3D Non-destructive Characterisation of Preformed Composites.

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Engineering and Physical Sciences Research Council

Acknowledgements

- Dr Rostand Tayong
- Dr Luke Nelson
- Dr Martin Mienczakowski
- **EPSRC Impact Acceleration Project**, Partners:
  - Jaguar Land Rover
  - AMRC
  - NCC
  - CCT (Hexion)
  - QinetiQ
- EPSRC Fellowship in Manufacturing

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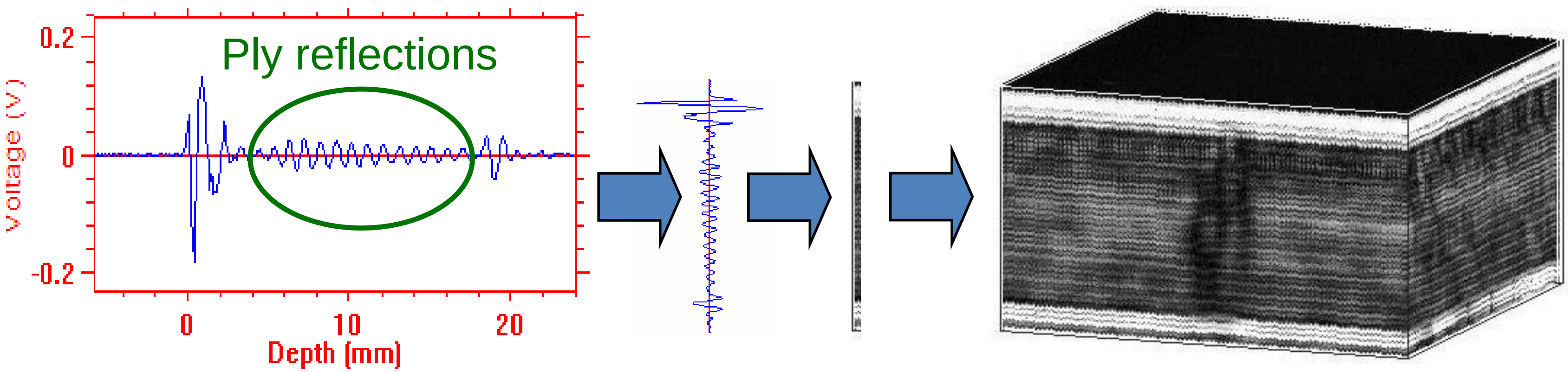
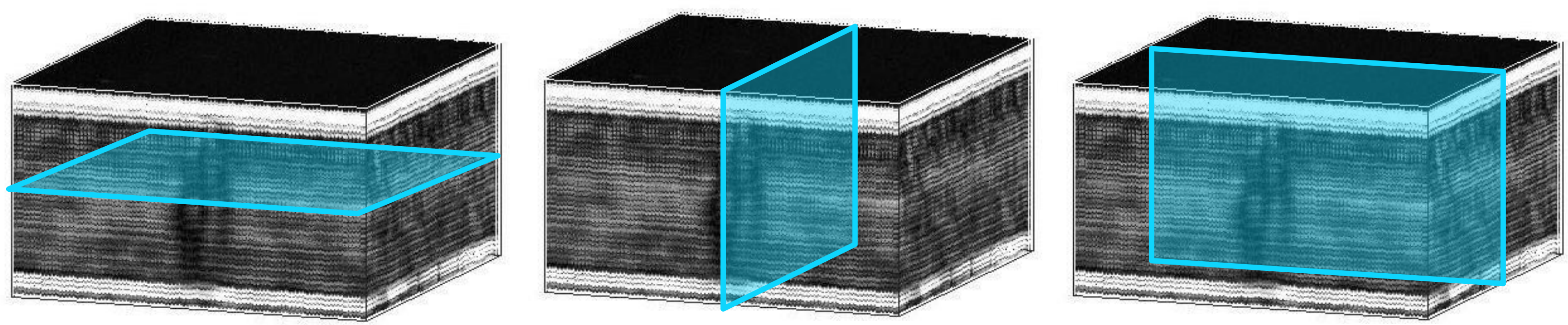
Content

- Introduction
  - 3D non-destructive characterisation
  - Analytic signal formulation
  - Ply Fingerprinting for woven fabrics
- EPSRC Impact Accelerator Results
  - 2D woven
  - 3D textile
- FE Materials Modelling of woven and 3D composites
- Conclusions

Ultrasound

- Grey level can be amplitude or phase response





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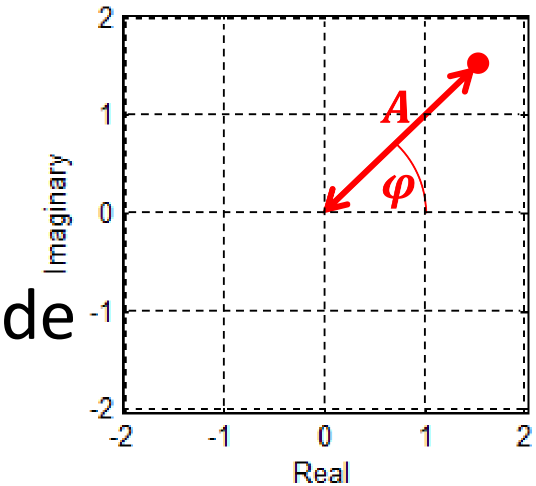
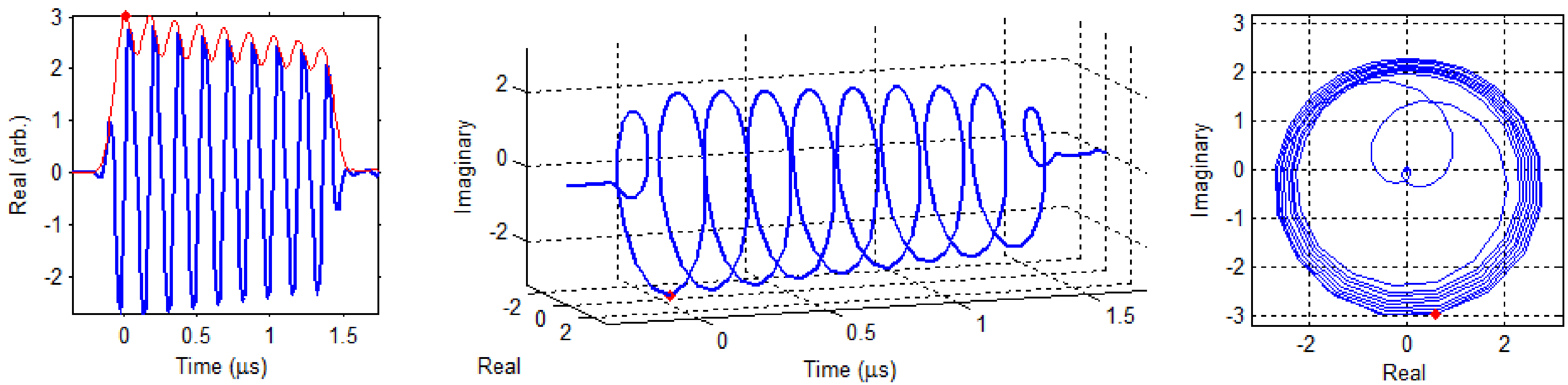
Analytic Signal Formulation

- Analytic Signal x(t):

$$x(t) = A(t)e^{i\varphi(t)}$$

where: A(t) is the instantaneous amplitude
φ(t) is the instantaneous phase





8-ply CFRP laminate, 0.25 mm ply spacing, in composite

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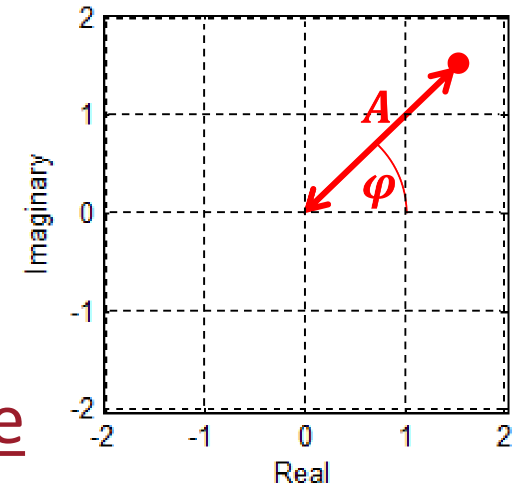
Analytic Signal Formulation

- Analytic Signal x(t)

$$\boldsymbol{x(t) = A(t)e^{i\varphi(t)}}$$



where: A(t) is the instantaneous amplitude

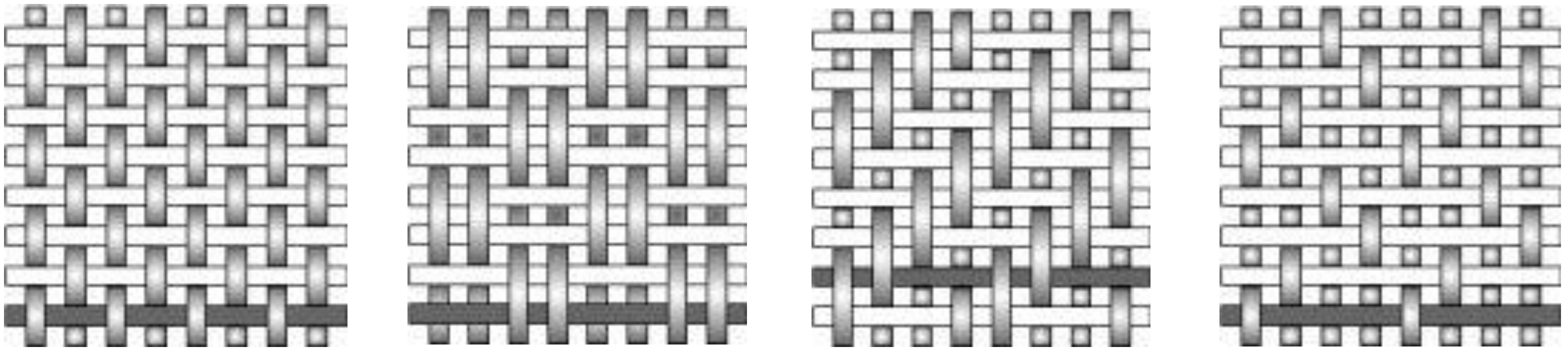
φ(t) is the instantaneous phase

$\frac{1}{2\pi}\frac{\mathrm{d}\varphi}{\mathrm{d}t}$ is the instantaneous frequency

(local rate of change of phase)

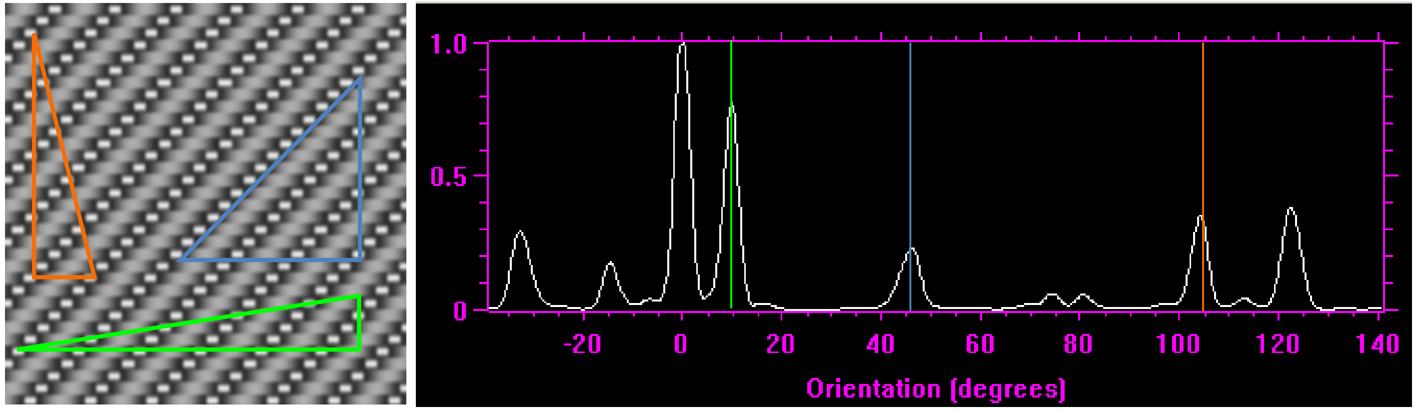
Ply Fingerprinting for woven fabrics

- Multiple peaks in:
  - Angular distribution, and
  - Spatial frequency distribution
- But each weave has a characteristic *Ply Fingerprint*

