intermittent shorting.
Contamination	Contamination as the result of normal operation or maintenance resulting in either enhanced flammability or likelihood of shorting.
Cockpit or Electronics Compartment	High consequence failure locations within the aircraft.
Arc Tracking Potential	The presence arc-track-susceptible materials in the bundle in conjunction with those conditions which could precipitate sustained arcing
Potential for excessive resistance heating	Wires with high current loads may fail as the result of excessive resistive heating at repair or splice locations. This failure can evolve into severely burnt, cracked, or melted insulation on the offending wire and its neighbors. With excessive heat and bare wire at these locations, the potential for fire is high.

Table 7-2: service conditions

³ Such practice was assessed in the ASTF non-intrusive inspection of 81 revenue-service aircraft.

Tables 7-1 and 7-2 are the basis for generic fault trees used to assess consequence severity. These fault trees indicate the severity of the potential (worst case) consequence, if the fault were allowed to reach its fully degenerate state. Each branch of the fault tree terminates in one of three possible conditions.

Undesirable – any condition that might – if left uncorrected – lead to a slight reduction in safety margins, slight increase in crew workload, or inconvenience to the occupants.

Severe – any condition that might – if left uncorrected – lead to significantly reduced safety margins or functional capabilities, a significant increase in crew workload impairing crew efficiency, or substantial discomfort to occupants.

Critical- any condition that might – if left uncorrected – lead to a large reduction in safety margins or functional capabilities, higher workload or physical distress such that the crew could not be relied upon to perform tasks accurately or completely, or adverse effects upon occupants.

The fault trees are presented in Appendix 7.1. They represent the expert judgment of the Working Group and its advisors. They are not a representation of severity derived from an analysis of data.

Combining the assumptions of the fault trees with the results in Table 5-3 we have sufficient information to assess the safety consequences of the various conditions (severity multiplied by probability of existence) as follows:

- For each unique flaw in Table 5-3 we would individually assess the severity of the condition and its probability of existence. We make recommendations for mitigation of the specific problem.
- For each infrequent condition in Table 5-3 we list and make recommendations on all conditions whose most severe aggravating factor is “critical”.
- For each frequent condition in Table 5-3 we list and make recommendations on all conditions whose most severe aggravating factor is “critical” or “severe”.

Recommendations resulting from this analysis suggest changes and additions to maintenance programs for wires subject to the conditions and influencing factors listed. The recommendations do not specifically document how repairs should be completed once the condition has been observed. Current best practices are sufficient in this regard. Furthermore, the working group’s recommendations should not be considered a comprehensive set of design and maintenance requirements for wire installations, nor should they be considered a substitute for specific detailed analysis. Each individual wire installation requires an analysis that considers, in addition to these recommendations, application specific requirements.

Specific Recommendations

Tables 7-5-1 through 7-5-6 summarize the results of this analysis. The first column contains interacting conditions, which together with the assumed flaw result in an unacceptable situation.⁴ The last column, *recommendations*, describes the scenario and its severity and lists possible remedial action(s). The possible actions are derived from the Potential Options for Prevention or Mitigation of Consequent Failure listed in Table 5-3.

The recommendations are specific options, which are neither necessarily comprehensive nor absolutely required. For any given application, a subset of the recommendations may constitute adequate intervention. For other specific applications additional intervention may be required.

⁴ The conditions in any single row of these tables are to be considered as additive: The recommendations are for situations involving all conditions taken together. In other words, the recommendations are valid only for situations involving (or potentially involving) all conditions specified.

In addition, the appropriate application of OEM/FAA approved practice and application of the Enhanced Zonal Inspection Program will, in almost all circumstances, result in improved safety margins. The absence of specific recommendations regarding these programs should not be interpreted as a lack of their utility to address the situations described below.

The recommendations are directed in any of the following ways:

- *To Task Group 3, Maintenance Criteria:* Any specific recommendation that could be implemented by a change in aircraft operators' organization and execution of maintenance programs.
- *To Task Group 4, Standard Practices:* Any specific recommendation that could be implemented by - enhancement of Electrical Standard Practices Manual.
- *To Task Group 5, Training Programs:* Any specific recommendation that could be implemented by changes to training programs for aircraft technicians, mechanics or their corporate oversight, or FAA designated personnel responsible for oversight of aircraft maintenance or operation.
- *Aircraft Manufacturers:* Any recommendation whose implementation requires the development a programmatic or technical approach by the manufacturer
- *Aircraft Operators:* Any recommendation that can be proactively pursued by the operators.
- *Others:* Other recommendations that are not sufficiently specific to allow immediate implementation by one of the above organizations

Development of an effective intervention strategy based these recommendations assumes that we can anticipate the type of flaw that will hazard the aircraft. Unless a flaw type can be ruled out as impossible (e.g. delamination for non-tape-wrapped insulation) or highly unlikely (cracking in relatively new installations) all flaw types should be considered possible.

