Enhancements in MWM-Array Hidden Corrosion Imaging

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November 20, 2003

*Work on Hidden Corrosion done under AFRL/MLSA SBIR.

**Work on F-15 done under WR-ALC Funding.
Outline

• MWM-Array Technology
• KC-135 Lap Joint Corrosion
• C-130 Flight Deck Chine Plate
• P-3 Orion Wing Plank
• F-15 Wing Pylon Rib
• Summary of Ongoing NDE, CBM, PHM Programs
MWM-Array Sensor with Manual Scanning Cart

- Probe
- Cart
- MWM-Array Sensor Tip
- Position encoder assembly

FA24
MWM-Array Sensor with Manual Scanning Cart

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Slide no. 3
7 Channel MWM-Arrays for Near-Surface Crack Detection
Measurement Grids for RAPID Data Analysis/Imaging

Example Grids for the MWM sensor on Titanium

158 kHz

6.3 MHz
Actual KC-135 Lap Joints Cut-Out from Aircraft

KC135_4 (A,B,C,D) top view

KC135_4 (A,B,C,D) bottom view

Doubler
Example GridStation Software Display

Corrosion loss regions

C-Scan

B-Scan

Data on Grid

Air Point
MWM-Array Advantages

Problem:
- Inspect KC-135 lap joint for hidden corrosion
  - Length > 200"
  - Correct for Gap, Alclad and Skin Conductivity & Lift-Off (paint)

MWM-Array Solution:
- 2 Unknowns
  - Air Calibration (10 min. setup for 1st lap joint; no setup for 2nd lap joint)
  - < 30 seconds scan time
  - < Few seconds processing time
- 3 Unknowns
  - Air Calibration
  - < 3 minutes scan time
  - ~ 10 minutes processing
- 4 Unknowns
  - Local scanning
  - Gap standards required
2-Unknown Image Assuming Equal Loss

Without Alclad in Model

With Alclad in Model

Negative loss shown in pink
Air Force Material Loss Calibration Standard as Configured for MWM-Array Demonstrations

Dimensions in Mils (1 mil = 0.001 in.)
Air Force Material Loss Calibration Standard as Configured for MWM-Array Demonstrations

B-B Cross Section

Layer one

Layer two

Dimensions in Mils (1 mil = 0.001 in.)
3-Unknown Method Results for MWM-Array Scan of KC-135 Reference Calibration Standard Panels

With 0.005 in. nominal gap across top 1 in. of entire sample length
Variable Lift-Off (e.g. Paint) and Variable Gap
Schematic of 13 Layered Model with Doubler Included for MWM-Array Hypercube Generation

13 Layer Model

MWM-Array

Alclad

Knowns
\( \sigma_1, \sigma_2, \sigma_{\text{Alclad}}, \Delta_{\text{Alclad}}, \Delta_{\text{Doubler}} \)

Unknows
\( h, \Delta_1, \Delta_2, \text{Gap} \)

Doubler Gap (Approximately only)
3-Unknown Results for Cut-Out Lap Joint

**Without Doubler**
- Included in Model

<table>
<thead>
<tr>
<th>Lift-Off (mils)</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>10</td>
</tr>
</tbody>
</table>

**With Doubler Correction**

<table>
<thead>
<tr>
<th>Lift-Off (mils)</th>
<th>Location</th>
</tr>
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<tbody>
<tr>
<td>15</td>
<td>0</td>
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<tr>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>10</td>
</tr>
</tbody>
</table>

**Lift-Off**

<table>
<thead>
<tr>
<th>Total Remaining Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>No doubler</td>
</tr>
<tr>
<td>Doubler</td>
</tr>
</tbody>
</table>

**Total Remaining Material**

<table>
<thead>
<tr>
<th>Maximum loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Doubler</td>
</tr>
<tr>
<td>Doubler</td>
</tr>
</tbody>
</table>

**Gap**

<table>
<thead>
<tr>
<th>Maximum gap</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Doubler</td>
</tr>
<tr>
<td>Doubler</td>
</tr>
</tbody>
</table>
MAUS data for same region as MWM-Array data in previous slide.
1\textsuperscript{st} Layer Loss vs. 2\textsuperscript{nd} Layer Loss Measurement Grids at 10 kHz for a Gap of 0.011 in.