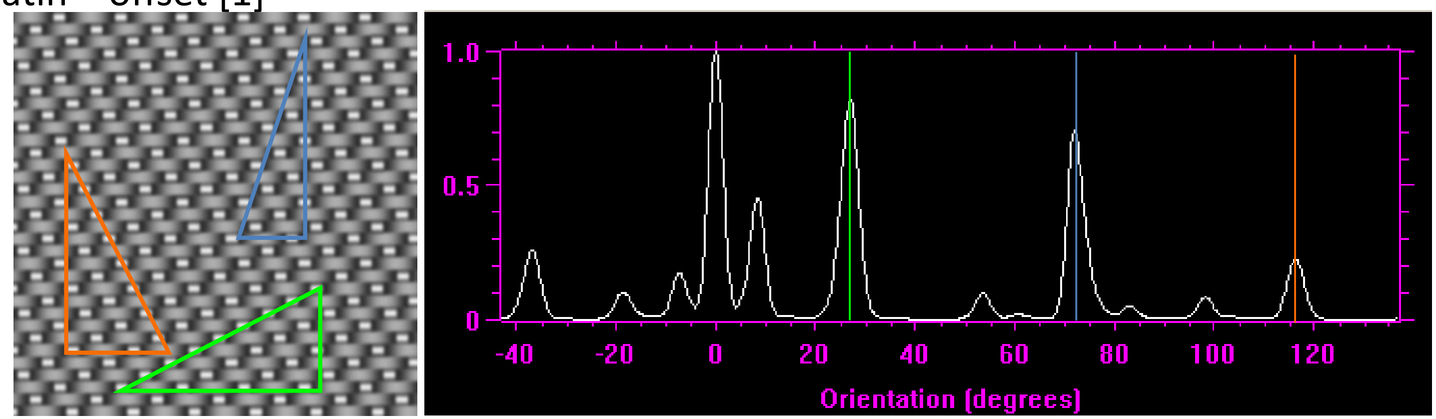


Plain | Basket 2*x*2 | Twill 2*x*2 | 4-harness satin with ‘crow’s-foot’ [1,2,3,2] repeat

Ply Fingerprinting for woven fabrics



- 5-harness satin – offset [1]



- 5-harness satin – offset [2]

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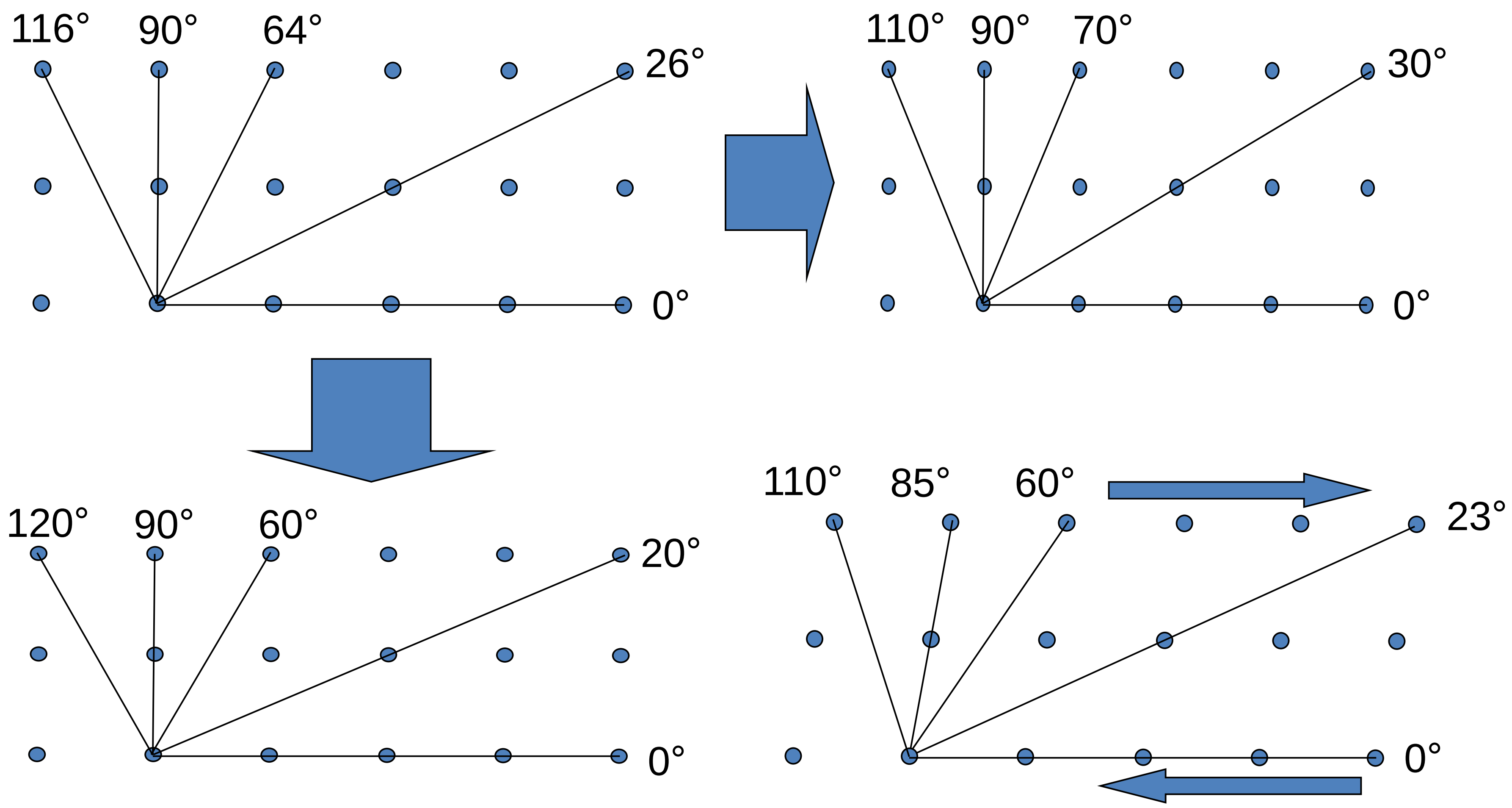
Woven fabrics – distortion/shear



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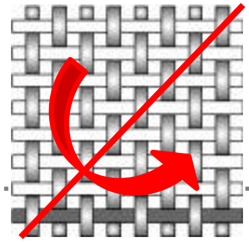
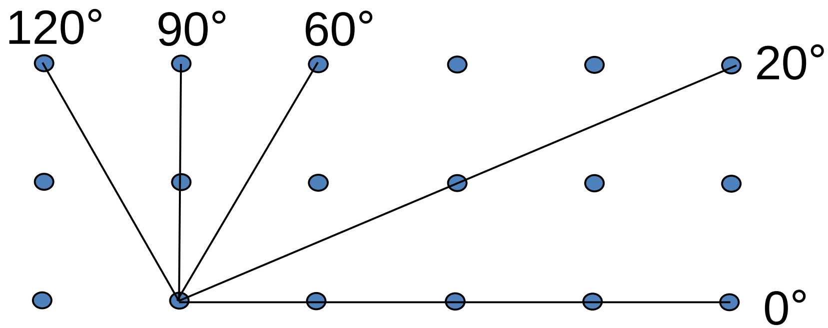
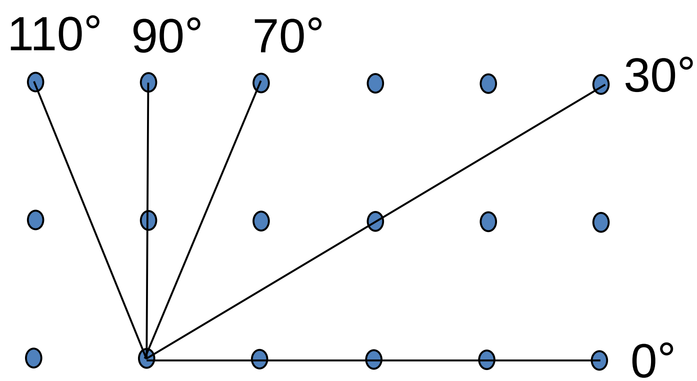


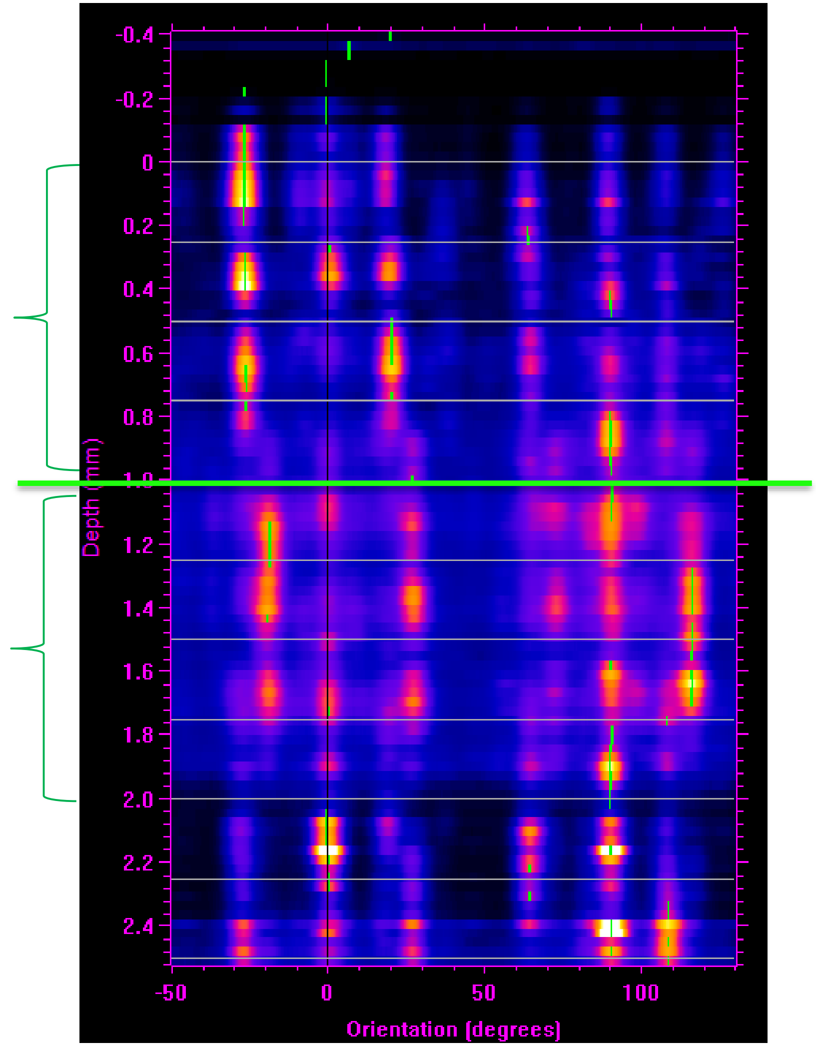
Experimental amplitude data

- ‘Fingerprint’ obtained for each ply
- Top half:



- Bottom half:





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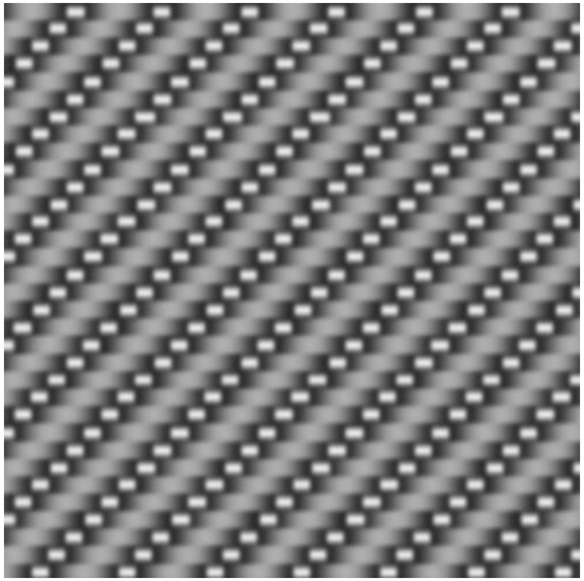
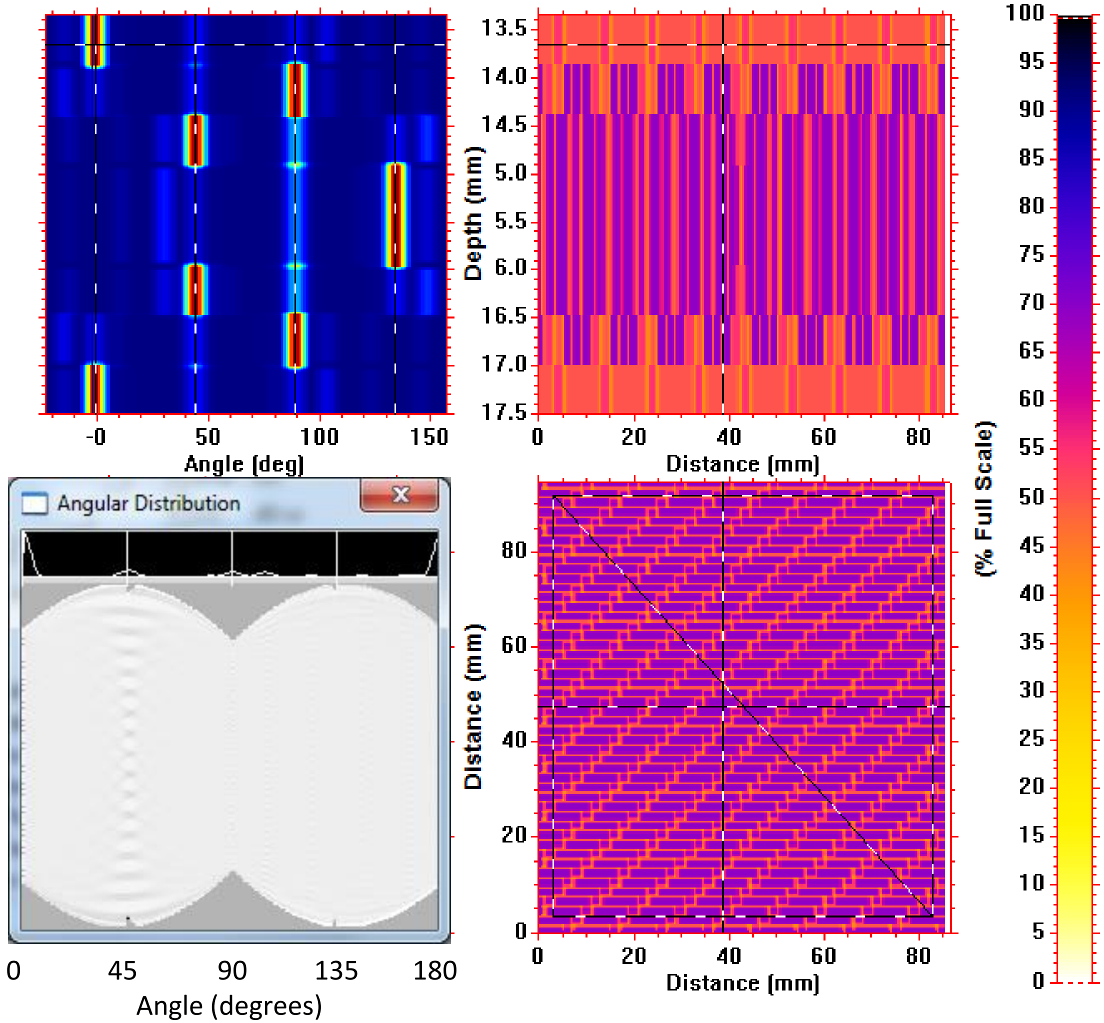
EPSRC Impact Accelerator Results…

- 2D woven sample from a partner
- 5-harness Satin Weave, Offset 1.
- Simulation…



2D Woven

- Ply fingerprinting shows the angular distribution.
- If the analysis of the radon transform uses gradients, it will high-pass filter.
- HP filter emphasises the narrow-spaced yarn orientations.



