WIRE DEGRADATION STUDY
PHASE I RESULTS

Prepared for:

Aging Transport Systems Rulemaking Advisory Committee

25 April 2002

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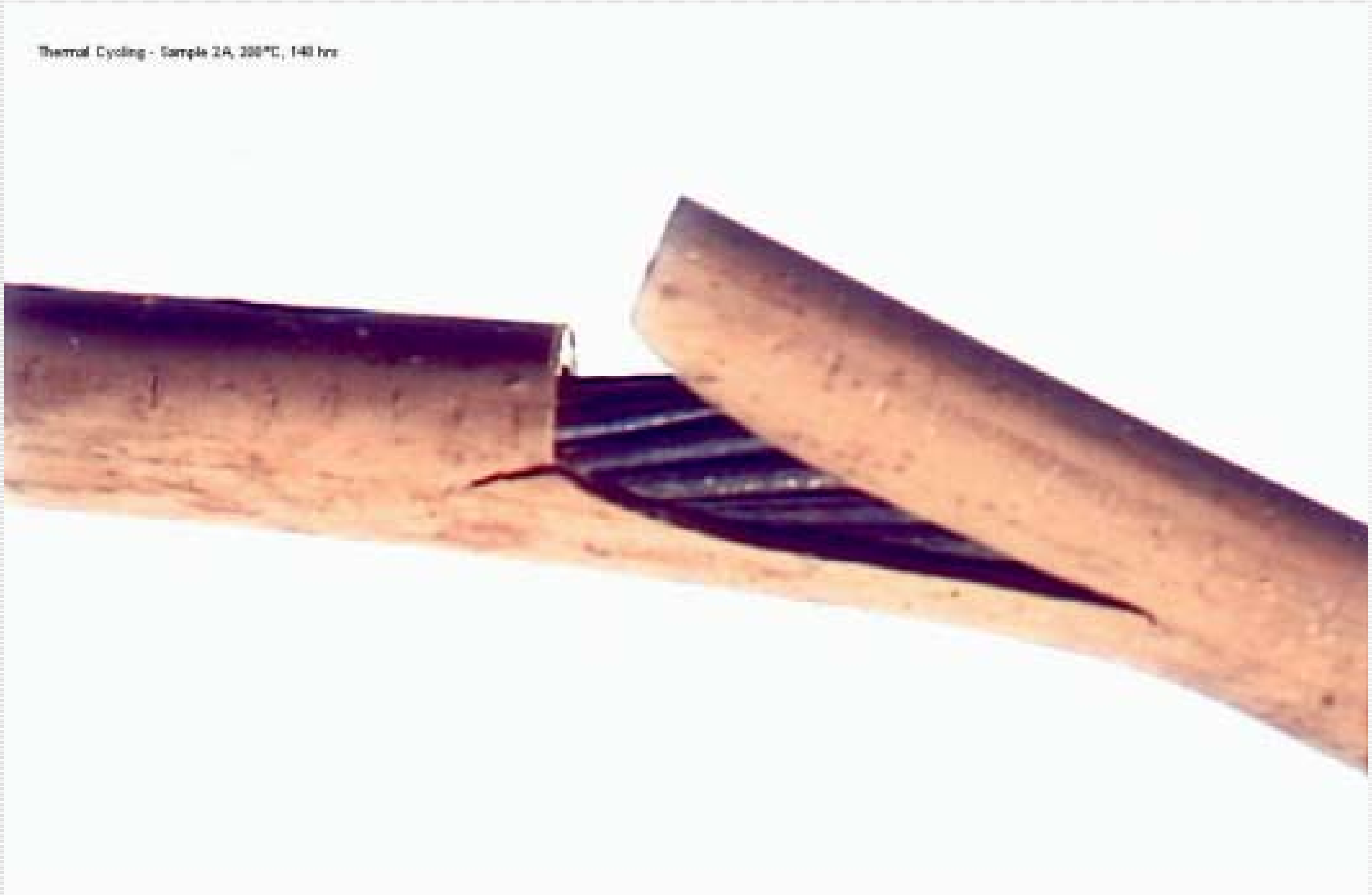
WIRE DEGRADATION STUDY



