A Composite NDI Training Course to Address the Growing Need for Composite Laminate Inspections

Airlines for America NDT – September 2016

Filament Diameters

- Carbon, Glass 7 microns
- Boron 50 microns
- Kevlar 12 microns
- Human Hair 75 microns

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FAA Airworthiness Assurance Center

Alex Melton
Delta Air Lines

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FAA
Presentation Overview

Introduction and Background

Class Modules and Objectives

Hands-On Training and Proficiency Specimen Set

First Deployment of the Composite NDI Training Class
Motivation for Composite NDI Training Class

Motivation - Extensive/increasing use of solid laminate composites on commercial aircraft and need for inspectors to maintain a level of proficiency via training and hands-on practice.

**Composite Structures on Boeing 787 Aircraft**

- Carbon laminate
- Carbon sandwich
- Fiberglass
- Aluminum
- Aluminum/steel/titanium pylons

**Airbus A350 XWB**

- 19% AUIALI
- 6% Steel
- 14% Titanium
- 8% Misc.

altairenlighten.com
**Motivation for Composite NDI Training Class**

**Boeing 787**

1,161 Ordered  
455 Delivered  

All Nippon Airways – 83, 50  
United – 49, 30  
American – 42, 17  
Delta – 18, 0

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**Airbus A350**

810 Ordered  
36 Delivered  

Qatar Airways – 80, 10  
United – 35, 0  
American – 22, 0  
Delta – 25, 0

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http://www.airbus.com/company/market/orders-deliveries/
Evaluate the performance of conventional ultrasonic inspection methods for flaw detection in solid laminate structures. 70 inspectors from 14 airlines participated.
**POD Curves for 12-20 Ply Solid Laminate Family**

**Individual and Cumulative Comparisons**

### Overall:
- $POD_{[90/95]} = 1.29''$ dia.

### Constant Thickness (12, 20, 28 plies):
- $POD_{[90/95]} = 0.86''$ dia.

### Complex Geometry (tapered, curved, substructure, fasteners, honeycomb):
- $POD_{[90/95]} = 1.49''$ dia.

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**False Calls:**
- Constant thickness = 0.4/inspector
- Complex Geometry = 4.0/inspector
- 34 ft.$^2$ inspection area
Composite NDI Training Survey

In addition to the POD experiment, a Composite NDI Training Survey was conducted.

Question 16 - In your opinion, do Level I, II, and III training/qualifications provide the necessary expertise for both metal and composite NDI or should additional training take place for composite inspections?

Airline and MRO NDI Survey

<table>
<thead>
<tr>
<th>Composite NDI Training Survey Participants</th>
<th>Completed Survey</th>
</tr>
</thead>
<tbody>
<tr>
<td>AAR-ASI (Indy)</td>
<td>Yes</td>
</tr>
<tr>
<td>American Airlines (Tulsa)</td>
<td>Yes</td>
</tr>
<tr>
<td>Aviation Technical Services, Inc (Seattle)</td>
<td>Yes</td>
</tr>
<tr>
<td>Delta Air Lines (Atlanta)</td>
<td>Yes</td>
</tr>
<tr>
<td>Delta Air Lines (MN)</td>
<td>Yes</td>
</tr>
<tr>
<td>FedEx (Indy)</td>
<td>Yes</td>
</tr>
<tr>
<td>FedEx (Los Angeles)</td>
<td>Yes</td>
</tr>
<tr>
<td>Goodrich Aerostructures (Chula Vista)</td>
<td>Yes</td>
</tr>
<tr>
<td>Kaltta Air LLC (Michigan)</td>
<td>Yes</td>
</tr>
<tr>
<td>Rohr Aero Services LLC (Alabama)</td>
<td>Yes</td>
</tr>
<tr>
<td>Southwest Airlines (TX)</td>
<td>Yes</td>
</tr>
<tr>
<td>Timco (Georgia)</td>
<td>Yes</td>
</tr>
<tr>
<td>United Airlines (Houston)</td>
<td>Yes</td>
</tr>
<tr>
<td>United Airlines (San Fran.)</td>
<td>Yes</td>
</tr>
<tr>
<td>UPS (KY)</td>
<td>Yes</td>
</tr>
<tr>
<td>US Airways (PA)</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Only 25% of responders currently have special composite NDI training in place
The POD experiment and NDI Training Survey led to several key recommendations resulting in the Composite Inspector Training Class.

- Increased exposure to representative composite inspections – common industry NDI Proficiency Specimens
- Increased, focused composite NDI training
- Enhanced NDI procedures – deployment, signal interpretation, clear schematics showing structural configuration
  - Use of inspection coverage aids
  - Divide large area inspections into a number of smaller regions
  - Follow procedures
- Identified need for specific training that specifically addresses composite inspection
  - Unique challenges associated with composites
  - Additional routine exposure to composite laminate inspections
Composite Laminate NDI Training Class

Class Definition – General Training Content (cont.)