Lift-off

1\textsuperscript{st} Layer

\sigma_1

\Delta_1

\Delta_{Alclad}

Gap

2\textsuperscript{nd} Layer

\sigma_2

\Delta_2

\Delta_{Alclad}

\sigma_{Alclad}

\text{gap of 11 mils}
4-Unknown Results $h$, $\Delta_1$, $\Delta_2$, Gap
MWM-Array Image of Wide Area

Using Multiple MWM-Array Scan Passes
Internal Geometric Feature and Hidden Damage Imaging: C-130 Flight Deck Chine Plate

Inaccessible Side

Accessible Side

Thickness Image from Accessible Side

Surface Topology Image

Piece of Paper
Hidden Damage Imaging of C-130 Flight Deck Chine Plate

Green: < 5% Material Loss
White: 5-20% Material Loss,
Black: >20% Material loss

Green: < 20% Material Loss
White: 20-40% Material Loss
Black: >40% Material loss

Green: < 40% Material Loss
White: 40-60% Material Loss
Black: >60% Material loss

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Hybrid Wound/Etched MWM-Array

- Wound drive winding - permits lower frequency operation
- Etched sense element array - controlled element geometry and registration

Patents Pending
MWM-Array Scans of a Wing Plank from Navy P-3 Aircraft

Scan Direction

MWM-Array Probe

MWM-Array

Probe

t = 0.130"

.020” .010” .005”

JENTEK Sensors, Inc.
MWM-Array Hidden Metal Loss Estimates for the Three Milled Out Regions vs. the Actual Depth Measured with a Depth Gauge

Approximate total thickness at the “metal loss” locations is 0.13 in.
Corrosion Images without Paint Removal

Images of reference Al 7075-T6 coupon (left) and the more severely corroded Al 7075-T6 coupon (right) obtained at 1 MHz

Reference

Corroded coupon 3

Note: 0.004 in. insulating shim used to simulate paint layer
Scan width 12 mm, scan length 100 mm
F-15 Wing Pylon Inspection

With Bushing in Place

MWM-Array
WR-ALC Training (on Mockup) with Bushing Removed
WR-ALC Training with Bushing Removed
MWM-Array Corrosion Pitting/Crack Imaging
Example MWM-Array Ongoing NDE, CBM and PHM Programs

**PHM**
- Health-Monitoring for JSF  
  (Navy SBIR Phase II)
- P-3 Orion Fatigue Test  
  (Navy/Lockheed Martin)
- Landing Gear Stress & Fatigue  
  (AF Phase II SBIR)
- Through-Wall Stress and Temperature Measurement  
  (NASA Phase II SBIR)
- Coupon Testing for Multi-Site Cracking  
  (Air Force/Lockheed, OEMs)

**CBM**
- C-130/P-3 Propeller Cold Work  
  (WR-ALC)
- Coating Degradation  
  (DOE Phase II SBIR)
- Grinding Rework, Repair Quality  
  (Air Force, Army)

**NDE**
- Engine Disk Slot Inspection (CFM 56)  
  (AFRL, NAVAIR)
- F-15 Wing Pylon Rib  
  (WR-ALC)
- F-16 Wing Attach Fittings  
  (Lockheed/Air Force)
- AV-8B/Harrier Turbine Blade Welds  
  (NADEP Cherry Point)
- Lap Joint Cracks/Corrosion  
  (Air Force, FAA, OEMs)
- Friction Stir Weld Quality Assessment  
  (Lockheed/NASA, Eclipse Aviation)
- Deep/Hidden Damage  
  (NASA Phase II SBIR)
- 2- and 3-D Buried Flaw Imaging  
  (Air Force SBIR Phase II, FAA)