WIRE DEGRADATION STUDY

Purpose

Identify degradation levels of currently used electrical wire insulation types as part of an effort to ensure safe, long term operation of commercial aircraft electrical interconnect systems

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Goals

- Determine degradation mechanisms
- Develop characterization data for the degradation mechanisms
- Characterize effect(s) of major perturbations to the aging process
- Model degradation behavior (Algorithms)
- Establish behavior/degradation relationships

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Schedule

- **Phase I – Planning** **9/1/01 – 4/30/02**
- **Phase II – Execution** **5/1/02 – 12/31/02**
- **Phase III – Reporting** **1/1/03 – 8/31/03**

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PHASE I - Planning

- **Determined the major degradation modes and influencing conditions**
  - **Comprehensive list**
  - **Considered the universe of variables**
  - **Prioritized to fit scope of effort**
- **Designed experiments to quantify/assess degradation modes**
- **Coordinated with major stakeholders**
- **Developed Quality Assurance Plan for test program**

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Coordination w/Stakeholders

- **Direct teaming with technical experts**
  - **Established team lead**
  - **Coordinated planning & execution**
  - **Built team with knowledge & skills**
- **Indirect teaming with aerospace industry**
  - **Obtained details related to environments, wire problems, wire degradation modes**

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Direct Team

- Raytheon Technical Services (lead)
  Brookhaven National Laboratories
  Sandia National Laboratories
  Lectromechanical Design Company
  Qualstat Services

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Indirect Team

Boeing Company
QinetiQ
Bombardier Aerospace
United Airlines
Barcel/CDT
NASA
Tyco Electronics (Raychem)
Dupont Company
Airbus Industries
Northwest Airlines
SR Technics
Tensolite Company
Airtran

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Degradation Modes

- **Performed extensive literature search**
  - **Qualified Product List performance data**
  - **FAA Intrusive/Non-Intrusive Inspection**
  - **Incident reports (Commercial and Military)**
  - **Professional organization reports & documents (SAE, NEMA, ASTM, IEEE, etc)**
- **Received direct aircraft industry input**
  - **Problem areas**
  - **Wire failure modes**
  - **Related conditions and environments**
- **Received industry comments on test methodology and test plan**

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Major Drivers/Factors of Degradation

- **Temperature**
  - **polymers soften/harden, out-gas, change state, accelerates other temperature dependant variables (oxidation, hydrolysis, and other chemical reactions)**
- **Humidity**
  - **enhances brittleness & molecular changes**
- **Fluids**
  - **high pH cleaners breakdown chemical structure, polymer swelling**
- **Mechanical stress**
  - **strains can induce yielding or fatigue, accelerate other stresses**
- **Electrical Potential**
  - **higher voltages can punch holes in insulation**
- **Time**
  - **common factor of all drivers**

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Other Degradation Drivers Not Included

- **Left out due to practical boundaries of program resources**
  - **Biological & Low Level Radiation**
  - **Environmental contamination (exhaust gases, pollution, Ozone, NOx, etc.)**
  - **Higher Level Radiation**
    - **Ultra-violet**
    - **Gamma**
  - **Low level electrical potential**
  - **Vacuum (pressure)**

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Information Received from Survey

- **Inputs to test methodology**
- **Inputs to test plan**
  - **Questioned some test methods**
  - **Recommendations of additional test methods**
  - **Recommendations of stressors**
- **Aircraft environmental conditions**
- **Anecdotal experiences of wire degradation modes**

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Degradation Evaluation Method

- **Expose wire samples to different sets of single & multiple environments**
- **Measure characteristics of the material(s) through standard and novel test methods**
- **Analyze data collected**
- **Compare to noted field issues**
- **Incorporate results into a degradation model**