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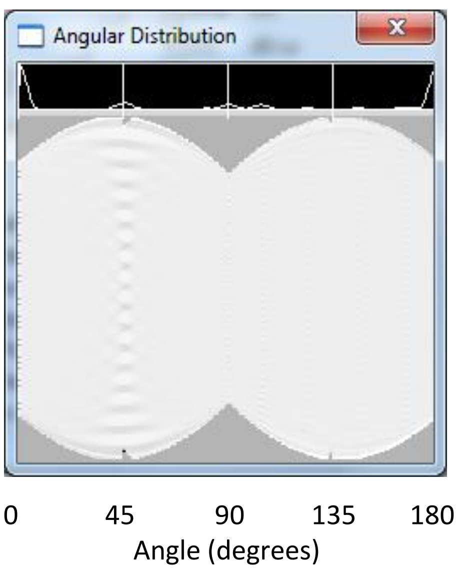
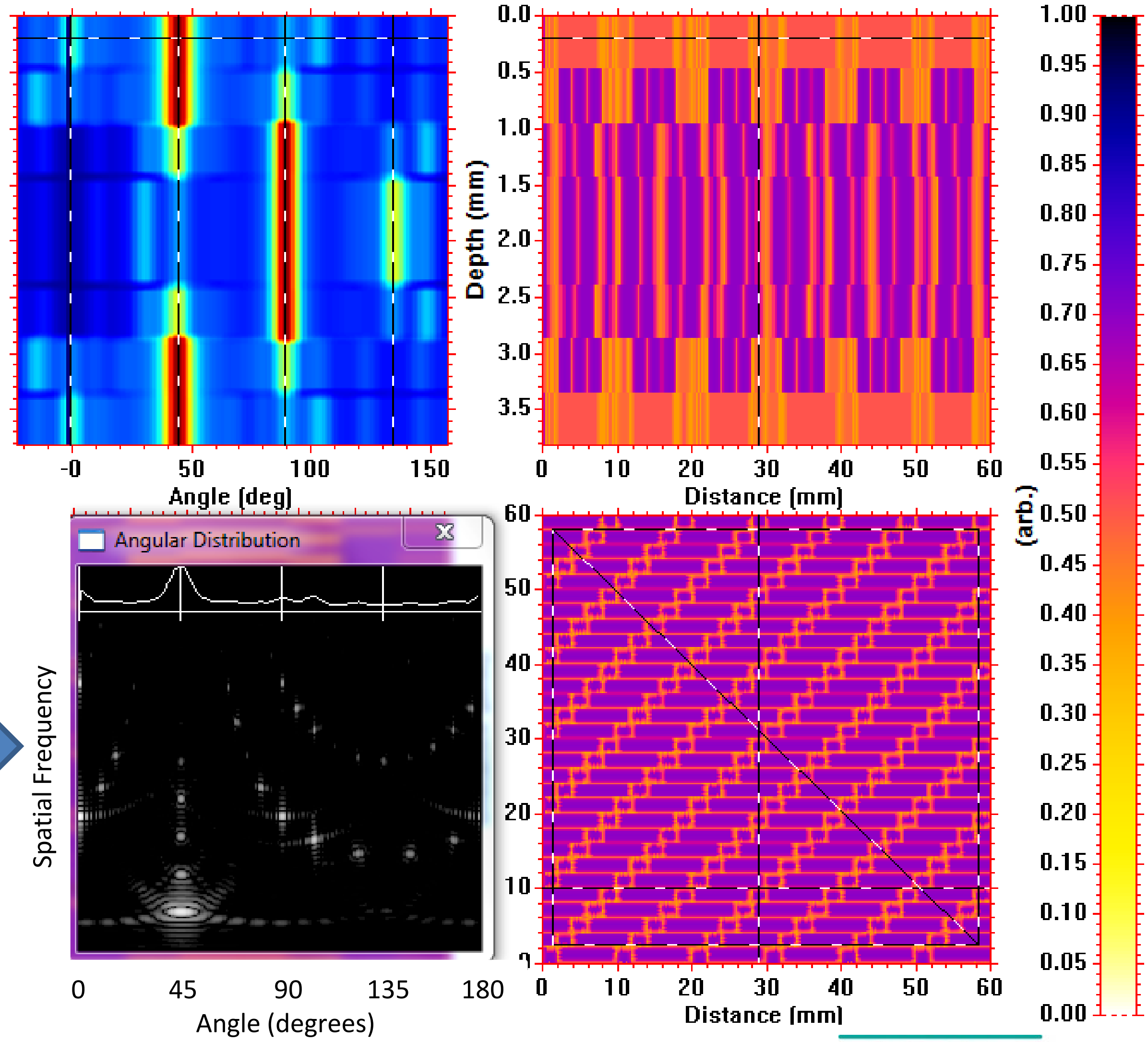
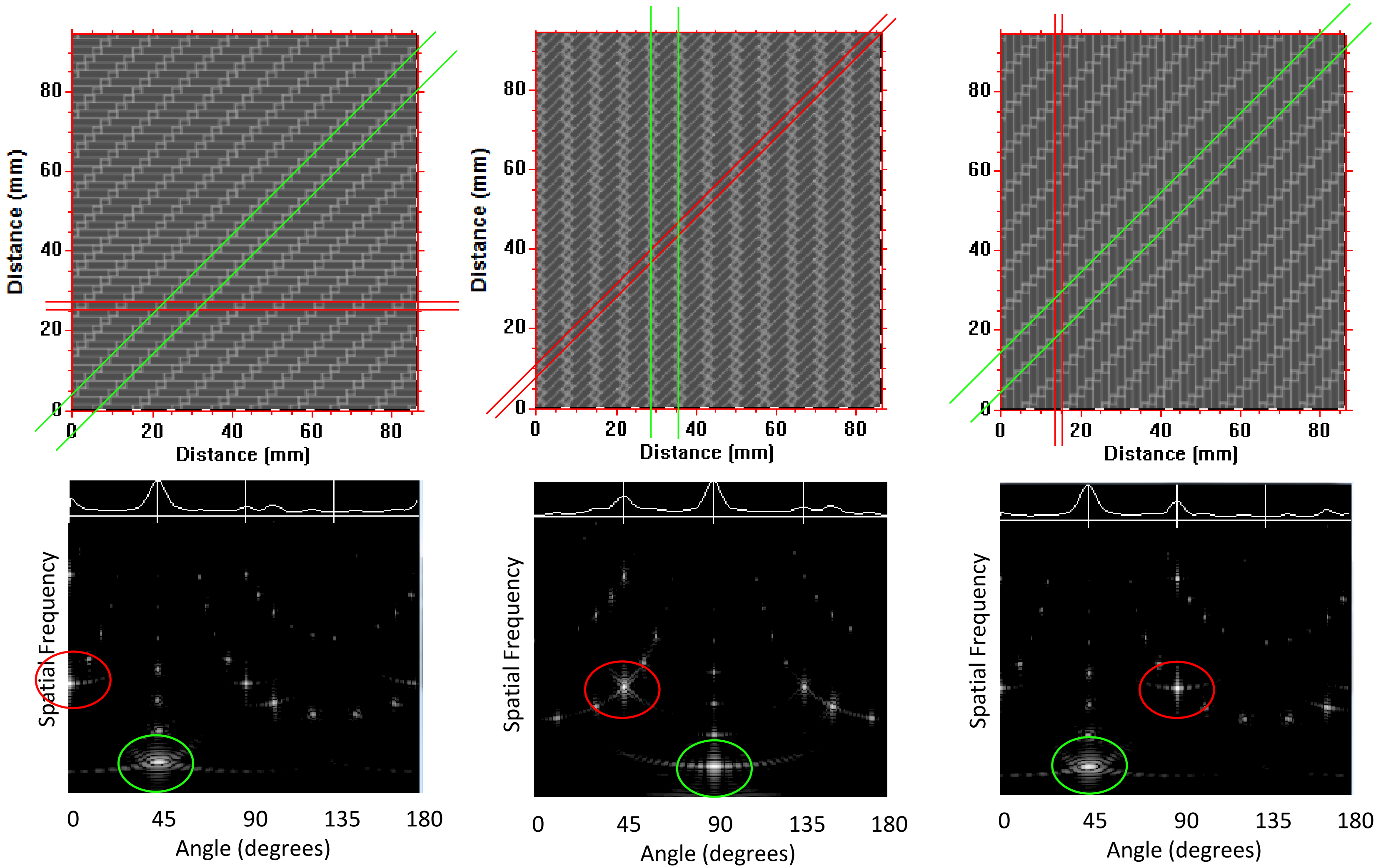
2D Woven

- Changed to 2D ply fingerprinting - can also show spacing (or Spatial Frequency)





2D Ply Fingerprinting



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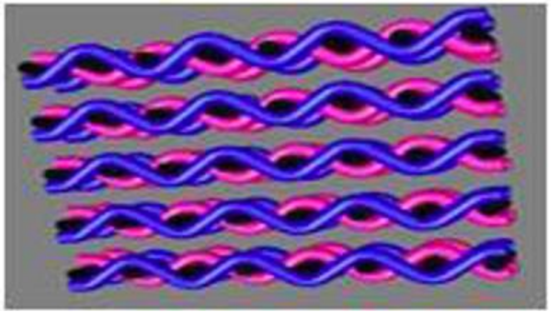
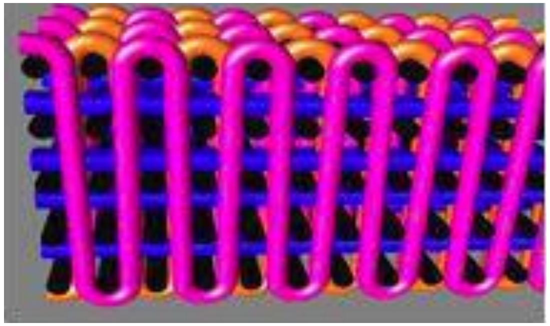
Automotive Composites

