Structural Response of CFRP Materials Subjected to Simulated Lightning Strikes

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Why study this?

- Lightning can strike wind turbines up to 30 times per year
- 5 times greater energy than aircraft standard (10 MJ/Ω)
- **Costing operator millions of pounds a year**

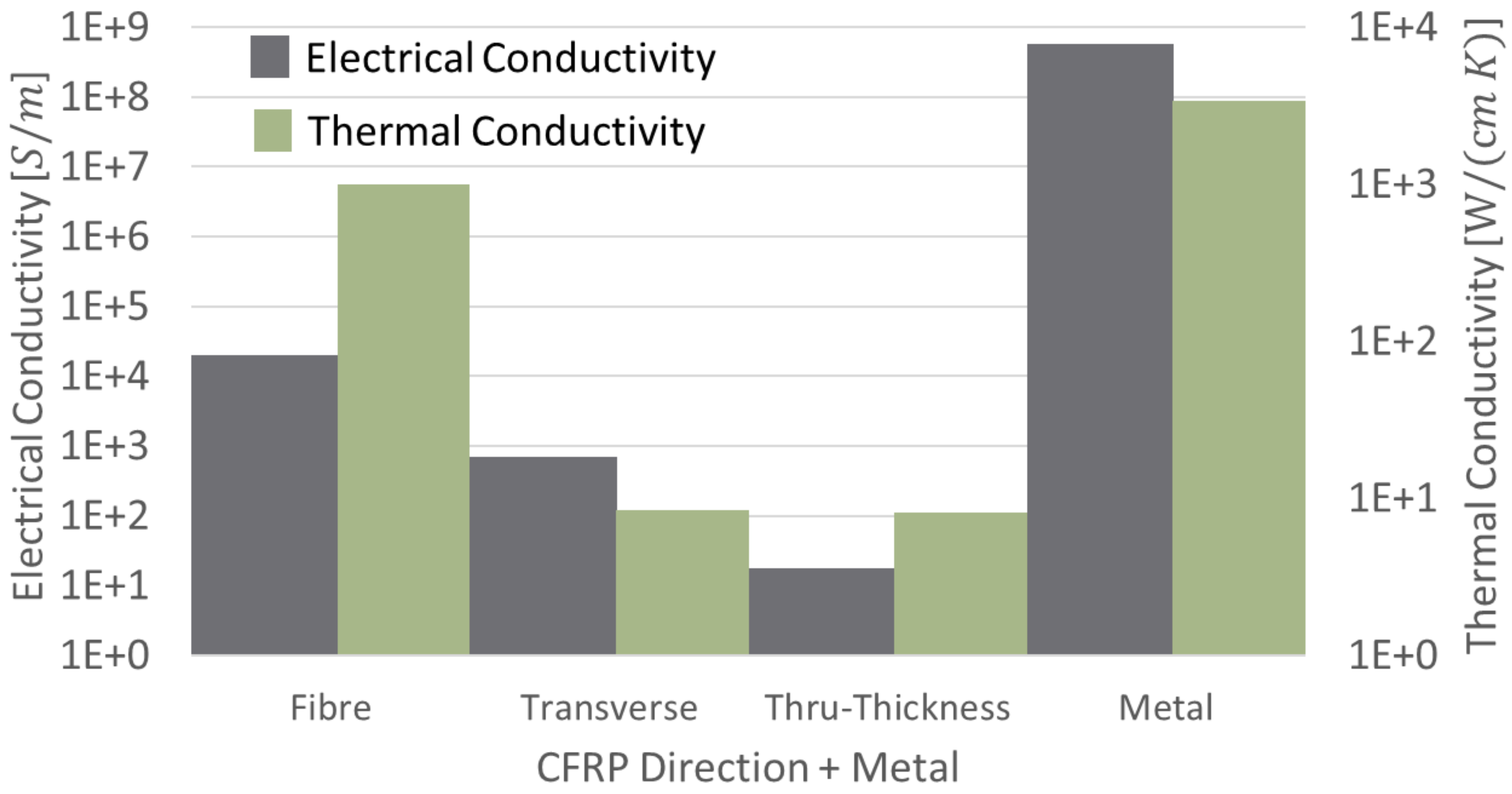
Burning/charring

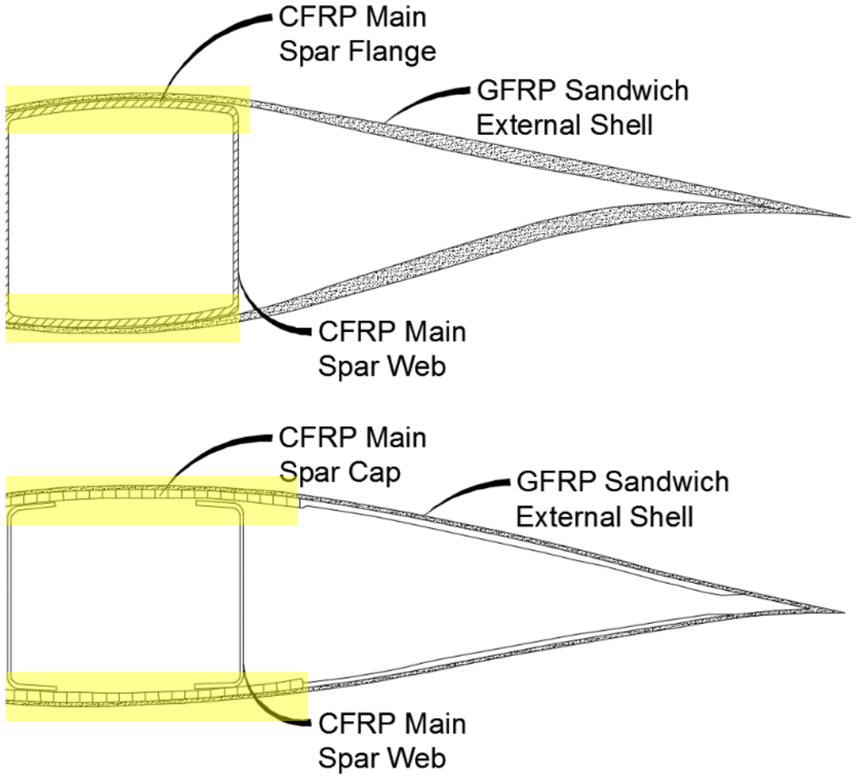
Blade Failure

Tip Detachment

CFRP Materials in Wind Turbine Blades

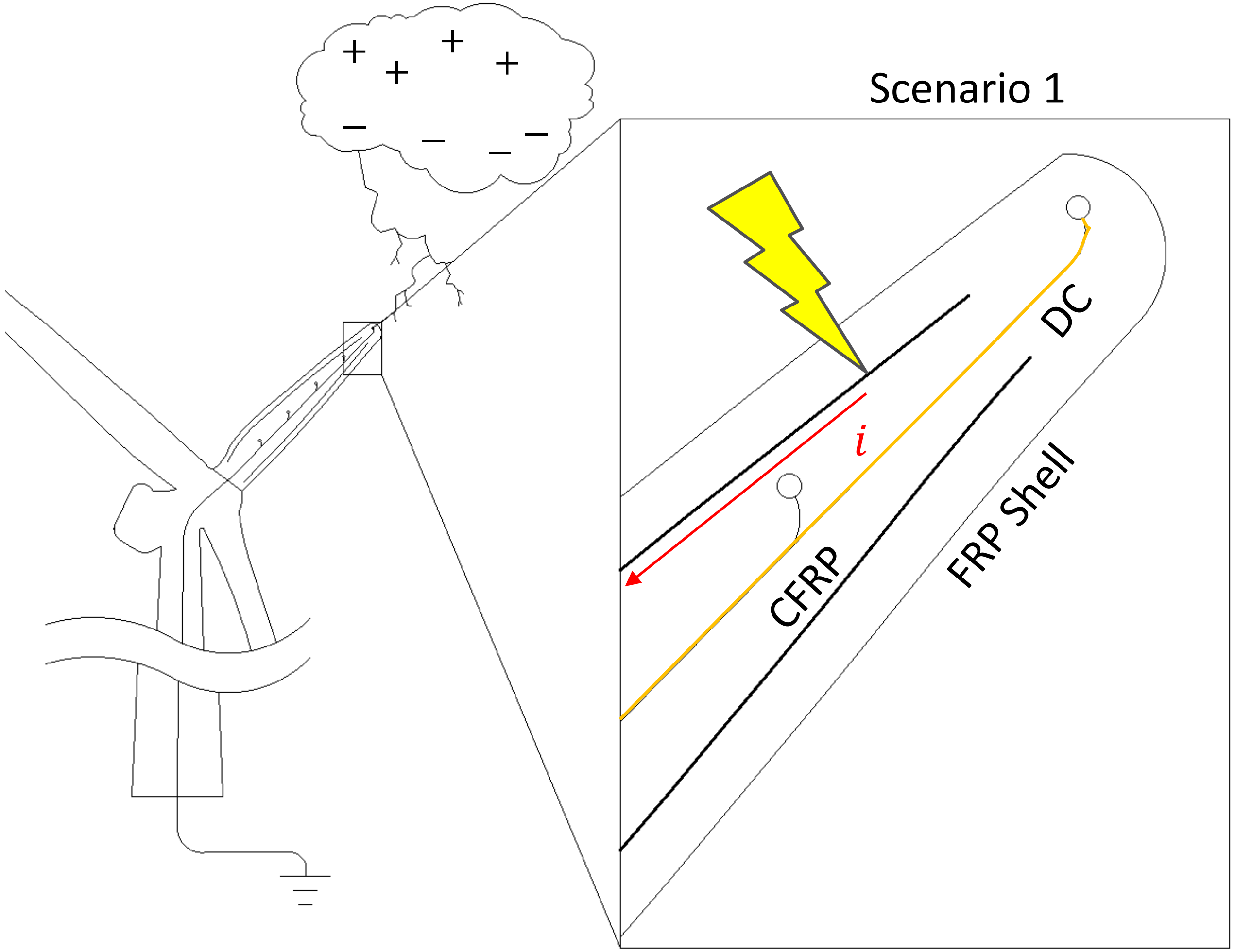
- CFRPs (relative to GFRP) enables longer wind turbine blades with





Lightning in Wind Turbine Blades

- CFRP materials (semi-conductors) provide a different path for lightning to take to ground.
- There are two typical scenarios where lightning enters CFRP perpendicular to the surface, also known as, arc-entry.
  - Scenario 1, direct strike to CFRP
- Arc-entry is the most severe lightning damage mechanism on CFRP as the conductivity severely restricts the flow of current causing heat.