Table 7-5-1: Degraded Splice

Situation	Recommendations
1. Any high current circuit with one of more of the conditions identified below.	<p>This finding is relatively infrequent. Pre-emptive replacement of spliced wire with new wire or the rework of splices can minimize the potential for repairs or splices to degrade beyond acceptable limits. Any repair should be accomplished using OEM/FAA approved methods and materials appropriate for the environment (which may exceed the requirements of originally approved practice for aged aircraft). Periodic diagnostic testing (e.g. resistance evaluation, time domain reflectometry) can help to identify failing (high resistance) repairs and splices.</p> <p>Recommendations:</p> <p><u>Task Group 4:</u> Update splicing practices as necessary. Consider procedure to tag locations of splices to aid in future visual inspections.</p> <p><u>Task Group 5:</u> Update training guidelines on a regular basis to correspond to ESPM updates. Emphasize the need to inspect splices closely for obvious deterioration as well as proper materials and workmanship.</p> <p><u>Aircraft Manufacturers:</u> Where appropriate utilize design practices which facilitate the repair of electrical interconnect systems without the need for splices. Develop splice vs. replacement of wire guidelines.</p> <p><u>Aircraft Operators:</u> Review initial and proficiency training practices for splice installation and inspection. Ensure full awareness of approved materials and techniques.</p> <p><u>Other:</u> The FAA should revise AC 43-13-1B to stipulates that environmental splices are the preferred method of repairing wire in both SWAMP and non-SWAMP areas.⁵ Develop wiring configuration management software that will track the installation and location of splices. Develop best practices regarding the maximum number of splices permitted for various types of circuits based upon frequency and severity of potential splice failures.</p>
1a. Potential for high resistance heating, flammable materials	<p>Given the specified conditions, the occurrence of this fault could lead to potentially critical consequences. In this situation the potential for fire exists.</p> <p>Additional Recommendations:</p> <p><u>Aircraft Manufacturers:</u> Consider updating splicing practice to reflect special considerations associated with 1) the proximity of the splice to non-fire-retardant materials and 2) the expected wire current.</p>
1b. Potential for high resistance heating, multiple critical systems	<p>Given the specified conditions, the occurrence of this fault could lead to potentially critical consequences. In this situation the potential exists for loss of several flight-critical systems.</p> <p>Additional Recommendations:</p> <p><u>Aircraft Manufacturers:</u> Consider updating splicing practice to reflect special consideration associated with high-current carrying splices in bundles with wires supporting multiple flight-critical systems.</p>

Table 7-5-2: Heat Damaged or Burnt Wire

Situation	Recommendations
2. Any situation	This finding is relatively common. Localized heat damage (from external source or internal conductor heating) on adjacent

⁵ The milspec should appropriately reference both Mil-S-81824 and Mil-T-7928. (Currently Mil-T-7928 is inappropriately referenced.)

Table 7-5-2: Heat Damaged or Burnt Wire

Situation	Recommendations
with one or more of the specific conditions identified below	<p>wires may make these wires particularly subject to the formation of neighboring cracks and the potential for arcing or shorting. Visual Inspection can detect some conditions. Use of in-situ nondestructive testing methods may be used to detect additional insulation faults, especially if the heat damage effects a local area with several bundles, several wires within a single bundle, or a substantial length of a single wire.</p> <p>Recommendations:</p> <p><u>Task Group 3:</u> Modify the MSG3 process to include the consideration of potential heat sources when developing zonal inspection instructions</p> <p><u>Task Group 4:</u> Insure heat shield installation and maintenance are appropriately specified.</p> <p><u>Task Group 5:</u> Review visual indications of overheating in order to more precisely characterize symptoms of heat-degraded wire.</p> <p><u>Aircraft Manufacturers:</u> Review design and maintenance practices regarding the use heat shields. Establish on-condition criteria for the replacement of wire in heat-damaged bundles (external and internal heat). Develop and implement configuration management processes to prevent load creep that may result in circuits operating near the rated capacity and conductor heating.</p> <p><u>Aircraft Operators:</u> Ensure awareness of the heat-shield requirements and proper maintenance.</p> <p><u>Other:</u> Develop diagnostic technologies and techniques to identify and prevent the development of high resistance interconnects.</p>
2a. Flammable materials, cockpit or electronics bay.	<p>Given the specified conditions, the occurrence of this fault could lead to potentially critical consequences. Though the specific presence of moisture or contamination (to enable short circuiting) is not necessarily anticipated in this scenario, the specified zones and installations within these zones are critical enough to warrant extra care and precaution.</p> <p>Additional Recommendations:</p> <p><u>Task Group 3:</u> Investigate periodic, selective inspection and nondestructive testing of cockpit and electronics bay wiring.</p> <p><u>Aircraft Manufacturers:</u> Investigate periodic, selective inspection and nondestructive testing of cockpit and electronics bay wiring.</p> <p><u>Aircraft Operators:</u> Investigate periodic, selective inspection and nondestructive testing of cockpit and EE bay wiring.</p> <p>Accelerate removal of flammable materials from the cockpit and electronics bay.</p>
2b. Moisture, flammable materials, multiple critical systems	<p>Given the specified conditions, the occurrence of this fault could lead to potentially critical consequences. Effective intervention can include reduction of moisture intrusion and minimization of flammable materials in the proximity of susceptible installations. Installation of heat shielding to protect susceptible installations can eliminate or mitigate heat damage. Because embrittled wires can fail collectively, proper separation of critical system wiring is essential.</p> <p>Additional Recommendations:</p> <p><u>Task Group 3:</u> Investigate periodic, selective inspection and nondestructive testing of wire bundles supporting multiple flight critical systems.</p> <p><u>Task Group 4:</u> Insure that drip guard installation and maintenance are appropriately specified.</p>