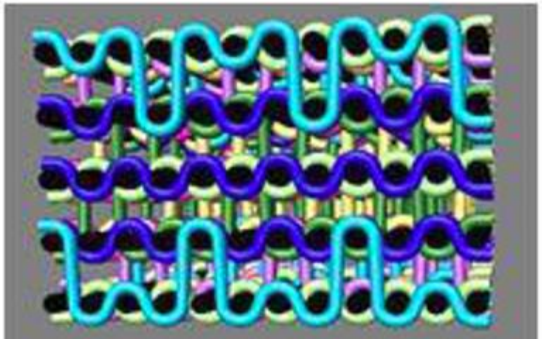
2D woven… & 3D textile



Plain weave



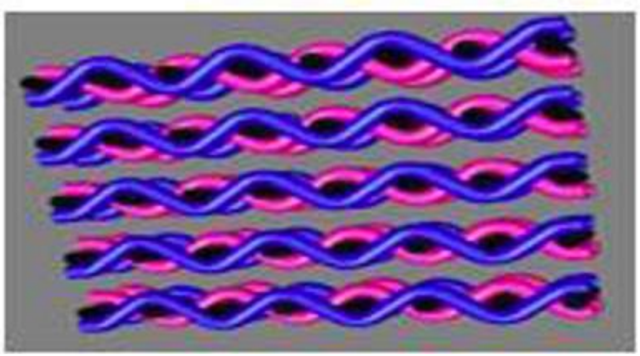
Orthogonal

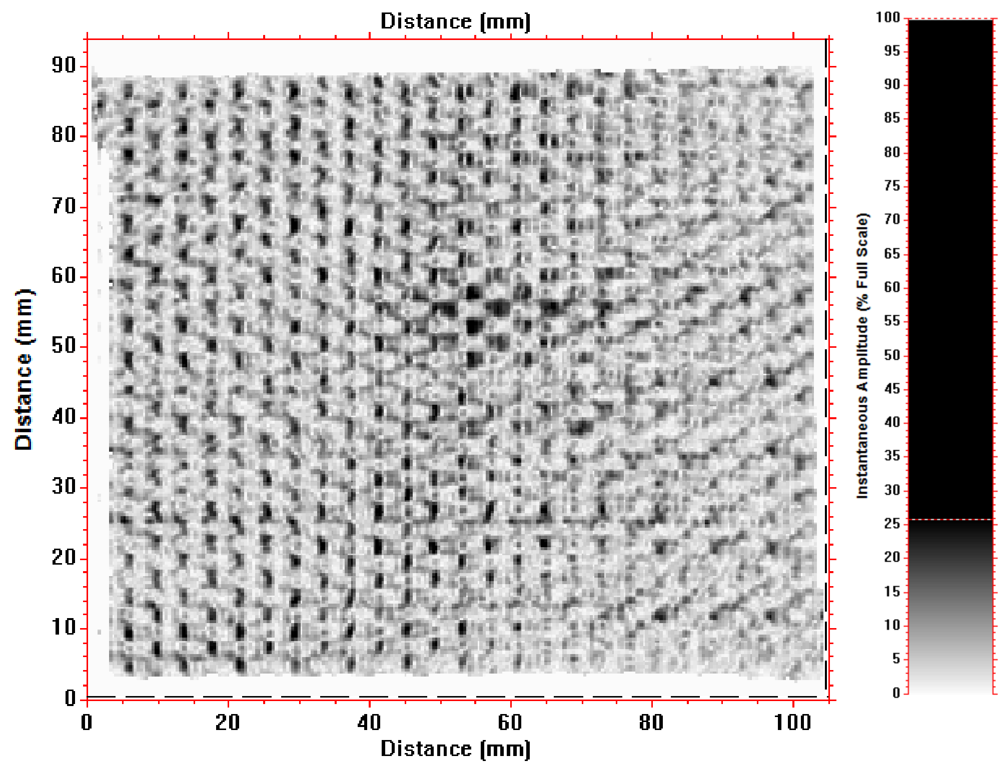


Multilayer 3D

2D Woven Composites

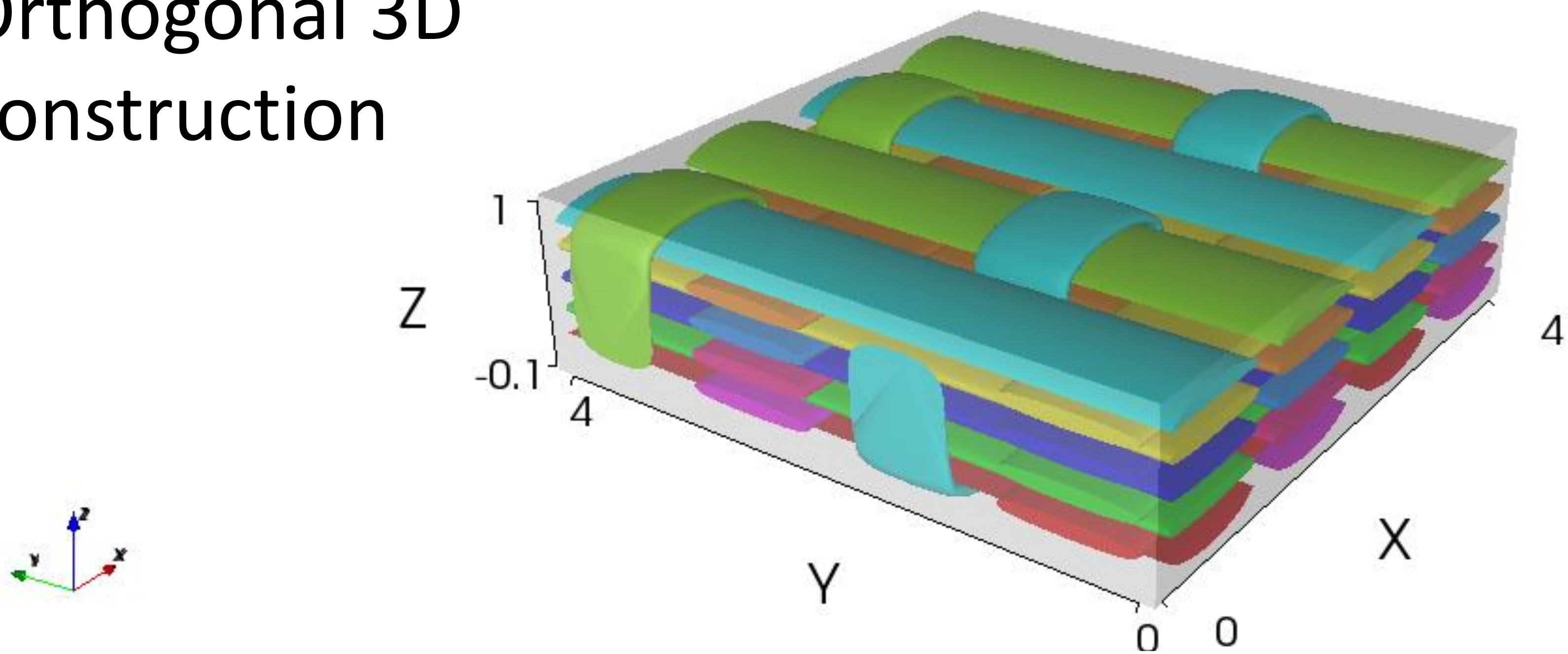
- In-plane C-scan of instantaneous amplitude
  - Plain weave
  - Depth approximately 1.0mm

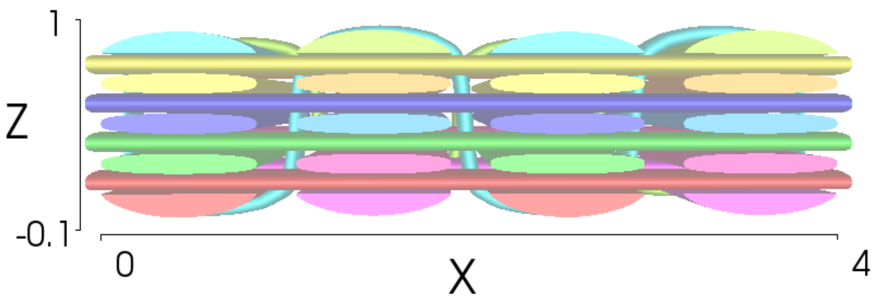


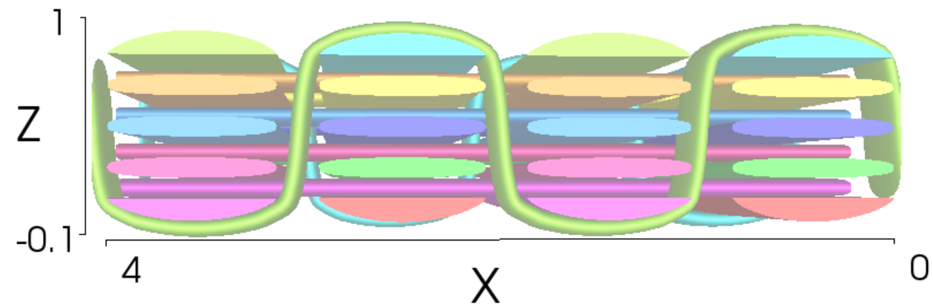


3D Textile Composites

- Orthogonal 3D construction

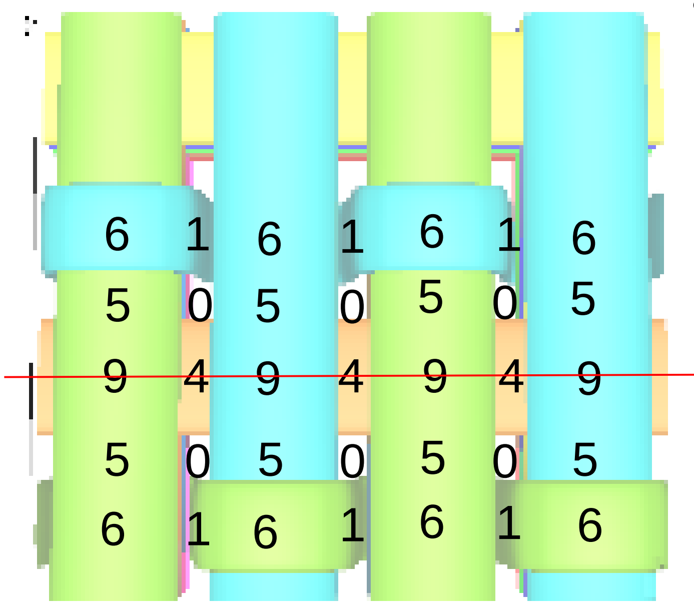




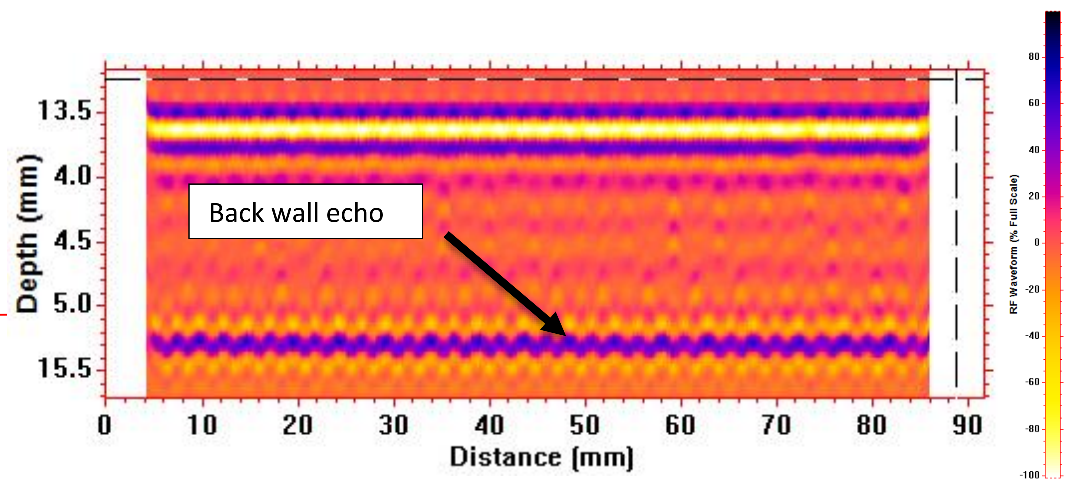


3D Textile Composites

- Orthogonal 3D construction
- Through-thickness yarns: 0, 1 (binder), 4, 5, 6, 9
- Different velocities - depend on fibre vol. fraction

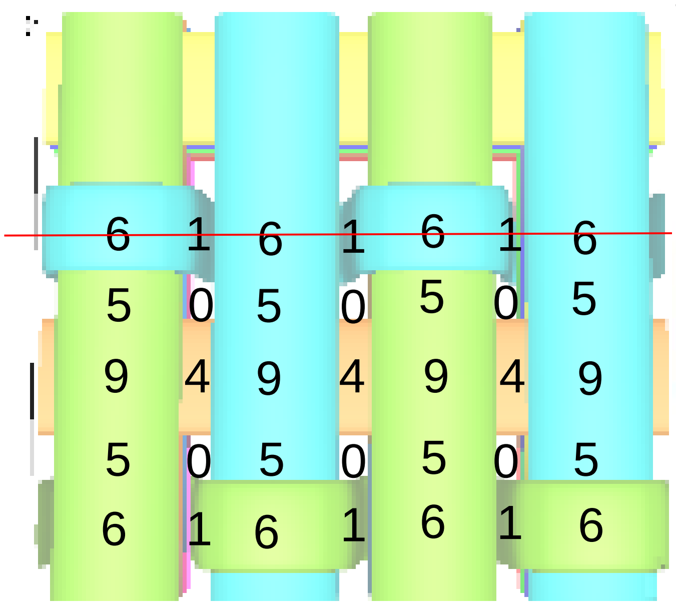


- 9-yarn region has a higher velocity

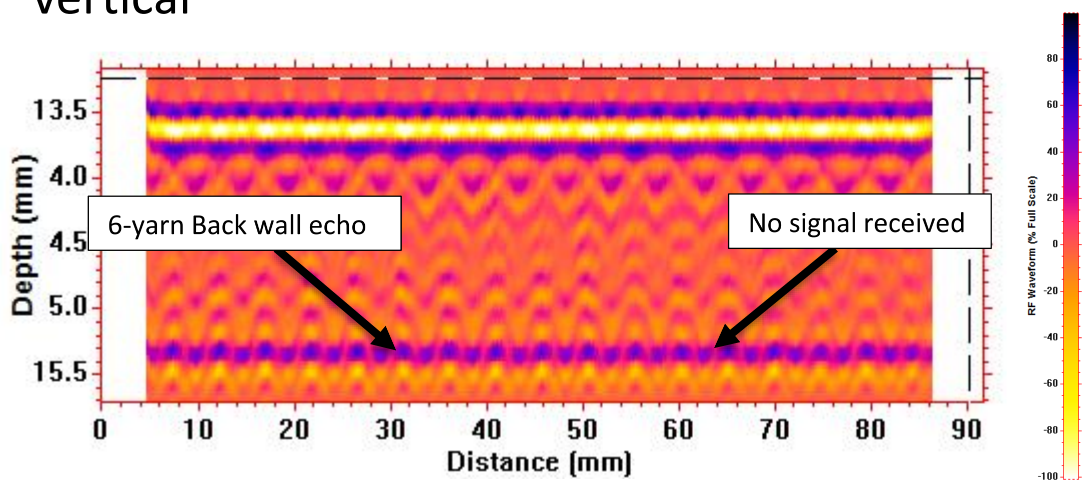


3D Textile Composites

- Orthogonal 3D construction
- Through-thickness yarns: 0, 1 (binder), 4, 5, 6, 9
- Different velocities - depend on fibre vol. fraction



