High-fidelity Ultrasonic 3D Characterisation of Composites

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  - NDT and Aerospace Structural Integrity
- Using NDT to characterise 3D material properties & model performance
  - 3D non-destructive characterisation
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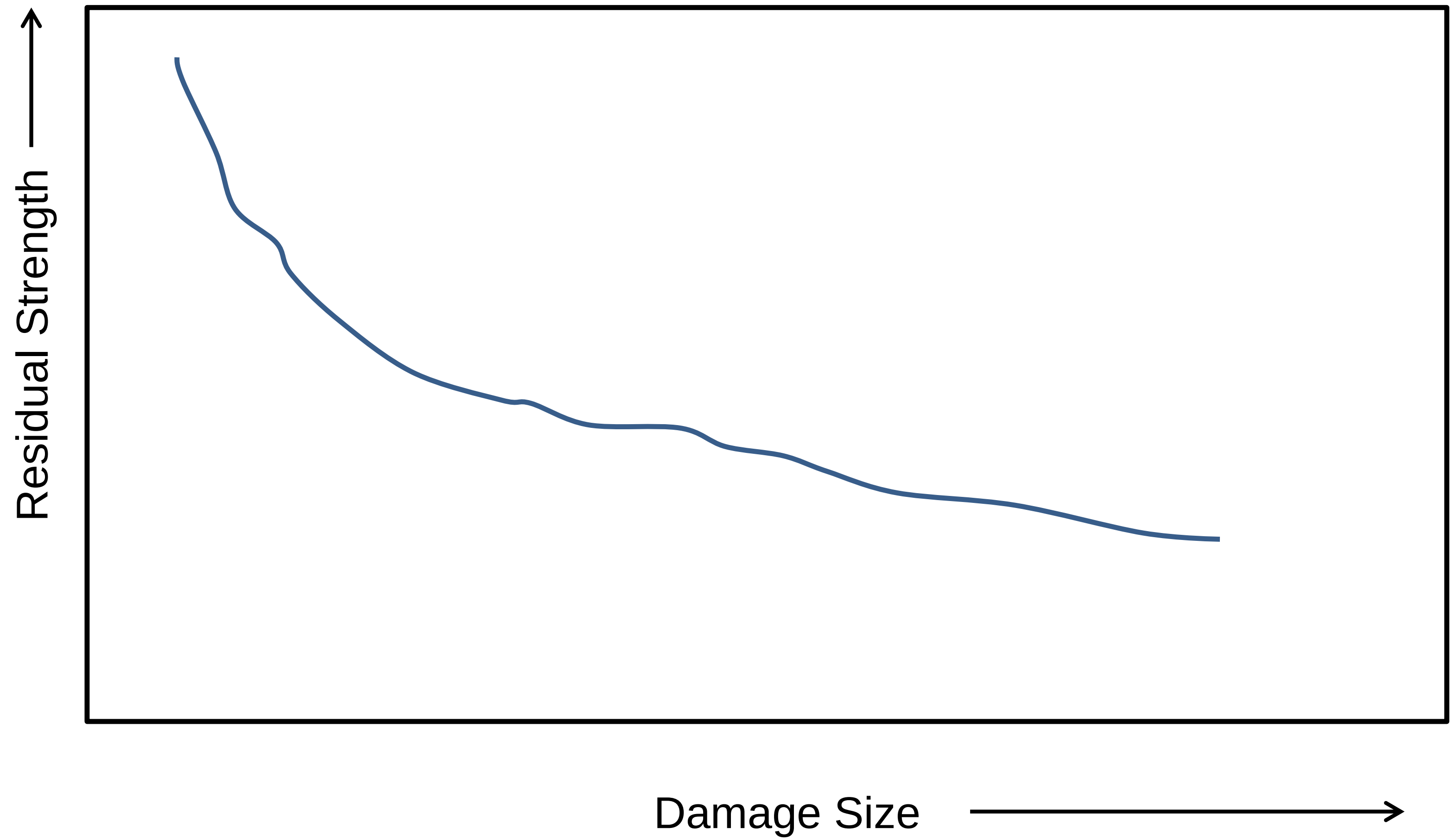
Introduction

NDT and Aerospace Structural Integrity

Ensuring performance & safety

- Mechanical Testing. Strength vs damage size.



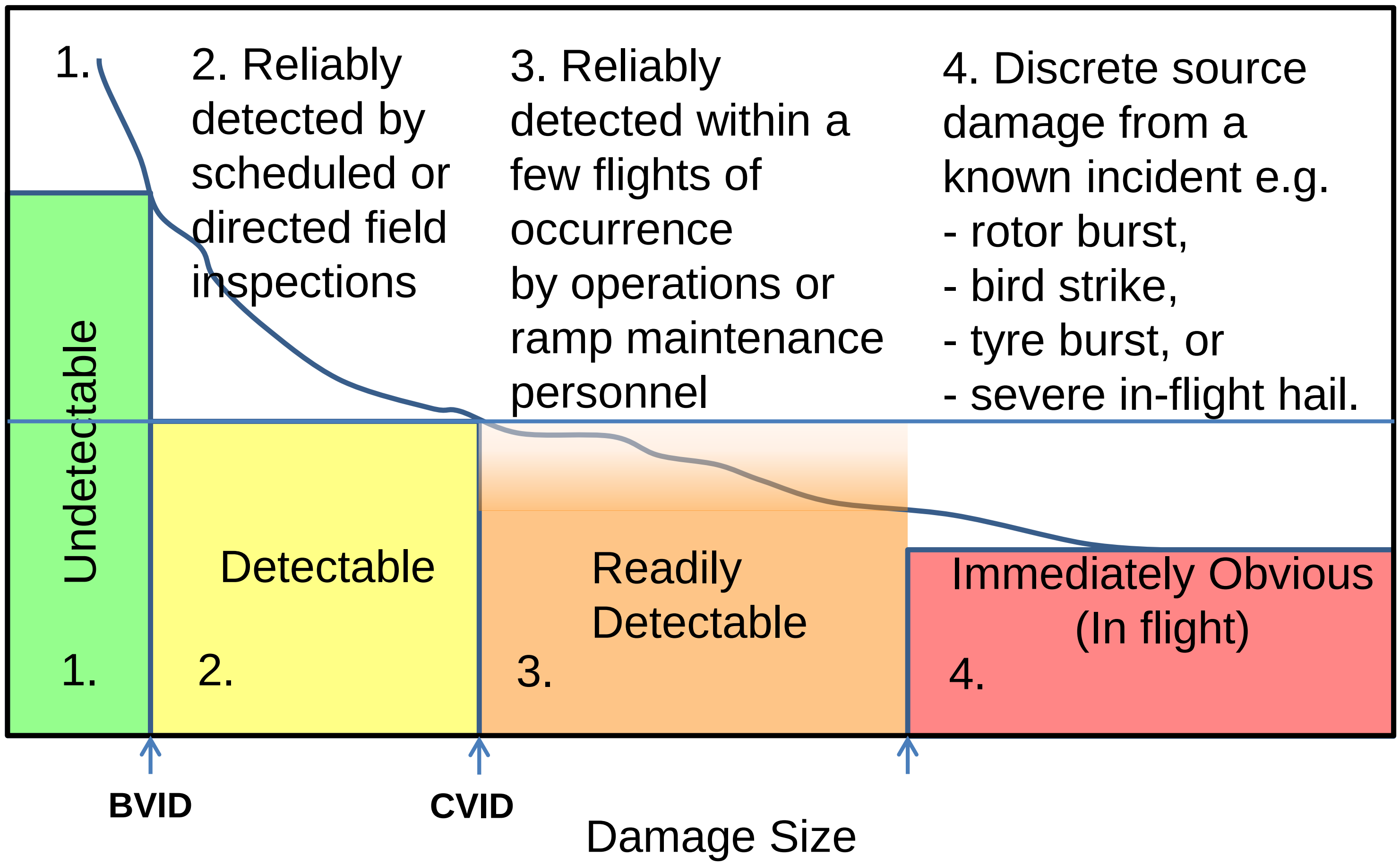
Source: EASA AMC 20-29 Effective: 26/07/2010

Maintenance Decisions

Action: None | Repair as normal | Repair immediately | Repair after flight

Category:

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



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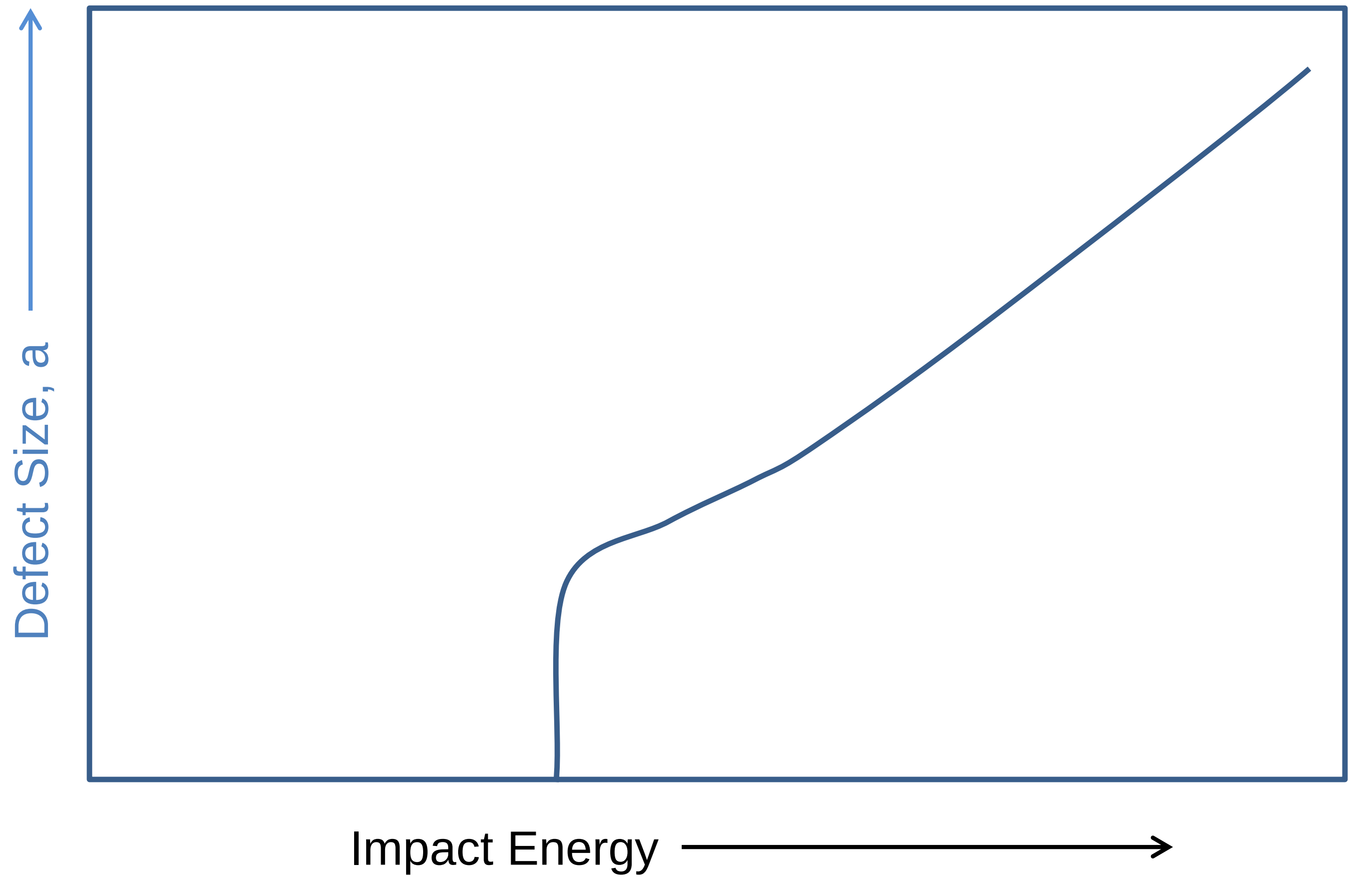
Potential design Strategy

- Design based on susceptibility to damage



Engineering and Physical Sciences Research Council

Potential design Strategy

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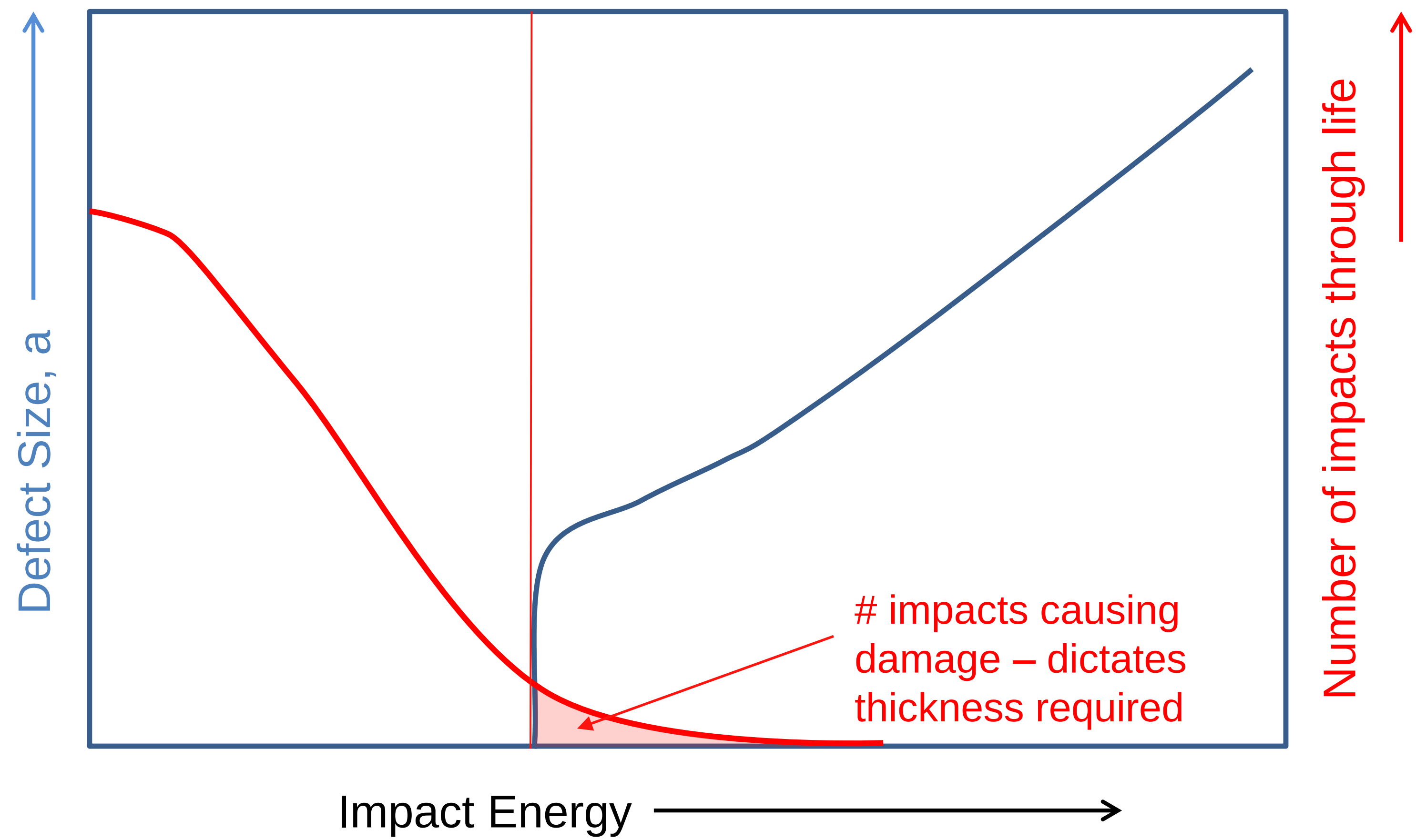