Table 7-5-2: Heat Damaged or Burnt Wire

Situation	Recommendations
	<p><u>Aircraft Manufacturers:</u> Review design practices regarding the use of drip guards for this specific situation. For this specific situation, investigate periodic, selective inspection and nondestructive testing of wiring. Develop updated wiring separation guidelines that consider loss of multiple critical functions from a common mode failure.</p> <p><u>Aircraft Operators:</u> For this specific situation, investigate periodic, selective inspection and nondestructive testing of wiring. Investigate segregation and separation of wire installed after manufacture of the aircraft.</p>
2c. Moisture, flammable materials	<p>Given the specified conditions, the occurrence of this fault could lead to potentially severe consequences. Effective intervention can include reduction of moisture intrusion, minimization of flammable materials in the proximity of susceptible installations, and installation of fire or heat barriers.</p> <p>Additional Recommendations:</p> <p><u>Task Group 4:</u> Insure that drip guard installation and maintenance are appropriately specified.</p> <p><u>Aircraft Manufacturers:</u> Review design practices regarding the use of drip guards for this specific situation. Investigate the use of nondestructive testing to troubleshoot suspect wire installations.</p>
2d. Moisture, multiple critical systems	<p>Given the specified conditions, the occurrence of this fault could lead to potentially severe consequences. Though the presence of flammable materials is not anticipated in this scenario, the potential for a common mode failure of many or all wires in a single bundle warrants extra care and precaution. Effective intervention can include reduction of moisture intrusion and installation of fire or heat barriers. Proper separation of critical systems wiring will mitigate the consequence of collective wire failure.</p> <p>Additional Recommendations:</p> <p><u>Task Group 3:</u></p> <p><u>Task Group 4:</u> Insure that drip guard installation and maintenance are appropriately specified.</p> <p><u>Aircraft Manufacturers:</u> Review design practices regarding the use of drip guards. Investigate use of nondestructive testing to trouble-shoot suspect wire installations. Investigate use of nondestructive testing to trouble-shoot suspect wire installations.</p> <p><u>Aircraft Operators:</u> Investigate separation and segregation of wire installed after manufacture of the aircraft.</p>
2e. Flammable materials or contamination, multiple critical systems	<p>Given the specified conditions, the occurrence of this fault could lead to potentially severe consequences. The potential for a common mode failure of many or all wires in a single bundle warrants extra care and precaution.</p> <p>Additional Recommendations:</p> <p><u>Task Group 3:</u></p> <p><u>Task Group 4:</u> Ensure that wiring separation and segregation guidelines that consider loss of multiple critical functions from a common mode failure are specified.</p> <p><u>Aircraft Manufacturers:</u> Investigate use of nondestructive testing to trouble-shoot suspect wire installations. Review sources of potential contamination. Investigate use of nondestructive testing to trouble-shoot suspect wire installations.</p> <p><u>Aircraft Operators:</u> - Investigate separation and segregation of wire installed after manufacture of the aircraft. Review sources of potential contamination.</p>
2f. Flammable	<p>Given the specified conditions, the occurrence of this fault could lead to potentially severe consequences. Though moisture</p>

Table 7-5-2: Heat Damaged or Burnt Wire

Situation	Recommendations
materials, multiple critical systems, vibration	<p>is not anticipated in this scenario, the potential for vibration (i.e. the relative motion of partially exposed conductors) to induce a common mode failure of many or all wires in a single critical bundle warrants extra care and precaution. Effective intervention can include reducing vibration potential with additional bundle security (clamps, ties, etc) and minimizing flammable materials in the proximity of susceptible installations.</p> <p>Additional Recommendations:</p> <p><u>Task Group 3:</u></p> <p><u>Task Group 4:</u> Ensure that wiring separation and segregation guidelines that consider loss of multiple critical functions from a common mode failure are specified.</p> <p><u>Task Group 5:</u> Insure that training adequately addresses wire bundle segregation, clamp and tie best practices specifically with regard to high vibration areas.</p> <p><u>Aircraft Manufacturers:</u> Review design practices regarding the clamping and tying of wire bundles. Investigate use of nondestructive testing to trouble-shoot suspect wire installations.</p> <p><u>Aircraft Operators:</u> Investigate use of nondestructive testing to trouble-shoot suspect wire installations. Investigate separation and segregation of wire installed after manufacture of the aircraft.</p>