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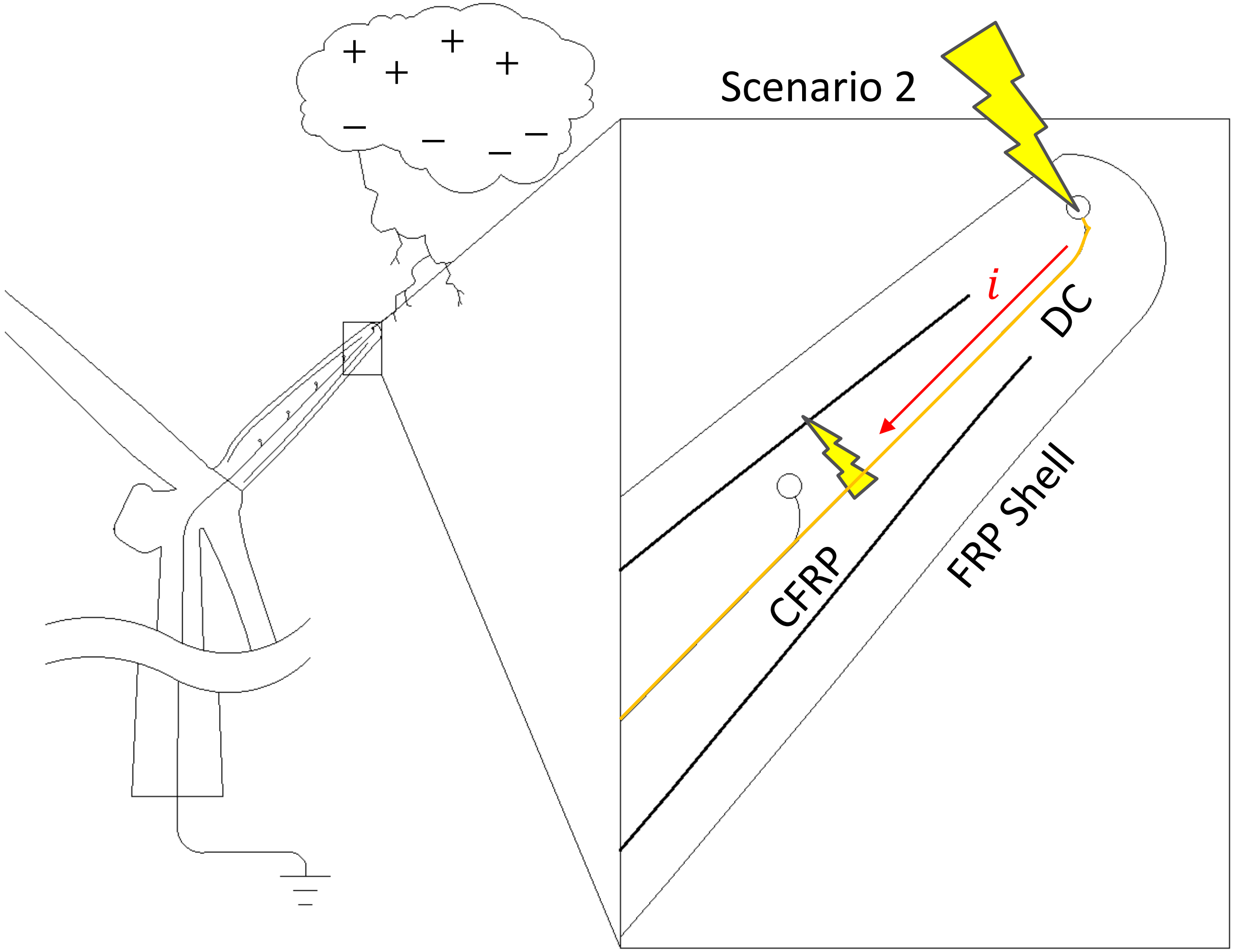
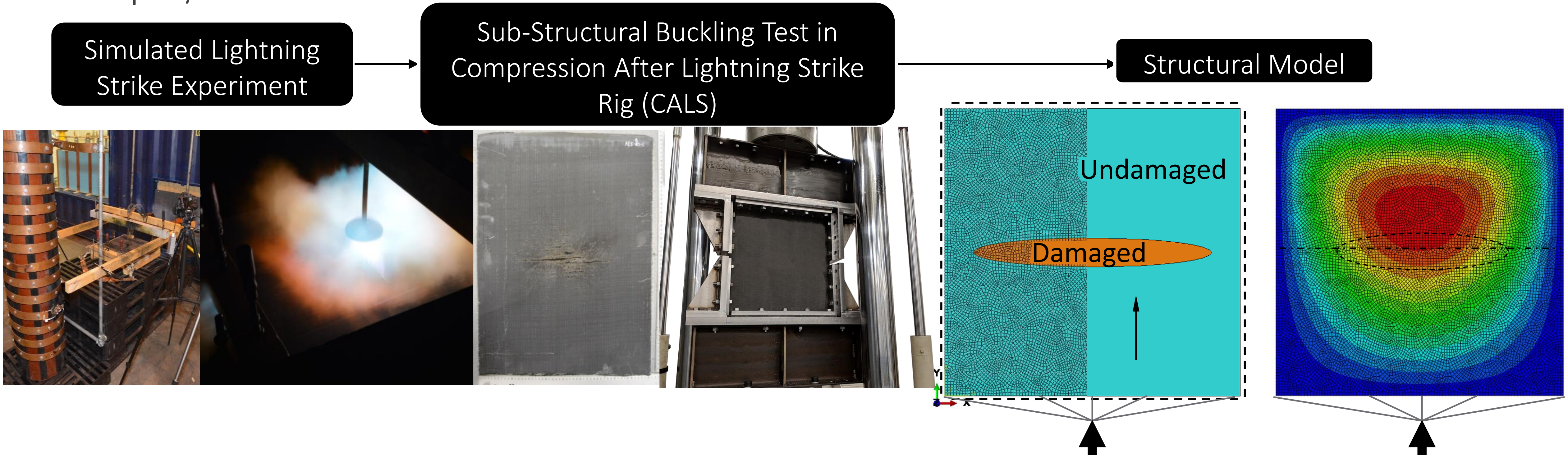
- There are two typical scenarios where lightning enters CFRP perpendicular to the surface, also known as, arc-entry.
  - Scenario 1, direct strike to CFRP
  - Scenario 2, internal flashover
- Arc-entry is the most severe lightning damage mechanism on CFRP as the conductivity severely restricts the flow of current causing heat.