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Test Methods

- **Dielectric Withstanding Voltage (DWV)**
- **Insulation Resistance (IR wet, IR dry)**
- **Conductor Resistance**
- **Die-electric Loss (Dissipation Factor)**
- **Time Domain Reflectometry (TDR)**
- **% Elongation & Tensile Strength**
- **Weight Loss**
- **Flammability**
- **Functional Performance Testing**
- ***Hardness Modulus***
- ***Tera-Hertz Reflectometry***
- ***Inherent Viscosity***
- ***Kinetics and mass loss by Thermal Gravimetric Analysis (TGA)***
- ***Density***
- ***Oxidation Induction Time***
- ***WIDAS***
- ***Fourier Transform Infrared Spectroscopy (FTIR)***
- ***Ultra-violet/Visible Spectroscopy (UV/VIS)***

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Environmental Exposures

- **Mechanical aging**
  - **Bending and flexing**
  - **Vibration w/abrasion**
- **Temperature aging**
- **Temperature cycling**
- **Fluid aging w/temperature and mechanical**
- **Humidity aging w/temperature and mechanical**
- **Electrical aging in all environments**

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Mechanical Degradation

- **Unbent sample**
- **10x static wrap (see AS50881A)**
- **10x dynamic bending**
  - **ASTM D3032 procedure for 2 cycles**
- **3x dynamic bending**
  - **ASTM D3032 procedure for 2 cycles**
- **Vibration/abrasion – MIL-W-22759 mark durability method or SAE AS4373 method 711 abrasion (modified)**

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Temperature Environments

- **Temperature cycling – SAE AS4373 Procedure**
  - **100 cycles from –55C to +85C**
- **Standard temperature exposure**
  - **Range of temperatures for each insulation type varies between 100C and 300C depending on the material type**
  - **Lowest temperature slightly above wire temperature rating**

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Fluid Soaking

- **Fluids**
  - **Common fluids seen by exterior aircraft components**
    - **Hydraulic fluid**
    - **Airframe cleaner**
    - **Glycol based de-icing fluid**
- **Immerse 1 hour @ 50C**
- **Temperature exposure (bake)**
  - **Temperature determined from first round of testing**
  - **Time of exposure determined from first round of testing**

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Humidity/Temperature Aging

- **Humidity levels**
  - **70%**
  - **85%**
  - **100%**
- **Temperature levels**
  - **70C to 95C**

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Wire Types for Evaluation

- **Aromatic Polyimide (BMS13-51)**
- **XL-Alkane-Imide (BMS13-42A & B)**
- **PVC/Glass/Nylon (BMS13-13)**
  - **to use PVC/Nylon versions in tests**

Wire Types for Future Evaluation

- **XL-ETFE (BMS13-48)**
- **PTFE/Polyimide/Composite (BMS13-60)**
- **Aromatic Polyimide (AK/CF Europe)**
  - **Extruded outer layer of FEP or PTFE**

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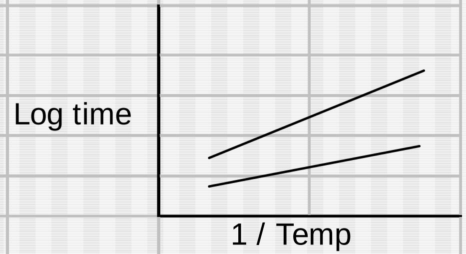
Modeling Degradation Times and Property Results

Model : Log Time = [a + b * (1 / Temp) + c * (# Cycles stressed)]

f (Property) = model of similar form? linear, quadratic, etc.