Potential design Strategy

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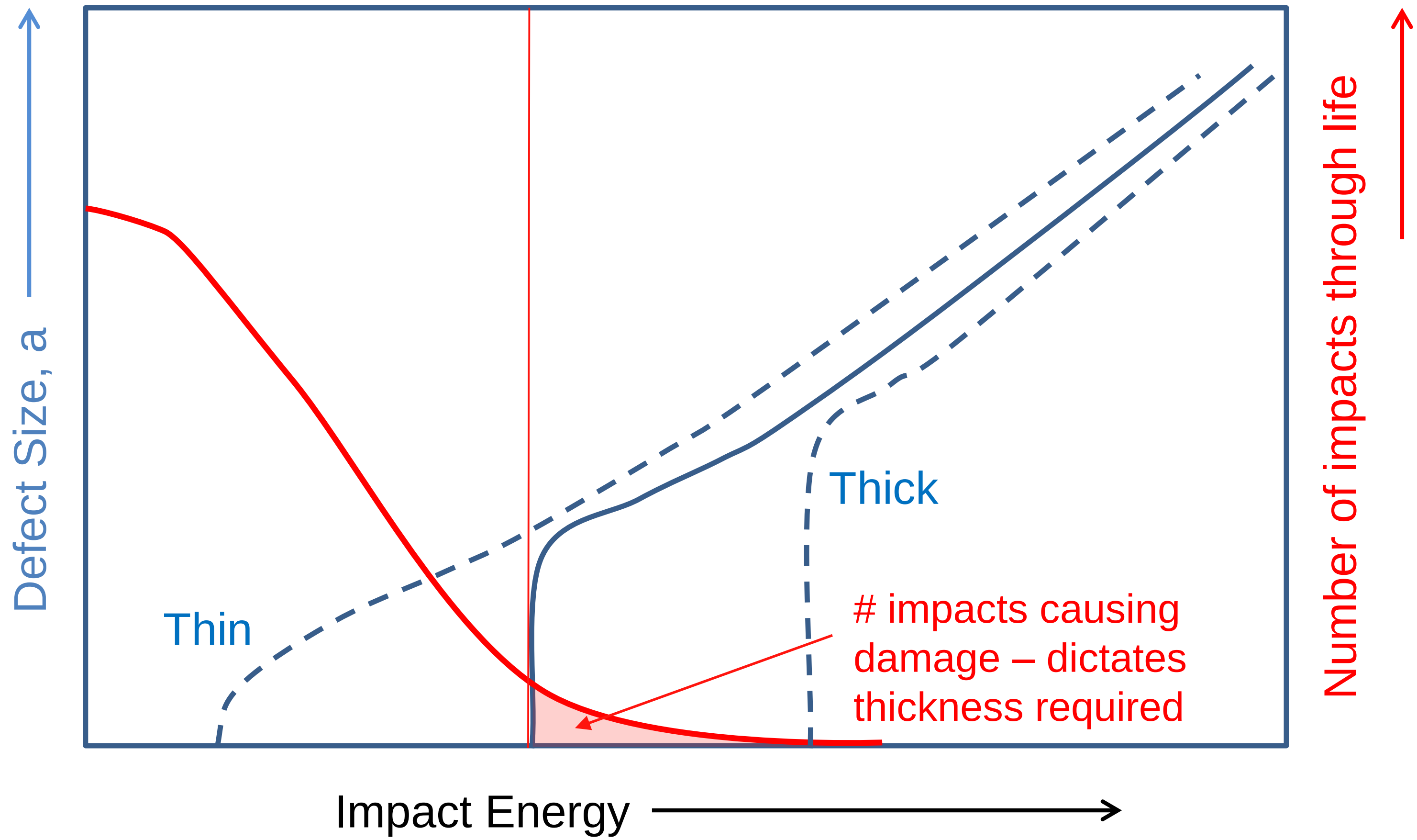


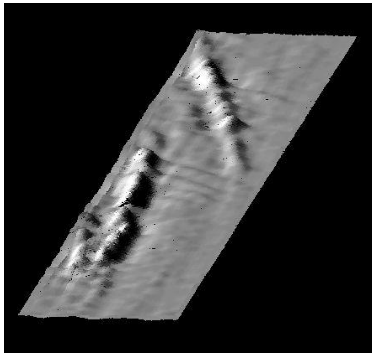
Using NDT to characterise 3D material properties & model performance

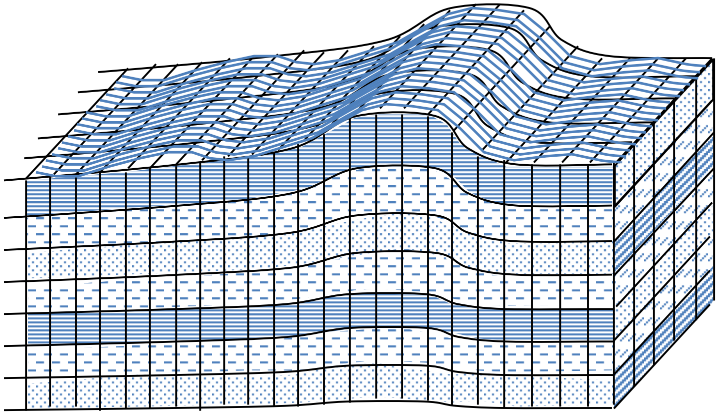
3D non-destructive characterisation

FE Materials Modelling

3D non-destructive characterisation

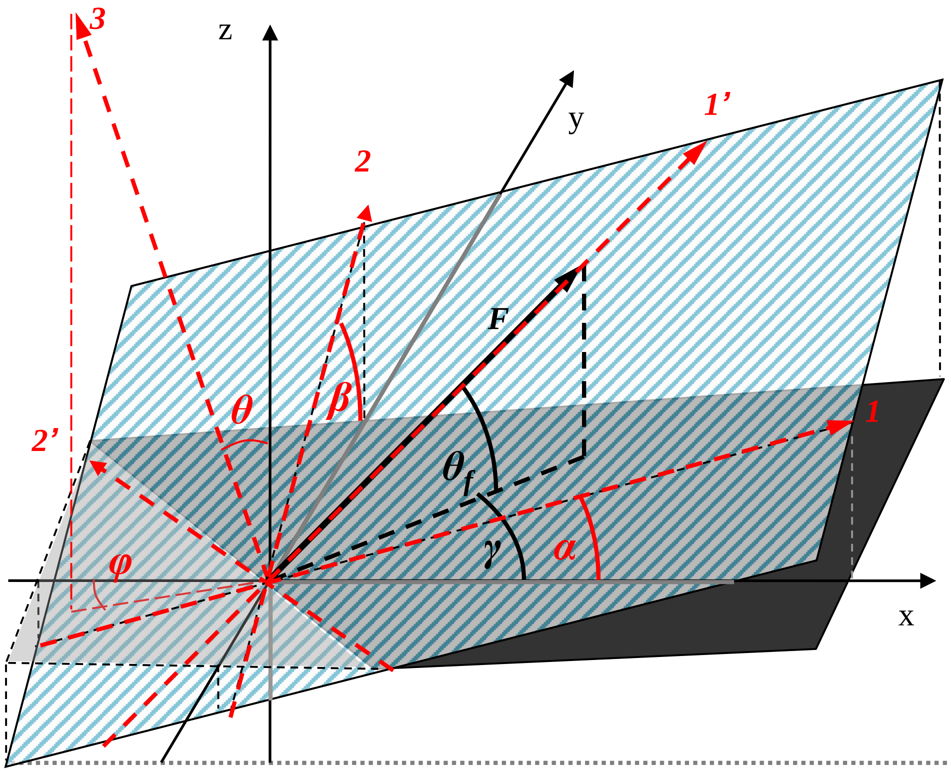
- Predict performance of as-manufactured component.
  - Materials model with actual 3D NDT data inputs
- Finite-element mesh created from NDT ply-wrinkling data.

