

## Chapter 5: Comparison of Inspection and Testing Results

Visual inspection, on-board testing, and laboratory analyses have distinct sensitivities and limitations. The results of the on-board testing can be used to identify specific limitations of the visual inspection, and the results of the laboratory testing – presumably the most discriminating test for wire insulation degeneration – can be used to identify specific limitations of the on-board testing.

Table 2-1 contains a number of observed conditions, which we may classify as direct or indirect contributors to failure. A *direct contributor to failure* is a condition, which, in its fully degenerated state, could itself result in failure. An *indirect contributor to failure* is one that, in its fully degenerated state, would not in itself constitute a failure condition, but might lead to the development of a direct contributor to failure. A loose clamp (an indirect contributor to failure) could, for instance, lead to chafing (a direct contributor to failure). Because indirect contributor to failure will not always lead to the development of direct contributor to failure, they are from a risk point of view less critical than direct contributors to failure.

Column 1 of Table 5-1 is a listing of all categories from Table 2-1 that we classified as direct contributors<sup>1</sup>. Columns 2, 3 and 4 indicate whether the corresponding category is a result of a degenerative condition (as opposed to mis-installation or trauma<sup>2</sup>), whether the threat includes the significant potential of fire, and whether the threat has substantial common mode failure potential<sup>3</sup>. Mis-installation, traumatic damage, and threats other than fire and common mode failure (i.e. single point failures leading to loss of functionality) are well understood and well managed by best-practice design and maintenance programs, and will not be considered further. Though, connectors and terminals have significant failure modes they too are well managed by best-practice design and maintenance programs, and they too will not be considered further.<sup>4</sup> The conditions which are the focus of this report are highlighted.

Tables 5-2 contains quantitative and other objective findings information for each selected class of conditions<sup>5</sup>. The visual and NDT findings are quantitative, while the laboratory results are arranged into magnitude categories.<sup>6</sup> A “0” in the column, additional lab findings, indicated no findings in addition to those found by on-aircraft visual and NDT, a “+” indicates some additional findings, and a “++” indicates many findings in addition to what was discovered in the field.

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<sup>1</sup> The categories of vibration damage and abrasion (non-traumatic) have been combined into a single category.

<sup>2</sup> Traumatic damage differs from degenerative conditions in three important ways:

- it's causes and nature are well understood,
- it can usually be effectively managed by proper training and maintenance, and
- the potential for common mode failure is less than with degenerative conditions.

<sup>3</sup> A common mode failure is the simultaneous or compound failure of several components or systems attributable to a single cause. (Defined more generally in SAE 4761 as “an event which affects a number of elements otherwise considered to be independent.”)

<sup>4</sup> Determination of hazardous conditions involving connectors or terminals involves the observation of usually very visible conditions, on small components, with generally good accessibility.

<sup>5</sup> Delamination, discovered first in the laboratory, has been added to the list.

<sup>6</sup> Because the lab tests were sampling inspections, it is not possible to make a direct comparison of number of flaws found with visual inspection or NDT testing.

|                                  | Degenerative | Fire Hazard | Common |
|----------------------------------|--------------|-------------|--------|
| <b>Connectors and Terminals</b>  |              |             |        |
| Insert Damage or Deterioration   | ✓            | ✓           |        |
| Connector corrosion              | ✓            |             |        |
| Contact fretting                 | ✓            | ✓           |        |
| Contact arcing                   | ✓            | ✓           |        |
| Condition or Security of Grounds | ✓            |             |        |
| Heat Damaged Terminals           | ✓            | ✓           |        |
| Corroded Terminals               | ✓            | ✓           |        |
| <b>Wire</b>                      |              |             |        |
| Inadequate Repair                |              | ✓           |        |
| Degraded Repair or Splice        | ✓            | ✓           |        |
| Heat Damage/Burnt Wire           | ✓            | ✓           |        |
| Arcing                           | ✓            | ✓           | ✓      |
| Vibration/Chafing                | ✓            | ✓           |        |
| Collateral Damage                |              | ✓           |        |
| Traumatic Damage                 |              | ✓           |        |
| Cracked Insulation               | ✓            | ✓           | ✓      |
| Wire Corrosion                   | ✓            |             |        |
| Broken Shield                    |              |             | ✓      |
| Broken Conductor                 |              |             |        |
| Exposed Shield                   |              |             |        |
| Exposed Conductor                |              | ✓           | ✓      |

**Table 5-1: Direct Potential Hazards**

| Wire Conditions                        | Findings                          |                                     |              |                         |
|--|-----------------------------------|-------------------------------------|--------------|-------------------------|
|  | Significant Findings in All Zones | Significant Findings on Preselected | NDT Findings | Additional Lab Findings |
| Degraded Repair or Splice <sup>7</sup> | 2                                 | 0                                   | ≤ 7          | 0                       |
| Heat Damage or Burnt Wire <sup>8</sup> | 15                                | 7                                   | 2            | +                       |
| Vibration Damage/Chafing <sup>9</sup>  | 46                                | 8                                   | 2+           | +                       |
| Cracked Insulation                     | 48                                | 16                                  | 12+          | ++                      |
| Arcing                                 | 2                                 | 0                                   | 2            | 0                       |
| Delamination                           | 1                                 | 0                                   | 1            | 0                       |

**Table 5-2: Observed Wire Conditions**

Table 5-3 is derived from the information in Table 5-2. The columns under the “found by” heading may contain one of the following:

- “A” for (almost) always found by this method, an
- “F” for frequently found (greater than 50% chance of discovery), an
- “O” for occasionally found (between 5 and 50 chance of discovery),
- “S” for seldom found (less than 5% chance of discovery).