Model developed for each combination of Dynamic Stressor Test and Aging Condition. Several models per wire type.
How are lines/curves different? Compare intercepts (a) and slopes (b) and other coefficients (c); linear, quadratic, etc.
Will also compare life estimates (e.g. temperature indexes) versus the design variables & interactions :

Index = f [wire type, orientation (straight; 10x, 6x, 1x wrap), dynamic stressor test, humidity, interactions]

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Perturbations Identified

- **Wiring system design anomalies**
  - **Uncontrolled chemical / mechanical / thermal stresses**
  - **Electrical overload & arcing**
- **Wirings system installation anomalies**
  - **Hot Stamp Marking Process**
  - **Excessively Tight Bends**
  - **Excessive force during pull through**
- **Wiring system maintenance practices**
  - **Excessive flexing**
  - **Handholds**
  - **Debris from drilling & grinding**
- **Operational Extremes**
  - **Exposure to dust & debris, sand**
  - **Lightning**
  - **Excessive vibrations**

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Quality Assurance Plan

- **Results must be**
  - **High Quality**
  - **Traceable**
  - **Defensible**
- **Strict Controls for**
  - **Documentation (Test procedures and Data)**
  - **Equipment calibration**
  - **Handling, storage, shipping of specimens**
- **Utilizes performance based independent assessments of the laboratories including audits (Raytheon QA department)**
- **Roles & responsibilities of participants**

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PHASE II

Execution

- **20 month effort**
- **Raytheon Technical Services Company**
  - **supported by the direct team**
- **Perform wire aging, testing and data collection**
- **Schedule**
  - **5/1/02 – 12/31/02**

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Evaluation Program

- **Mechanical / temperature / fluid aging**
  - **approximately 147 test setups**
- **Humidity / temperature aging**
  - **approximately 25 test setups**

172 total test setups

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		CONDITIONS									
		A/A[2]	B	C/C[3]	D	E/E[3]	F	G	H	I	J
		0% RH - ovens			70% RH		85% -25% RH, cycled	85% RH		100% RH (Immersion)	
WIRE TYPE	STRESSORS	Straight	10x static strain	6x/1x static strain	10x static strain	6x/1x static strain	10x static strain	Straight	10x static strain	Straight	10x static strain
PI	1. No "stressor" protocol (only DWV test)	260[2], 280, 300[2]	260, 280, 300	300/300	95	95/95					95
PI	2. Dynamic bend (rollup/down x 2) - 10x mandrel (ASTM std.)	250[2]*, 265, 280, 300[2]	250, 280, 300		70*, 95		70	95*	70, 95	95	45, 70, 95
PI	3. Dynamic bend (rollup/down x 2) - 3x mandrel	250, 275, 300	280		Unfailed to J			Unfailed to J			Others to failure, 70
PI	4. Temp Shock (100 cycles, -55° to +85° C)	1	3								
PI	5. Vibration (abrasion)	3	1								
PI	6. Fluid soak preceded by 10x mandrel bend	1	1								
PI/PTFE	1. No "stressor" protocol (only DWV test)	a[2], b, c[2]	3								
PI/PTFE	2. Dynamic bend (rollup/down x 2) - 10x mandrel (ASTM std.)	260[2], 275, 285, 300[2]	3						95		70, 95
PI/PTFE	3. Dynamic bend (rollup/down x 2) - 3x mandrel	3	1								
PI/PTFE	4. Temp Shock (100 cycles, -55° to +85° C)	1	3								
PI/PTFE	5. Vibration (abrasion)	3	1								
PI/PTFE	6. Fluid soak preceded by 10x mandrel bend	1	1								
XLETFE	1. No "stressor" protocol (only DWV test)	a[2], b, c[2]	3								
XLETFE	2. Dynamic bend (rollup/down x 2) - 10x mandrel (ASTM std.)	200[2], 220, 235, 250[2]	200, 230, 250								95
XLETFE	3. Dynamic bend (rollup/down x 2) - 3x mandrel	3	1								
XLETFE	4. Temp Shock (100 cycles, -55° to +85° C)	1	3								
XLETFE	5. Vibration (abrasion)	3	1								
XLETFE	6. Fluid soak preceded by 10x mandrel bend	1	1								
XPI	1. No "stressor" protocol (only DWV test)	3	3								95
XPI	2. Dynamic bend (rollup/down x 2) - 10x mandrel (ASTM std.)	4	3						70, 95	95	70, 95
XPI	3. Dynamic bend (rollup/down x 2) - 3x mandrel	3	1								
XPI	4. Temp Shock (100 cycles, -55° to +85° C)	1	3								
XPI	5. Vibration (abrasion)	3	1								
XPI	6. Fluid soak preceded by 10x mandrel bend	1	1								
PVC/Nylon	1. No "stressor" protocol (only DWV test)	3	3								
PVC/Nylon	2. Dynamic bend (rollup/down x 2) - 10x mandrel (ASTM std.)	4	3								95
PVC/Nylon	3. Dynamic bend (rollup/down x 2) - 3x mandrel	3	1								
PVC/Nylon	4. Temp Shock (100 cycles, -55° to +85° C)	1	3								
PVC/Nylon	5. Vibration (abrasion)	3	1								
PVC/Nylon	6. Fluid soak preceded by 10x mandrel bend	1	1								