- **Target Class Length** – 2 days (1/2 classroom, 1/2 hands-on)
- **Format** – stand-alone course but assumption is minimum of Level I student
- **Instructor** modifies for specific needs

*Goal of training is to enhance aircraft safety & optimize aircraft utilization by improving NDI flaw detection performance in composite aircraft structure.*
Class Modules

1. Introduction, Objectives & Expected Outcome from Class
2. Composite Awareness – Materials, Design, Fabrication and Use
3. Composite NDI – Theory and Practice
4. Special Cases - Challenges & Lessons Learned
5. NDI Proficiency Specimens
6. Hands-On Exercises
2. Composite Awareness – Materials, Design, Fabrication and Use

What are Composites?

Common Materials used

Carbon, Glass 7 microns
Kevlar 12 microns
Boron 50 microns
Human Hair 75 microns

Types of Damage

Introduction to Repairs

Autoclave and VARTM Processing
3. Composite NDI – Theory and Practice

- Visual inspection of composites
- Basic ultrasonic inspection theory
- Ultrasonic deployment and options
- Ultrasonic equipment set up
- Mapping damage
- Ultrasonic signals from normal and damaged structure
- Phased array inspection
  - C-Scan generation
- Solid laminate inspection methods and sample results

Reference Standards

Transducers and Delay Lines

TCG Curves

Deployment Options

Setting Gates
3. Composite NDI – Theory and Practice

A-Scan, B-Scan, C-Scan

“Go” / “No-Go” Devices

Sizing Damage

Scan Indexing, Tapers and Substructure
3. Composite NDI – Theory and Practice

Brief introduction and sample results from:

- Various phased array systems
- CT Scanning
- DolphiCam
- Thermography
- Roller Probes
- LaserUT
- Digital Acoustic Video
4. Special Cases – Challenges & Lessons Learned

- Examples of operational damage and field inspection results
- Read and Follow the Procedures
  - *Caution using saved settings*
- Embrace New Technology – It Can Be Helpful
- Follow OEM Documentation

Accidental Damage from Ground Handling Equipment

Lightning Strike Damage
5. NDI Proficiency Specimens

Initial design guidelines were assembled at the 1st (August 2014) project kick-off meeting with industry partners and the FAA.

• Thickness, materials, flaw types, structural configurations etc.

Development Considerations:

• Support hands-on training exercises
• Support recurrent training and composite NDI exposure
• Can be used in “blind mode” to demonstrate inspector proficiency
• Multiple flaw profiles and configurations designed so that end users can put together a set that fits their specific training needs and budget
• All lessons and teaching points will be encompassed in a limited number of panel configurations (minimize cost)
• Specimen geometry designed for ease of construction
5. NDI Proficiency Specimens

**Panel Configuration Summary** - 8 total panels
- Configuration 1 - 3 variations
- Configuration 2 - 2 variations
- Configuration 3 - 3 variations

<table>
<thead>
<tr>
<th>Panel Configuration</th>
<th>Structure</th>
<th>Test Specimen</th>
<th>Primary Variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Configuration 1</td>
<td>24&quot;x18&quot; Panel with complex taper (10:1 and 20:1) and secondary bond</td>
<td>1a</td>
<td>Standard configuration 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1b</td>
<td>Additional Secondary bond and more subtle flaws (different flaw profile)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1c</td>
<td>Additional thickness (up to 64 plies) and different flaw profile</td>
</tr>
<tr>
<td>Configuration 2</td>
<td>24&quot;x18&quot; Panel with pads, fasteners, co-cured bonds, sealant, sound dampers</td>
<td>2a</td>
<td>Standard configuration 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2b</td>
<td>Different flaw profile</td>
</tr>
<tr>
<td>Configuration 3</td>
<td>16 ply solid laminate skin</td>
<td>3a</td>
<td>Standard configuration 3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3b</td>
<td>Subtle impact</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3c</td>
<td>Large impact</td>
</tr>
</tbody>
</table>

**Configuration 1**
- Flat solid laminate skin

**Configuration 2**
- 24"x18" Panel with pads, fasteners, co-cured bonds, sealant, sound dampers

**Configuration 3**
- 16 ply solid laminate skin
5. NDI Proficiency Specimens

Example Engineered Flaws in Proficiency Specimens
*Embedded in the panels*

- Pillow insert
  - Delamination

- Grease
  - Contamination

- Carbospheres
  - Localized porosity

- Grafoil® insert
  - Tight delamination

- Paper backing in the laminate
  - Foreign object damage

- Paper Backing in the bond line
  - Foreign object damage

- Pillow insert in the bond line
  - Disbond
Example Engineered Flaws in Proficiency Specimens