Table 7-5-3: Vibration Damage or Chafing

Situation	Recommendations
3. Any Situation involving one or more of the conditions identified below	<p>This finding is relatively common. If the chafing agent is a conductive to ground or if multiple adjacent wires are chafing, short-circuiting can occur even in the absence of moisture or a conductive contaminant (i.e. through direct physical contact). Augmenting general visual inspection with a detailed or directed visual inspection in critical areas can mitigate this condition. The necessity for rework or redesign may result from identification of chronic or widespread chafing condition. An AFCB can mitigate this condition by minimizing damage and preventing electrical fire.</p> <p>Recommendations:</p> <p><u>Task Group 3:</u> For these high consequence situations, specify more detailed inspection (possibly requiring some disassembly of support hardware) to ensure potential chafing problems are spotted and corrected. .</p> <p><u>Task Group 4:</u> Develop a catalog of unacceptable wire bundle configurations.</p> <p><u>Task Group 5:</u> Develop enhanced training to ensure proper mechanical use of OEM/FAA approved tie downs, clamps, and wire separation/segregation are used in areas were wires or cables cross or come in contact. Ensure maintenance personnel recognize potential areas of chafing.</p> <p><u>Aircraft Manufacturers:</u> Continue development of arc-fault circuit breaker technology. Develop generic implementation plans for the potential retrofit of arc-fault circuit breakers onto in-service aircraft.</p> <p><u>Aircraft Operators:</u> Ensure that maintenance personnel are aware of the need to verify the security of all mounting hardware (i.e. specify tactile inspection). Develop generic implementation plans for the potential retrofit of arc-fault circuit breakers</p>

Table 7-5-3: Vibration Damage or Chafing

Situation	Recommendations
	onto in-service aircraft.
3a. Flammable materials or contamination, cockpit or electronics bay	<p>Given the specified conditions, the occurrence of this fault could lead to potentially critical consequences. Wire or wire bundle chafing in the presence of flammable materials in the cockpit or electronics bay could result in wire-to-structure or wire-to-wire shorting arcing resulting in fire. Flammable contaminants increase the potential for ignition. More emphasis on cleaning and prevention of fluid contamination (e.g. drip shields) can mitigate the risks presented by contaminants and aid in the detection of chafing conditions. Nondestructive testing can detect wire chafing (after significant dielectric breakdown) and aid in repair.</p> <p>Additional Recommendations: <u>Task Group 3:</u> Develop situation-specific guidance to ensure the proper attention to protection and cleaning wire bundles. Develop guidance on the separation of wire bundles from non-fire-retardant materials. <u>Task Group 4:</u> Specify situation-specific standards to ensure wire bundles are properly protected and cleaned based on OEM approved practice. Specify nondestructive testing procedures for validating wire integrity in response to undiagnosed malfunctions of cockpit electrical equipment. <u>Aircraft Manufacturers:</u> Develop design modification to minimize potential for contamination.</p>
3b. Flammable materials or contamination, multiple critical systems	<p>Given the specified conditions, the occurrence of this fault could lead to potentially critical consequences. Wire chafing in the presence of flammable materials or contaminants with wires from multiple critical systems in close proximity could result in smoke and/or fire and loss of multiple flight-critical systems. Maintaining wire segregation for critical and redundant systems can mitigate the risk of multiple system failures. More emphasis on cleaning and prevention of fluid contamination (e.g. drip shields) can mitigate the risks presented by contaminants and aid in the detection of chafing conditions.</p> <p>Additional Recommendations: <u>Task Group 3:</u> Develop situation-specific guidance to ensure the proper attention to protection and cleaning wire bundles. Develop guidance on the separation of wire bundles from non-fire-retardant materials. <u>Task Group 4:</u> Specify situation-specific standards to ensure wire bundles are properly protected and cleaned. Specify updated wiring separation and segregation guidelines that consider loss of multiple critical functions from a common mode failure. Specify nondestructive testing procedures for validating wire integrity in response to undiagnosed malfunctions of flight critical equipment. <u>Aircraft Manufacturers:</u> Develop design modification to minimize potential for contamination. <u>Other:</u> Develop and understanding of how vibration and contamination (solid and liquid) interact.</p>
3c. Multiple critical systems, arc tracking potential	<p>Given the specified conditions, the occurrence of this fault could lead to potentially critical consequences. Wire chafing with arc tracking potential and wires from critical systems in close proximity could result in arcing and propagation to other wires, smoke and/or fire, and loss of multiple critical systems which can lead to excessive crew workload.</p> <p>Additional Recommendations: <u>Task Group 3:</u> Specify guidelines to ensure the proper attention to protection and cleaning wire bundles. Develop guidance to ensure the proper attention to protection of wire bundles.</p>