Notes: * – these conditions are not expected to fail, but will be removed in one year and placed in the WIDAS test to failure.

2 – Condition A2 will be run at the identified temperatures.

3 – Condition C3 and E3 will be run at the identified temperatures.

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		CONDITIONS	
		A/A[2]	B
		0% RH- ovens	
WIRE TYPE	**STRESSORS**	Straight	10x static strain
PI	1. No "stressor" protocol (only DWV test)	260[2], 280, 300[2]	260, 280, 300

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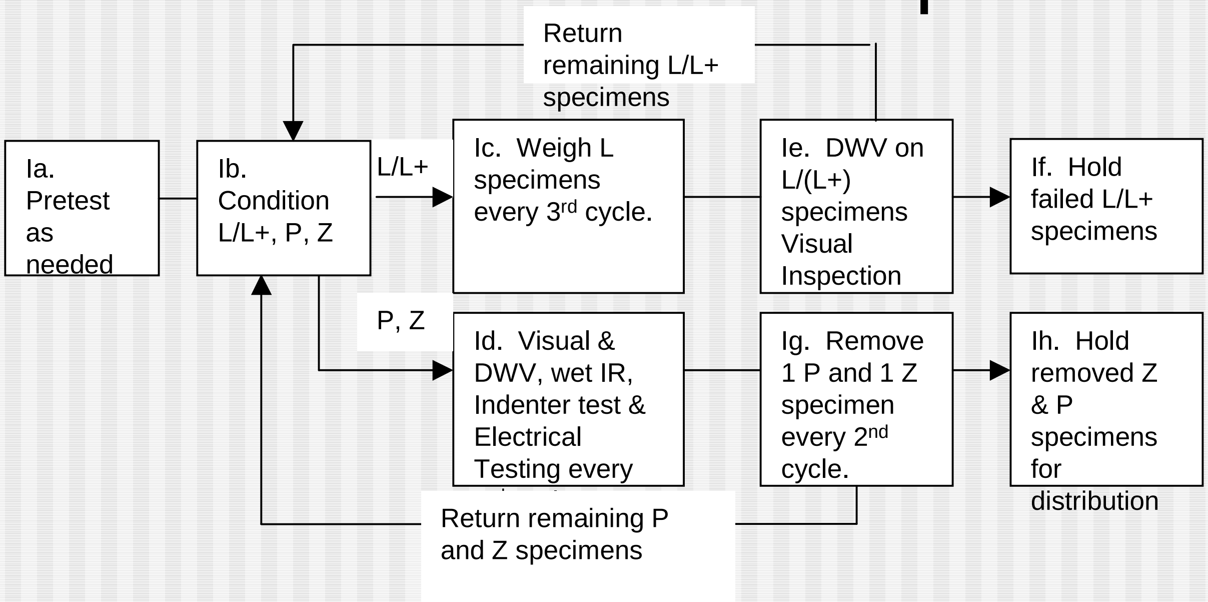
Test Protocol for 1 Stressor @ 1 Condition for 1 Temperature



11 Specimens (L), 14 Property Specimens (P), 6 control specimens (z)

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PHASE III

Reporting

- **Data analysis**
- **Formulate Models**
- **Final Report**

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Questions

&

Answers