Added to the panels after fabrication

- Concentric flat bottom holes
  *Impact damage

- Flat bottom holes
  *Significant delamination

- Grinder Cut
  *Cracked or broken substructure

- Grinder Disk Grove
  *Gouge or deep scratch

- Missing Sealant

- Sealant
  *Raised material, not a flaw
5. NDI Proficiency Specimens

Specimen Design 1c – Flaw Profile
Structure: Thick Specimen - Taper (10:1 and 20:1) and secondary bond

Fabrication support from NORDAM Interiors and Structures
Darryl Graham and Jeff Harper
5. NDI Proficiency Specimens

Specimen 1c – Inspection Results
Structure: *Thick Specimen* - Taper (10:1 and 20:1) and secondary bond

**Teaching Points:**
Follow procedures to set proper gates and detect second layer defects
Teaching Points:
- Defect detection using PA can require combination of Amp., TOF and A-Scan.
- dB drop criteria
5. NDI Proficiency Specimens

**Configuration 2**

Structure: Uniform thickness skin, pads, fastened shear tie flanges, co-cured stiffeners, sealant

- Built-up pad section (8 plies)
- Co-cured stiffener flanges (8 plies)
- Shear tie flange
- Sealant between flange and pad
- Fastened shear tie flange
- Sound damper (acoustic tiles)
- 16 Ply thick skin
5. NDI Proficiency Specimens

Specimen Design 2a – Flaw Profile

<table>
<thead>
<tr>
<th>ITEM #</th>
<th>FLAW TYPE</th>
<th>SIZE</th>
<th>PLY LAYER</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>MISSING SEALANT</td>
<td>AS SHOWN</td>
<td>BTN PLY 8 &amp; SHEAR TIE FLANGE</td>
</tr>
<tr>
<td>2</td>
<td>PILLOW INSERT</td>
<td>Ø 2.00</td>
<td>BTN PLY 16 &amp; SOUND DAMPER</td>
</tr>
<tr>
<td>3</td>
<td>PILLOW INSERT</td>
<td>1.00 X 1.00</td>
<td>BTN LAM PLY 16 &amp; ST PAD PLY 1</td>
</tr>
<tr>
<td>4</td>
<td>PILLOW INSERT</td>
<td>1.00 X 1.00</td>
<td>BTN PLY 2 &amp; 3 OF STIFFENER</td>
</tr>
<tr>
<td>5</td>
<td>PILLOW INSERT</td>
<td>Ø 1.50</td>
<td>BTN PLY 4 &amp; 5 (25%)</td>
</tr>
<tr>
<td>6</td>
<td>PILLOW INSERT</td>
<td>1.75 X 0.50</td>
<td>BTN PLY 4 &amp; 5 OF ST PAD</td>
</tr>
<tr>
<td>7</td>
<td>PILLOW INSERT</td>
<td>Ø 1.25</td>
<td>BTN PLY 8 &amp; 9 (50%)</td>
</tr>
<tr>
<td>8</td>
<td>PILLOW INSERT</td>
<td>Ø 0.50</td>
<td>BTN PLY 6 &amp; 7 OF ST PAD</td>
</tr>
<tr>
<td>9</td>
<td>DREMEL CUT</td>
<td>~0.05 X 1.00</td>
<td>SHEAR TIE FLANGE AS SHOWN</td>
</tr>
<tr>
<td>10</td>
<td>FLAT BOTTOMED HOLE</td>
<td>Ø 0.25</td>
<td>0.015&quot; &quot; (BTN PLIES 6 &amp; 7)</td>
</tr>
<tr>
<td>11</td>
<td>FLAT BOTTOMED HOLE</td>
<td>Ø 0.75</td>
<td>0.070&quot; &quot; (BTN PLIES 12 &amp; 13)</td>
</tr>
<tr>
<td>12</td>
<td>PREFREG BACKING</td>
<td>1.25 X 1.25</td>
<td>BTN PLY 16 &amp; STIFFENER PLY 1</td>
</tr>
<tr>
<td>13</td>
<td>PREFREG BACKING</td>
<td>2.00 X 2.00</td>
<td>BTN PLY 8 &amp; 9 (50%)</td>
</tr>
<tr>
<td>14</td>
<td>GREASE</td>
<td>Ø 1.50</td>
<td>BTN PLY 8 &amp; 9 (50%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ITEM #</th>
<th>DESCRIPTION</th>
<th>QUANTITY</th>
<th>DESIGNATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>FLAT HEAD BOLT</td>
<td>12</td>
<td>100&quot; FL HD, 1/4-20UNC-2A X 0.500</td>
</tr>
<tr>
<td>16</td>
<td>HEX NUT</td>
<td>12</td>
<td>1/4-20UNC-2B</td>
</tr>
<tr>
<td>17</td>
<td>SHEAR TIE FLANGE</td>
<td>2</td>
<td>SEE SHEAR TIE FLANGE DRAWING</td>
</tr>
<tr>
<td>18</td>
<td>SOUND DAMPER</td>
<td>4</td>
<td>4.5&quot; X 5.0&quot; SMACSONIC PADS</td>
</tr>
<tr>
<td>19</td>
<td>SEALANT</td>
<td>AS NEEDED</td>
<td></td>
</tr>
</tbody>
</table>

