High-fidelity Ultrasonic 3D Characterisation of Composites

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• Introduction
  • NDT and Aerospace Structural Integrity

• Using NDT to characterise 3D material properties & model performance
  • 3D non-destructive characterisation
  • FE Materials Modelling

• Ply Tracking

• Summary
Introduction

NDT and Aerospace Structural Integrity
• Mechanical Testing. Strength vs damage size.

Source: EASA AMC 20-29 Effective: 26/07/2010
Maintenance Decisions

Action:

Category:  
1. Allowed
2. Repair as per normal process
3. Repair immediately
4. Repair after flight

<table>
<thead>
<tr>
<th>Category</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undetectable</td>
<td>None</td>
</tr>
<tr>
<td>Detectable</td>
<td>Repair as normal</td>
</tr>
<tr>
<td>Readily Detectable</td>
<td>Repair immediately</td>
</tr>
<tr>
<td>Immediately Obvious (In flight)</td>
<td>Repair after flight</td>
</tr>
</tbody>
</table>

Source: EASA AMC 20-29 Effective: 26/07/2010
• Design based on susceptibility to damage
• Design based on susceptibility to damage

![Diagram showing impact energy, defect size, and number of impacts through life.]

- Impact Energy
- Defect Size, \( a \)
- Number of impacts through life

# impacts causing damage – dictates thickness required
• Design based on susceptibility to damage
Using NDT to characterise 3D material properties & model performance

3D non-destructive characterisation

FE Materials Modelling
3D non-destructive characterisation

• Predict performance of as-manufactured component.
  • Materials model with actual 3D NDT data inputs
• Finite-element mesh created from NDT ply-wrinkling data.
• Populate cells with **3D Fibre Angle** \((\alpha, \beta, \gamma)\), vector field, stiffness axes 1’, 2’ & 3
Ultrasound

- Grey level can be amplitude or phase response

![Graph showing voltage vs. depth with labeled Ply reflections]
• Quantitative 3D fibre orientation ‘inversion’

\[ \alpha, \beta \] – out-of-plane fibre angle

\[ \gamma \] – in-plane fibre angle

Surface Heights
• Quantitative ply surface height...
• Vector Field

• Fibre-tow maps of ‘streamlines’ (analogy with fluid dynamics), vectors, $F$

0.125 mm thick plies.

$[45^\circ, 0^\circ, -45^\circ, 90^\circ, -45^\circ, 0^\circ, 45^\circ]_3$
NDT-based prediction of strength

Miss Ningbo Xie, PhD student
Miss Ningbo Xie, PhD student
Ply tracking
Ultrasonic Propagation in CFRP

- CFRP
  - Ultrasonic propagation is complex
  - Interfering reflections from resin layers
  - Weak resonances
    - 6 MHz for 0.25 mm plies
  - Resonances disrupted
    - Ply thickness variations
    - Material property variations
  - Localised response

Low Reflection Coefficients (R). R peaks at resin layers - thin, so thickness-dependent R.
Ply-drop specimen

Optical Micrograph

Analytic-signal
X-ray CT
Overlaid
Impact Damage - delaminations

• Defect Characterisation
  • Delaminations due to impact damage

Green: Resin layer. Red: front, back or delamination. Note: multiple reflections are not colour coded

• Instantaneous amplitude with Ply tracking...
• **Defect Characterisation**
  
  • **Delaminations due to impact damage**

  Red: front, back or delamination.  
  **Note:** multiple reflections are not colour coded

• **Instantaneous amplitude with Ply tracking...**
• Tape gaps and overlaps can cause wrinkling

X-ray CT data
Front-wall, back-wall, ply-drops

- Instantaneous amplitude with resin layers, FWE, BWE
- Note white line at peak amplitude
Tape gaps, overlaps, wrinkling

X-ray CT scan

With analytic-signal overlay
• Ultrasound offers:
  • 3D characterisation
  • Inversion to map 3D material properties
  • Automated creation of FE materials models
  • Prediction of performance
  • Only scale limitation is time for scan and analysis

• NDT-based FE Materials modelling offers potential benefits