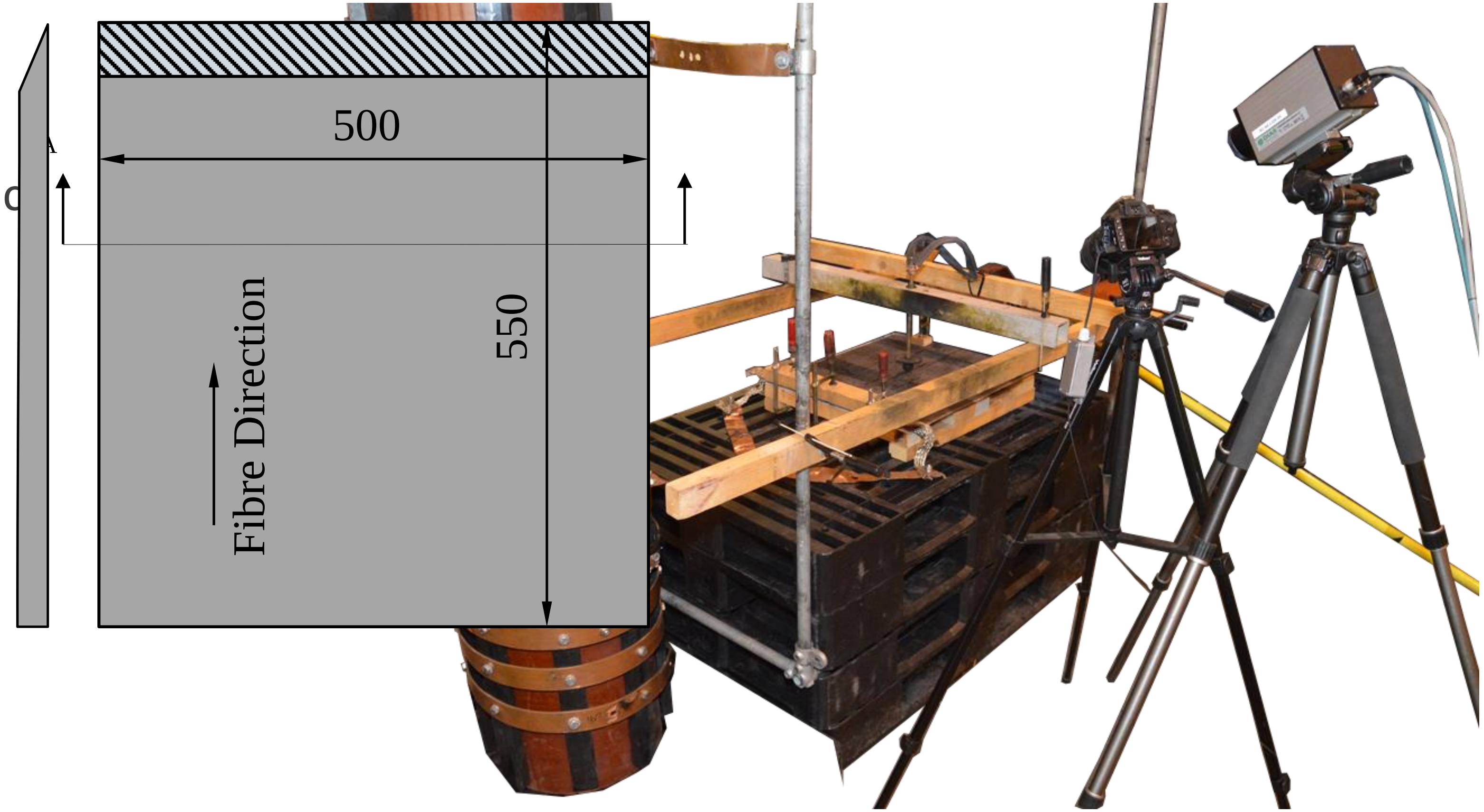
Aims and Objectives

- Predict structural response of CFRP after a lightning strike:
  - Developing experimental procedure
  - Development of modelling framework
  - Compare/Validate



Simulated Lightning Strike Experiments

- 14 x CFRP unidirectional (UD) eight ply laminate
  - 800 gsm fabric
  - Epoxy Resin Matrix
- 550 mm long x 500 mm wide x 7 mm thic
- 10/350μs waveform
- Peak Current shown:
  - 50kA
  - 125kA



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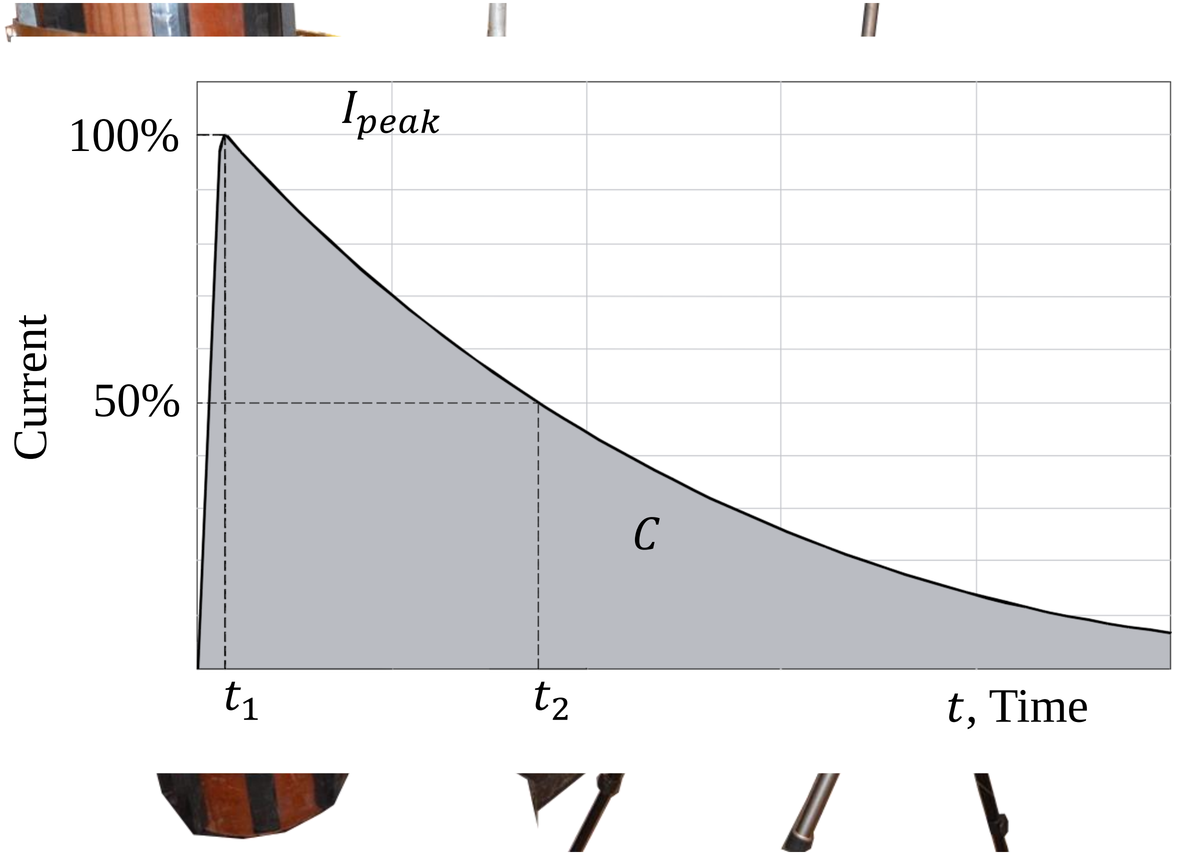