Table 7-5-3: Vibration Damage or Chafing

Situation	Recommendations
	<p><u>Task Group 4:</u> Specify situation-specific standards to ensure wire bundles are securely fastened and out of harm's way. Develop situation specific wiring separation guidelines that consider loss of multiple critical functions from a common mode failure. Specify nondestructive testing procedures for validating wire integrity in response to undiagnosed electrical malfunctions.</p> <p><u>Aircraft Manufacturers:</u></p>
3d. Flammable materials	<p>Given the specified conditions, the occurrence of this fault could lead to potentially severe consequences. Wire chafing in the presence of flammable materials can lead to arcing, smoke and /or in-flight fire and increased crew workload. Augmenting general visual inspection with a detailed or directed visual inspection in critical areas can mitigate this condition. Emphasis on minimizing flammable materials in close proximity to wiring can mitigate this condition.</p> <p>Additional Recommendations:</p> <p><u>Task Group 3:</u> Specify guidelines on the separation of wire bundles from non-fire-retardant materials.</p>
3e. Contamination	<p>Given the specified conditions, the occurrence of this fault could lead to potentially severe consequences. Wire chafing in the presence of contamination can lead to arcing, smoke and /or localized. Augmenting general visual inspection with a detailed or directed visual inspection in critical areas can mitigate this condition. Emphasis on cleaning of contaminants can mitigate the risk of enhanced flammability and aids in the inspection process.</p> <p>Additional Recommendations:</p> <p><u>Task Group 4:</u> Specify enhanced standards to ensure that these wire bundles are properly protected and cleaned.</p> <p><u>Aircraft Manufacturer:</u> Consider design modification to minimize potential for contamination.</p> <p><u>Other:</u> Develop and understanding of how vibration and contamination (solid and liquid) interact.</p>
3f. Multiple critical systems	<p>Given the specified conditions, the occurrence of this fault could lead to potentially severe consequences. Wire chafing with wires from critical systems in close proximity can lead to arcing and loss of multiple critical systems and increased crew workload. Augmenting general visual inspection with a detailed or directed visual inspection for bundles with multiple critical systems can mitigate this condition. Maintaining wiring separation for critical and redundant systems can mitigate the risk of multiple system failures.</p> <p>Additional Recommendations:</p> <p><u>Task Group 4:</u> Specify situation-specific separation and segregation guidelines specifically for this situation.</p> <p><u>Aircraft Manufacturers:</u></p>
3g. Feeder cable	<p>Given the specified conditions, the occurrence of this fault could lead to potentially severe consequences. Chafing of a primary power feeder cable can lead to loss of a primary power source and violent arcing with damage to other systems and structure. Augmenting general visual inspection with a detailed or directed visual inspection (emphasizing the special requirements for integrity and configuration of power feeder cables) can mitigate this condition. Nondestructive testing can detect wire chafing (after significant dielectric breakdown) and aid in expedient repair. Because there are relatively few power feeder cables, more sophisticated testing is practical and should be specified.</p> <p>Additional Recommendations:</p>

Table 7-5-3: Vibration Damage or Chafing

Situation	Recommendations
	<p><u>Task Group 3:</u> Specify more detailed inspection and testing to ensure potential chafing problems are spotted and corrected.</p> <p><u>Task Group 4:</u> Establish specific nondestructive testing protocols for power feeder cable. Establish enhanced separation requirements specifically for this situation.</p> <p><u>Aircraft Manufacturers:</u></p> <p><u>Aircraft Operators:</u> Ensure awareness of best-practice considerations for feeder cables.</p>

Table 7-5-4: Cracked Insulation

Situation	Recommendations
4. Any situation involving one or more of the conditions identified below	<p>This finding is relatively common. Concentrations of cracks (through to the conductor) may under special circumstances result arcing or shorting. Visual inspection cannot be relied upon to detect cracks directly, and while testing technologies can detect certain bulk changes in insulation properties, there is no reliable and convenient means of identifying cracks⁶. An AFCB can mitigate this condition by minimizing damage and preventing electrical fire.</p> <p>Recommendations:</p> <p><u>Aircraft Manufacturers:</u> Continue development of arc-fault circuit breaker technology. Develop generic implementation plans for the potential retrofit of arc-fault circuit breakers onto in-service aircraft.</p> <p><u>Aircraft Operators:</u> Develop generic implementation plans for the potential retrofit of arc-fault circuit breakers onto in-service aircraft.</p> <p><u>Other:</u> Research and develop nondestructive testing techniques capable of identifying and locating insulation cracks. Consider using these techniques for both inspection and troubleshooting of suspect wires. Consider utilization of such techniques to establish on-condition criteria for replacement of endemic cracking wire.</p>
4a. Flammable materials, cockpit or electronics bay	<p>Given the specified conditions, the occurrence of this fault could lead to potentially critical consequences. Though moisture may or may not be present in this scenario, the specified zones and installations within these zones are critical enough to warrant extra care and precaution. If visual inspection is used, it should be supplemented by the removal of flammable materials from these locations.</p> <p>Additional Recommendations:</p> <p><u>Task Group 3:</u> Specify accelerated removal of flammable materials.</p> <p><u>Aircraft Manufacturers:</u> Consider local design modification to replace non-fire-retardant materials.</p> <p><u>Aircraft Operators:</u> Accelerate removal of flammable materials from the cockpit and electronics bay.</p> <p><u>Other:</u> Research and develop fire retarding and suppressing materials and systems for cockpit or electronics bay use.</p>
4b. Moisture, flammable	<p>Given the specified conditions, the occurrence of this fault could lead to potentially critical consequences. The potential for fire and multiple critical system failures exists. Multiple cracks in a localized area of a bundle serving multiple critical</p>

⁶ Lectromec's Deltest does identify cracks, but it requires good physical access to the entire wire length, and can be a lengthy process.

