Comparison of 3 emerging optical NDI techniques on complex shaped composite structures based on carbon fiber

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Simulated space environment testing
Large chambers with optical benches

Development of optical
Space instrumentation

Development of Advanced Technologies

- Vacuum-Cryogeny
- Quality insurance
- Thermal Design
- Signal Processing
- Spaceborne Electronics
- Smart sensors
- Surface processing
- Optical Design
  - Optical Metrology
  - Non Destructive Testing
The Laser & NDT Lab

Research in laser and optical metrology and NDT for aerospace

Dimensional measurement
- Fringe projection
- Digital Image Correlation

Thermography
- Pulsed + Lock-in
- Vibrothermography (ULg)

Deformation measurement
- Holography
- Speckle interferometry
- Shearography

Combined Speckle-Thermography

Laser Ultrasonics
**Motivation of the study**

- Efficient Composite Technologies for Aircraft Components (ECOTAC) – Wallonia DG06 – Marshall plan
- Phase 1: benchmarking (2011-2012)
  - Study emerging laser/optical NDT techniques
  - Complex shape aeronautical structures in CFRP

**Techniques considered**
- Thermography
- Shearography
- Laser Ultrasound
Partners for NDT

- Laser Ultrasound
- Thermography
- Shearography

- Vibrothermography

- Thermography
- Vibrothermography

Yutz, October 1, 2013
Techniques used

- Shearography with heating
Techniques used

- Thermography: Optical Pulse Thermography (OPT)

Surface observation of thermal wave and its effect on internal defect

\[ t \approx \frac{z^2}{\alpha} \]

The observation time \( t \) is related to the defect depth

(\( \alpha \): thermal diffusion coefficient)
Techniques used

- Thermography : OPT
  - Pulse Phase Thermography (PPT)

\[
\begin{align*}
  f_n &= \frac{n}{N \Delta t} \\
  f &= \text{basse (n petit)} \\
  t &= \text{grand} \\
  z &= \text{profond}
\end{align*}
\]
Techniques used

• Thermography: Modulated halogen + lock-in
  – Optical Lock-in Thermography (OLT)

\[
\Delta \phi = \tan^{-1}\left[\frac{I(0) - I(T/2)}{I(T/4) - I(3T/4)}\right]
\]
Techniques used

- Vibrothermography
  - Ultrasound lock-in Thermography (ULT)
  - Ultrasound Burst Thermography (UBT)
Techniques used

• Thermography investigations

- CTA Montreal
  - Cooled cameras
  - 640x512

- CTA Spain

- GEL-MIVIM / VisioOImage (Québec)
  - Uncooled camera
  - Jenoptik LWIR
  - 640x480

- OPT

- OPT
Techniques used

• Laser Ultrasounds

Generation of ultrasound by laser
Thermoelastic effect

Detection of ultrasound by laser
Interferometric probe (with laser) and Two-Wave Mixing

✓ No couplant – No water
✓ Signal independent of geometry
✓ Economically interesting for curved parts (see. EADS-Lockheed Martin publications)
Techniques used

• Equipements used

CTA Montreal

- Generation : pulsed CO2 laser (10.6 µm)
- Detection : pulsed YAG laser (1064 nm)
- Probe TWM
- repetition rate : 100 Hz
- Laser Spot : 2 mm
- Scanning step : 0.5 mm
- manufacturer TECNAR
Samples

Monolithic samples
Calibrated defects (teflon inserts, flashbreaker, …)
Results

- Sample 1: Comparison

![Image of comparison results]

- Ultrason laser
- Shearography
Results

- Sample 1 by Laser Ultrasound
Results

• Sample 2 : Comparison
Results

• Sample 3 : Comparison

OLT

Face concave observée

USL

Face convexe observée

OPT

Shearographie
Results

- Sample 4: Thermography - Shearography
Results

- **Sample 4 : Thermography - Shearography**
• Sample 4

CTA Montréal
Results

• Sample 4: Laser Ultrasound
## Comparison

<table>
<thead>
<tr>
<th></th>
<th>Thermography</th>
<th>Shearography</th>
<th>Laser UT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Depth</strong></td>
<td>1.5 mm</td>
<td>&gt; 1.5 mm</td>
<td>&gt;&gt;&gt;&gt; 1.5 mm</td>
</tr>
<tr>
<td><strong>Dimensions</strong></td>
<td>3-4 mm</td>
<td>3-4 mm</td>
<td>2 mm</td>
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<tr>
<td><strong>Interpretation</strong></td>
<td>+</td>
<td>-</td>
<td>++</td>
</tr>
<tr>
<td><strong>Measurement</strong></td>
<td>Qualitative</td>
<td>Qualitative</td>
<td>Quantitative</td>
</tr>
<tr>
<td><strong>Depth assessment</strong></td>
<td>-</td>
<td>-</td>
<td>++</td>
</tr>
<tr>
<td><strong>Set-up</strong></td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td><strong>(scanning)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td>$$</td>
<td>$</td>
<td>$$$$$</td>
</tr>
</tbody>
</table>

Calibrated Defects are made of teflon to represent delaminations for UT technique
No fast conclusion!

NDT techniques must be envisaged in complementarity
Discussion - 1

- Laser Ultrasound shows high potential
  - Develop this technique in Phase 2 of ECOTAC project
  - Purchase of generation and detection equipments
  - Study combination of both segments
  - Implement robot-arm for scanning complex parts (2014)
Discussion - 2

• Thermography and Shearography
  – High potential (full-field – no scanning)
  – Suffer from interpretation

• New projects have started
  – Dimensioning of defects by NDI techniques
    • Thermography - Shearography
    • Scientific collaboration between CTA (Montreal) and CSL
    • Academic projects (Ulg, …)
    • Industrial projects (under evaluation)
  – New post-processing applied to shearography for easier interpretation
    • Dé-Composit project
    • Wallonia, DG06 (Cwality program)
    • Optrion S.A.
New developments

- Shearography: automated detection
New developments

• Shearography: ease of interpretation

Temporal sequence shows various defects at different instants
Heat wave travelling through the sample

New post-processing provides
• A single image
• With all defects
• Same visibility of defects independent of depth
The Future

- R&D of optical-laser NDT-NDI techniques
- Composite thermo-mechanical characterization (dilatation, etc…)
- Collaboration with research center and industries
  - Materials
  - Simulation
  - NDT-NDI
- Lectures
- Service to industry
- *Maybe with you?*

*Thanks for your attention!*  
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