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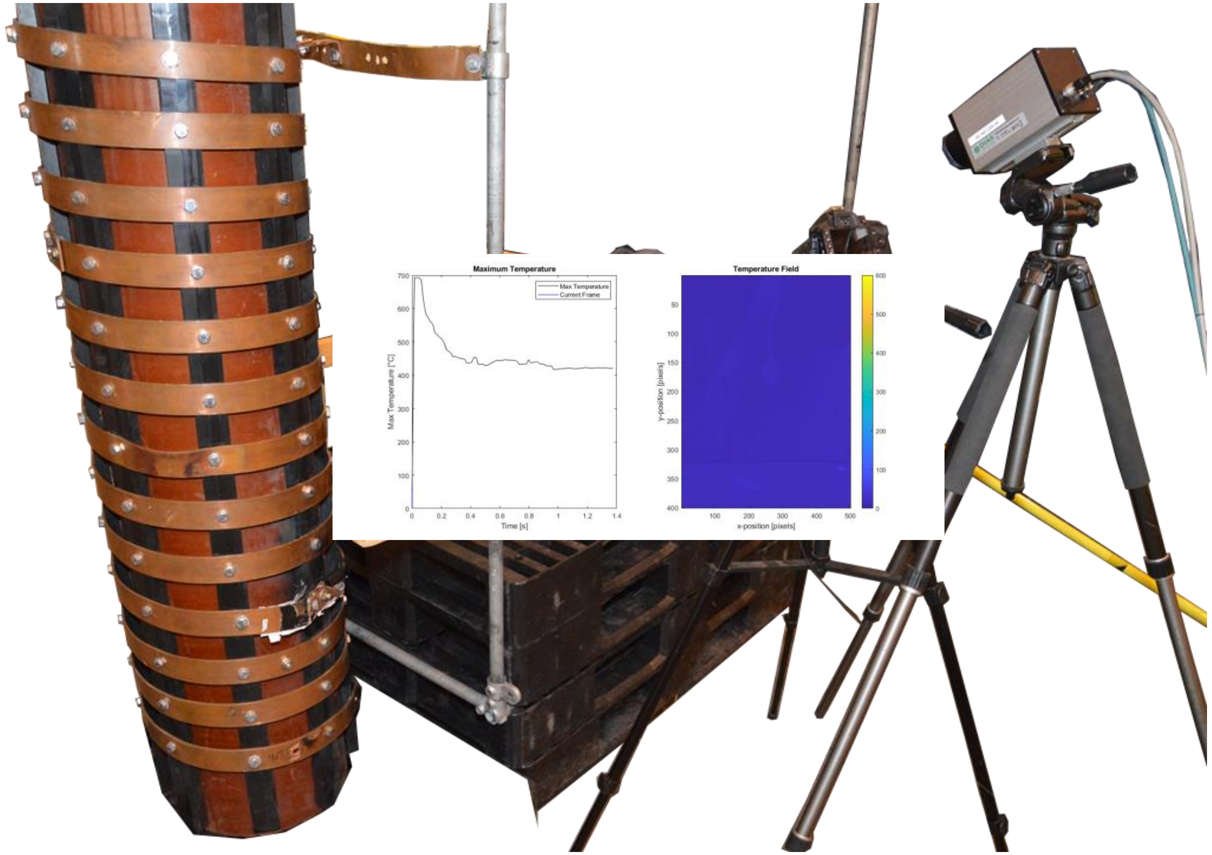
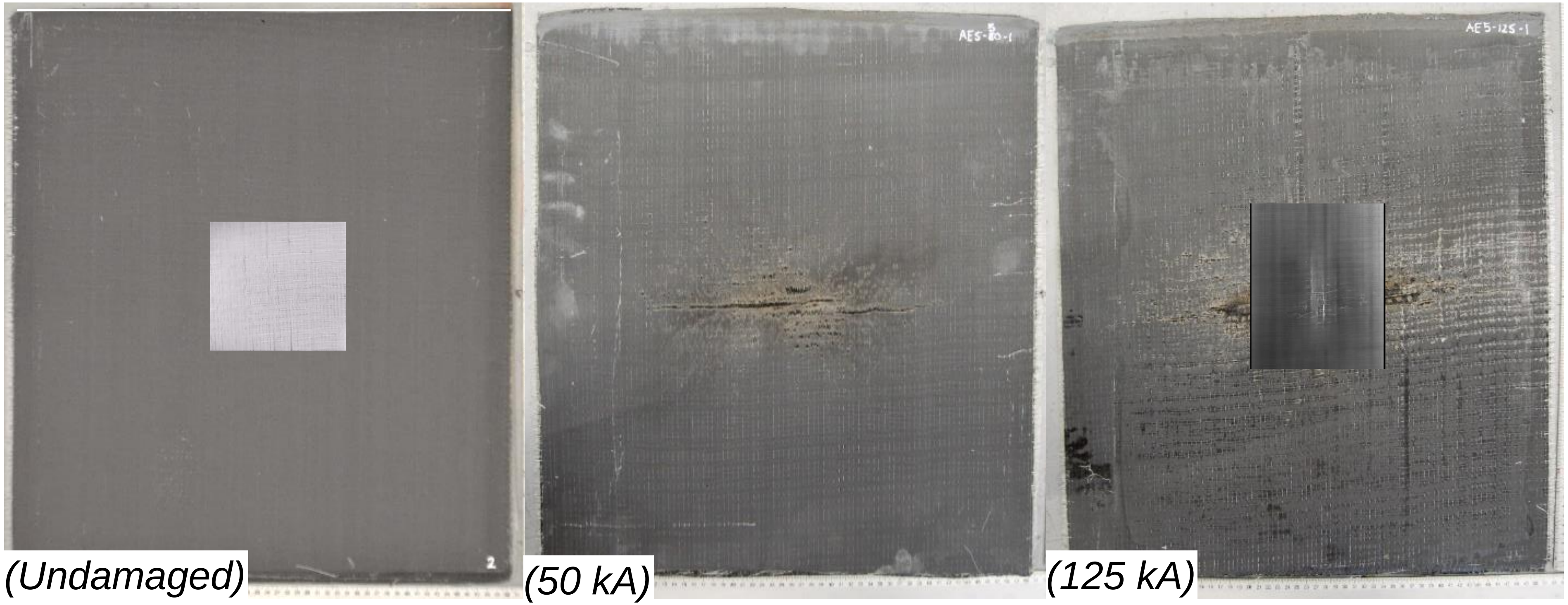


