# Research and State-of-the-art NDT

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Director of the Research Centre for NDE (RCNDE)

Past President - British Institute of NDT

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- Introduction
  - RCNDE
  - New ‘FIND’ CDT for EngDs in NDE
- Composite materials
  - Using NDT to characterise 3D material properties & model performance
  - Ply Tracking
- Wind-turbine wrinkles
- Summary

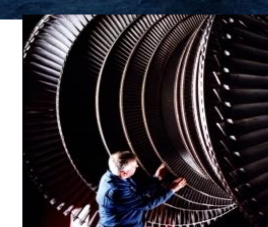
# Introduction

# UK Research Centre in NDE

- RCNDE is a collaboration between universities & industry for the purpose of making an impact through NDE research and training
- Established in 2003, it has EPSRC funding until at least 2020
- Full industrial membership has grown from 5 to 15; 34 Associate members from supply chain
- 6 main university partners

# RCNDE Industrial members



## Current full members

- **Aerospace** (Airbus, Rolls-Royce, BAE Systems, DSTL, IHI)
- **Power** ( NNL, EDF, IHI)
- **Nuclear** (National Nuclear Lab, Rolls-Royce, IHI, Wood, EDF, Hitachi, ONR)
- **Defence** (DSTL, Rolls-Royce, BAE Systems)
- **Public sector** (ONR, DSTL)
- **Oil & gas** (Shell, BP, Petrobras, Wood)
- **Manufacturing** (SKF, Tenaris, IHI, Rolls-Royce, Airbus, BAE Systems, Hitachi)
- **Transport** (Hitachi)



Images courtesy of Rolls-Royce, Drax Power, RWE npower, Shell & Airbus

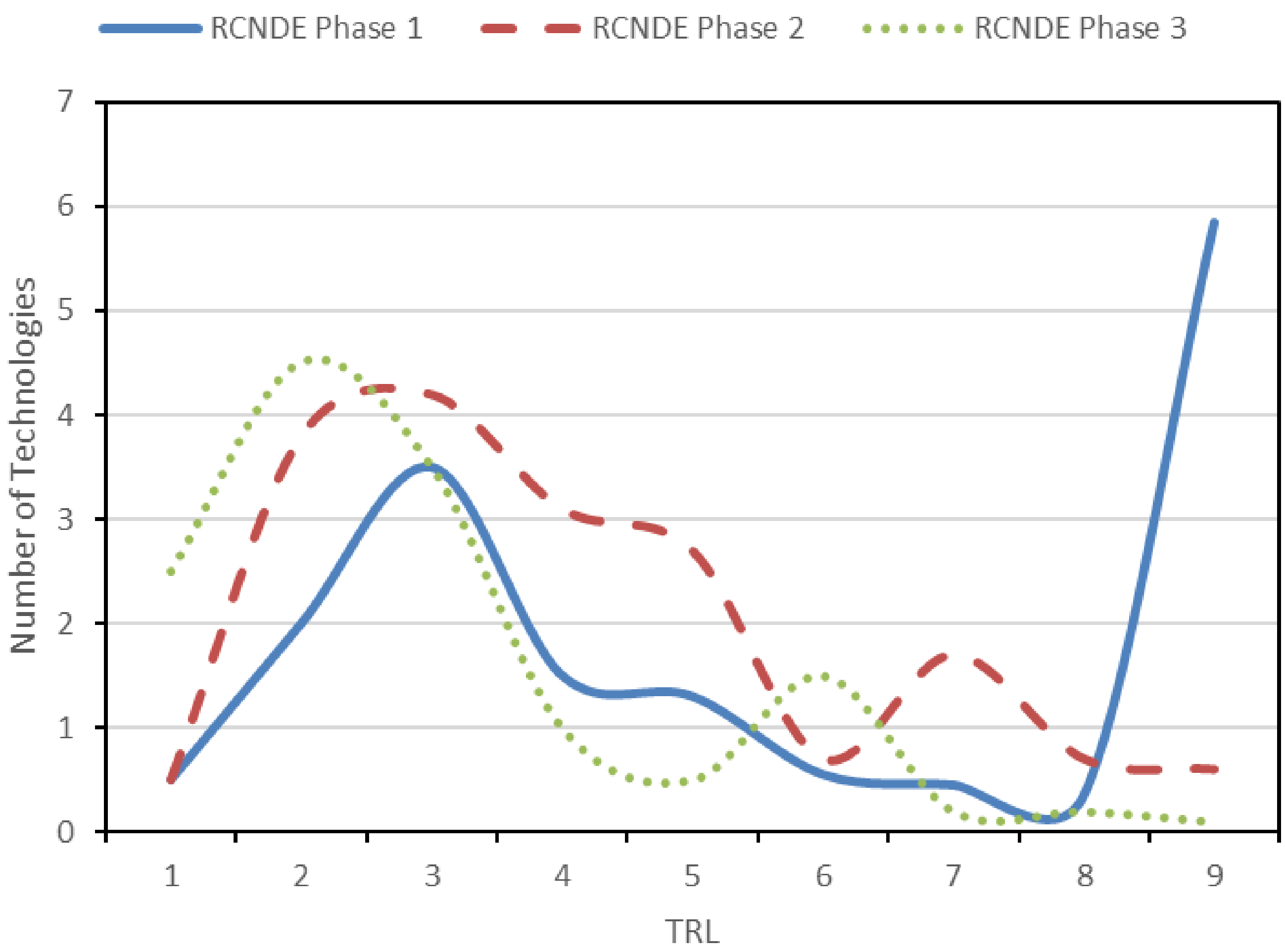
# Industrial vision for NDE


| | | |
|---|---|---|
| Currently at ~TRL 3 or above.<br><br>Principles are well understood & estimate of capability.<br><br>Match found with business need. | Issues that known technologies could address if they were more advanced. | Where we want to be in the ideal world.<br><br>Includes issues with no current solution identified from known technology streams. |

# RCNDE outputs

- Pipeline of more than 50 exploitable products across a range of TRL levels from TRL2-9
- Some implemented by industrial members with significant benefits, some taken up by the market and some undergoing further development & tech transfer
- Significant exploitation successes with benefits to members, associate members and the wider UK NDT market.
  - But we recognise that we struggle with the traditional issue of transitioning technologies through the 'valley of death'.
- More than 80 NDE specialists recruited to industry (Post doc researchers, EngD students etc) with benefit of technologies transitioned into sponsor companies.

# Technology Transition



# New Centre for Doctoral Training

- "EPSRC Centre for Doctoral Training in Future Innovation In Non-Destructive Evaluation"
  - the 'FIND CDT'
- £4m from EPSRC, matched with £3m from industry (mainly RCNDE members).
- This will fund 5 annual cohorts of 10 students

# FIND CDT – research strategy

- We refreshed the research strategy to align with the latest 5-10-20 year NDEvR vision
  - This strategy is focused on NDE's role in the 4$^{th}$ Industrial Revolution
- We have 3 themes;
  - Future NDE technologies
  - Future infrastructure NDE
  - Future manufacturing NDE

# FIND CDT – recruitment

- The website is www.rcnde.ac.uk/home-cdt
- We need a strong list of potential EngD and PhD projects (that link to the strategy) – urgent
- These projects will form the basis for project specific adverts for students.
- General enquiries to find-cdt@bristol.ac.uk, or b.drinkwater@bristol.ac.uk

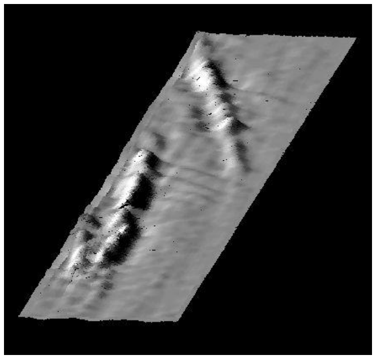
# Using NDT to characterise 3D material properties & model performance

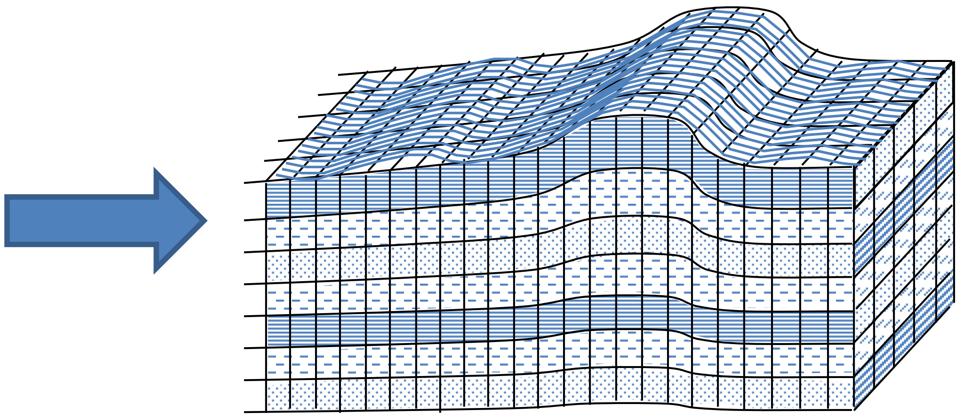
3D non-destructive characterisation

FE Materials Modelling

# 3D non-destructive characterisation

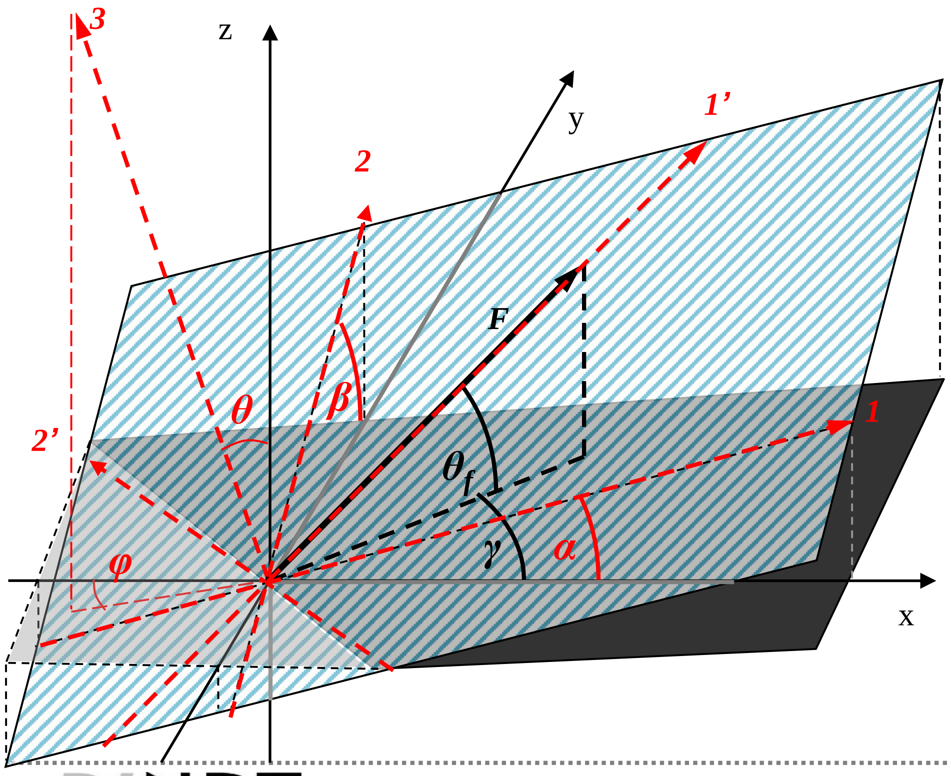
- Predict performance of as-manufactured component.
  - Materials model with actual 3D NDT data inputs
- Finite-element mesh created from NDT ply-wrinkling data.