INSPECTION SIDE (TOOL SIDE)
5. NDI Proficiency Specimens

Specimen 2a – Inspection Results
Structure: Uniform thickness skin, pads, fastened shear tie flanges, co-cured stiffeners, sealant

OmniScan 3.5L64 (3.5 MHz)
### A-Scan Exercises

<table>
<thead>
<tr>
<th>Panel</th>
<th>Description</th>
<th>Panels</th>
</tr>
</thead>
<tbody>
<tr>
<td>General A-Scan Inspection Procedure</td>
<td>All panels</td>
<td></td>
</tr>
<tr>
<td>1 - Calibration - Set Material Velocity and TCG Curve</td>
<td>Ref Std</td>
<td></td>
</tr>
<tr>
<td>2 - Mark substructure on surface</td>
<td>1a,1b,1c,2a,2b</td>
<td></td>
</tr>
<tr>
<td>3 - Defect detection in uniform thickness skin</td>
<td>1a,1b,1c,3a,3b,3c</td>
<td></td>
</tr>
<tr>
<td>4 - Defect detection in tapered skin</td>
<td>1a,1b,1c</td>
<td></td>
</tr>
<tr>
<td>5 - Inspection of bonded substructure</td>
<td>1a,1b,1c</td>
<td></td>
</tr>
<tr>
<td>6 - Inspection of co-cured substructure</td>
<td>2a,2b</td>
<td></td>
</tr>
<tr>
<td>7 - Defect detection around other aircraft elements</td>
<td>2a,2b</td>
<td></td>
</tr>
</tbody>
</table>

### PA Exercises

<table>
<thead>
<tr>
<th>Panel</th>
<th>Description</th>
<th>Panels</th>
</tr>
</thead>
<tbody>
<tr>
<td>General C-Scan Inspection Procedure</td>
<td>All panels</td>
<td></td>
</tr>
<tr>
<td>1 - PA Calibration</td>
<td>Ref Std</td>
<td></td>
</tr>
<tr>
<td>2 - Set up TCG Curve</td>
<td>ST8872</td>
<td></td>
</tr>
<tr>
<td>3 - Setting gates</td>
<td>All panels</td>
<td></td>
</tr>
<tr>
<td>4 - Analyzing C-Scan results</td>
<td>All panels</td>
<td></td>
</tr>
</tbody>
</table>
6. Hands-On Exercises

- Students follow inspection procedure and exercises to conduct inspections on the Proficiency Specimens
- Templates are used to check inspection results
- Immediate instructor feedback to identify hits, misses and false calls
- Markings on panel are compared to C-Scan inspection results
First Deployment of the Composite NDI Training Class - July 2016

- Conducted the class at Delta Air Lines
- 20 inspectors, engineers, and FAA participants
- Presented the full class and conducted hands-on exercises using the Proficiency Specimens

Feedback from the first class deployment:
- Helpful background on composite materials and NDI refresher
- TCG, inspection over acoustic tiles, C-Scan data analysis, set up and calibration of phased array transducer, new appreciation for setup files, immediate hit/miss feedback
- Comfort level increased
Outcome and Path Forward

- Development of NDI training class is complete
- Successful completion of first class deployment with an airline
- Class will provide:
  - A general understanding of composite materials
  - An in-depth understanding of the nondestructive testing methods used to inspect carbon fiber parts
  - An **overall inspection proficiency** on composite aircraft parts made up of a variety of structural configurations
- Airlines/users customize for their particular needs

In the process of making the class materials available to the public:
- Class modules
- Proficiency specimen drawings and specifications
- Generalized A-Scan and C-Scan inspection procedures
- Hands-on exercises
- Grading and instructor materials
Questions?

If you are interested in obtaining the Composite Inspector Training materials, contact me:

Stephen Neidigk
sneidig@sandia.gov