Table 7-5-4: Cracked Insulation

Situation	Recommendations
materials, multiple critical systems	<p>systems can also result in stray currents which adversely affect the functionality of those systems. If visual inspection is used, it should be supplemented by efforts to eliminate the potential for moisture intrusion and the removal of flammable materials. Maintaining wiring separation for critical and redundant systems can mitigate the risk of multiple system failures.</p> <p>Additional Recommendations:</p> <p><u>Task Group 3:</u> Specify accelerated removal of flammable materials. Specify guidelines to minimize moisture intrusion into wire bundles (e.g. specify drip shields over bundles running under lavatories). Specify guidelines to minimize moisture accumulation on or near bundles.</p> <p><u>Task Group 4:</u> Specify situation-specific wiring separation and segregation guidelines that consider loss of multiple critical functions from a common mode failure.</p> <p><u>Aircraft Manufacturers:</u> Consider design modification to enhance wire separation requirements for this specific situation. Consider local design modification to replace non-fire-retardant materials.</p> <p><u>Aircraft Operators:</u> Accelerate removal of flammable materials.</p> <p><u>Other:</u> Research and develop fire retarding and suppressing materials and systems suitable for this situation.</p>
4c. Moisture, flammable materials	<p>Given the specified conditions, the occurrence of this fault could lead to potentially severe consequences. If visual inspection is used, it should be supplemented by efforts to eliminate the potential for moisture intrusion and the removal of flammable materials.</p> <p>Additional Recommendations:</p> <p><u>Task Group 3:</u> Specify guidelines to minimize moisture intrusion. Specify guidelines to minimize moisture accumulation on or near bundles.</p> <p><u>Aircraft Operators:</u> Accelerate removal of flammable materials.</p>
4d. Moisture, multiple critical systems	<p>Given the specified conditions, the occurrence of this fault could lead to potentially severe consequences. The potential for multiple critical system failures exists. Multiple cracks in a localized area of a bundle serving multiple critical systems can also result in stray currents which adversely affect the functionality of those systems. If visual inspection is used, it should be supplemented by efforts to eliminate the potential for moisture intrusion.</p> <p>Additional Recommendations:</p> <p><u>Task Group 3:</u> Specify guidelines to minimize moisture intrusion. Specify guidelines to minimize moisture accumulation on or near bundles.</p>
4e. Contamination, multiple critical systems	<p>Given the specified conditions, the occurrence of this fault could lead to potentially severe consequences. Concentrations of cracks (through to the conductor) can (in the presence of some conductive contaminant) result arcing or shorting. Though flammable materials may or may not be present in this scenario, the potential for combustion (with flammable contaminants) or multiple critical system failures exists. In addition, multiple cracks in a localized area of a bundle serving multiple critical systems can also result in stray currents which adversely affect the functionality of those systems. If visual inspection is used, it should be supplemented by efforts to eliminate the potential for contamination (i.e. drip or splatter shields).</p> <p>Additional Recommendations:</p>

Table 7-5-4: Cracked Insulation

Situation	Recommendations
	<p><u>Task Group 4:</u> Develop enhanced standards to ensure that these wire bundles are properly protected and cleaned.</p> <p><u>Aircraft Manufacturers:</u> Consider design modification to minimize potential for contamination.</p>
<p>4f. Flammable materials, multiple critical systems, vibration</p>	<p>Given the specified conditions, the occurrence of this fault could lead to potentially severe consequences. Concentrations of large cracks (through to the conductor) can (if brought into physical contact by vibration) result arcing or shorting. In addition, vibration of cracked insulation can accelerate the degeneration of this condition. The potential for combustion or multiple critical system failures exists. In addition, multiple cracks in a localized area of a bundle serving multiple critical systems can also result in stray currents which adversely affect the functionality of those systems. If visual inspection is used, it should be supplemented by efforts to minimize exposure to flammable materials. Additional security (clamps, ties, etc) should be used to reduce the potential for accelerated damage and failure.</p> <p>Additional Recommendations:</p> <p><u>Task Group 3:</u> Specify accelerated removal of flammable materials. Establish guidelines to ensure, and enhance where necessary, the secure installation of wire bundles.</p> <p><u>Aircraft Operators:</u> Accelerate removal of flammable materials in suspect areas.</p>

Table 7-5-5: Delamination

Situation	Recommendations
<p>5. Any situation involving one or more of the conditions identified below</p>	<p>This finding is relatively infrequent. Delaminations (through to the conductor) may under special circumstances result arcing or shorting. Visual inspection may not be able to detect delamination. (Data on the visual detectability of delamination is very limited.) If visual inspection is used, it should be supplemented by efforts to eliminate the potential for moisture intrusion and efforts to minimize exposure to flammable materials. An AFCB can mitigate this condition by minimizing damage and preventing electrical fire.</p> <p>Recommendations:</p> <p><u>Task Group 3:</u> Specify guidelines that precipitate an invasive inspection or nondestructive testing of wire bundles exposed to suspected high or low pH contaminants. Specify guidelines for decontamination procedures for wire to neutralize the effects of chemically aggressive contaminants.</p> <p><u>Aircraft Manufacturers:</u> Continue development of arc-fault circuit breaker technology. Develop generic implementation plans for the potential retrofit of arc-fault circuit breakers onto in-service aircraft.</p> <p><u>Operators:</u> Specify maintenance procedures and training to instruct technicians on use of techniques to identify suspect wires.</p> <p><u>Other:</u> Specify use of in-situ indicators to identify exposure to precipitating agents or conditions – a “canary”. (In particular, use in-situ litmus testing to identify exposure of wrapped construction wire to high or low pH solutions or contaminants.)</p> <p>Develop updated wiring separation guidelines that consider loss of multiple critical functions from a common mode failure.</p>
<p>5a. Flammable</p>	<p>Given the specified conditions, the occurrence of this fault could lead to potentially critical consequences. Though moisture</p>