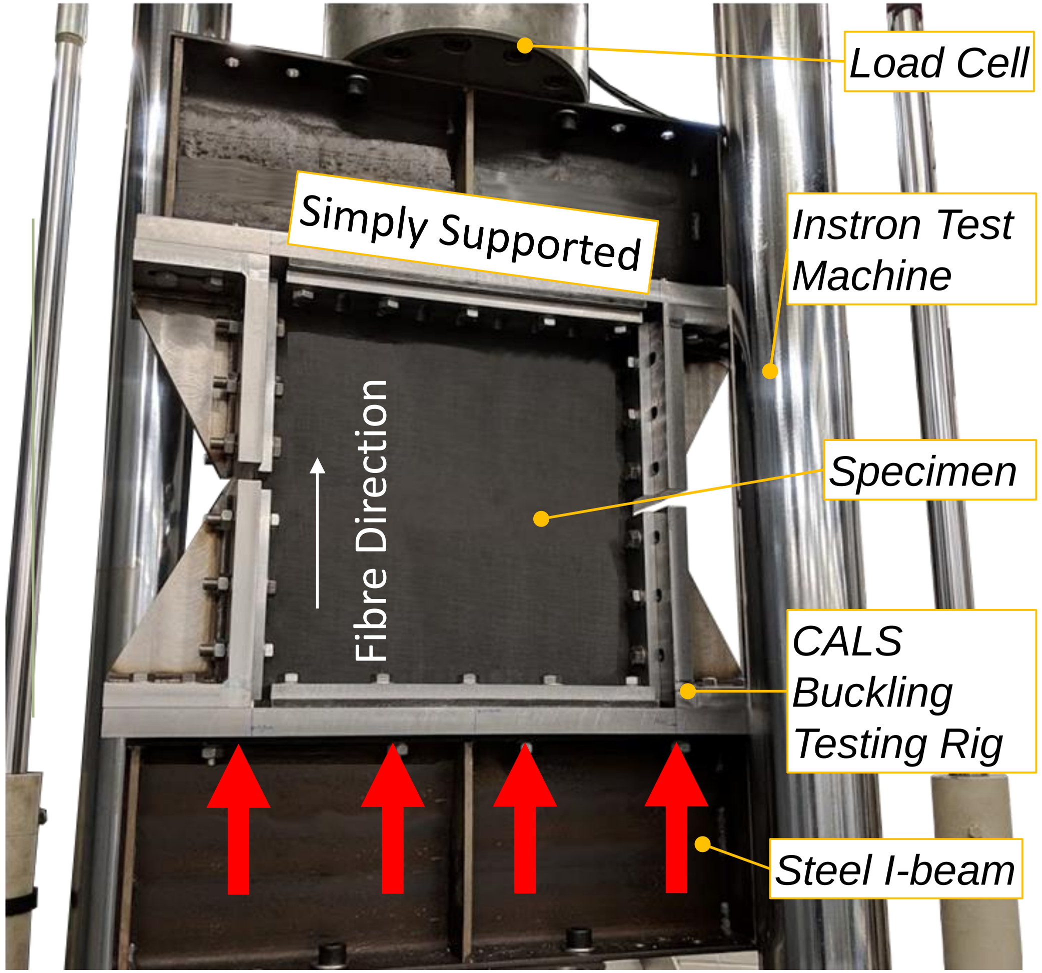
Damage Assessment of Lightning

- Damaged samples:
  - Assessed via visual inspection and CT scans.
  - Waterjet cut to remove the chamfered edge and centre the damage.
  - Representative of the typical lightning damage seen in literature [1] – [4]



Compression After Lightning Strike (CALS)

- Lightning damage worst effects are seen in compression
- Rig large enough to evaluate structural scale effects
- Instron Schenck test rig 630kN load capacity
- Loaded in compression 0.5mm/min
- Stereo DIC was performed on both sides of the plate