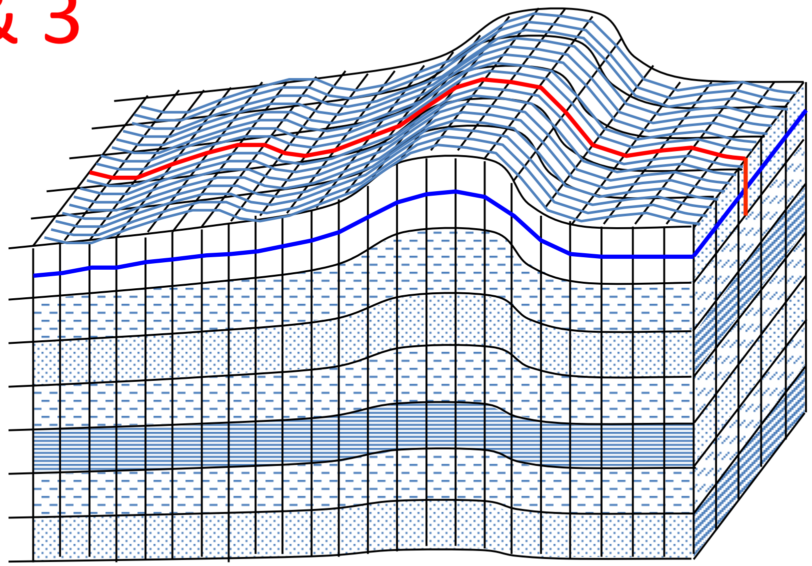




Materials Modelling

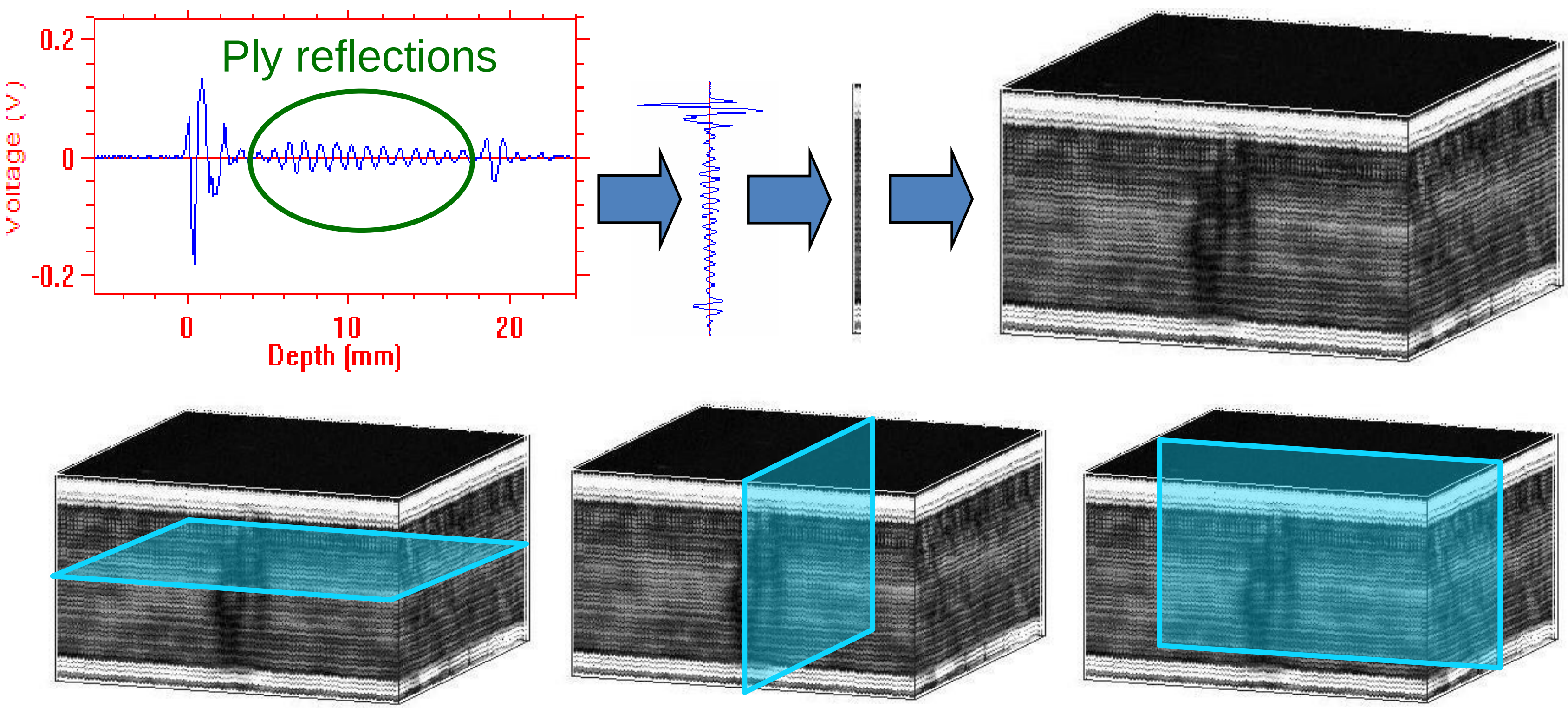
- Populate cells with 3D Fibre Angle (α,β,γ), vector field, stiffness axes 1’, 2’ & 3





Ultrasound

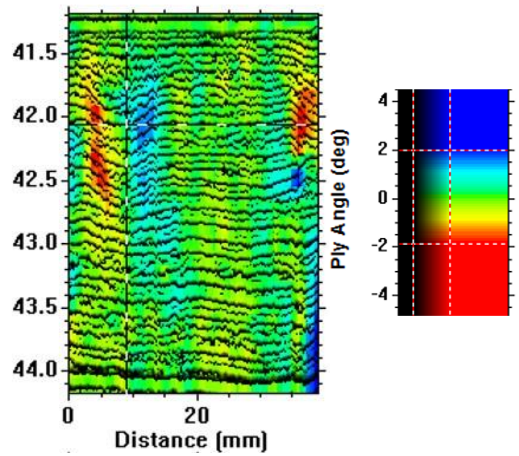
- Grey level can be amplitude or phase response



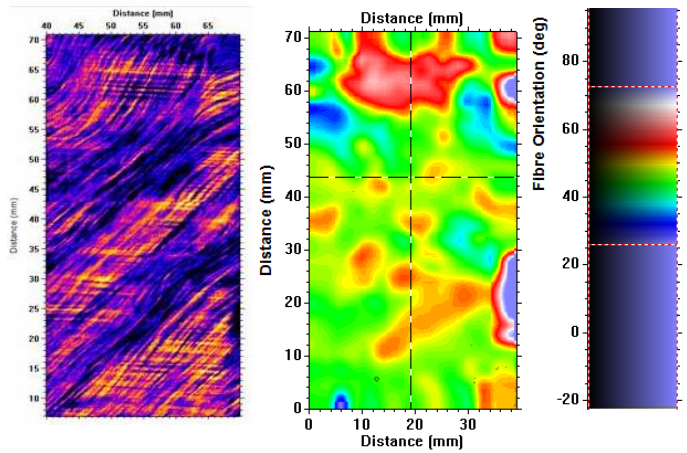
3D non-destructive characterisation

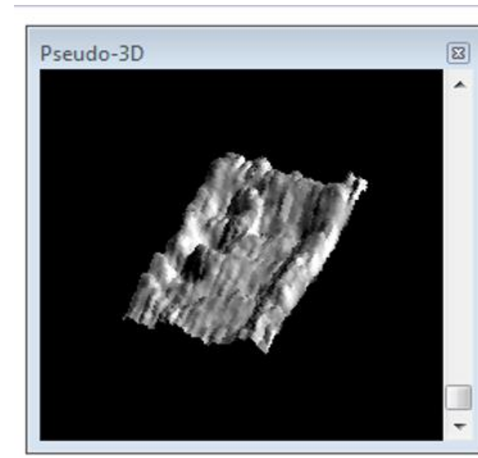
- Quantitative 3D fibre orientation ‘inversion’