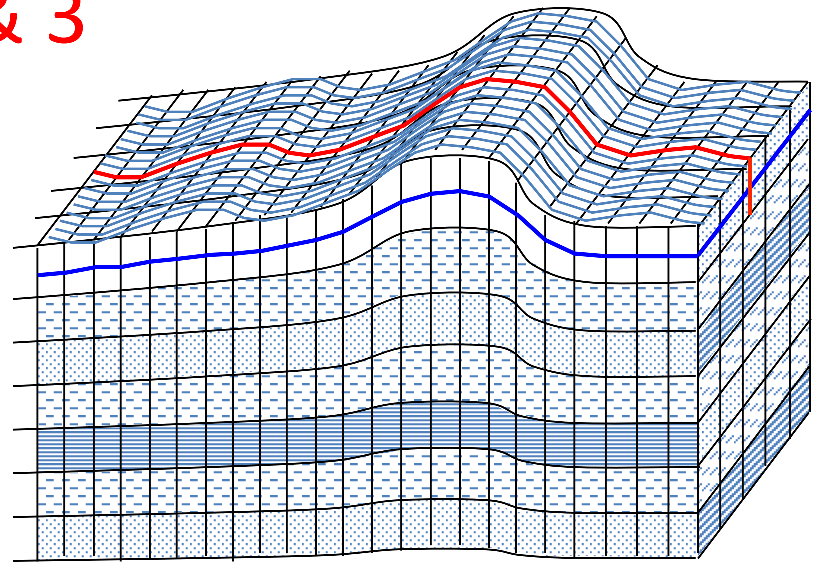




# Materials Modelling

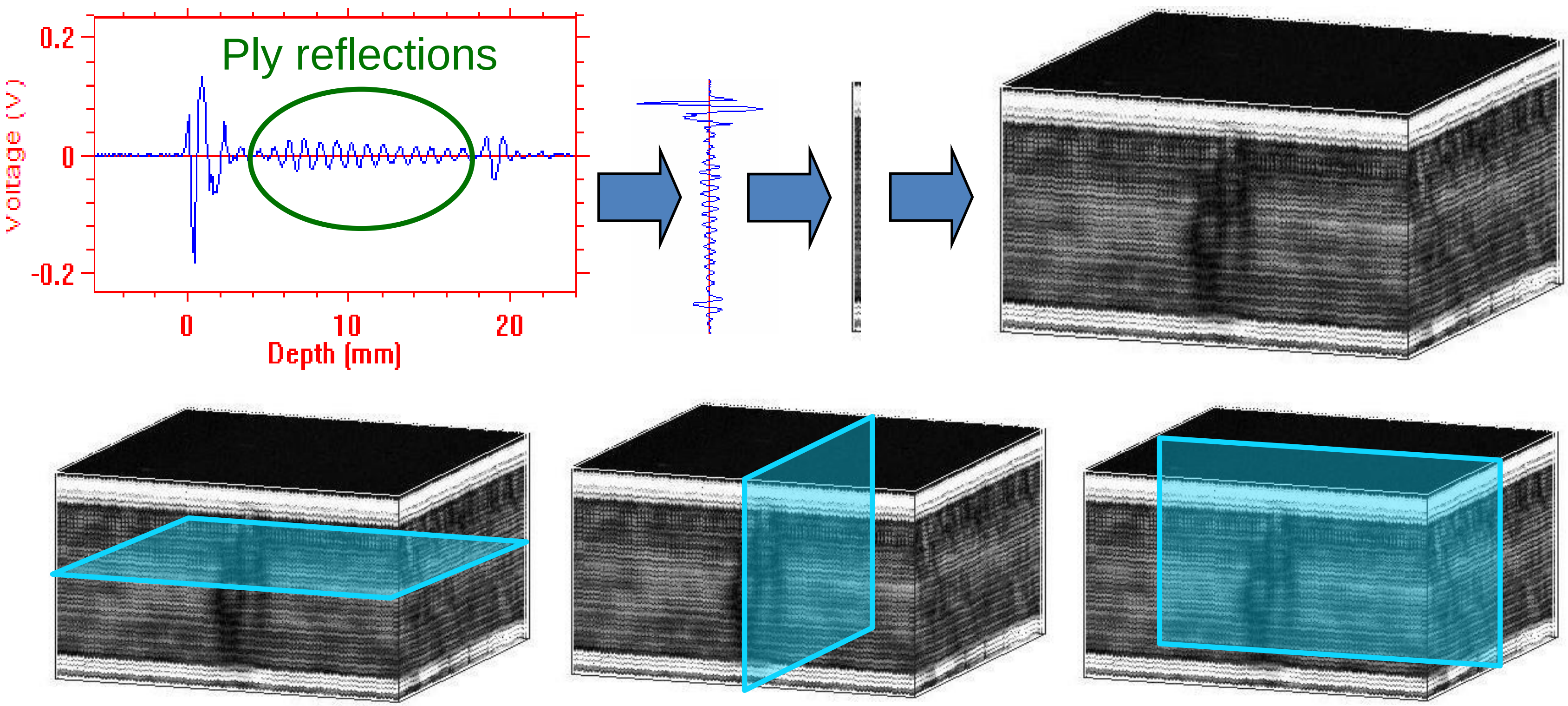
- Populate cells with 3D Fibre Angle (α,β,γ), vector field, stiffness axes 1', 2' & 3



# Ultrasound

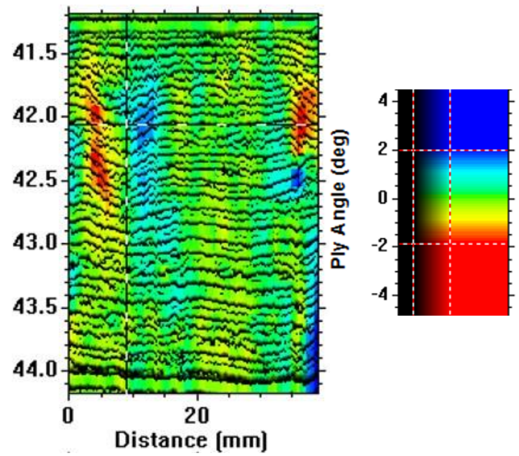
- Grey level can be amplitude or phase response



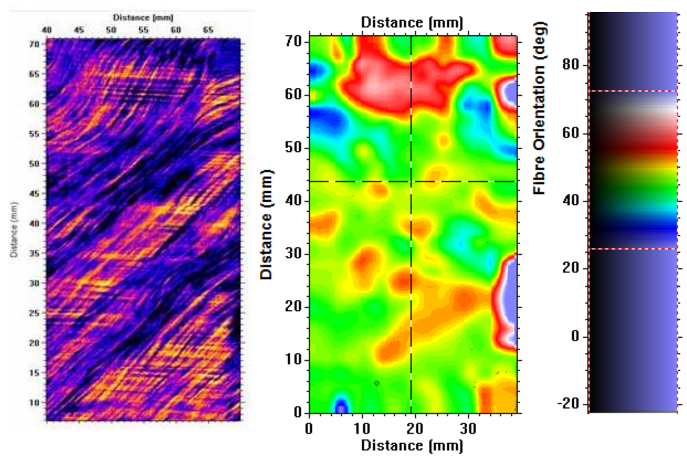
# 3D non-destructive characterisation

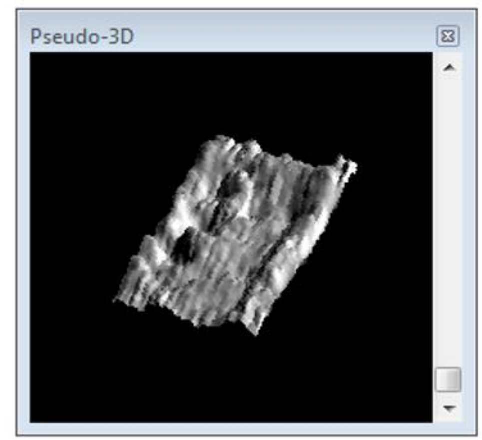
- Quantitative 3D fibre orientation 'inversion'

B-scan




C-scan

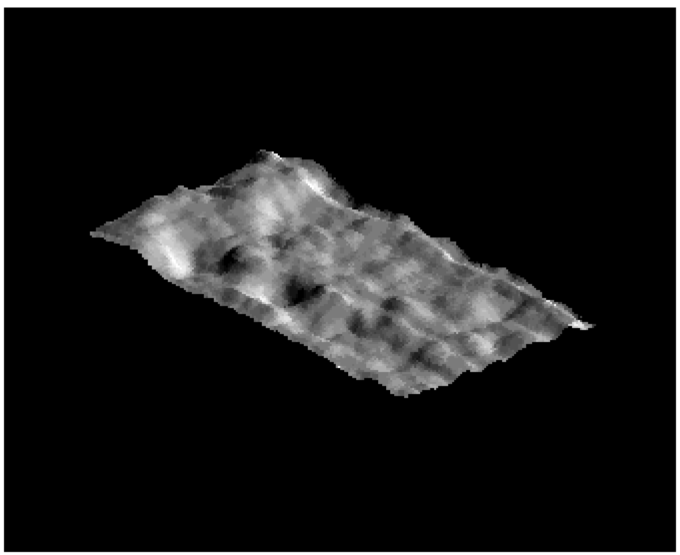


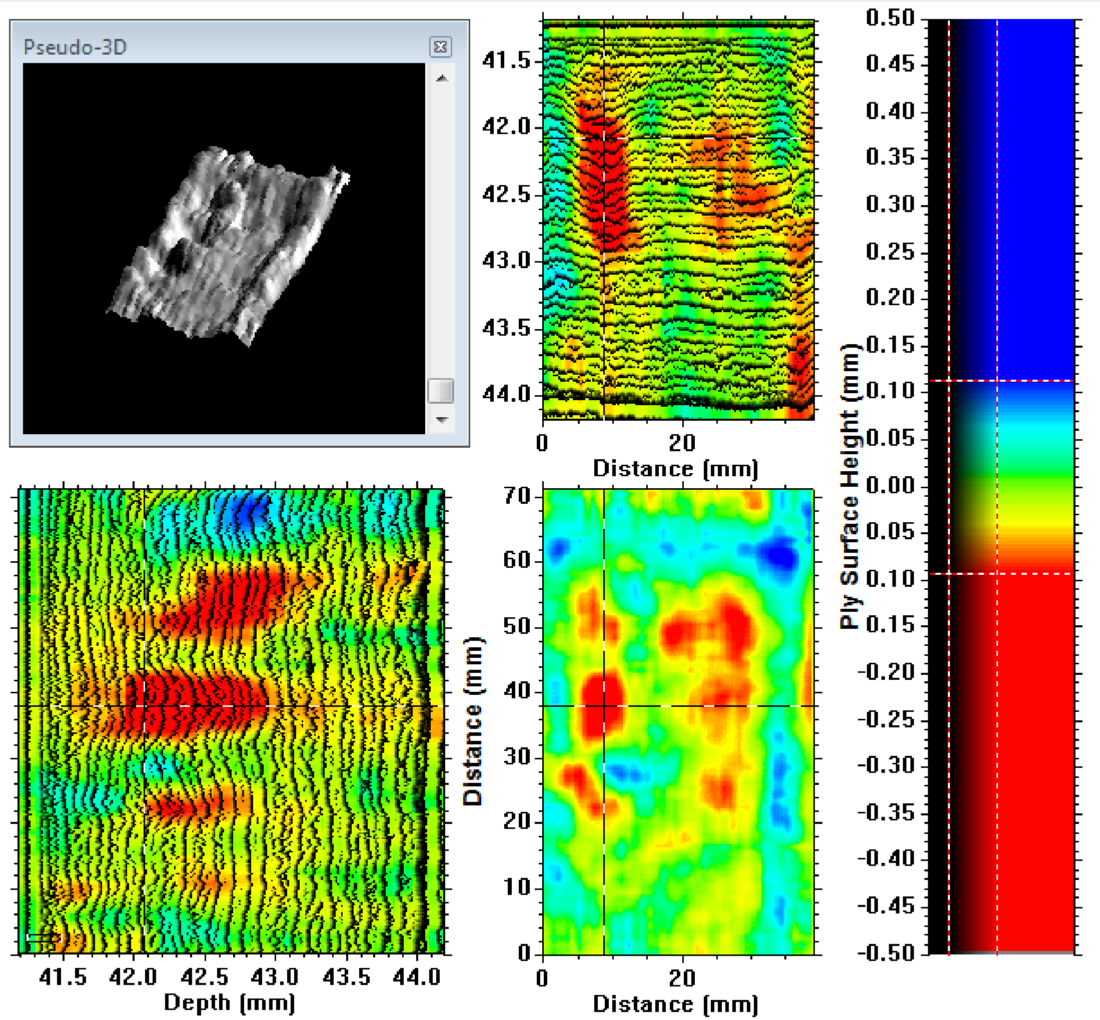




$\alpha, \beta$ – out-of-plane fibre angle + $\gamma$ – in-plane fibre angle → Surface Heights