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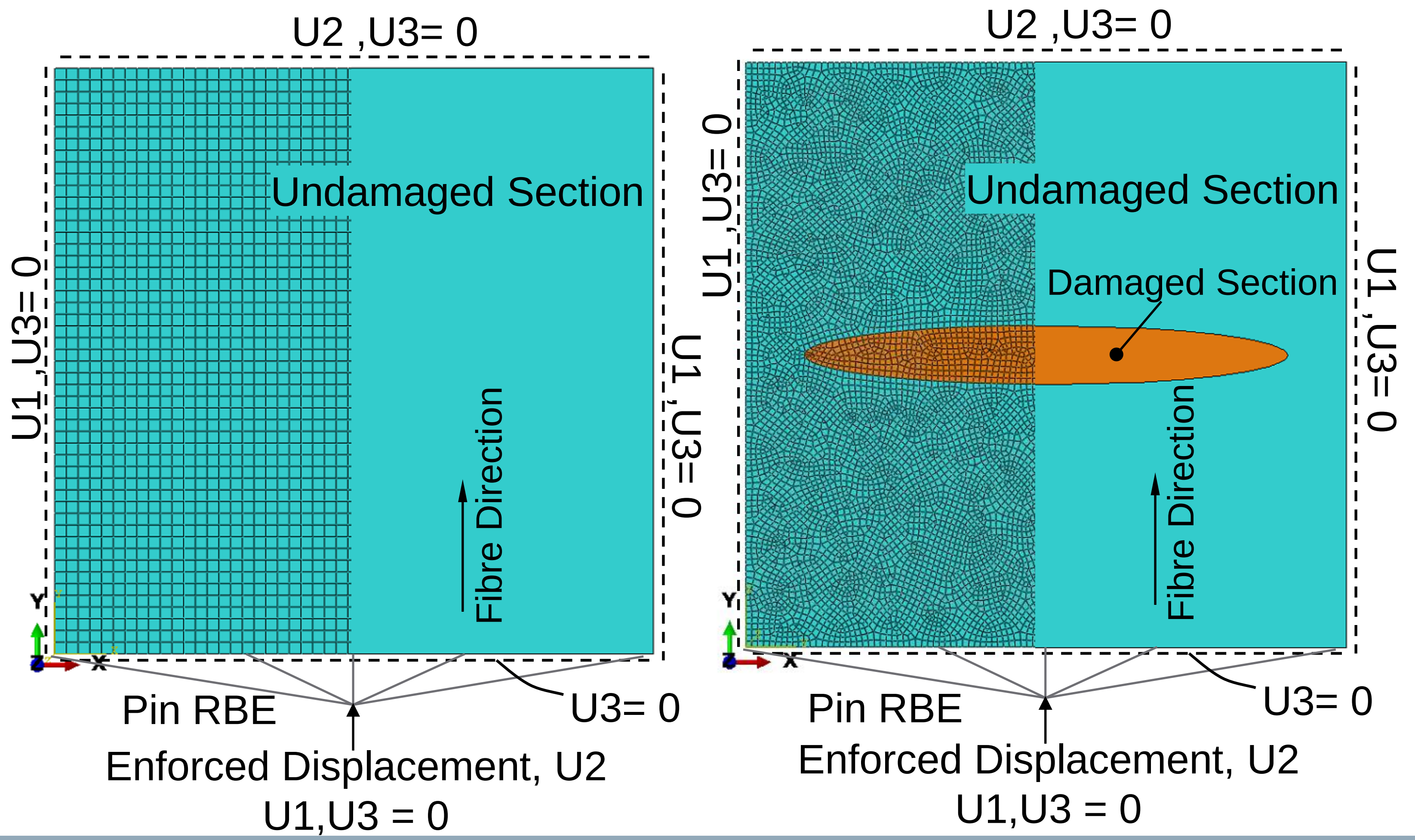
DIC Test Setup	
Technique Used	2 x Stereo 3D Image Correlation (2 cameras measuring top surface and 2 cameras measuring bottom surface)
Camera	4 x MANTA G504B (gigabit Ethernet)
Sensor	12 bit, 2452 x 2056 pixels
Lens	2 x AF NIKKOR 28mm F/8D 2x AF NIKKOR 50mm F/8D
Lightning	4 x NILA ZAILA LED Lights
Imaging distance	~2 m from bottom surface ~4m from top surface
Field of View	400 mm x 400 mm x 100 mm
Pixel resolution	~ 1px = 0.27 mm
Correlation Setup	
DIC Software	MatchID 2018.2.2
Correlation Procedure	Zero Normalized Sum of Differences Squared
Subset Size	33 px
Step Size	16 px
Sub-pixel interpolation	Bicubic Spline
Shape Function	Quadratic
Stereo Transformation	Quadratic
Strain Calculation	Logarithmic Euler-Almansi strain tensor
Displacement Noise Floor (u, v, w)	(0.026227, 0.0089122, 0.13067) mm
Strain Noise Floor ($\varepsilon_{xx}, \varepsilon_{yy}, \gamma_{xy}$)	(150, 95, 120) μm/m