B-scan



C-scan

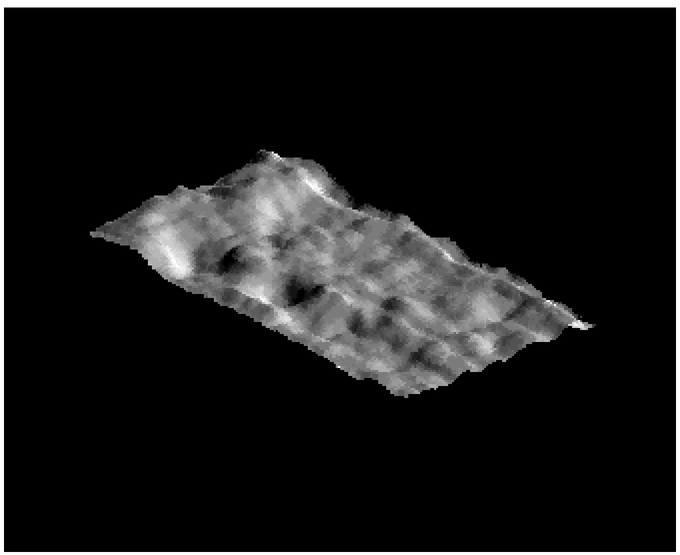


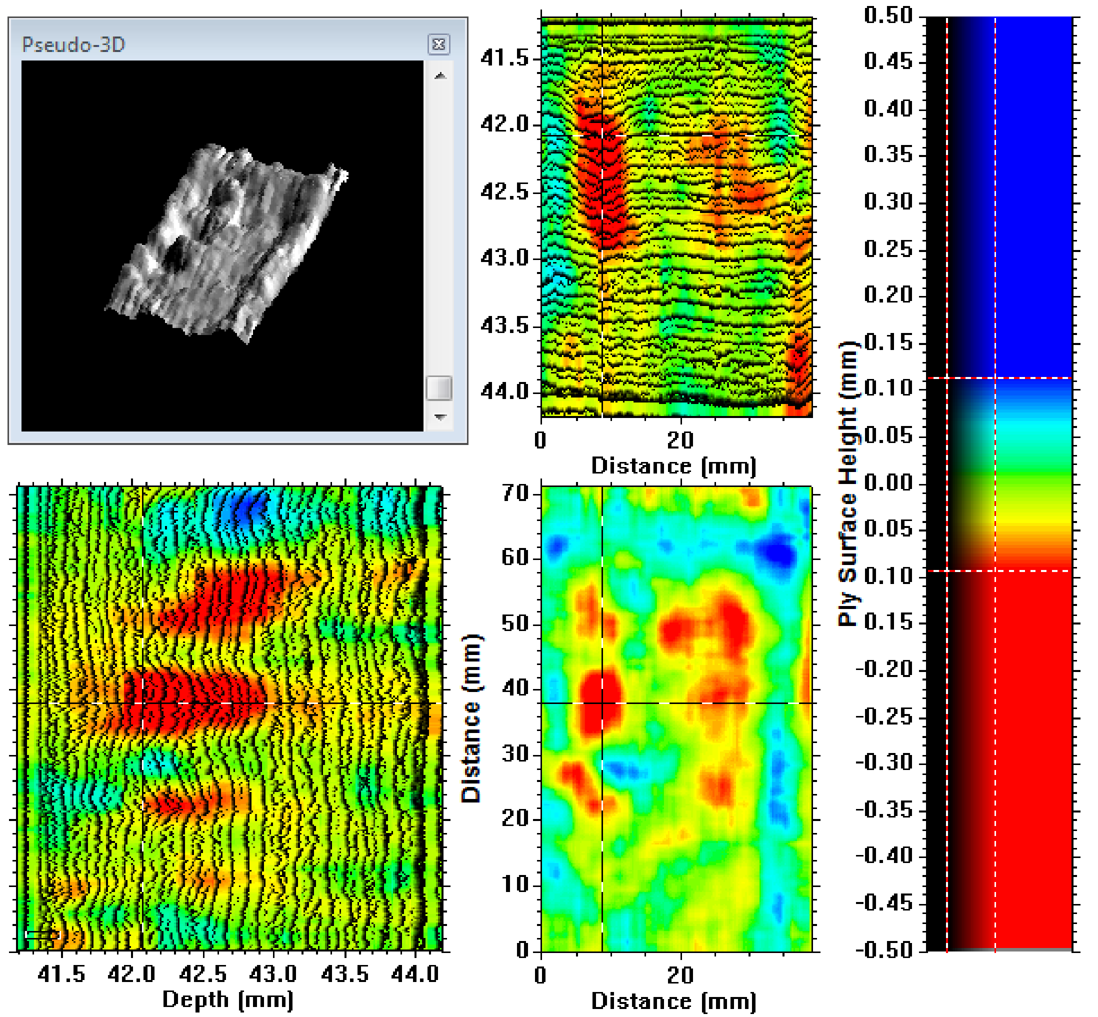


α,β – out-of-plane fibre angle + γ – in-plane fibre angle → Surface Heights

3D non-destructive characterisation

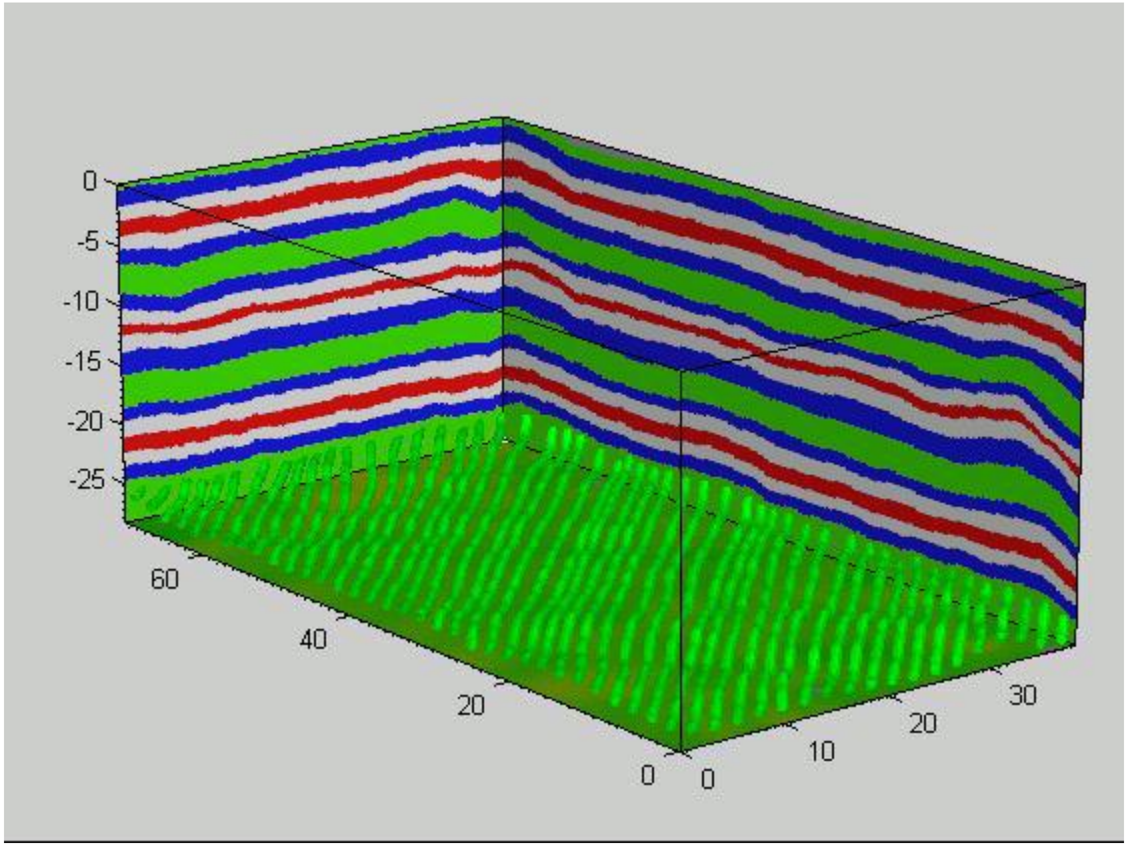
- Quantitative ply surface height…





3D Vector Map of Fibre-tow orientation

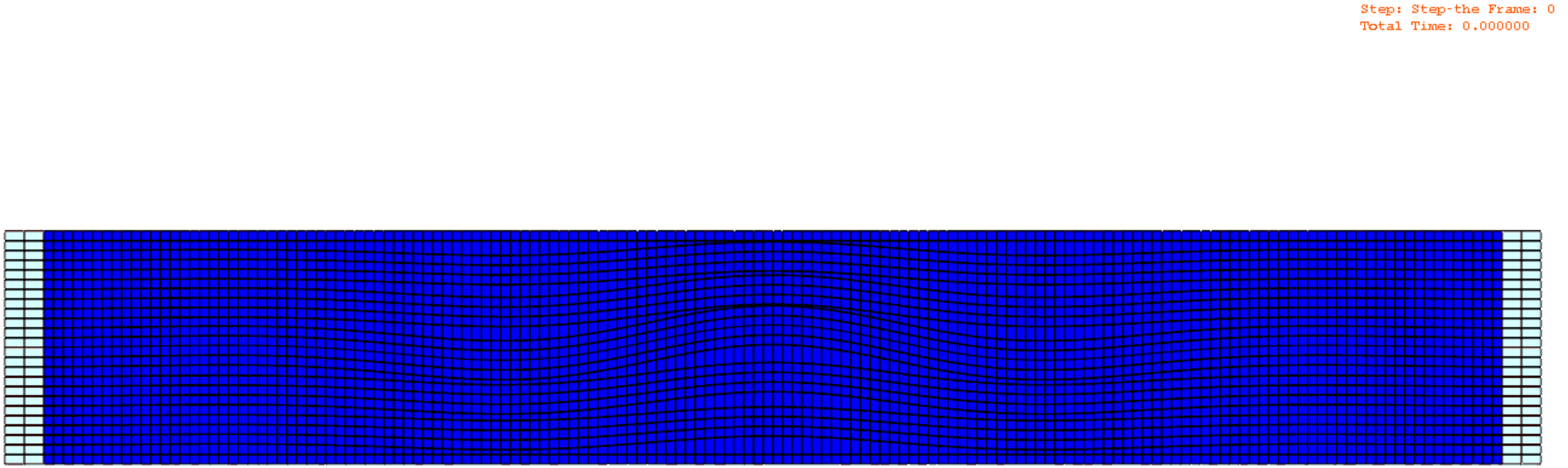
- Vector Field
- Fibre-tow maps of ‘streamlines’ (analogy with fluid dynamics), vectors, $\boldsymbol{F}$

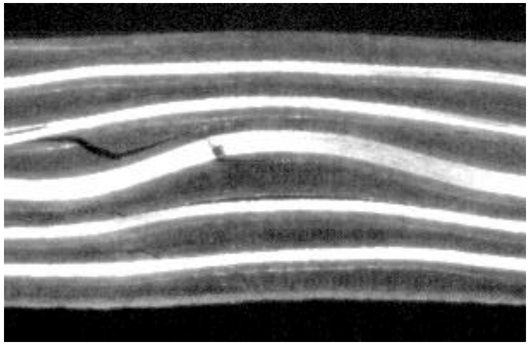


0.125 mm thick plies.