- No back-surface signal where binder yarn is vertical



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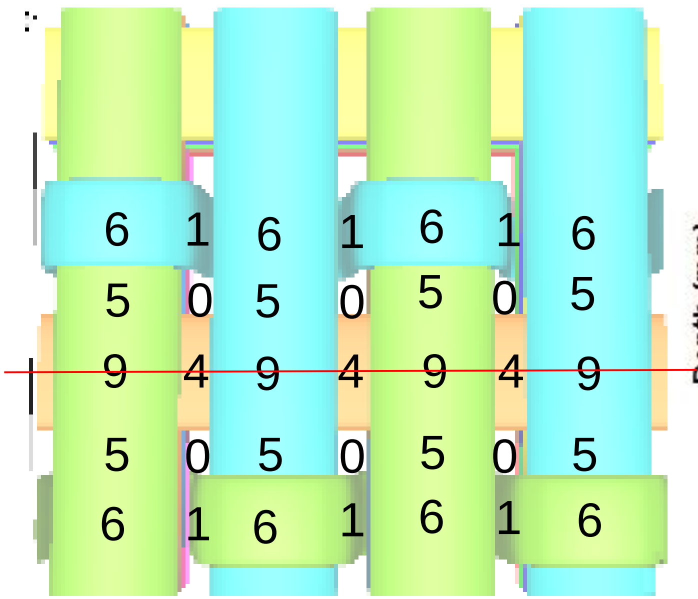
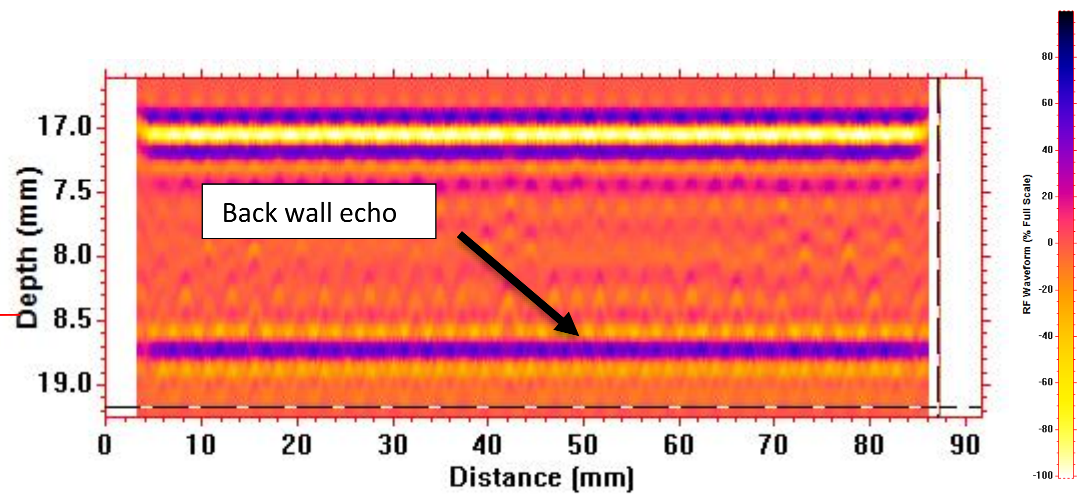
3D Textile Composites

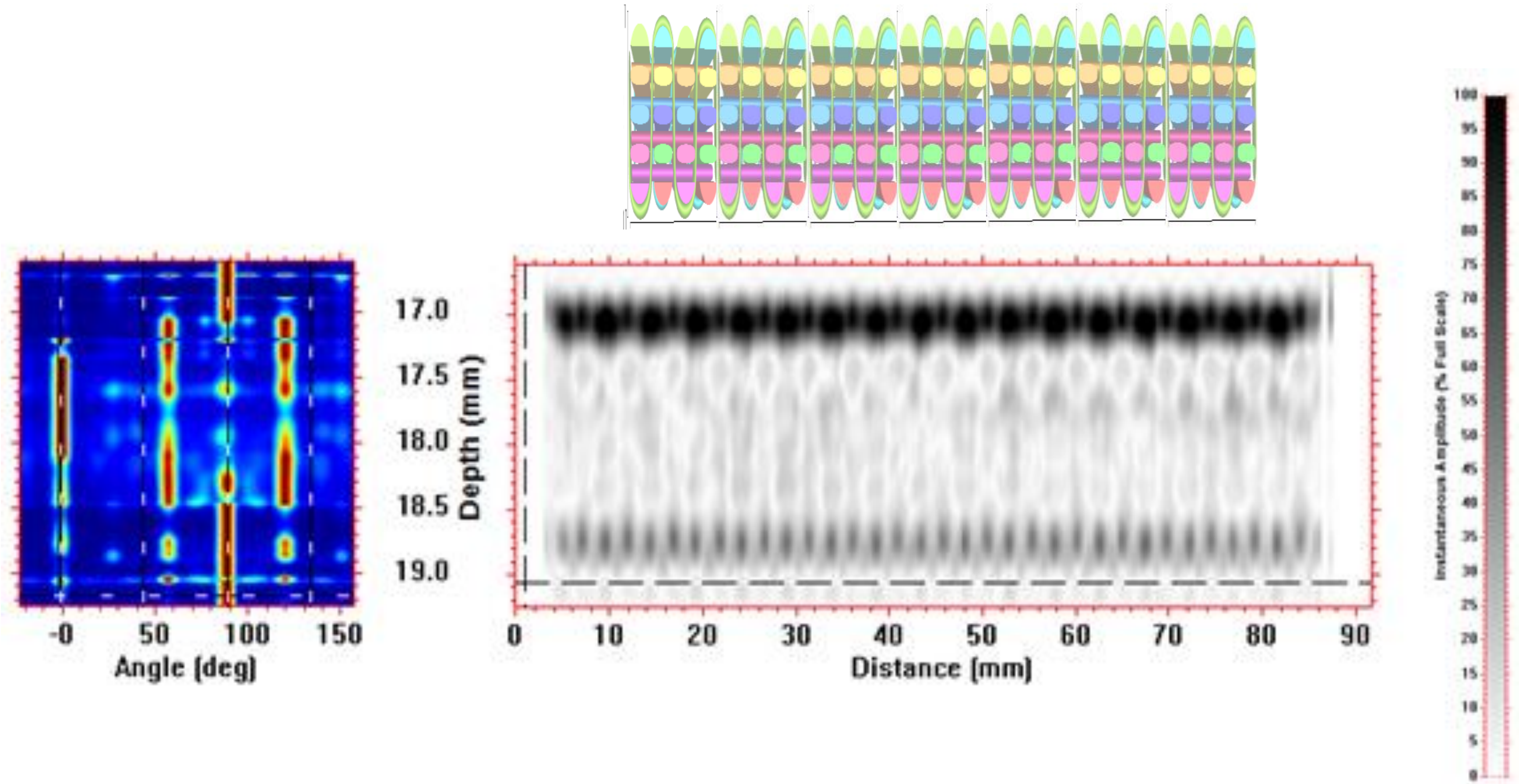
- Orthogonal 3D construction
- Correct for varying velocity.





3D Textile Composites

- Instantaneous Amplitude



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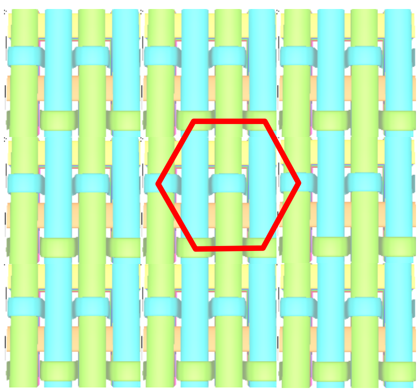
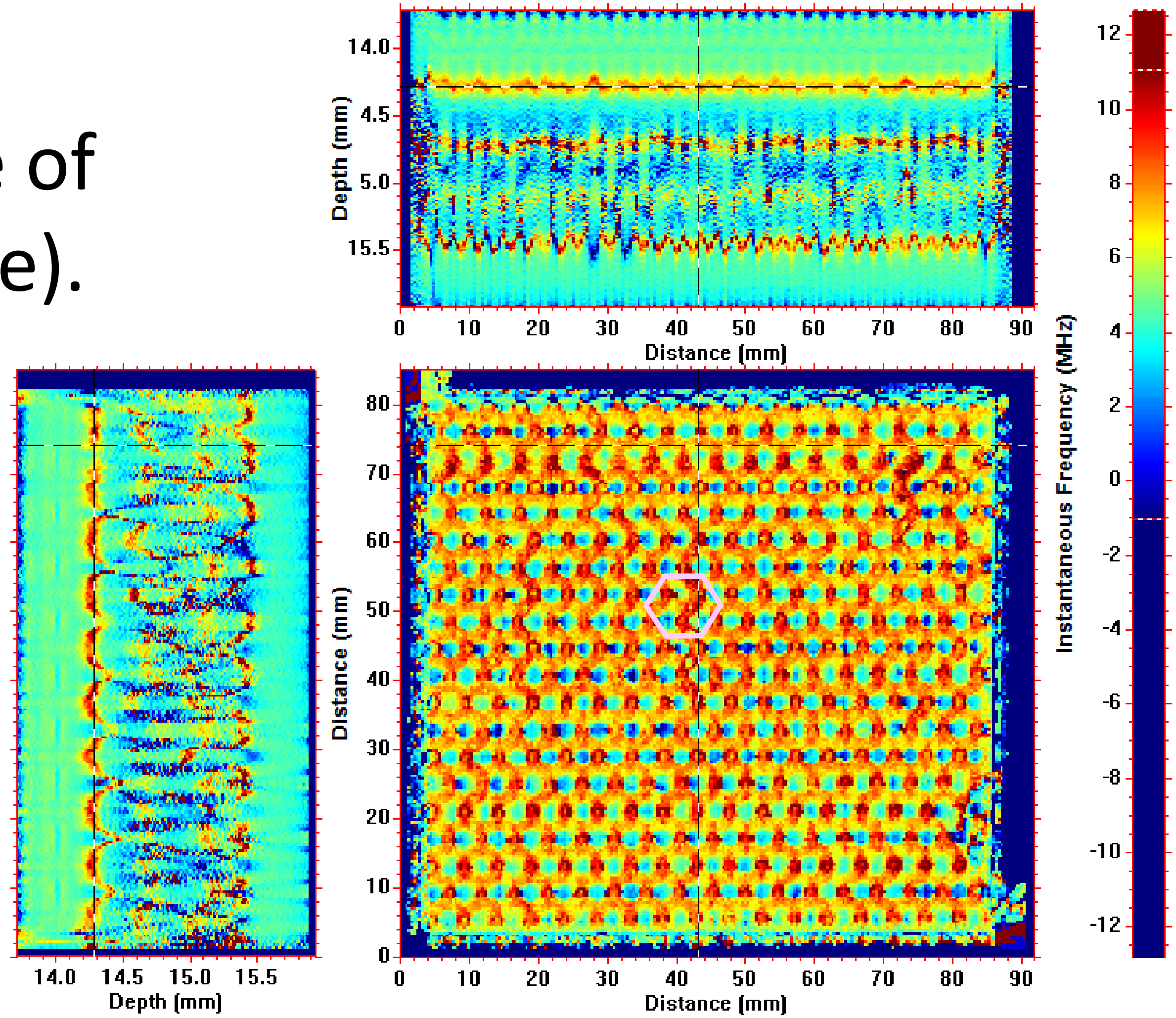
3D Textile Composites

- Instantaneous frequency (rate of change of phase).