# 3D non-destructive characterisation

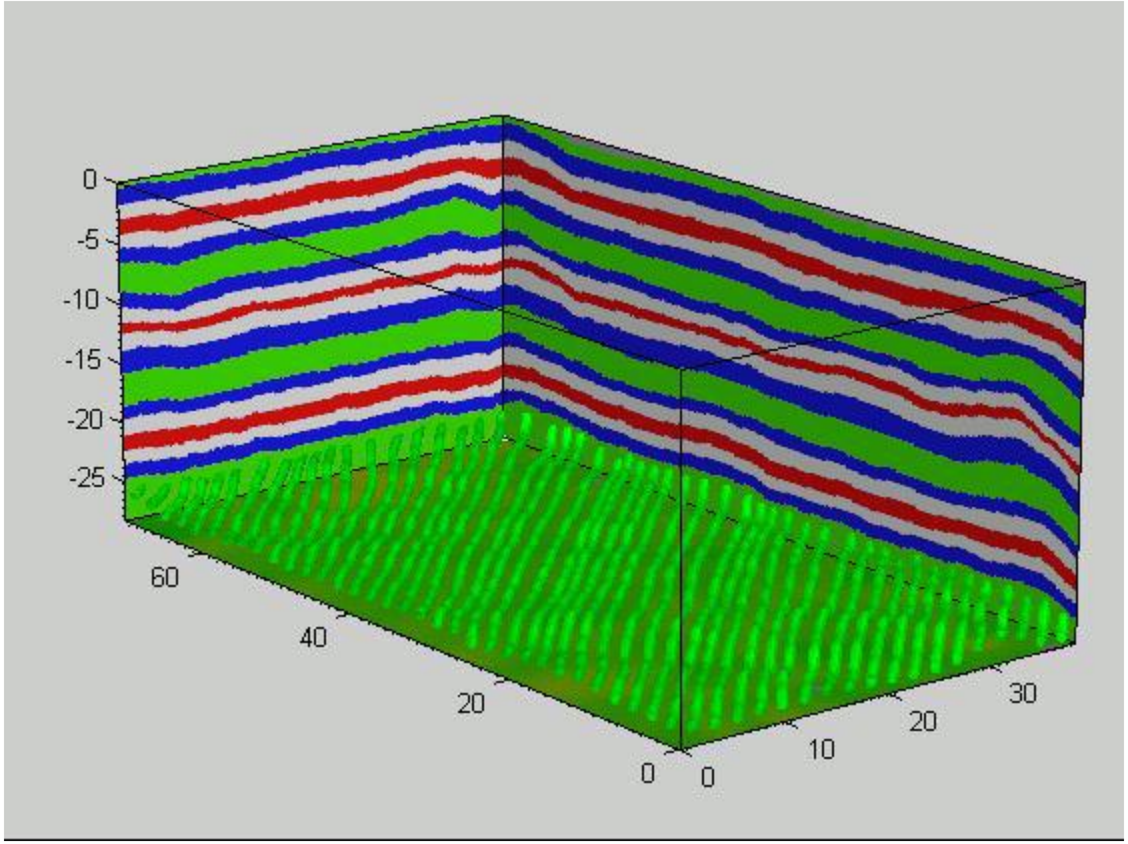
- Quantitative ply surface height…





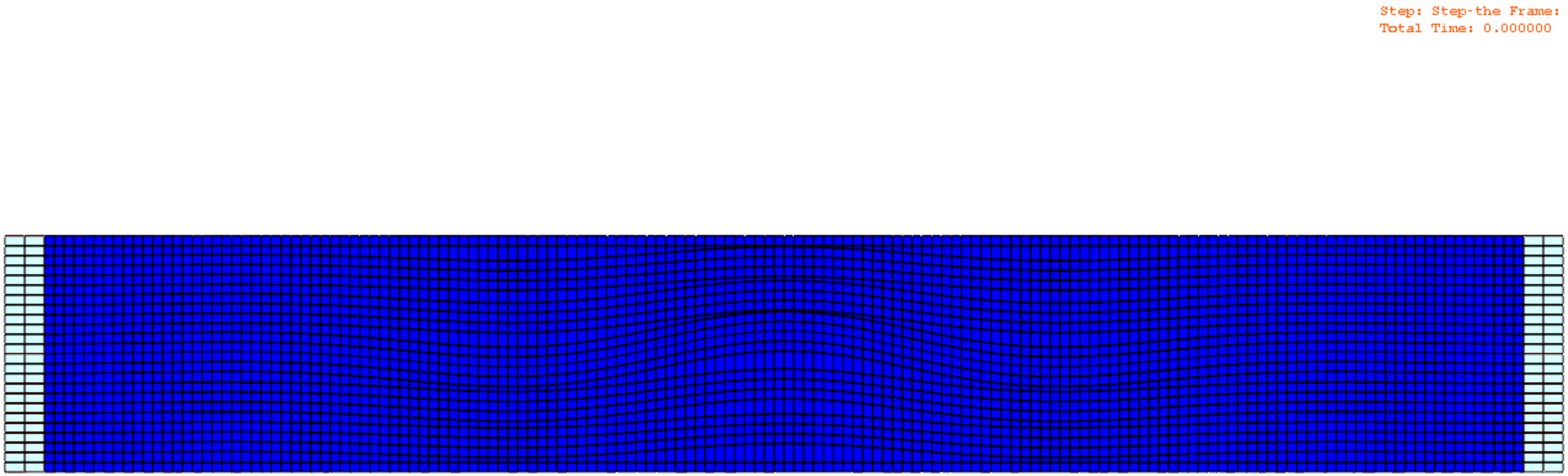
# 3D Vector Map of Fibre-tow orientation

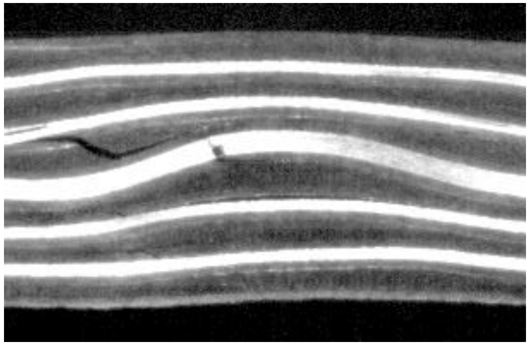
- Vector Field
- Fibre-tow maps of ‘streamlines’ (analogy with fluid dynamics), vectors, ***F***