Table 7-5-5: Delamination

Situation	Recommendations
materials, cockpit or electronics bay	<p>may or may not be present in this scenario, the specified zones and installations within these zones are critical enough to warrant extra care and precaution.</p> <p>Additional Recommendations: <u>Aircraft Manufacturers:</u> Consider design modification to eliminate non-fire-retardant materials. <u>Operators:</u> Accelerate removal of flammable materials.</p>
5b. Moisture, flammable materials, multiple critical systems	<p>Given the specified conditions, the occurrence of this fault could lead to potentially critical consequences. The potential for fire and multiple critical system failures exists. If visual inspection is used, it should be supplemented by efforts to eliminate the potential for moisture intrusion and the removal of flammable materials. Maintaining wiring separation for critical and redundant systems can mitigate the risk of multiple system failures.</p> <p>Additional Recommendations: <u>Task Group 4:</u> Specify situation-specific separation and segregation guidelines. <u>Aircraft Manufacturers:</u> Consider design modification to eliminate non-fire-retardant materials.</p>

Table 7-5-6: Arcing

Situation	Recommendations
6. Any situation involving one or more of the conditions identified below.	<p>This finding is relatively infrequent. Arcing can result from degraded or damaged wire or non-environmental or degraded splices. Because visual inspection will probably not detect initial arcing, efforts should focus on minimizing wire exposure to chafing, traumatic impact during maintenance operation in the area. Use of environmental splices can reduce the potential for a hazardous arc. Use of an AFCB can mitigate the consequences of arcing. Operational procedures, including Flight Standards Information Bulletin 00/08A, can also mitigate the consequences of initial failure.</p> <p>Recommendations: <u>Task Group 5:</u> Develop guidelines that ensure that all maintenance personnel, not just electrical maintenance technicians, are made aware of those actions that could result in breached wire. Small breaches (such as those resulting from the needling of wire) should not be dismissed as inconsequential. <u>Aircraft Manufacturers:</u> Continue development of arc-fault circuit breaker technology. Develop generic implementation plans for the potential retrofit of arc-fault circuit breakers onto in-service aircraft. <u>Operators:</u> Develop generic implementation plans for the potential retrofit of arc-fault circuit breakers onto in-service aircraft. Make maintenance personnel aware of the dangers of arcing. <u>Other:</u> Continue research necessary to support the development of arc-fault circuit breakers and incorporate AFCB into other circuit switching devices and selected electrical components. Conduct research into other technologies that mitigate the risk of arcing.</p>
6a. Flammable materials, cockpit or electronics bay	<p>Given the specified conditions, the occurrence of this fault could lead to potentially critical consequences. The existence of an arcing condition in the presence of flammable materials is unacceptable. The cockpit and electronics bay warrant special attention. Elimination of flammable materials can mitigate the consequences of arcing.</p> <p>Additional Recommendations:</p>

Table 7-5-6: Arcing

Situation	Recommendations
	<u>Operators:</u> Accelerate removal of flammable materials from the cockpit and electronics bay.
6b. Flammable materials, multiple critical systems	Given the specified conditions, the occurrence of this fault could lead to potentially critical consequences. The existence of an arcing condition in the presence of flammable materials is unacceptable. In addition to the fire threat, multiple critical systems may fail. Elimination or segregation of flammable materials can mitigate the consequences of arcing. Additional Recommendations: <u>Operators:</u> Accelerate removal of flammable materials. Ensure separation of wire bundles from flammable materials.
6c. Contamination, cockpit or electronics bay	Given the specified conditions, the occurrence of this fault could lead to potentially critical consequences. The existence of an arcing condition in the presence of flammable contaminants is unacceptable. The cockpit and electronics bay warrant special attention. Exposure of wire to fluid contaminants (e.g. water waste, hydraulic) and solid debris (e.g. drill shavings, foreign objects) must be minimized. Susceptible wire bundles should be kept free of flammable dust and lint build-up. Additional Recommendations: <u>Aircraft Manufacturers:</u> Consider design modification to minimize potential for contamination. <u>Operators:</u> Use additional precautions when performing maintenance in the cockpit and electronics bay.
6d. Contamination, multiple critical systems	Given the specified conditions, the occurrence of this fault could lead to potentially critical consequences. The existence of an arcing condition in the presence of flammable contaminants is unacceptable. Exposure of wire to fluid contaminants (e.g. water waste, hydraulic) and solid debris (e.g. drill shavings, foreign objects) must be minimized. Susceptible wire bundles should be kept free of flammable dust and lint build-up. Additional Recommendations: <u>Aircraft Manufacturers:</u> Consider design modification to minimize potential for contamination. <u>Operators:</u> Use additional precautions when performing maintenance in the vicinity of wire bundles supporting multiple flight-critical systems.
6e. Multiple critical systems, arc-tracking potential	Given the specified conditions, the occurrence of this fault could lead to potentially critical consequences. Though this scenario does not assume the presence of flammable materials or contaminants, arc-tracking on a bundle with multiple critical system wires can result in multiple flight-critical system failures. Separation of critical wiring into physically separate and smaller bundles can reduce the possibility of cascading failure. Additional Recommendations: <u>Task Group 4:</u> Specify enhanced separation requirements for wires with known arc-tracking potential. Specify enhanced routing requirements for wires with known arc-tracking potential that prohibit or minimize hazardous conditions such as chaffing, or damage from regular activities in/about the aircraft.