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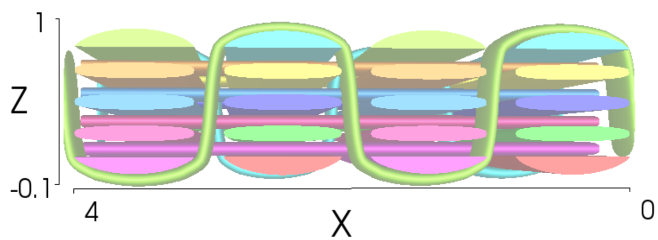
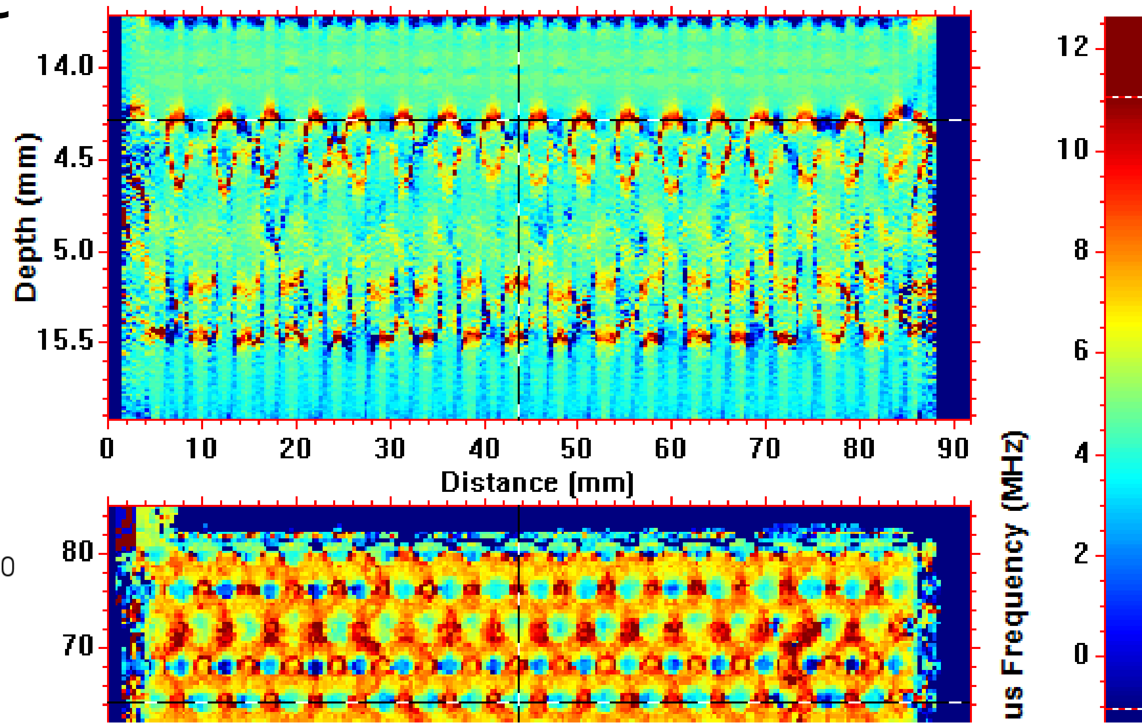
3D Textile Composites

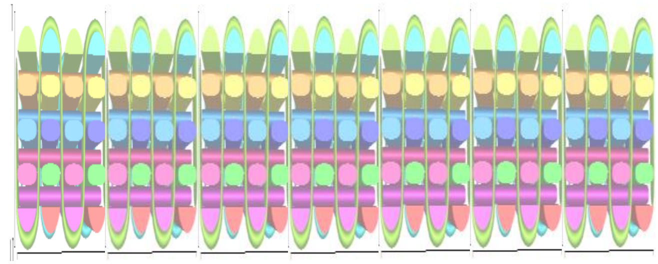
- Instantaneous frequency (rate of change of phase)

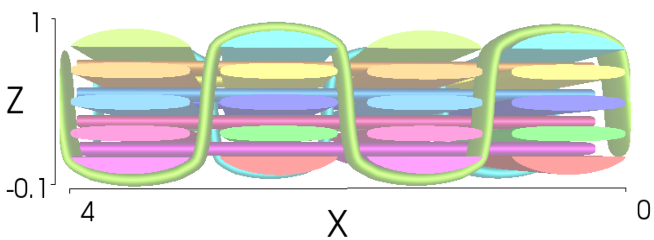


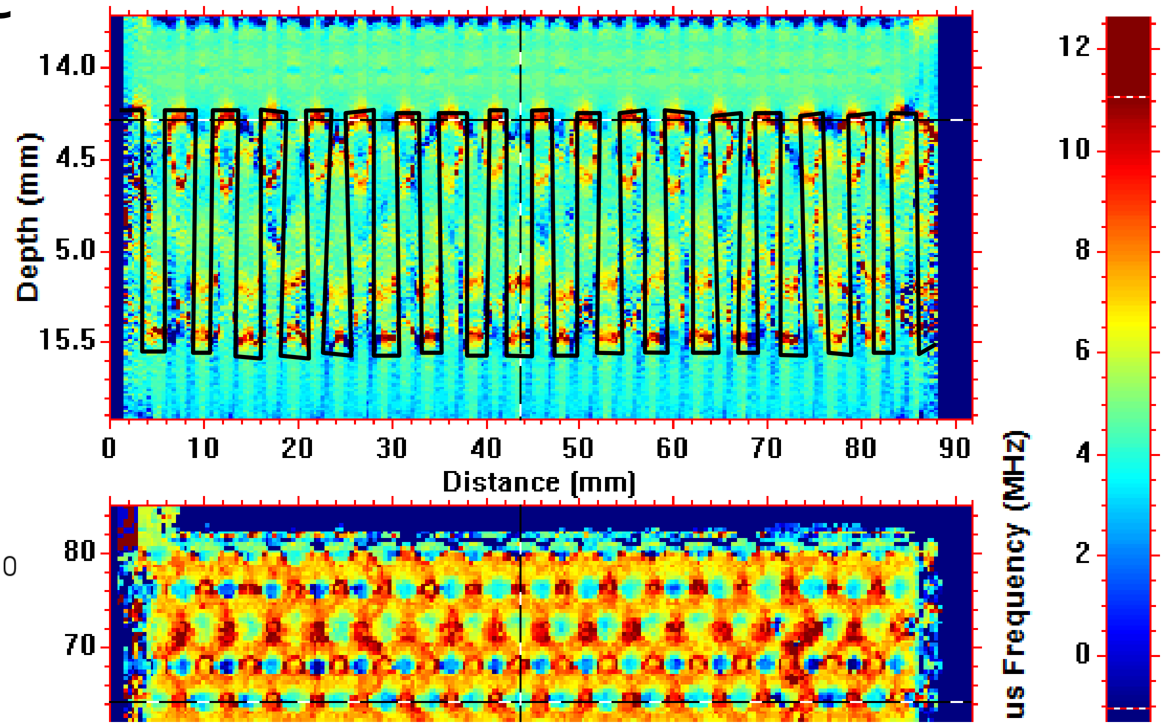


3D Textile Composites

- Instantaneous frequency (rate of change of phase)







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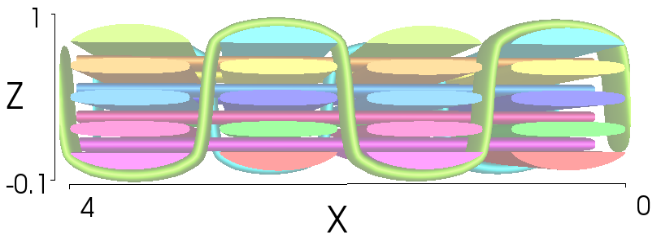
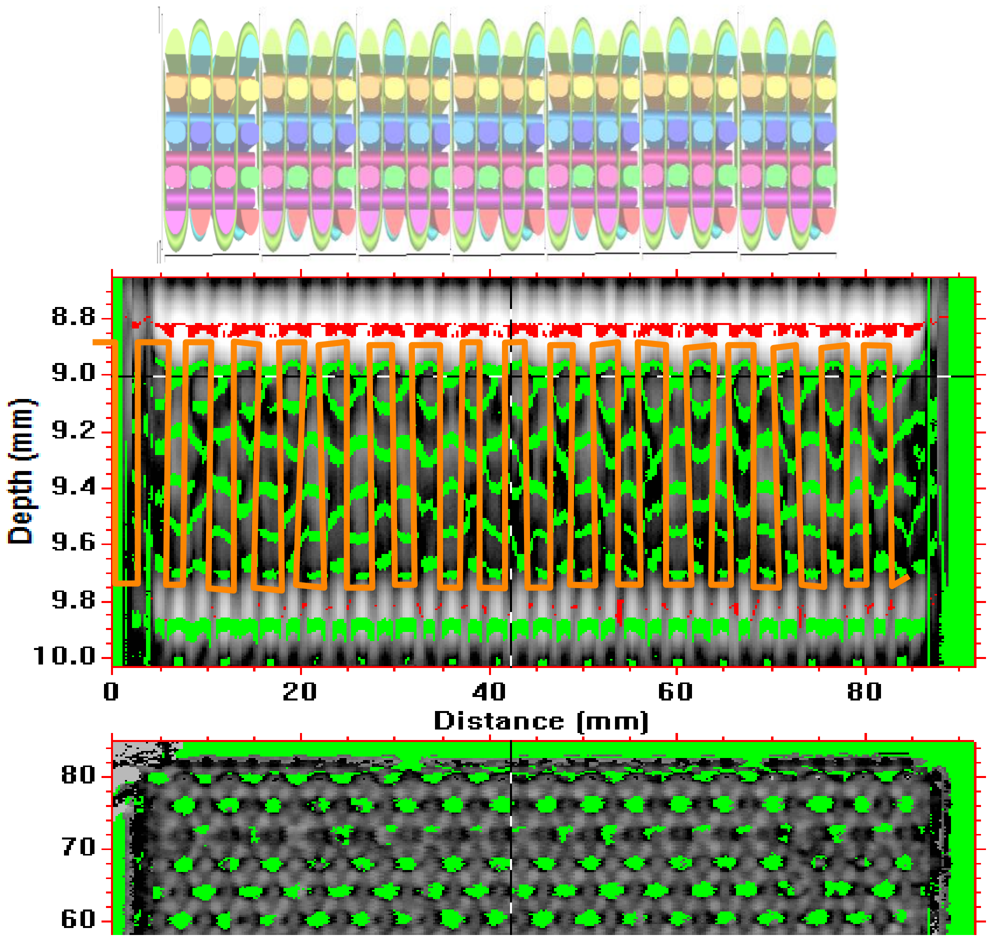
3D Textile Composites

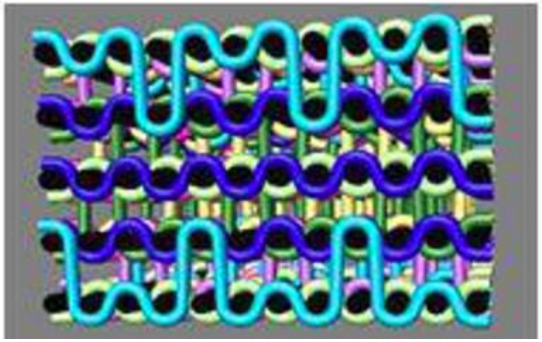
- Ply tracking…

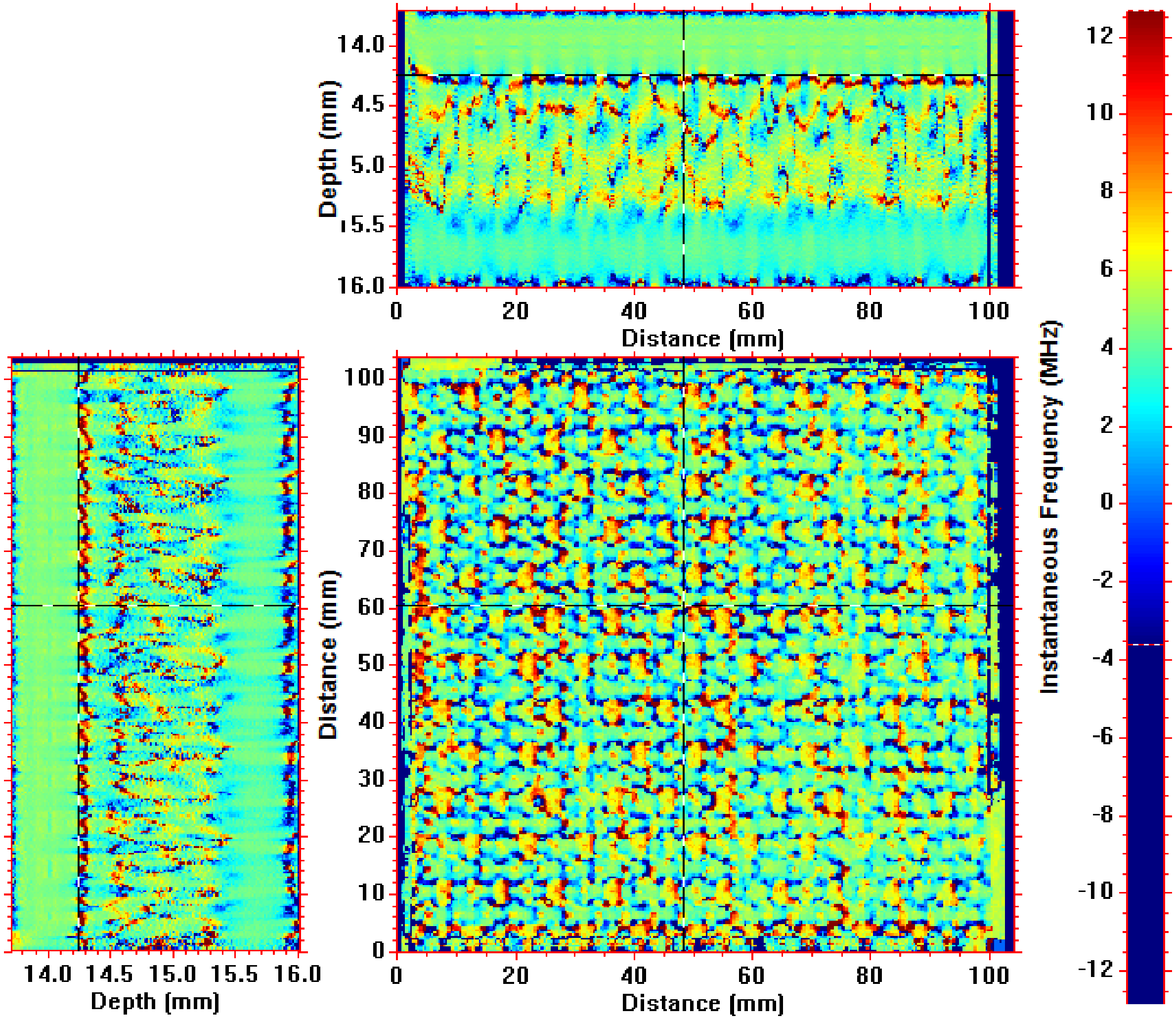




3D Textile Composites

- Multilayer 3D





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FE Materials Modelling

Mechanical properties of 'as-manufactured' component

Better-informed concession decisions

EPRC Institutional Sponsorship

6-month project to develop a capability to model ultrasonic propagation in woven and 3D composites. Oct 2016-Mar 2017.