0.125 mm thick plies.
$[45°, 0°, -45°, 90°, -45°, 0°, 45°]_3$

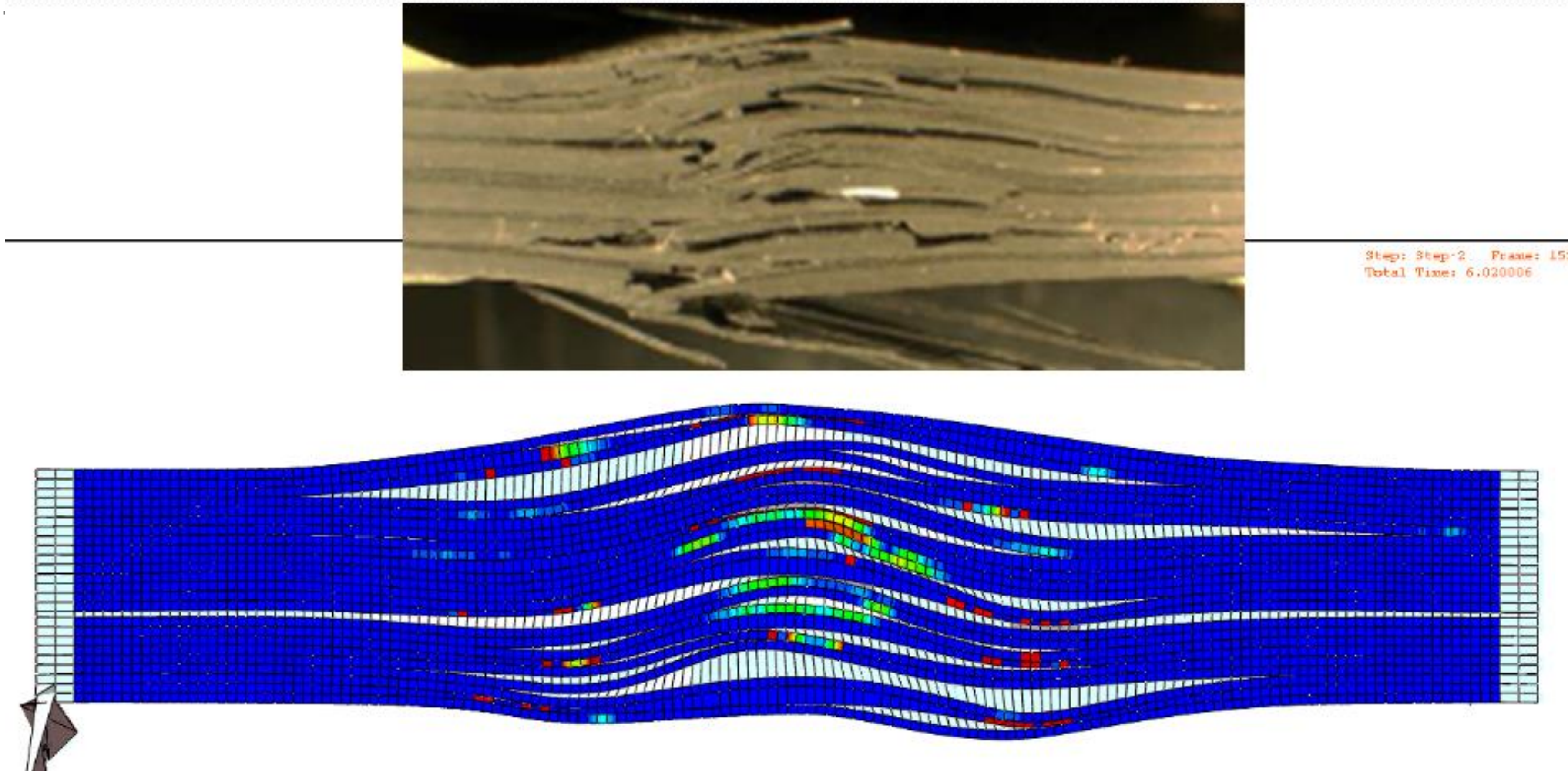
# NDT-based prediction of strength



Miss Ningbo Xie, PhD student

# Simulation and modelling



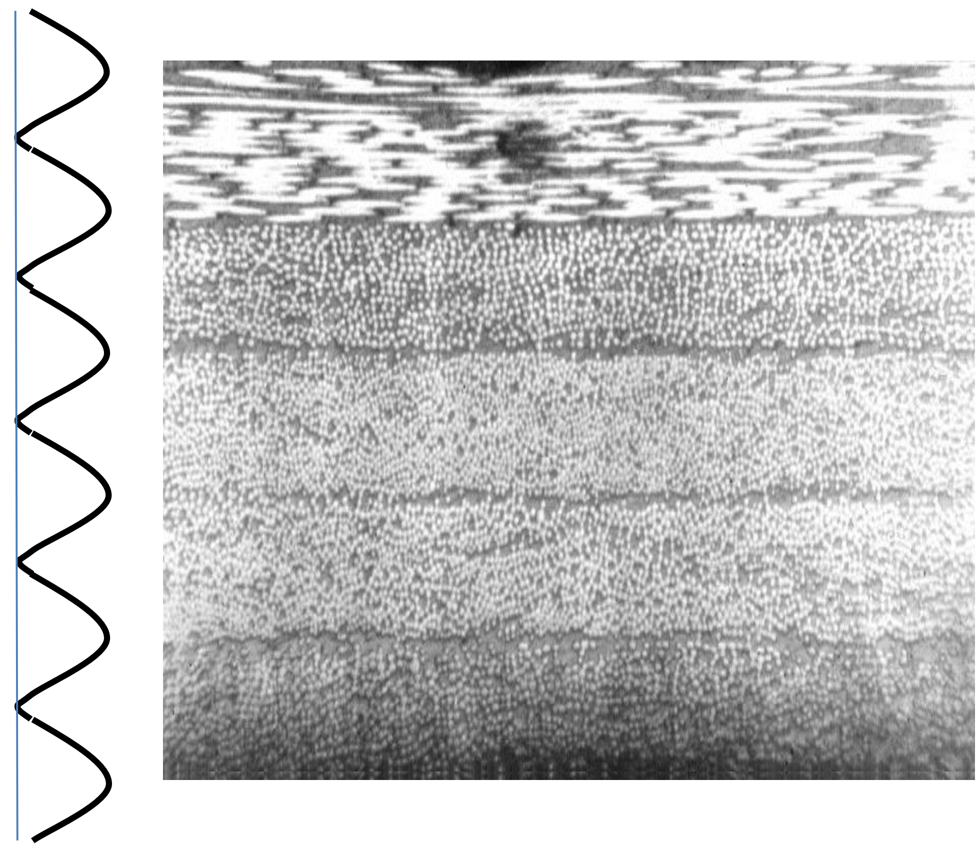

Miss Ningbo Xie, PhD student

# 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.



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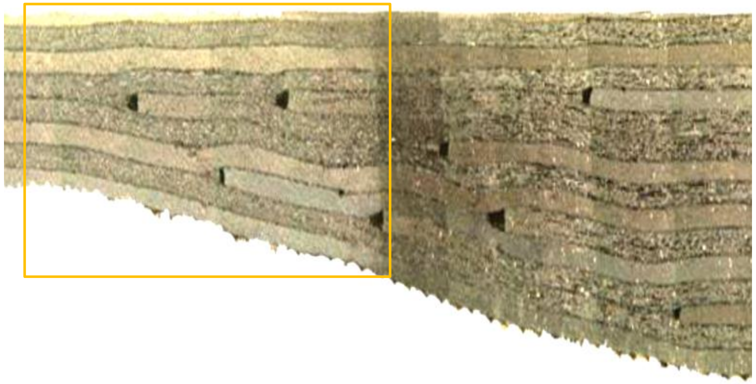
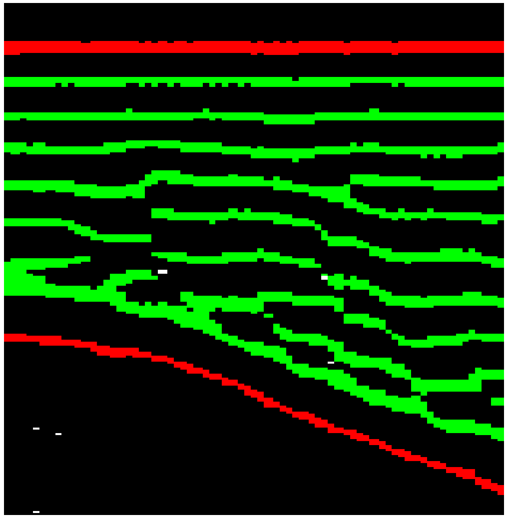
# Ply-drop specimen