General Recommendation

There are many ATSRAC supported activities that will result in great improvement to the inspection and maintenance of aircraft electrical systems. The recommendations stemming from these activities are extremely important. The following general recommendation is meant to supplement those other recommendations. This recommendation should be considered in conjunction with those recommendations without any presumption regarding priority or importance:

Inspection and maintenance personnel should be made aware of the characteristic degenerative failure modes for specific wire types. Furthermore these personnel should be made aware of the types of wire they are likely to encounter on the aircraft they maintain. Task Group 5 should implement this recommendation by including appropriate material in their proposed training curricula.

Research Recommendations of the Intrusive Inspection Working Group

The intrusive inspection project is only a first look at state of wire in aged aircraft. As with most investigative studies of this nature, it answered some questions, failed to fully answer other questions, and raised still more questions. Cognizant of the results of this project, the working group makes the following recommendations for further research:

- The FAA should fully support its commitment to its wire degradation assessment project to begin this year. With reference to this report, the degradation assessment project should attempt to explain observed or suspected – but yet unanalyzed – phenomena on the dominant aged wire types. This research should focus on characteristic failure modes and the factors that aggravate or retard degradation. The goal of such research should be a methodology that allows us to predict with a high degree of certainty the fitness for service of wire subject to a known service environment.

As part of the degradation assessment project the FAA should analyze the effects of wire-to-wire chaffing. Wires are currently selected by the aircraft manufacturer based on their specific application and their proximity to other wires in a bundle. Maintenance and subsequent modifications may result in the mixing of wire types not anticipated during original design. There is lingering concern that wires with different insulations can damage each other if bundled together. Building upon the work of the Navy Avionics Center report TR 2333 and Airbus investigations into this issue, this suspicion should be re-examined.

Also as part of the degradation assessment project the FAA should analyze the effects of common contaminants on wire. Special attention should be paid to corrosion control compounds.

This follow-on effort should be fully consistent with and build upon the work presented in the Intrusive Inspection Working Group Report. In particular, the analysis of wire bundles taken from retired aircraft is an essential part of any such effort. The FAA should consider pursuing further laboratory testing per the intrusive inspection protocol on the currently available specimens. This would include:

- Perform additional laboratory visual analysis of 747-, L1011-, and A300- specimens.
 - Perform additional laboratory tests based on original intrusive inspection laboratory test protocol.
 - Investigation of the effects of lavatory fluid contamination of PVC insulation. Also investigate other fluids/chemicals used in aircrafts.
 - Determine probable cause of the observed degenerative conditions (e.g. internal or external heating, fluid contamination, aging).
 - For PVC/Glass/Nylon, correlate the specific symptoms of aging with the mechanical and electrical properties of the insulation.
- Excessive wire heating presents the risk of electrical fire or ignition of surrounding combustible materials. High resistance inter-connections⁷ where electrical heating is sufficient to damage the wire insulation are typically detected by visual inspection for embrittled, charred or missing insulation. However, the relationship of observable thermal damage to wire hot enough to hazard the aircraft is still unknown. It is recommended that the FAA conduct research to determine how best to manage this issue.

⁷ Such high resistance inter-connections (e.g. splices, terminals, connectors) are a function of aging or inappropriate maintenance.

- The FAA should aggressively pursue and promote arc-fault circuit breaker development. Many of the recommendations of this report specify this as a potential option to eliminate or mitigate electrical hazards.
- The FAA should aggressively pursue and promote the development of nondestructive test equipment for aircraft wiring. Many of the recommendations of this report specify this as a potential option to eliminate or mitigate electrical hazards.
- By their very nature connectors and terminals are designed to be serviceable, and they are physically localized. This suggests that these components should be less problematic than wires, which may stretch from one end of the aircraft to the other. On the other hand their relatively frequent handling and exposure to collateral damage, make connectors, terminals, their lead wires subject to repetitive stress and accidental damage. Furthermore, experience has shown that we cannot rule-out the possibility of a fire resulting from a defective or broken connector.

The intrusive inspection project did not fully consider connector issues. The military and commercial aviation community should sponsor efforts to scope the problem and establish research projects and maintenance guidelines to address the issue.

- Though wires and connectors are the most obvious component in electrical interconnect systems, there are others. The FAA should investigate the physical and functional integrity of any electrical system component whose failure could hazard the aircraft. This includes: circuit breakers, relays, switches, wire support and bundling systems (including conduit), shielding, ground blocks, etc.
- The working group observed wires with breaches and non-environmental splices, and found reduced insulation resistance in certain wet wires. Though the working group did not document wire bundles with numerous, collocated breaches or non-environmental splices, the possibility should be considered. In the presence of moisture this situation could result in stray electrical currents affecting multiple systems. The FAA should investigate the possibility of this situation and its potential to hazard the aircraft.