Though these designations are defined quantitatively, our assessment is somewhat subjective: Because the conditions detected by the visual inspection do not correlate one-to-one with NDT or lab findings<sup>10</sup>, and because lab results are not comprehensive, the working group had to use its best judgment to categorize the detectability of conditions.

Frequency (of findings on the six subject aircraft) is also somewhat subjective. Greater than 10 findings found visually or by NDT constituted a *frequent finding*, between two and nine findings constituted an *infrequent finding*, and a single finding would have been considered *unique*.

<sup>7</sup> There were 7 splices within bundles which allowed leakage current to flow resulting in NDT findings. It is not clear how many (if any) of these splices were intended to be environmentally sealed.

<sup>8</sup> All visual findings were on aircraft DC-9-2.

<sup>9</sup> Some Deltest NDT findings were inconclusive with regard to the cause of the insulation breach.

<sup>10</sup> Deltest, for instance, finds breaches regardless of the cause. A degraded splice does not necessarily result in leakage current, and an un-degraded splice is not necessarily environmentally sealed.

| Wire Conditions           | Found By          |              | Frequency |            |        | Potential Options for Prevention or Mitigation of Consequent Failure                                   |
|---------------------------|-------------------|--------------|-----------|------------|--------|--|
|                           | Visual – All Wire | On-board NDT | Unique    | Infrequent | Common |  |
| Degraded Repair or Splice | S                 | F            |           | ✓          |        | Staggering of splices, design modification, re-fabrication with environmental splice, periodic rework. |
| Heat Damage or Burnt Wire | F                 | S            |           |            | ✓      | Visual inspection, periodic rework, design modification, installation of heat or fire shielding.       |
| Vibration Damage/Chafing  | F                 | S            |           |            | ✓      | Visual inspection, AFCEB, NDT, design modification, periodic rework.                                   |
| Cracked Insulation        | O                 | F            |           |            | ✓      | AFCEB, DelTest, periodic rework, wire segregation or separation  |
| Arcing                    | O                 | A            |           | ✓          |        | AFCEB, design modification, wire segregation or separation, periodic rework.                           |
| Delamination              | O                 | F            |           | ✓          |        | AFCEB, design modification, wire segregation or separation, contamination prevention and clean-up      |

**Table 5-3: Observed Wire Conditions – Derivative Results**

Potential options for prevention or mitigation of consequent failure can include (but are not limited to) the following:

- **Design modification (general):** renewal of the wire installation using approved materials, design, or installation practice. May also include rework of the wire environment to eliminate aggravating factors (e.g. moisture).
  - **Installation of Fire or heat shield:** Separation of potential ignition sources from flammable materials.
  - **Installation of Contamination shielding:** Sheathing to protect wire from contaminants which might precipitate a short circuit or serve as a fuel source for a fire.
  - **Wire separation or segregation:** Approved routing or re-routing of wire and wire cables to limit exposure to common mode failure.
- **Periodic rework (general):** renewal of the wire installation using original or approved alternative materials, design and installation practice.
  - **Rework with environmental splice:** Many older repair splices were never established as moisture proof and those that were may have used technology inferior to what is available today. Rework of certain splices may establish or re-establish the environmental sealing reducing the potential for short circuit and increased resistance due to corrosion of the conductors at the joint.

- **Staggering of splices:** Positioning of splices with sufficient physical separation such that leakage current from one degraded splice to another is not likely.
- **Visual inspection:** Zonal, directed, or detailed visual inspection for a specific condition. The ATSRAC Task 3 Working Group is addressing what the content of such inspection should be and how these inspections should be specified.
- **Non-destructive Testing (NDT):** Currently available electrical test equipment can identify anomalous conditions indicative of failed or seriously damaged wire. Emerging NDT has the potential to identify wire failure precursors (e.g. chafing, dielectric degradation of the insulation).
- **Arc Fault Circuit Breakers (AFCB):** Arc Fault Circuit Breakers can minimize the occurrence of intermittent high impedance shorting which can serve as an ignition source for fires. Current circuit breakers may not trip under these circumstances.

The following conclusions regarding the adequacy of visual inspection are based on the assumption that the intrusive visual inspection was both thorough and representative. Because only six aircraft were inspected for a total of less than one thousand wire observations, certain flaws were not often enough observed to allow us to ascribe high certainty to our estimates of detectability. Nevertheless the working group feels that the following conclusions are reasonable and conservative. When combined with the results of other ATSRAC tasks, this information can serve as a good foundation for general advisory material.

- Visual inspection is an effective tool in the management of wires subject to heat damage, burning, and chafing. In high-risk situations (where frequent – but not 100% - detection is inadequate), visual inspection must be combined with other means of preventing or mitigating failure.
- Visual inspection should 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.