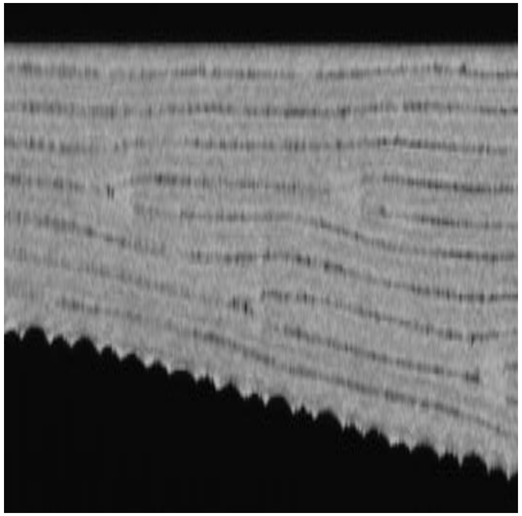


Optical Micrograph

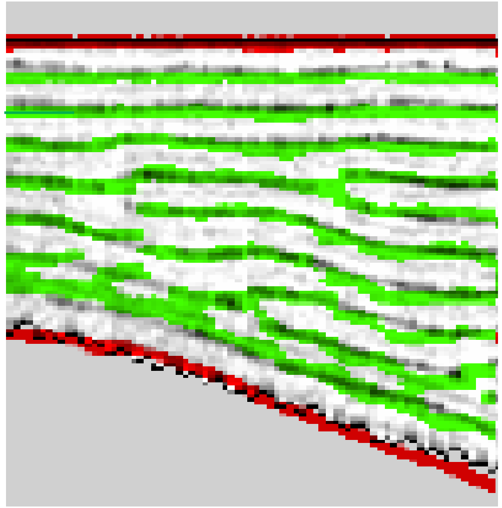
Analytic-signal



X-ray CT



Overlaid



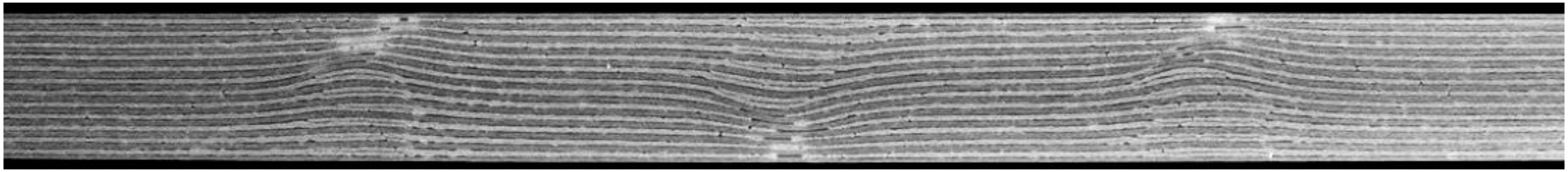
BINDT THE BRITISH INSTITUTE OF NON-DESTRUCTIVE TESTING

EPSRC Engineering and Physical Sciences Research Council

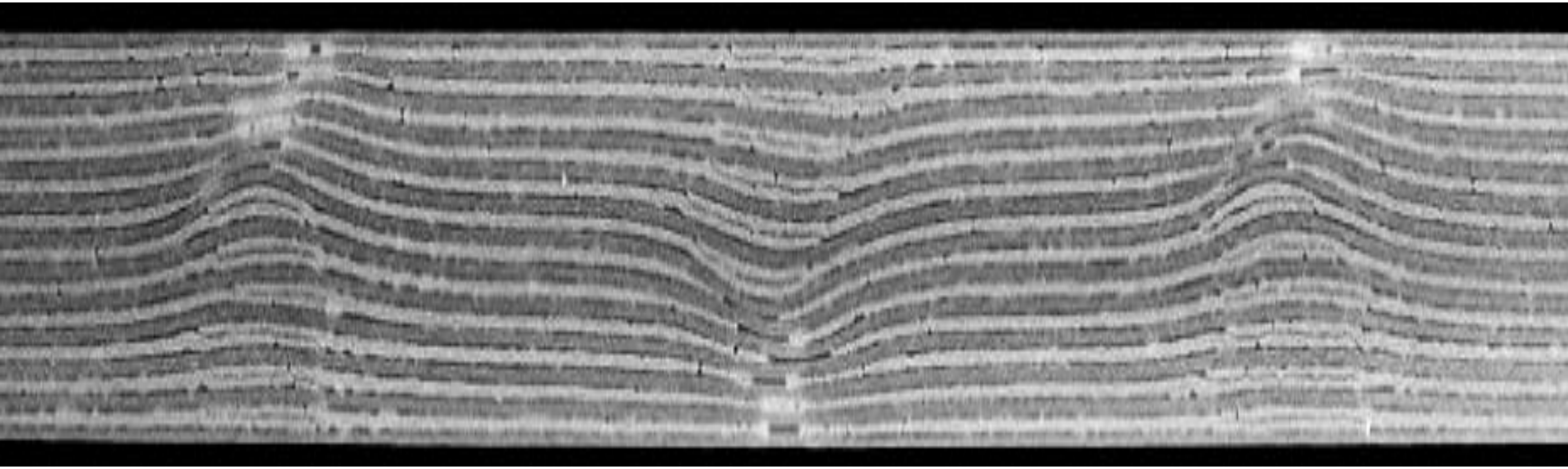
RCNDE UK Research Centre in NDE

# Tape gaps, overlaps, wrinkling

- Tape gaps and overlaps can cause wrinkling



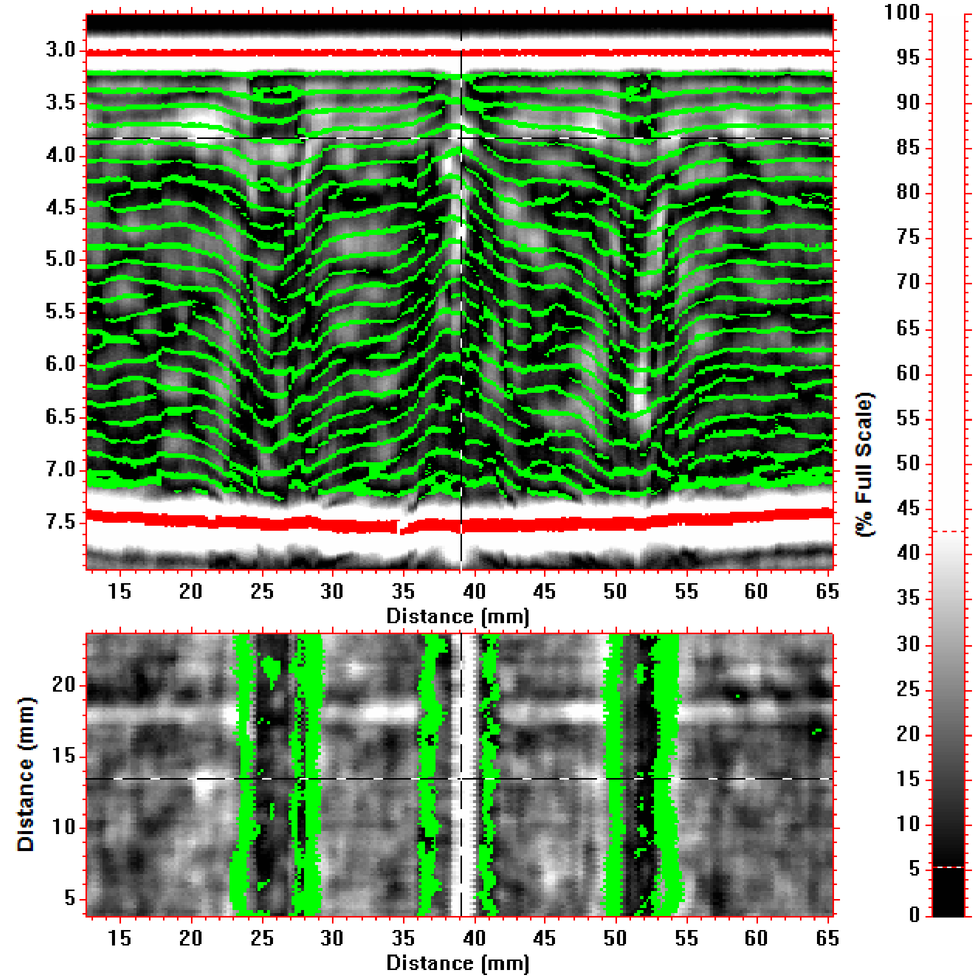
X-ray CT data



# Tape gaps, overlaps, wrinkling

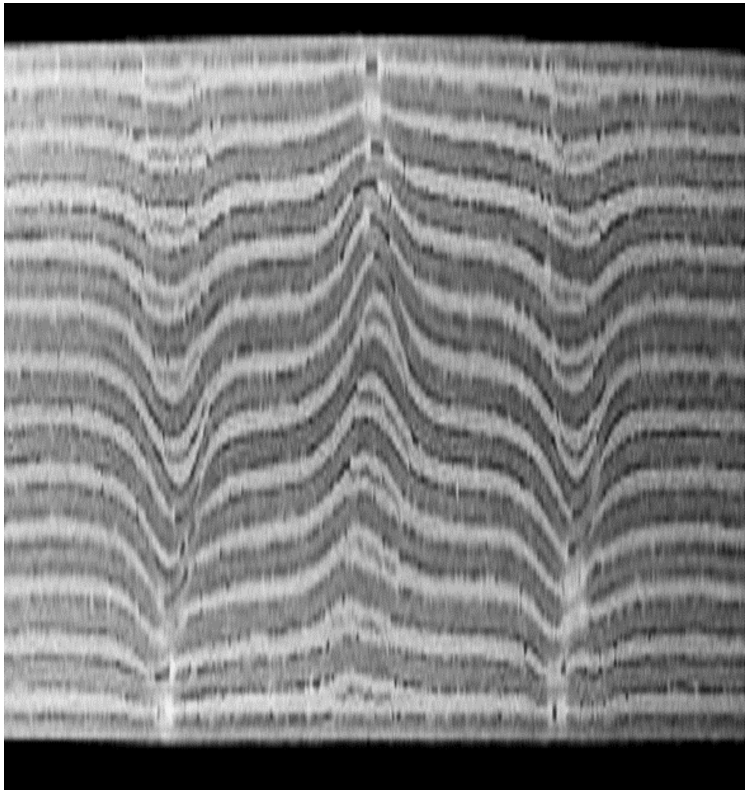
Front-wall, back-wall, ply-drops

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

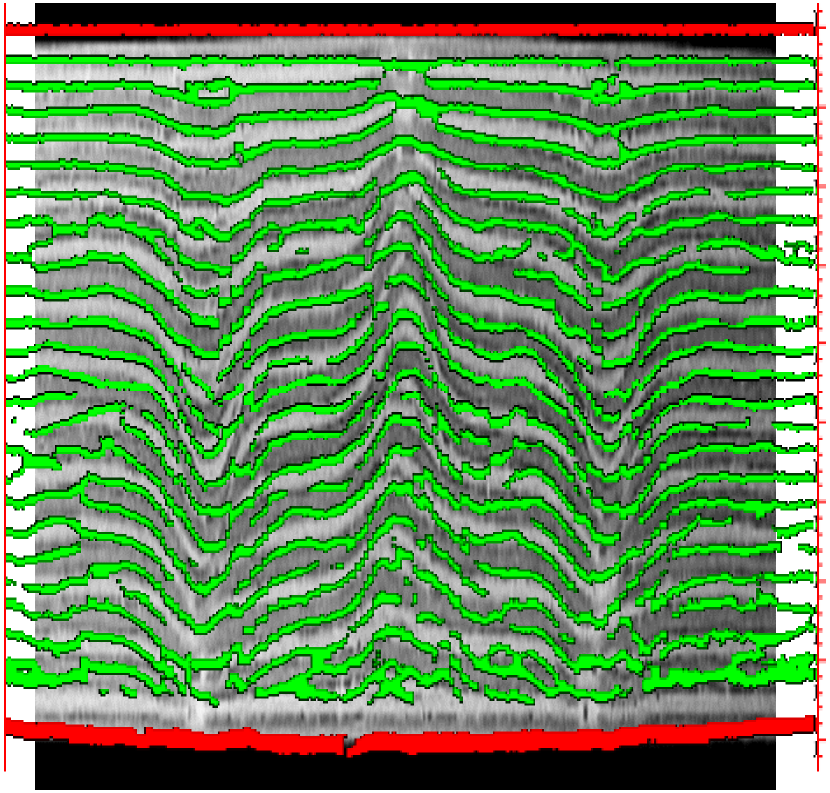


# Tape gaps, overlaps, wrinkling

X-ray CT scan



With analytic-signal overlay



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# Wind-turbine wrinkles

- Paper by Beatriz Larranaga - PhD student, Madrid
- Wind-turbine wrinkles in carbon/glass composite

Composites Part A 114 (2018) 225–240

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Composites Part A

journal homepage: www.elsevier.com/locate/compositesa


## Wrinkle measurement in glass-carbon hybrid laminates comparing ultrasonic techniques: A case study

Check for updates

Beatriz Larrañaga-Valsero[a,*], Robert A. Smith[b], Rostand B. Tayong[b], Antonio Fernández-López[a], Alfredo Güemes[a]

[a] *Department of Materials and Aerospace Production, Polytechnic University of Madrid, Spain*
[b] *Department of Mechanical Engineering, University of Bristol, BS8 1TR, UK*

# Wind-turbine wrinkles

- 0.6 mm CFRP ply spacing.
- 0.44 mm GRP every 6th ply.

# Wind-turbine wrinkles

- Manufacturing process

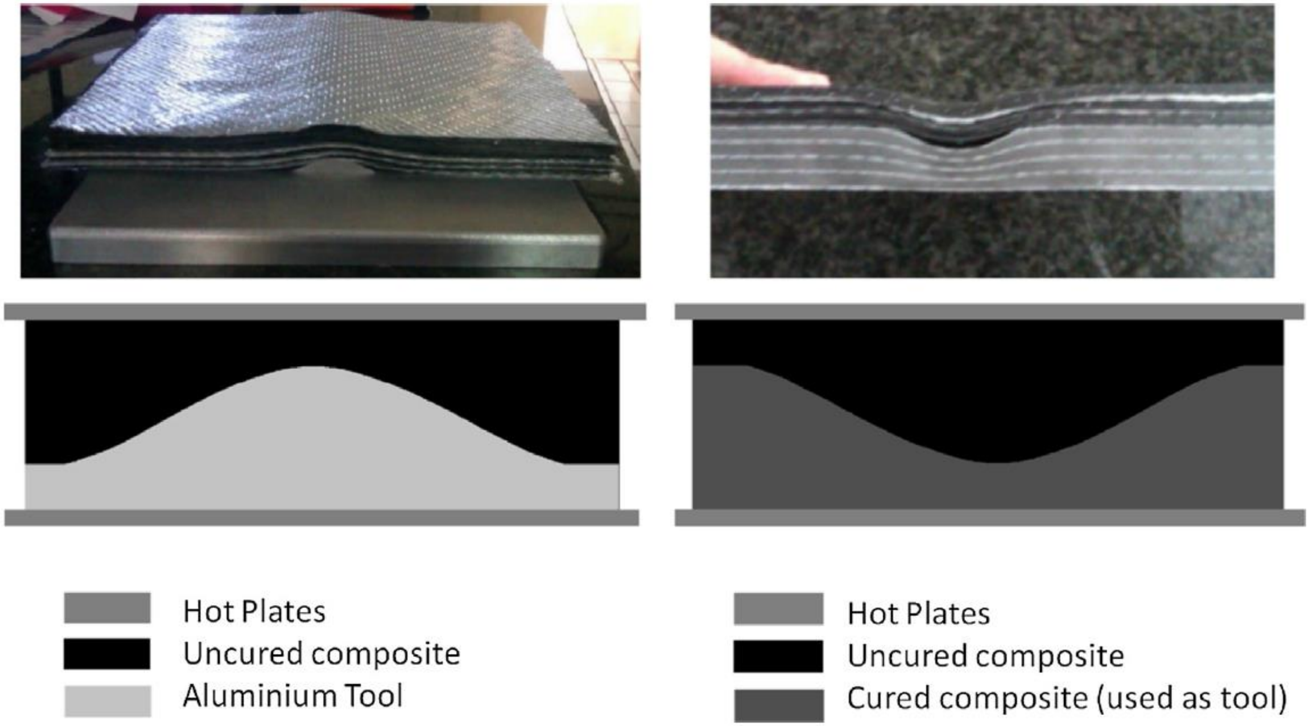
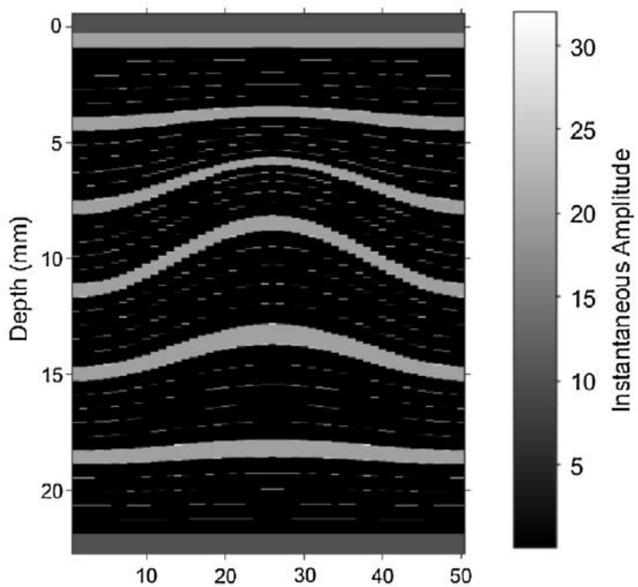


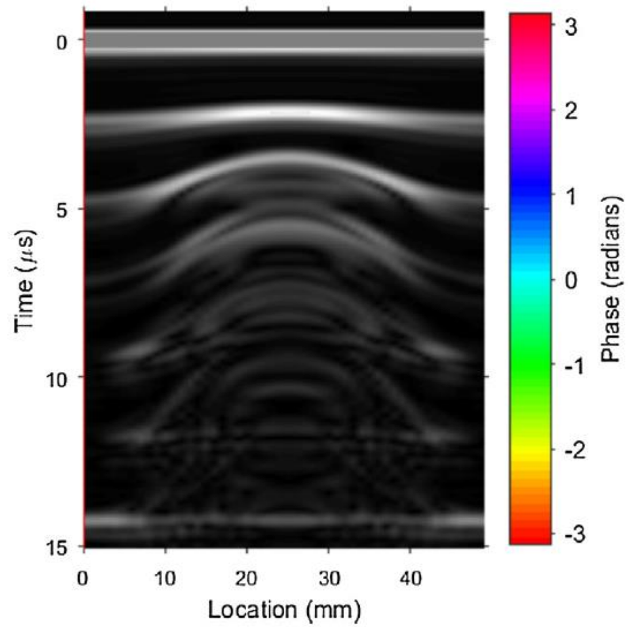

**Fig. 3.** Diagram of the two steps of the manufacturing process (first step on the left, second step on the right). Aluminium tool used during the manufacture of the specimens with half of the plies stacked on it before curing (Top left). The effect where the layers do not conform to the geometry of the tool can be seen clearly (Top).

# Wind-turbine wrinkles

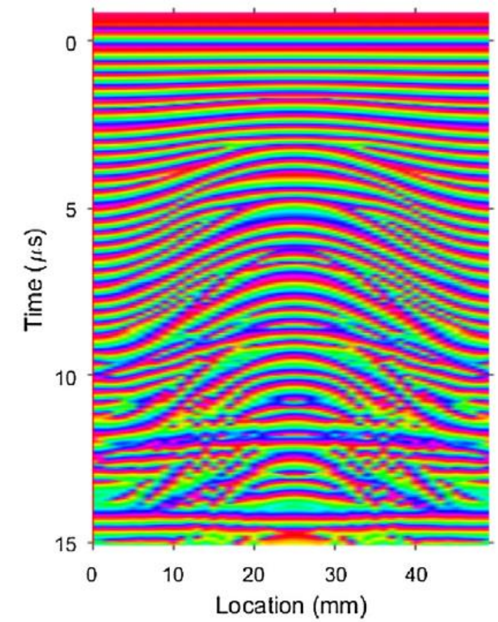
- Simulated response. 2.25 MHz centre freq. & bandwidth. 0.6 mm ply spacing. 0.44 mm GRP every 6th ply.