Main researcher: Dr Rostand Tayong Boumda

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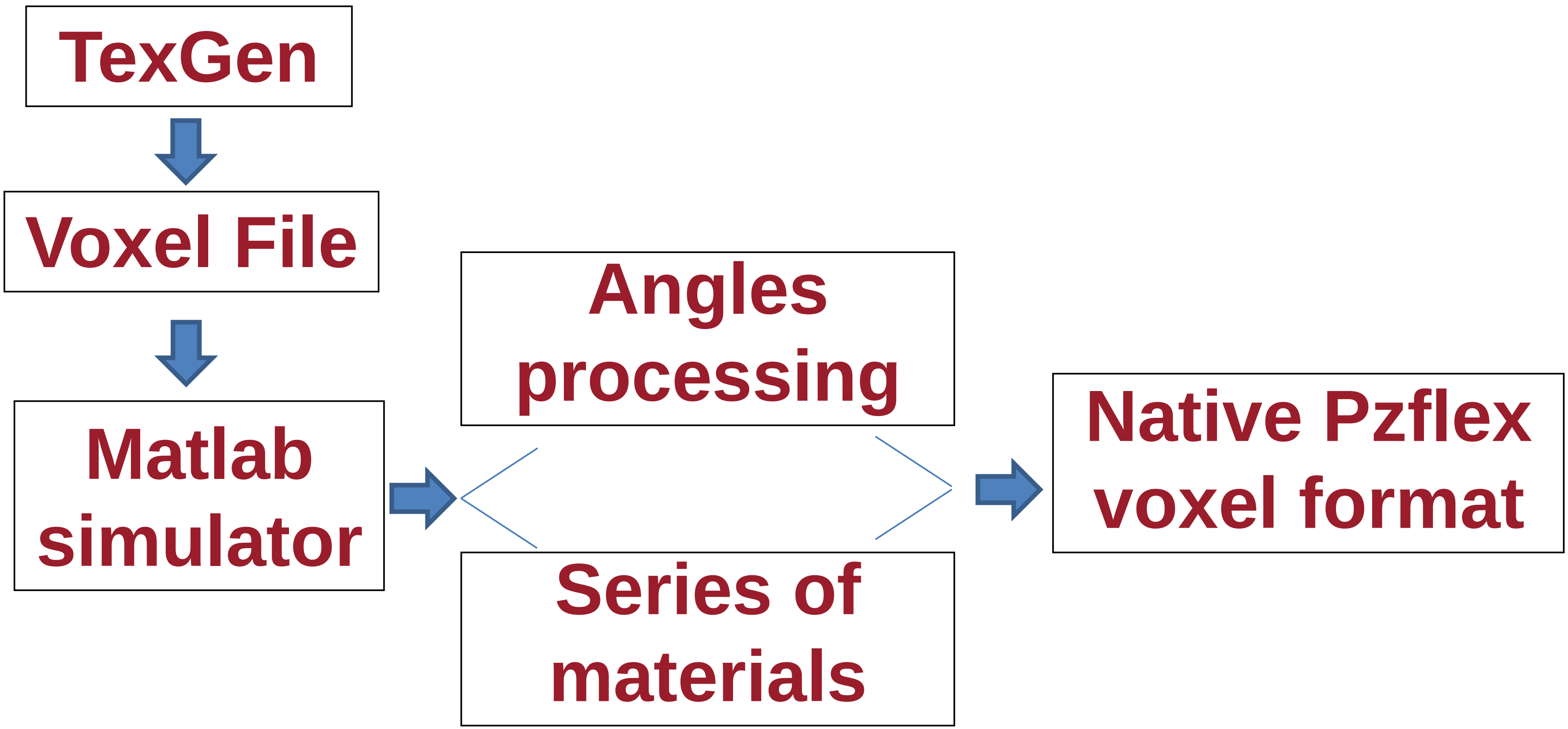
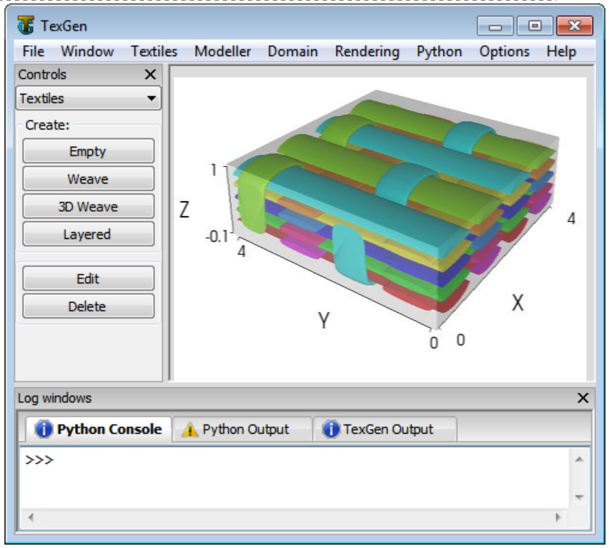
From TexGen to Pzflex (Principle)



About TexGen

- Open source – Free code
  - Developed at the University of Nottingham
  - Uses a GUI (Graphical User Interface)



- Output
  - Textile nodes, surfaces and volume rendering
  - Textile path, orientation and interference rendering
- Calculation of yarn Fibre Volume Fraction

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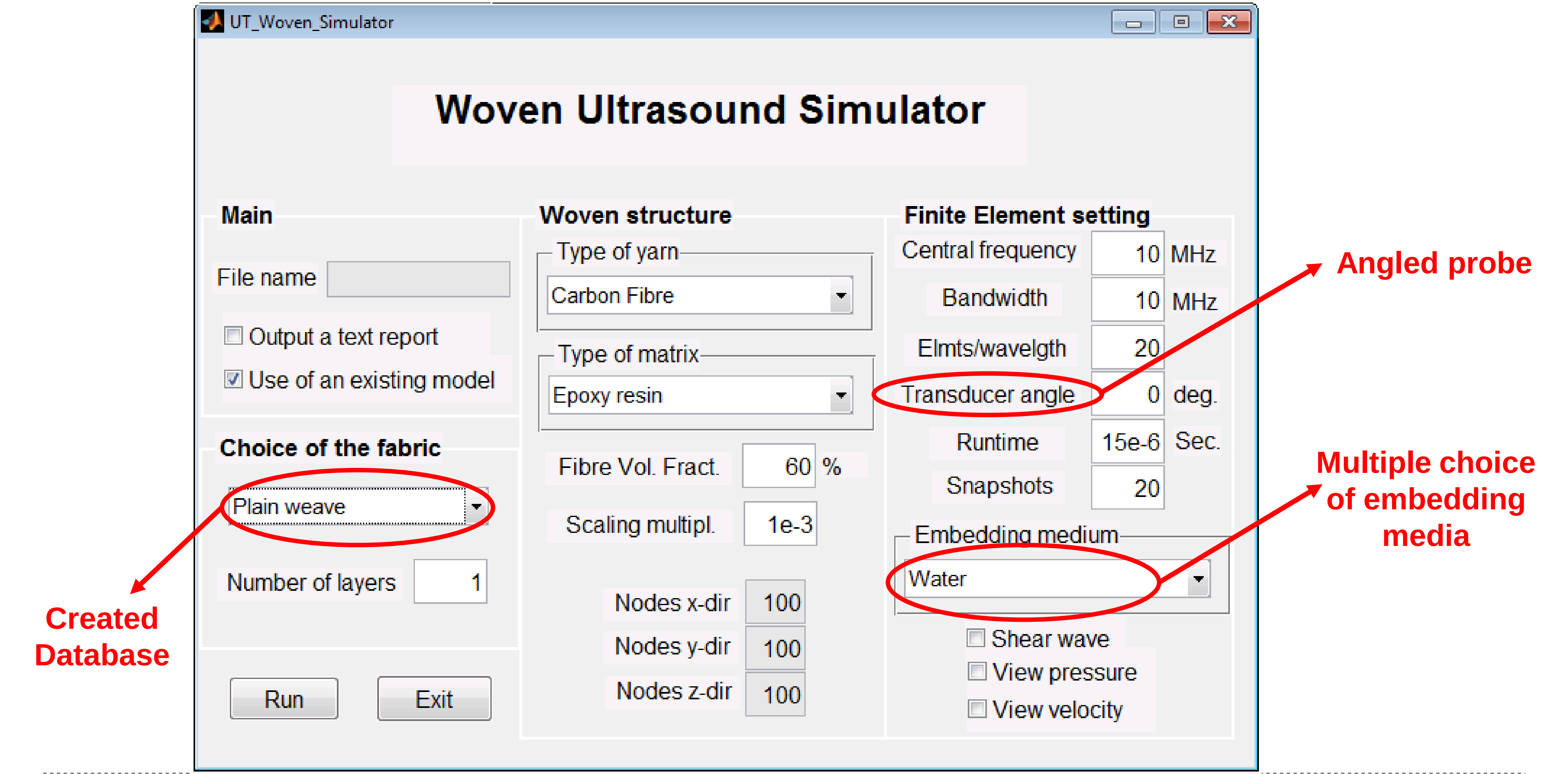
FE modelling

GUI simulator



FE modelling of specimens

- 1. Finite size transmitting and receiving transducers

- 2. Meshing: ≥20 elements/wavelength to ensure that any stress gradients are properly recreated.

  This setting allows a good accuracy and stability of the FE model.

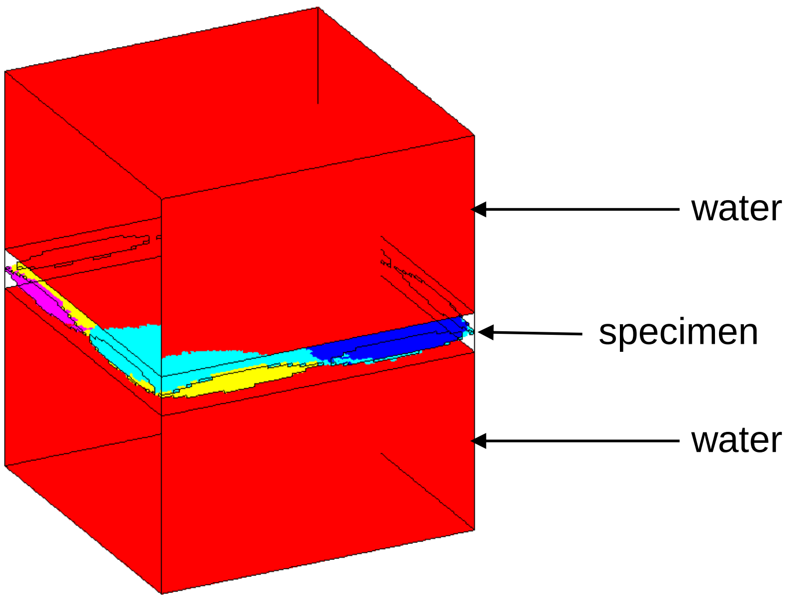
  A ‘run’ is composed of about 7 million elements which suggest a runtime of about half an hour on a standard machine.

- 3. An alternative using an impedance boundary condition on the bottom of the model is considered.

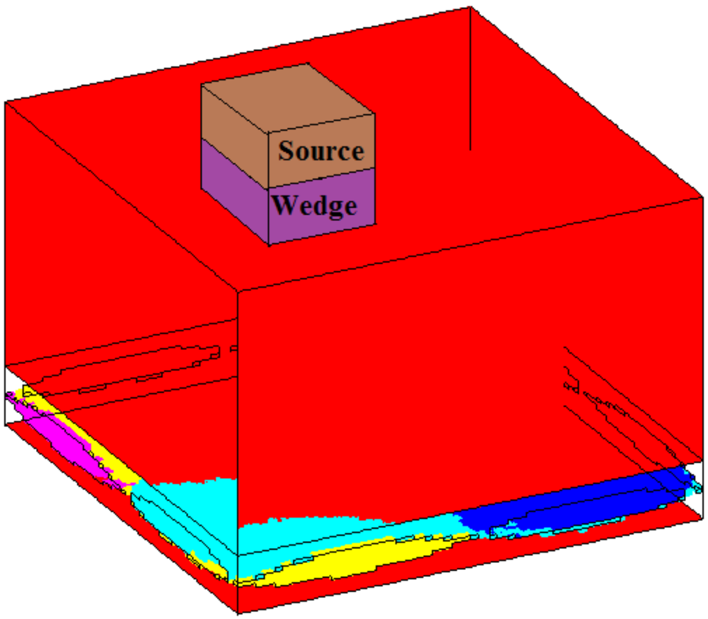
  This reduces the total number of elements and allows larger model simulations.