[45º, 0º, -45º, 90º, -45º, 0º, 45º]$_3$

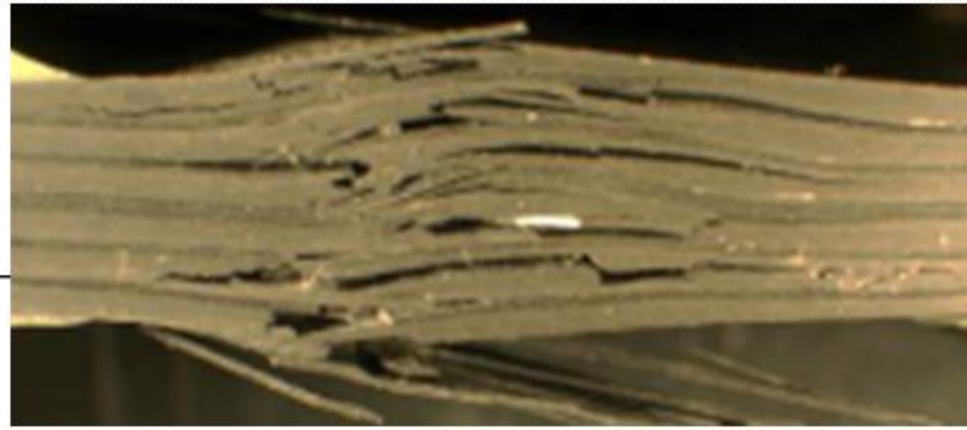
NDT-based prediction of strength

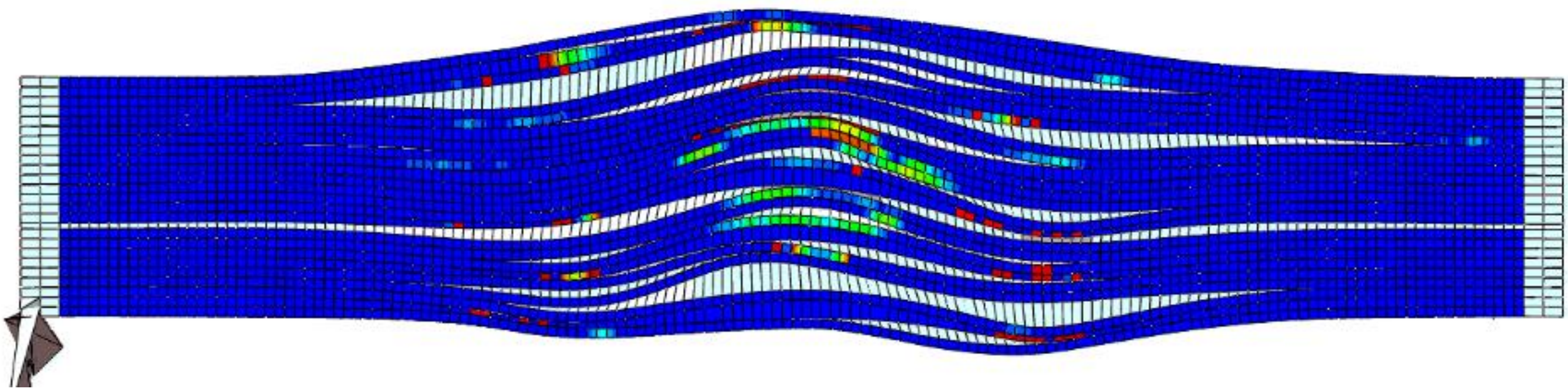




Miss Ningbo Xie, PhD student

Simulation and modelling





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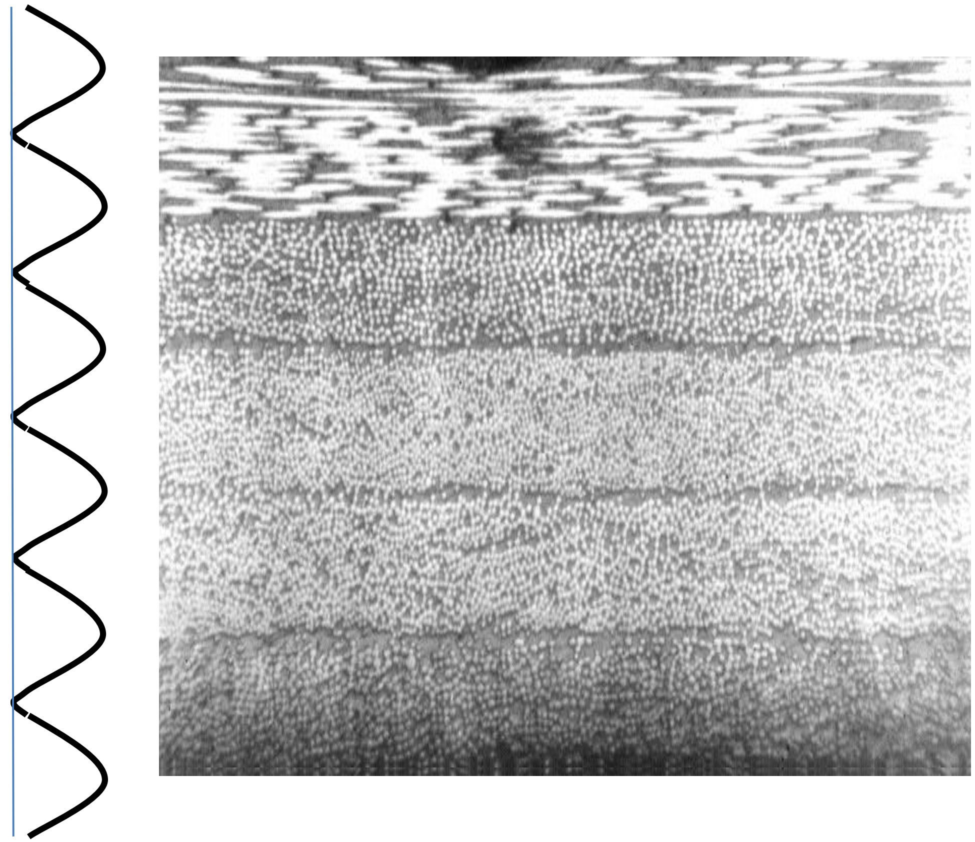
Ply tracking

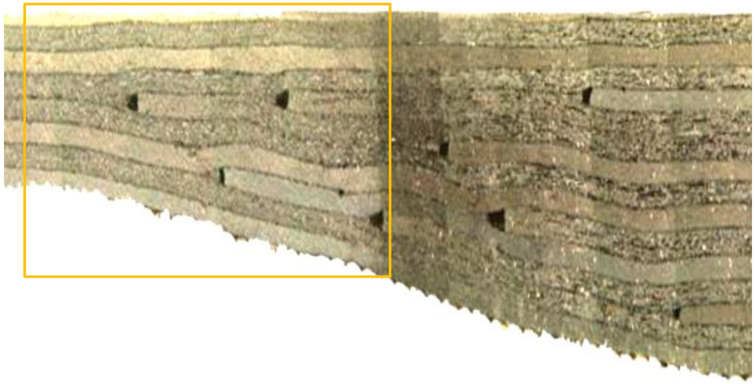
Ultrasonic Propagation in CFRP

- 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.