Model

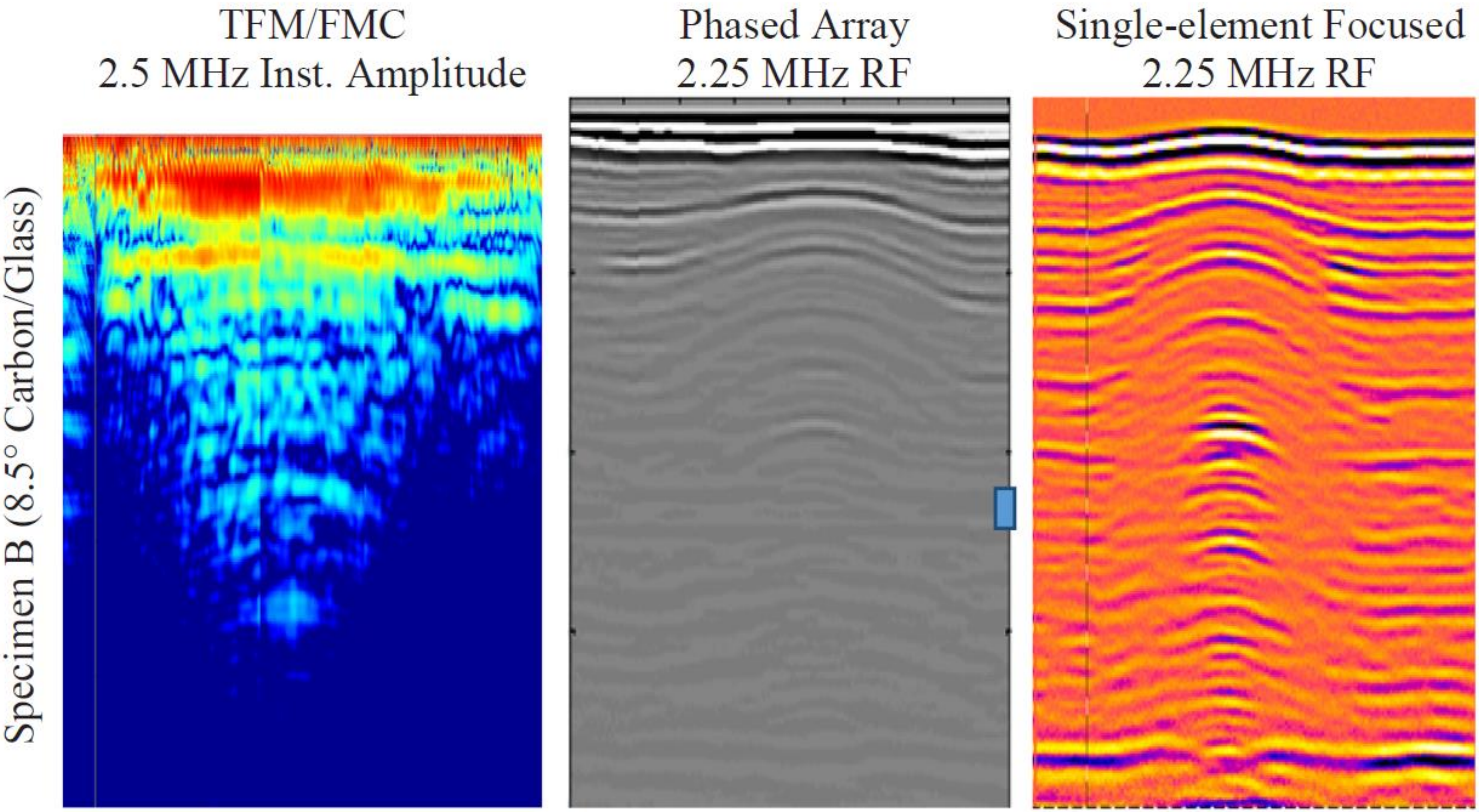



Instantaneous amplitude

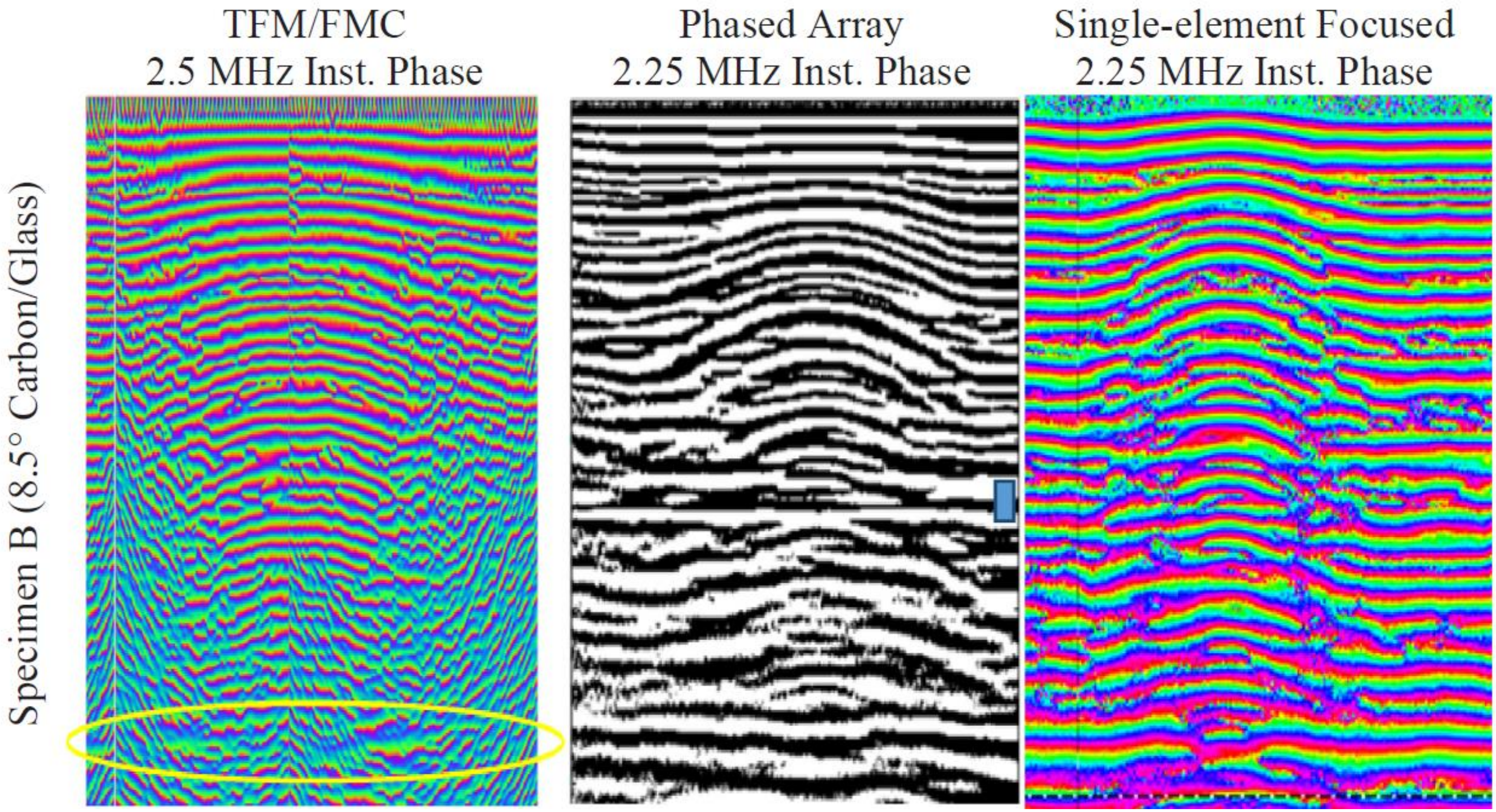



Instantaneous phase

# Wind-turbine wrinkles



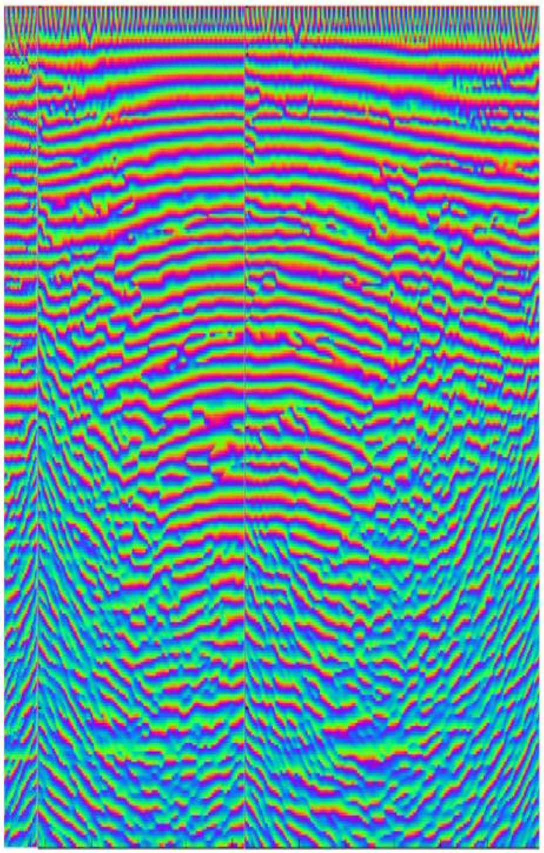
# Wind-turbine wrinkles



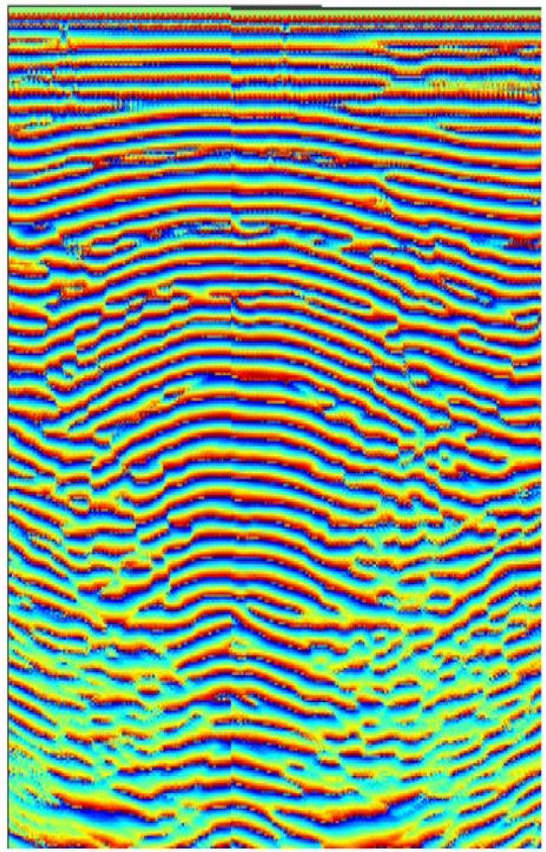
# Wind-turbine wrinkles

## 2.25 MHz Instantaneous phase

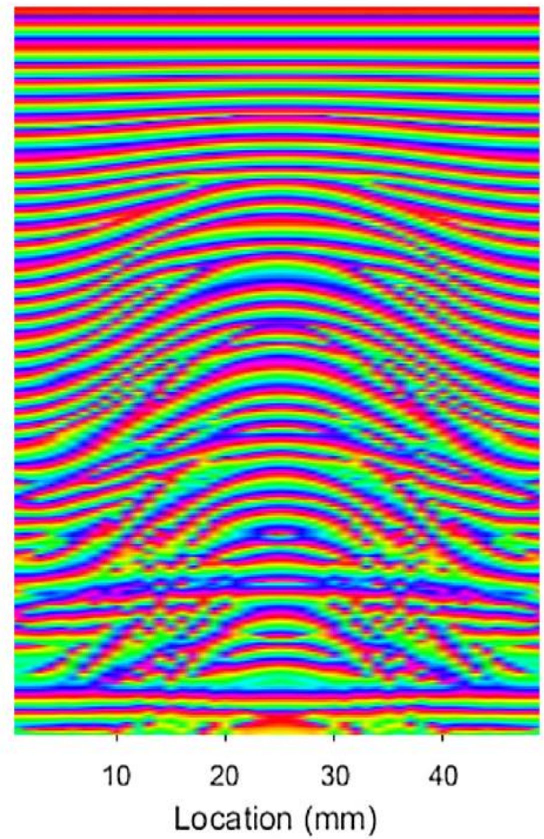