FE Modelling

Transducer on the top of Plain-weave geometry



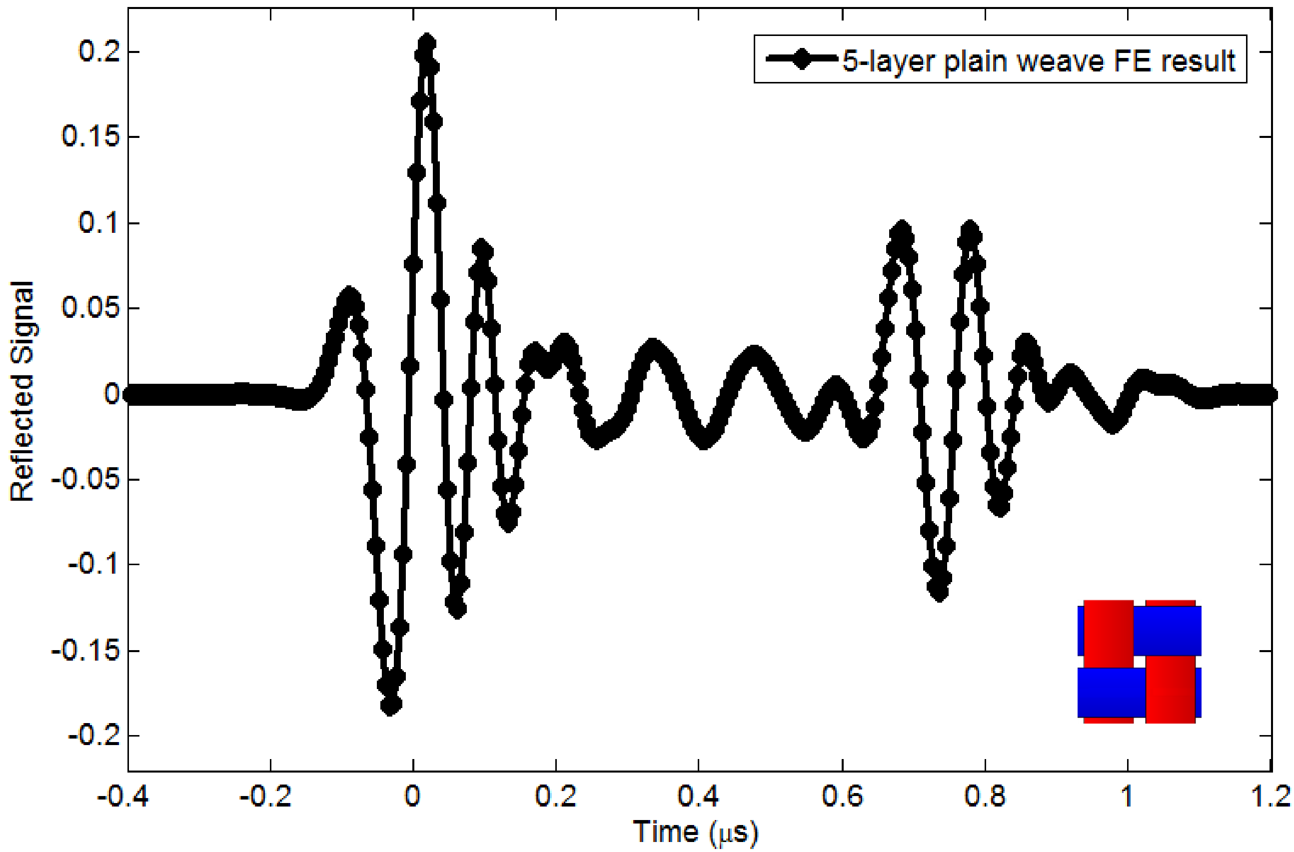
Initial geometry



Geometry with Transducer + Impedance BC below the sample

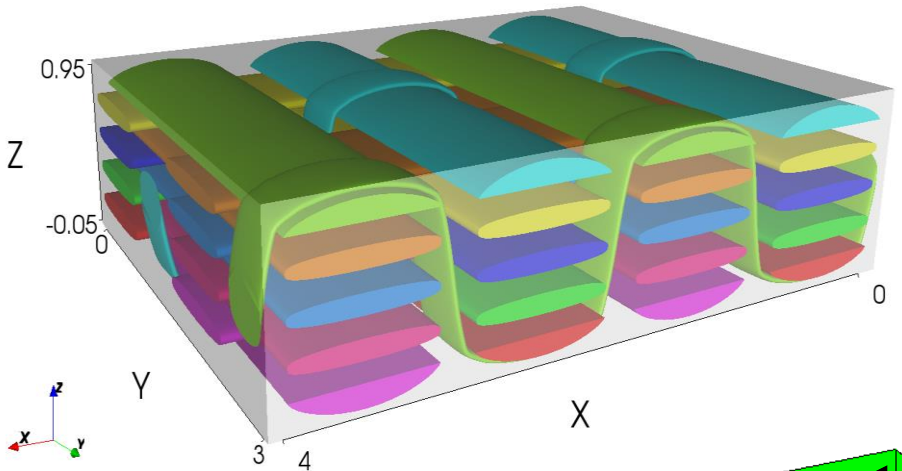
Example of plain weave result

5-layer plain weave in water 5 MHz

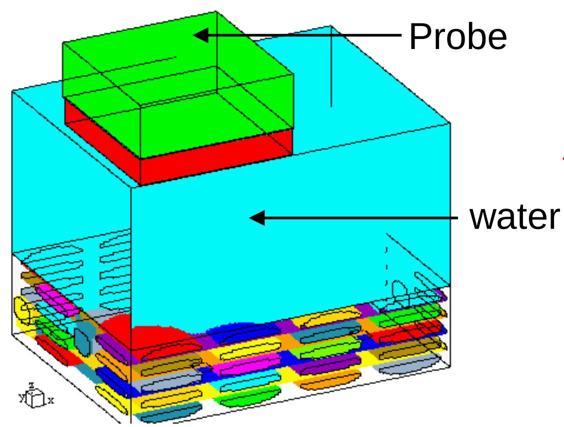


FE Modelling

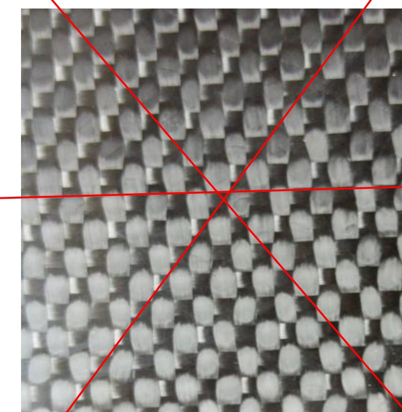
Sample AS2410-O-NDT-01



TexGen construction



Pzflex model ready to run



Specimen

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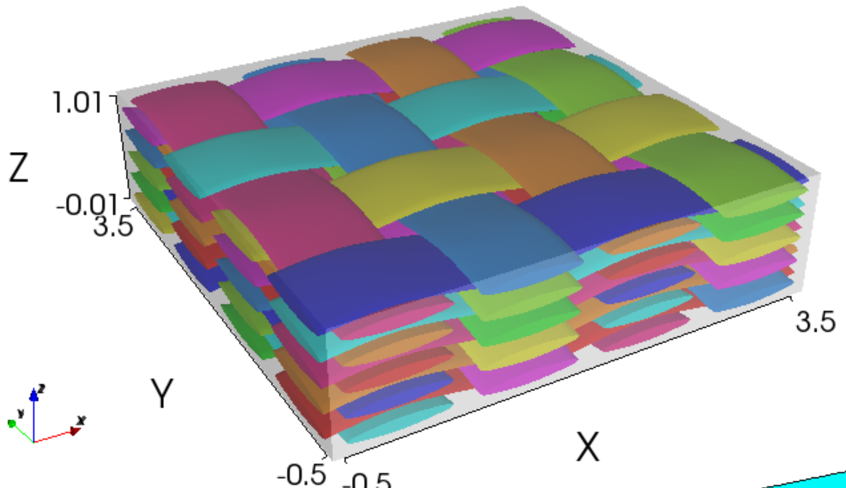
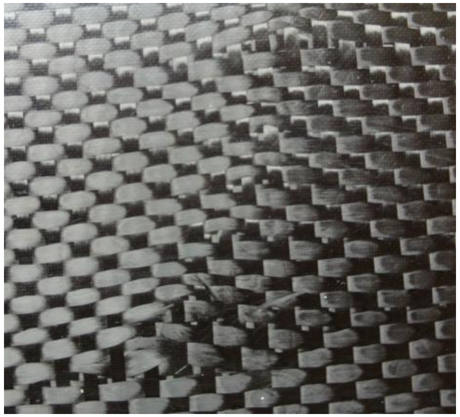
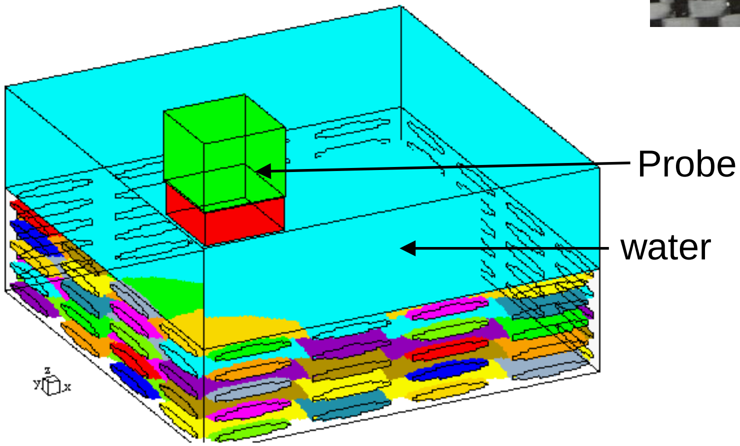
Sample AS2410-2D-NDT-01



TexGen construction


Specimen



Pzflex model ready to run

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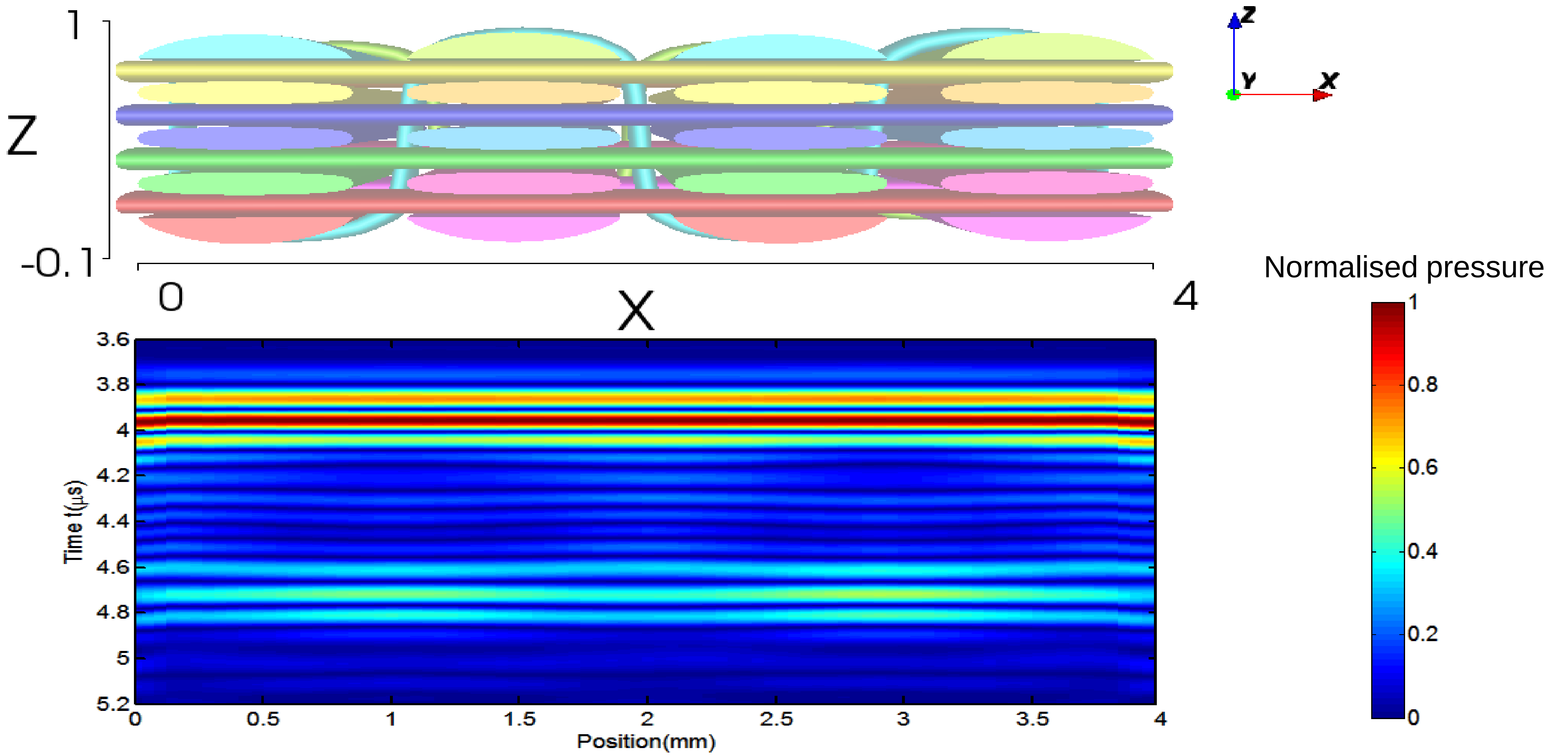
Sample AS2410-O-NDT-01: FE rectified B-scan



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Conclusions

- Ply fingerprinting extended to 2D to include spatial-frequency information.
- Ordered velocity variations are large in 3D textile composites
- Velocity variations can be corrected for.
- Instantaneous frequency shows potential for tracking yarns in 3D textile composites.
- FE modelling of ultrasonic propagation in woven and 3D composites has been achieved.