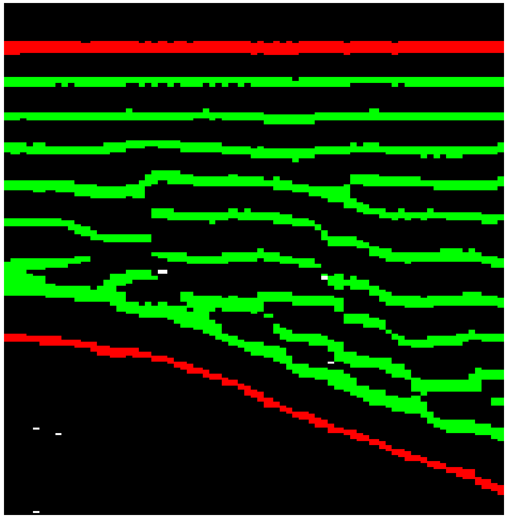


Ply-drop specimen

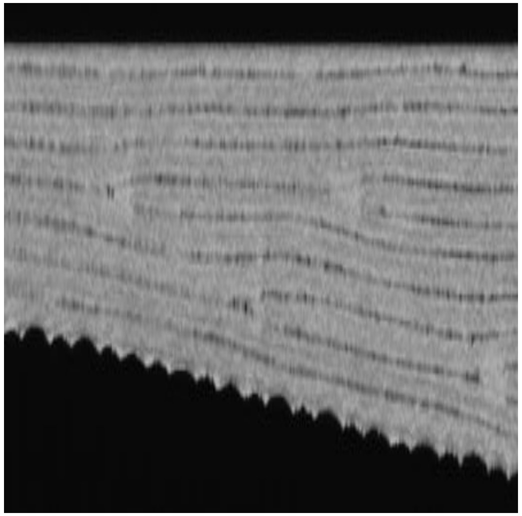


Optical Micrograph

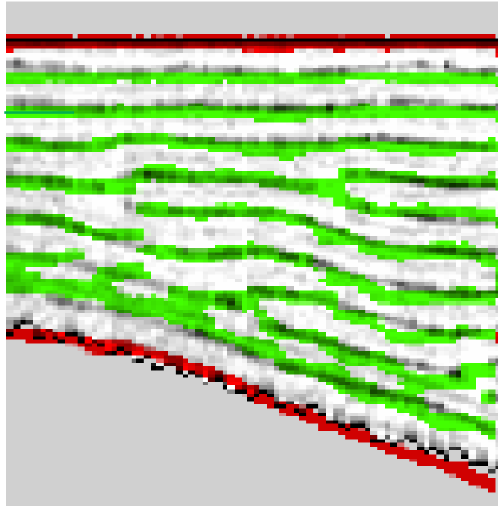
Analytic-signal



X-ray CT



Overlaid

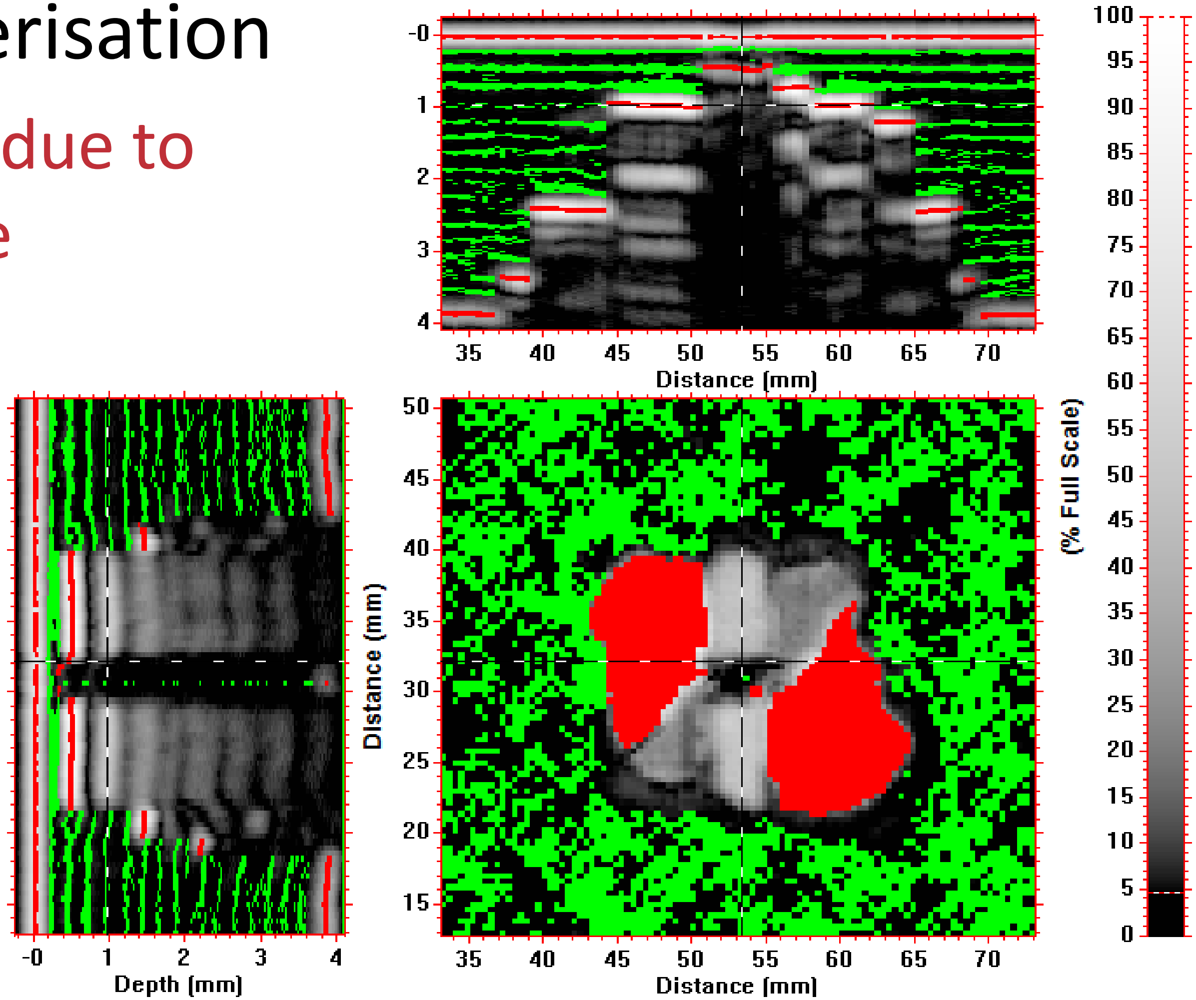


Impact Damage - delaminations

- 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…



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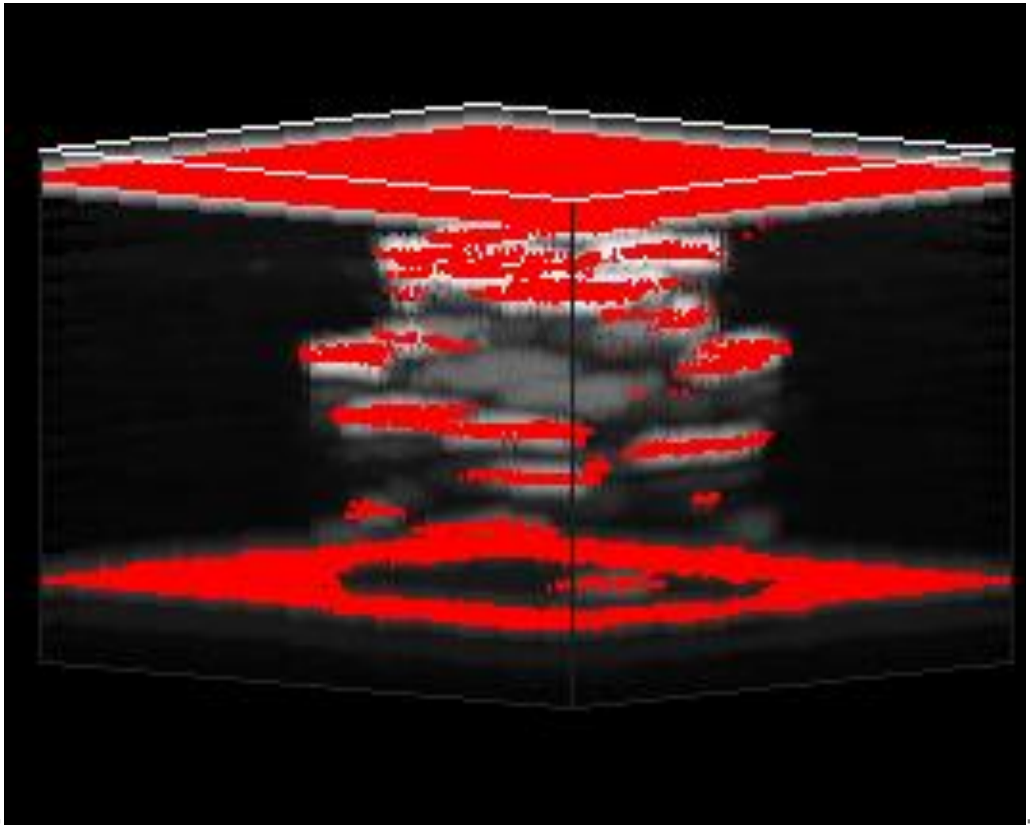
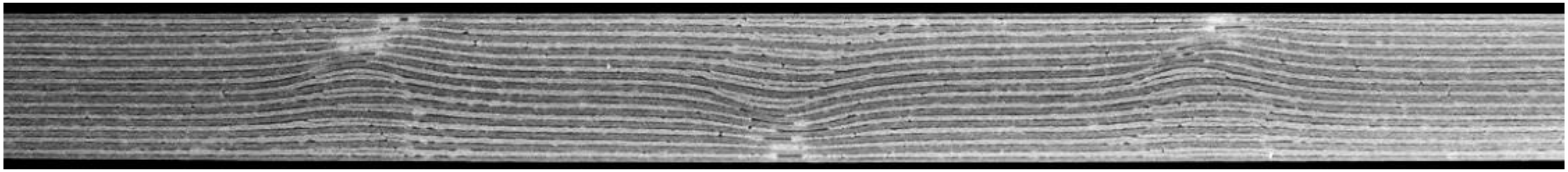


Red: front, back or delamination.
Note: multiple reflections are not colour coded