### Isotropic TFM



### Anisotropic TFM

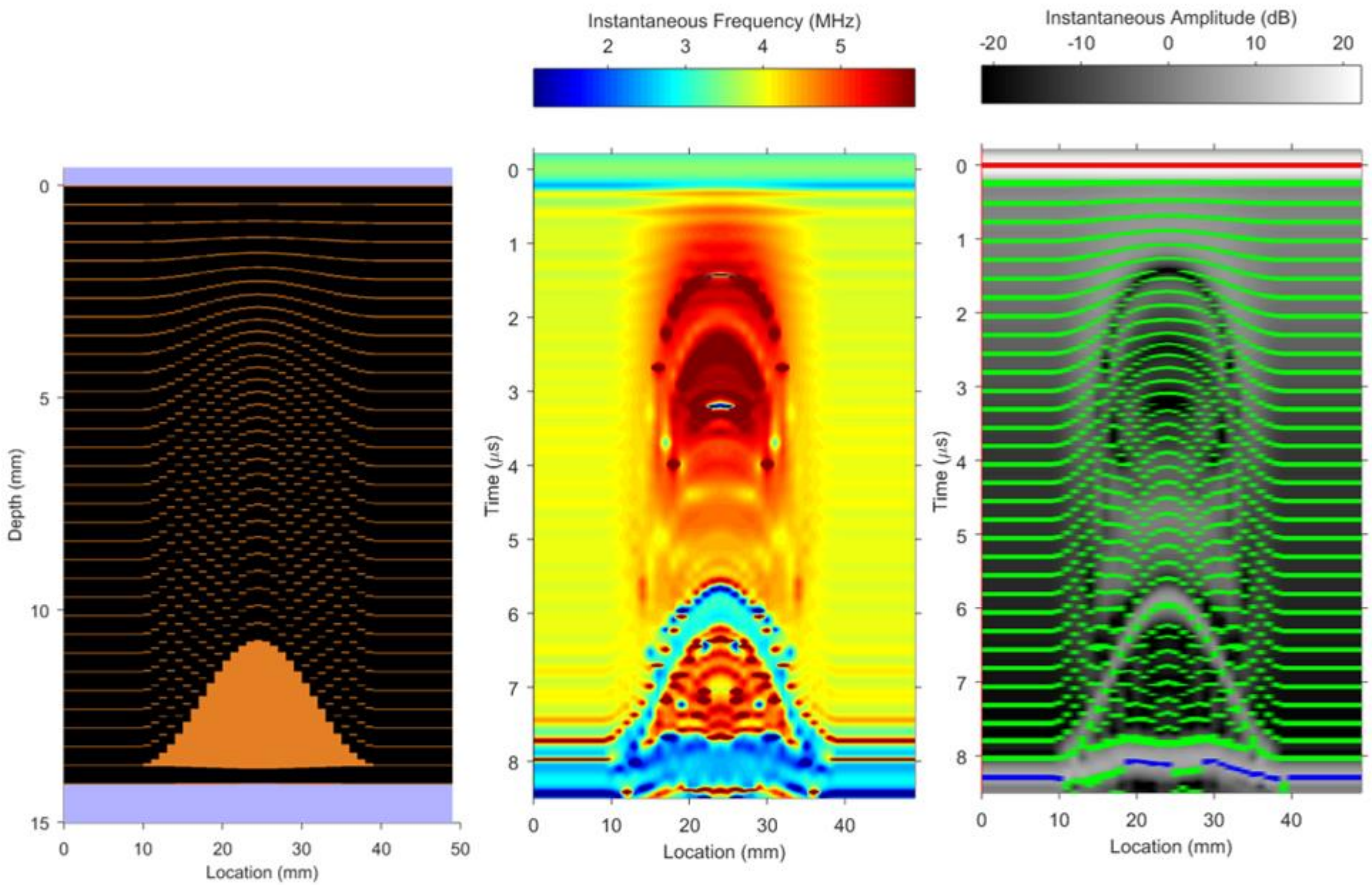


### 1D Simulation



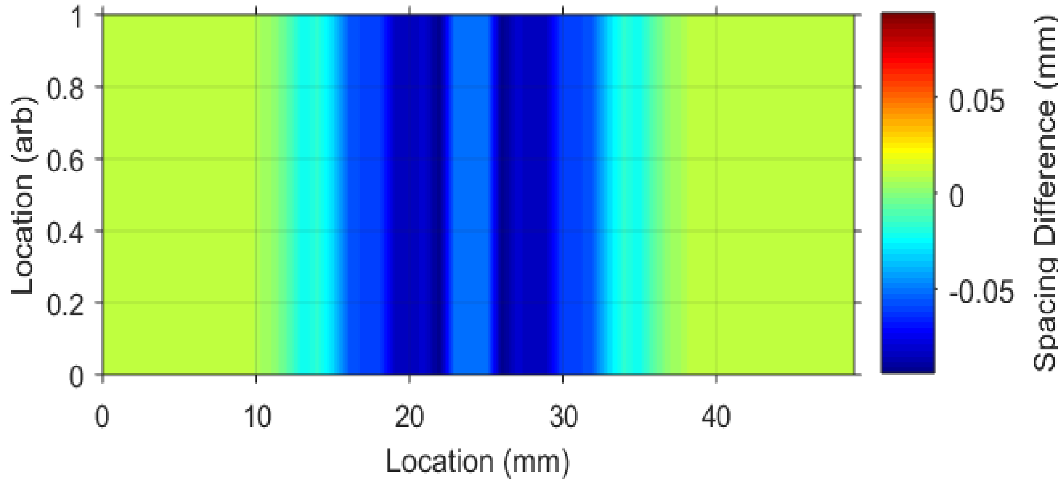
# Instantaneous frequency

- Proportional to 1 / ply-spacing

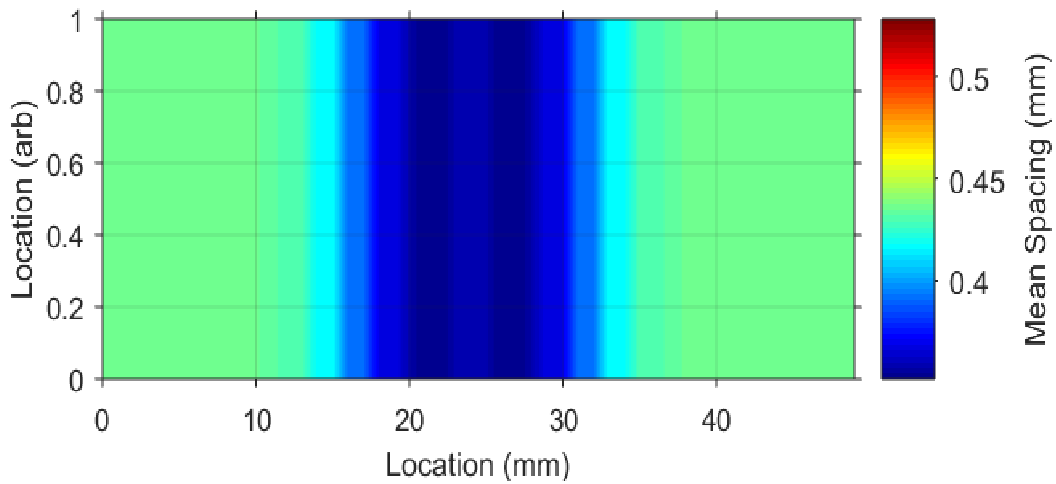


# Instantaneous frequency

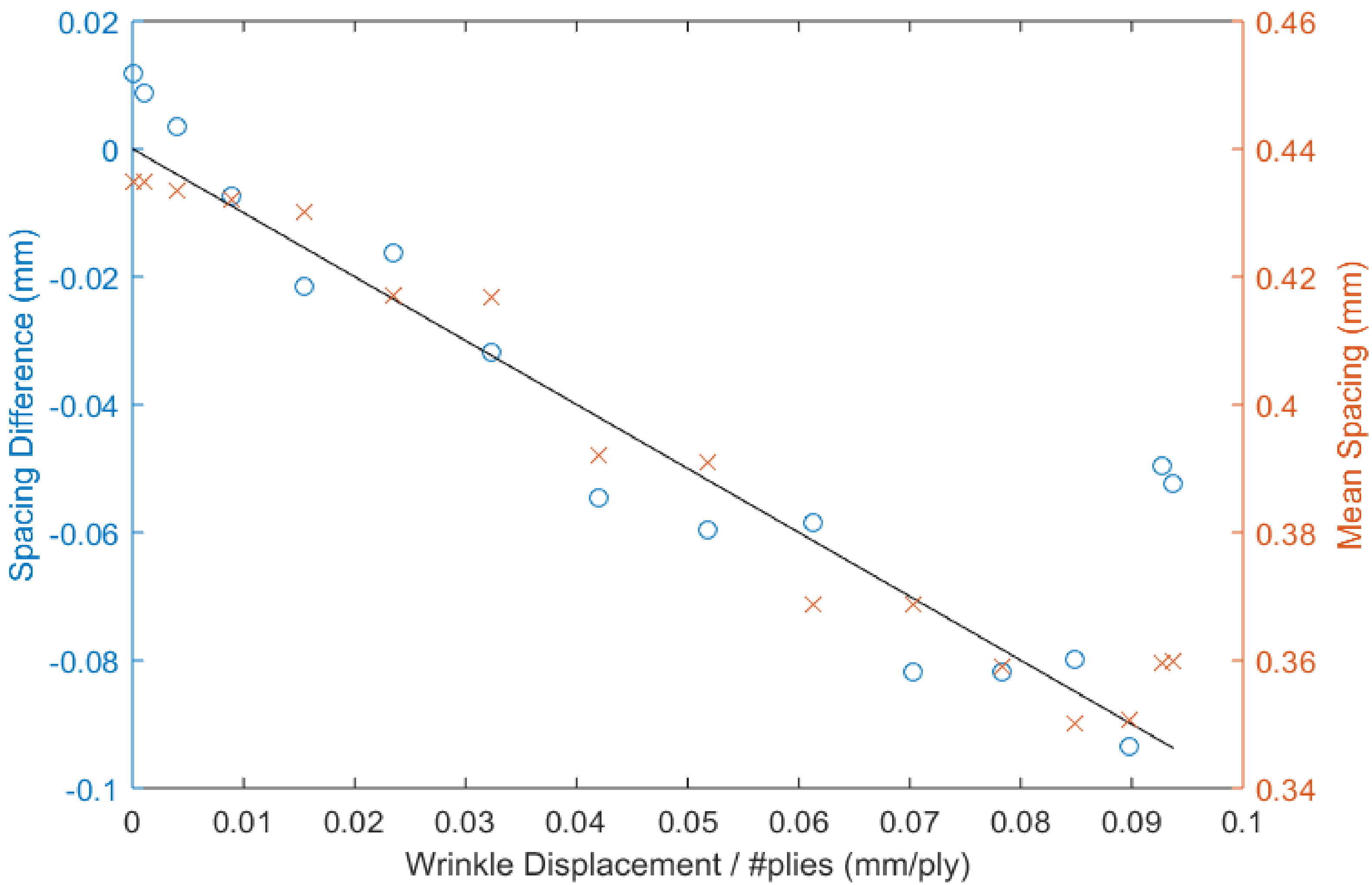
- 2 new parameters:
  - Spacing difference (between top and bottom halves of the structure)




  - Mean spacing



# Instantaneous frequency






Engineering and Physical Sciences Research Council

UK Research Centre in NDE

# Folded wrinkle

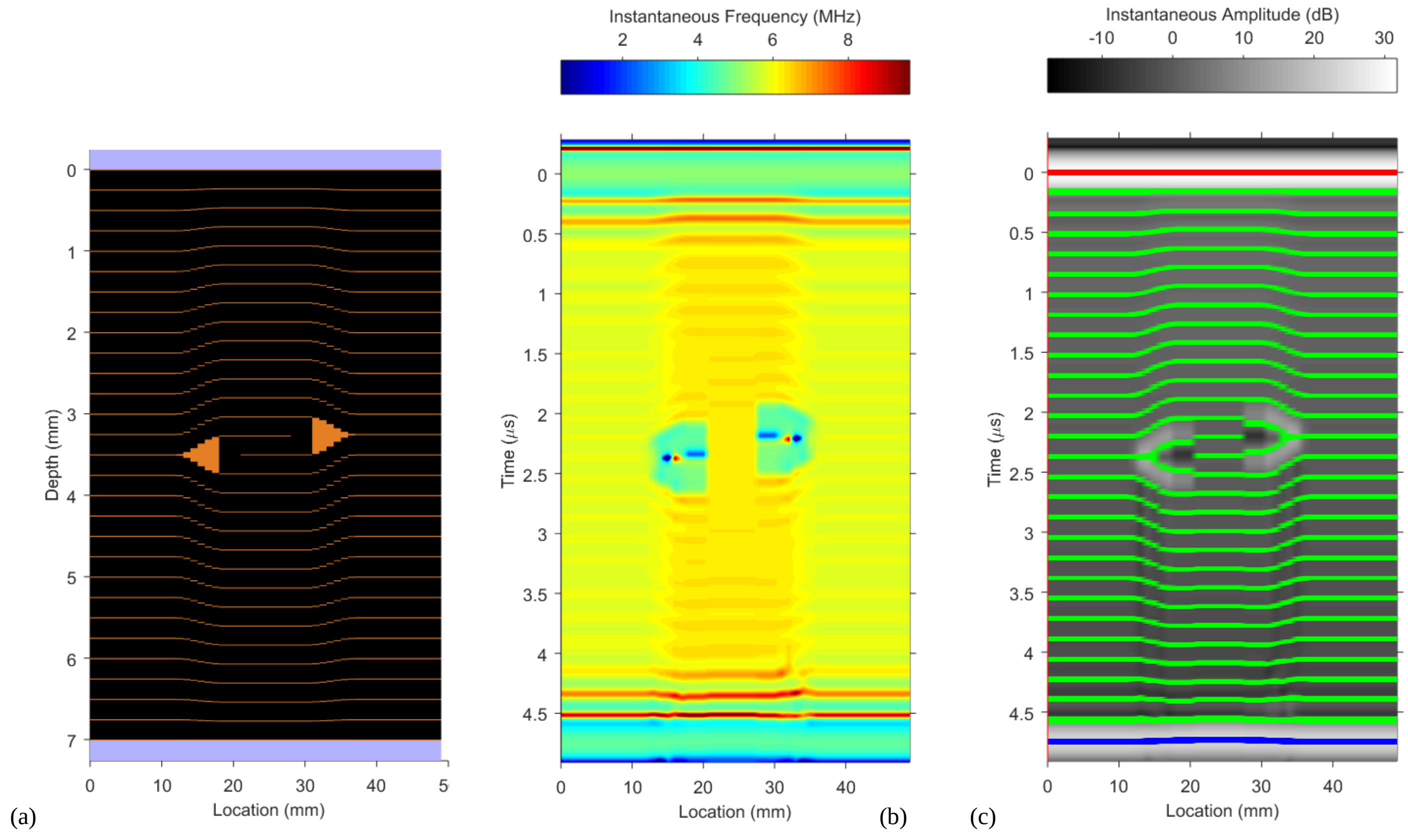



*Figure 14. Instantaneous parameters modelled for 28 plies of nominal 60% FVF carbon-fibre composite of ply spacing 0.25 mm with 0.01 mm resin layers and a folded wrinkle involving one ply folded over in the central section. (a) Model diagram showing water (blue), resin layers (brown), and CFRP (black); (b) instantaneous frequency; (c) ply tracking superimposed on instantaneous amplitude where green represents the phase locked to resin layers, red is the front-surface echo and blue is the back-surface echo.*

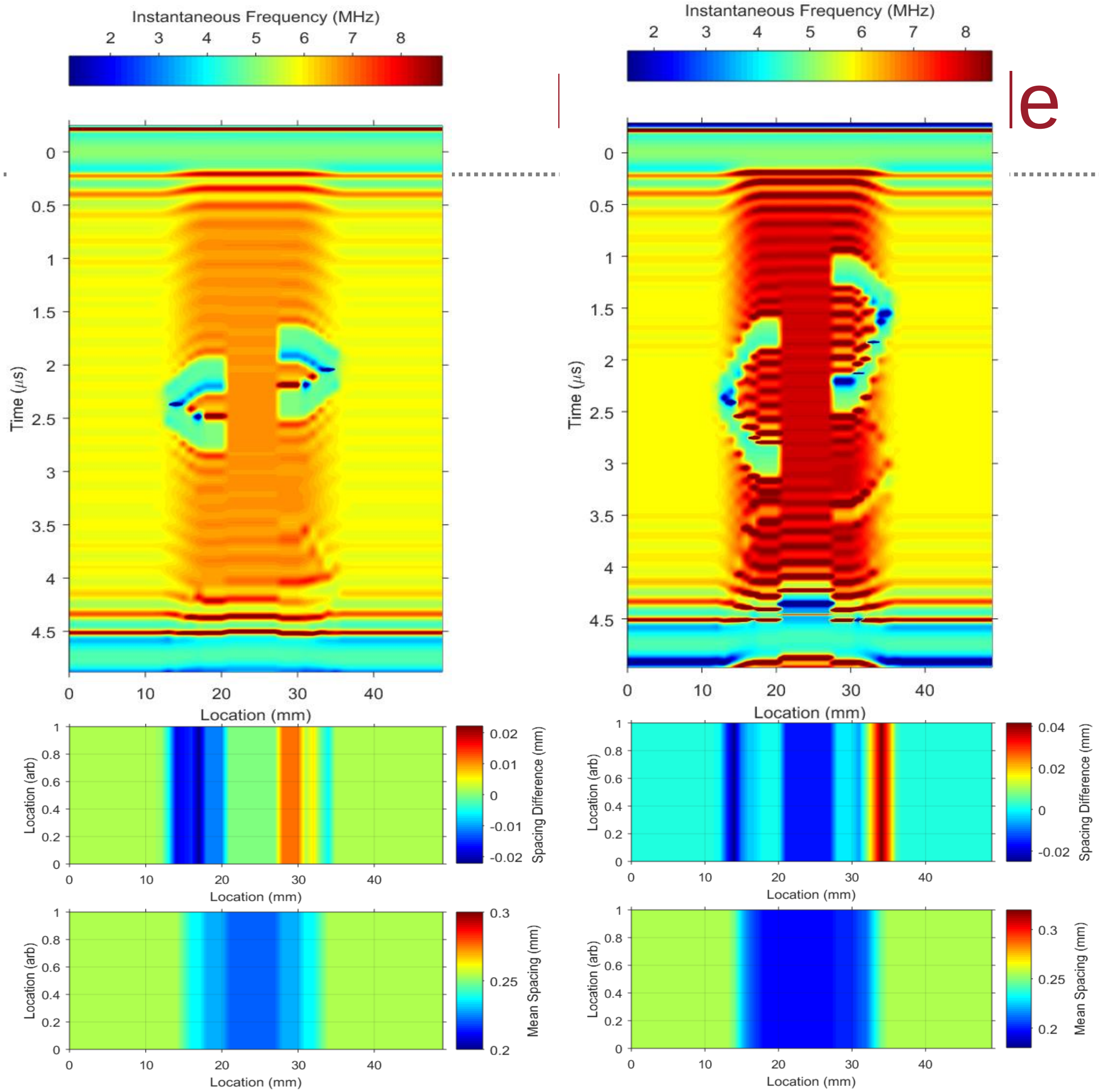



*Figure 16. Instantaneous-frequency maps (top), Spacing Difference (middle) and Mean Spacing (bottom) metrics plotted for the two-ply folded wrinkle (left) and a five-ply folded wrinkle (right).*

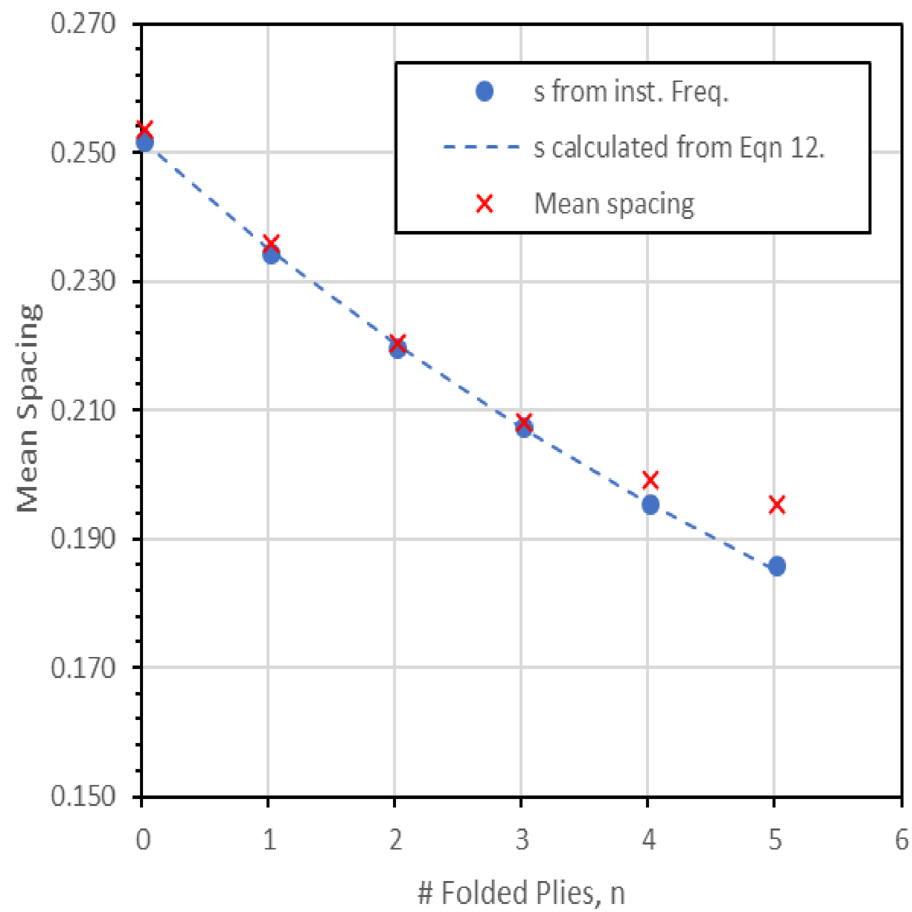
# Folded wrinkle

Mean Spacing determined from the time window from the bulk plies, excluding the first and last plies (red crosses),

Local spacing calculated from instantaneous frequency at the depth of the fold (circles),

as a function of the number of folded plies.

The Mean Spacing calculated from Eqn. 12 is also shown (dashed line).



# Conclusions

- Ultrasound offers:
  - Ply tracking through wrinkles
  - Detection and measurement of wrinkles
  - Inversion to map 3D material properties
  - Automated creation of FE materials models
- NDT-based FE Materials modelling offers potential benefits
  - Prediction of performance
  - Only scale limitation is time for scan and analysis