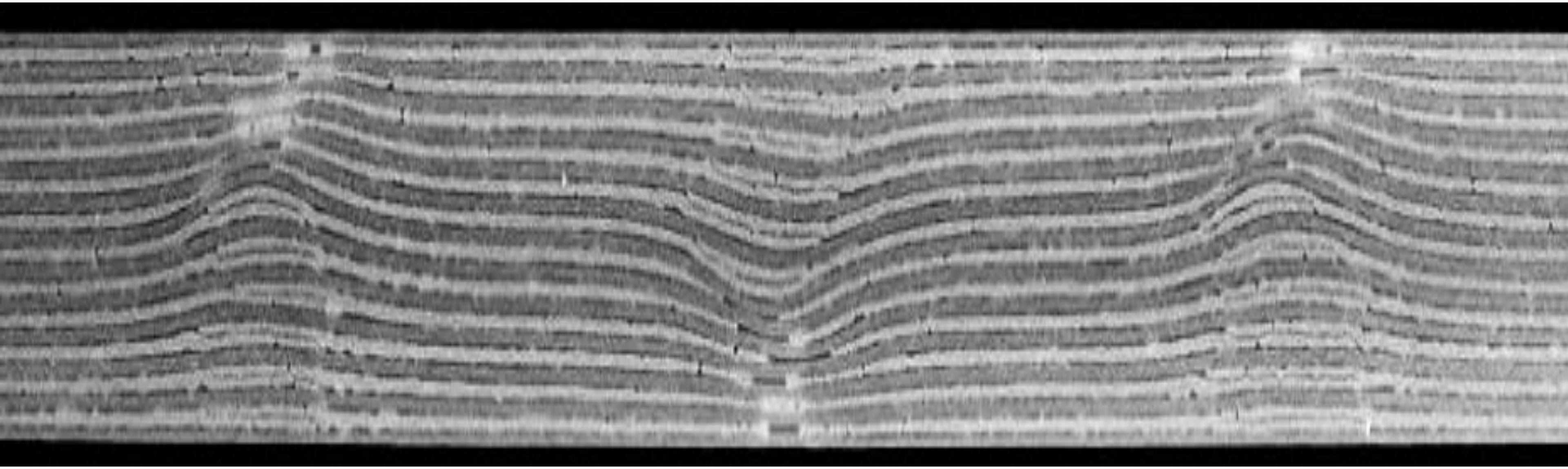
- Instantaneous amplitude with Ply tracking…

Tape gaps, overlaps, wrinkling

- Tape gaps and overlaps can cause wrinkling



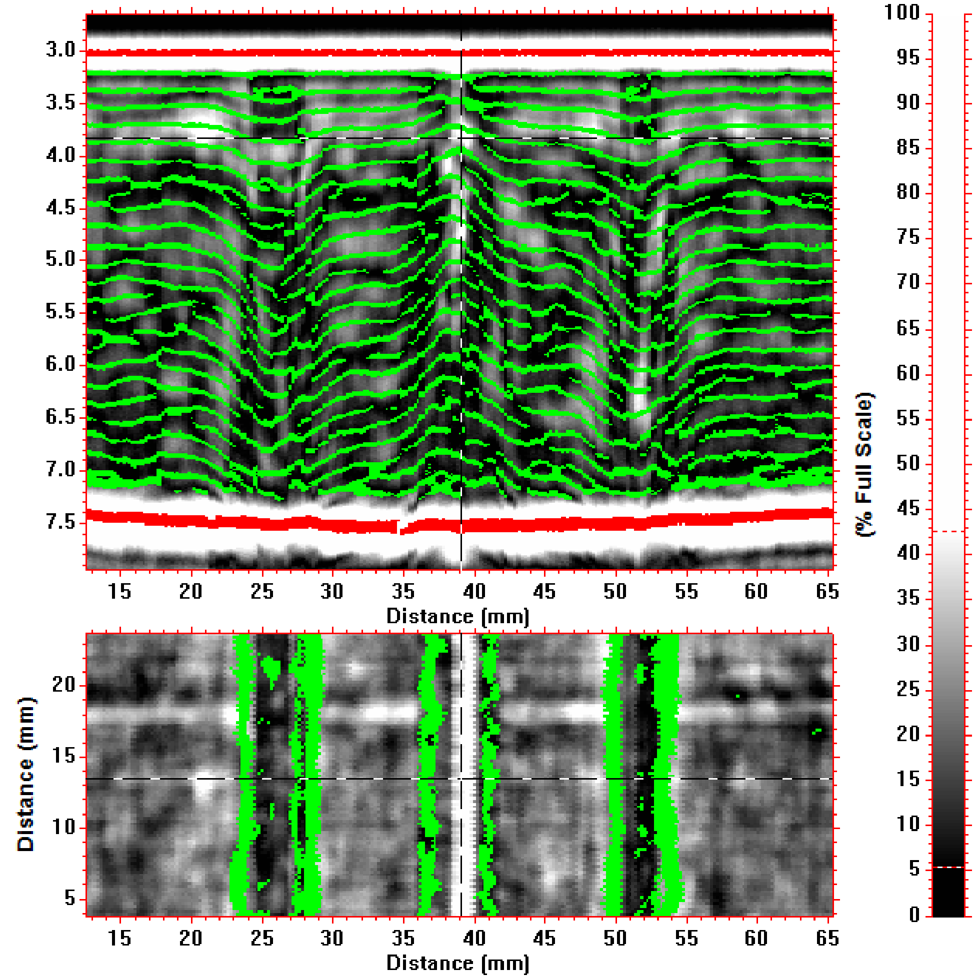
X-ray CT data



Tape gaps, overlaps, wrinkling

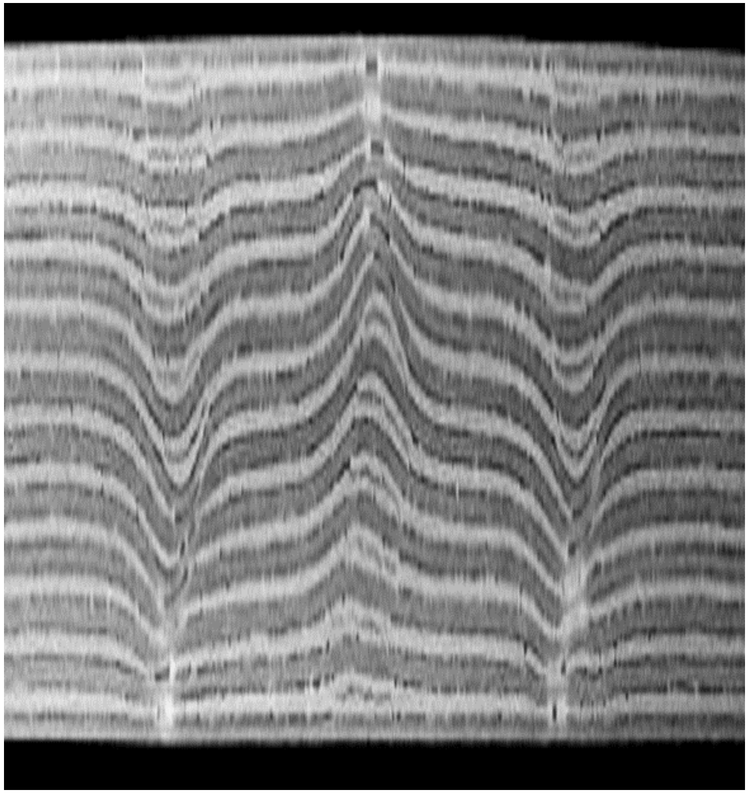
Front-wall, back-wall, ply-drops

- Instantaneous amplitude with resin layers, FWE, BWE
- Note white line at peak amplitude

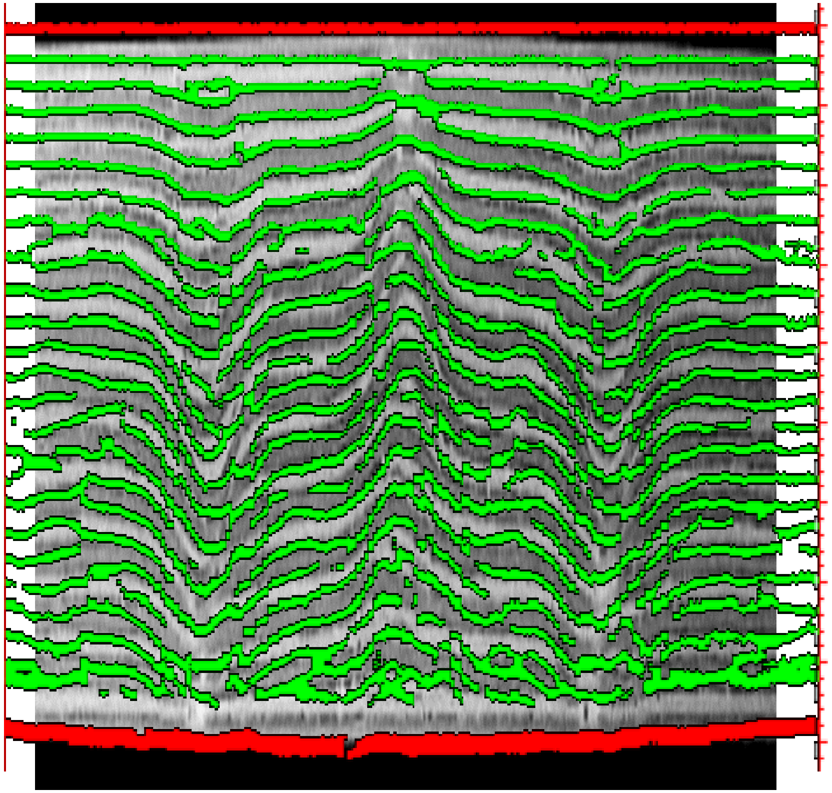


Tape gaps, overlaps, wrinkling

X-ray CT scan



With analytic-signal overlay



Conclusions

- 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