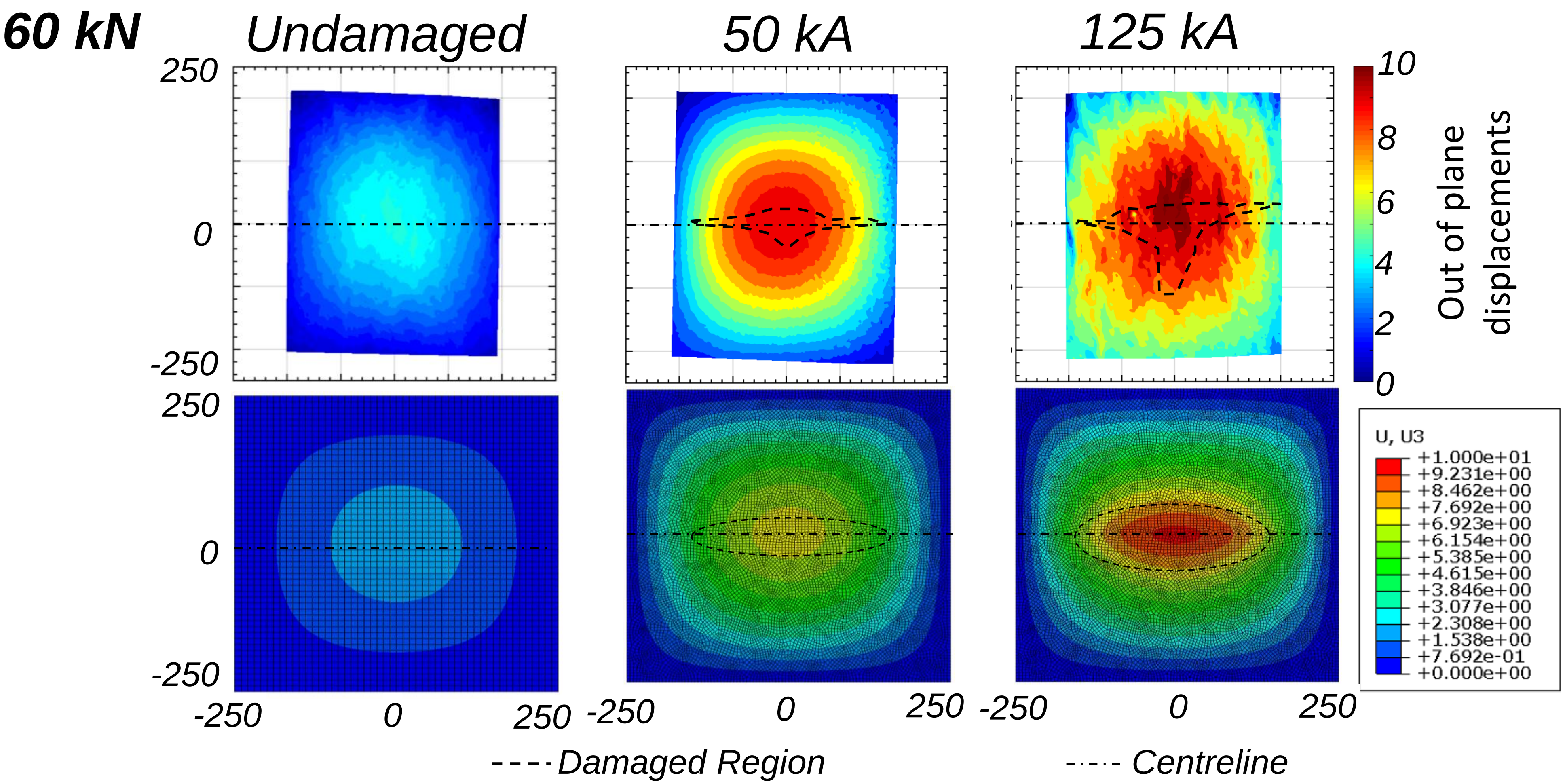
Numerical Modelling

- Shell post-buckling finite element model with large deformations
- Abaqus 6.14 Riks Method with S4R shell elements
- The area of the damage was assessed using the visual inspection and CT
- Damaged areas taken into account by reducing stiffness to essentially zero



Out of Plane Displacements

- The most severely damaged specimen (lightning strike of 125kA) for all load levels showed:
  - highest displacement levels
  - a change in the displacement field moving away from the damaged region.



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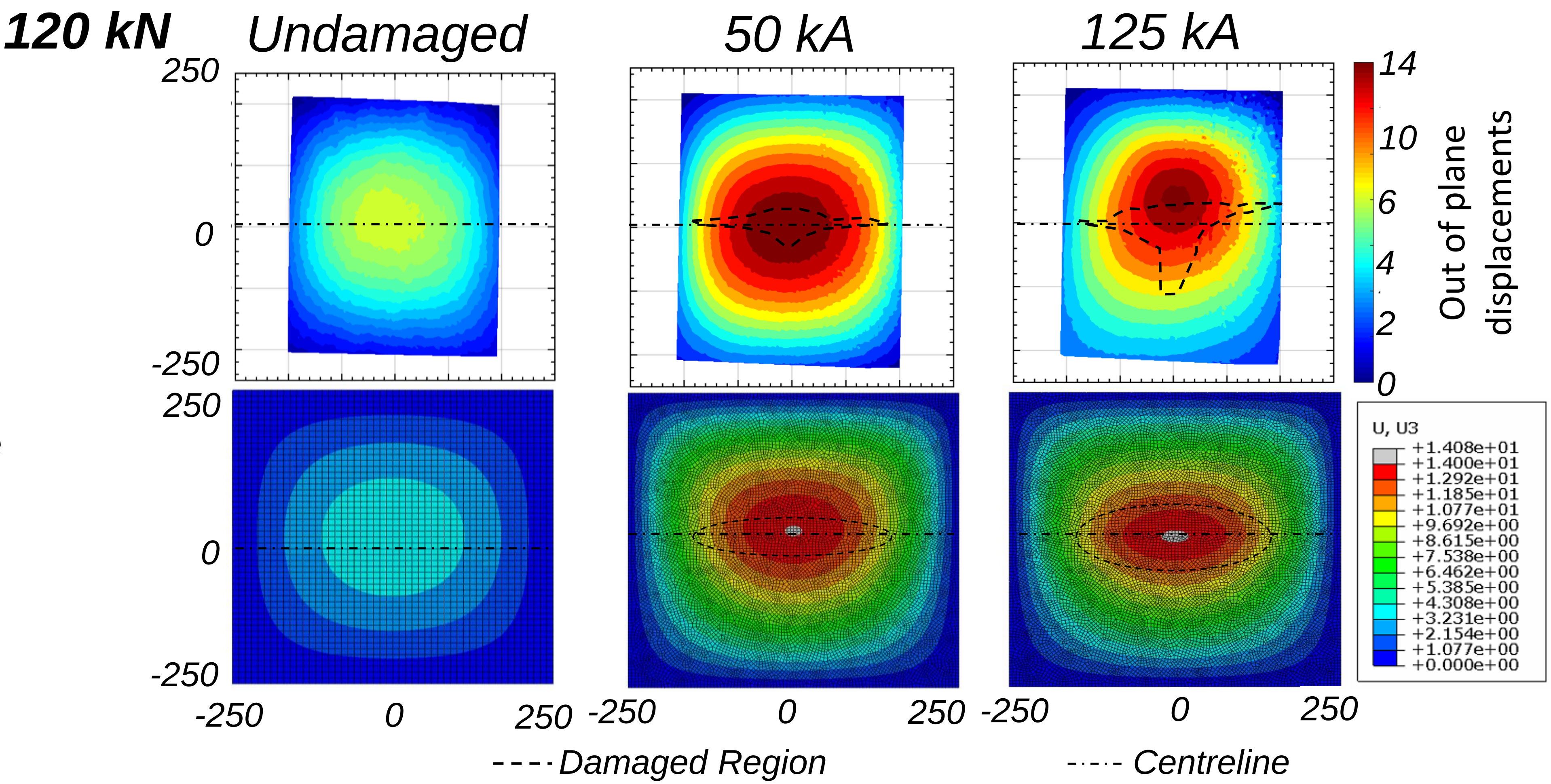

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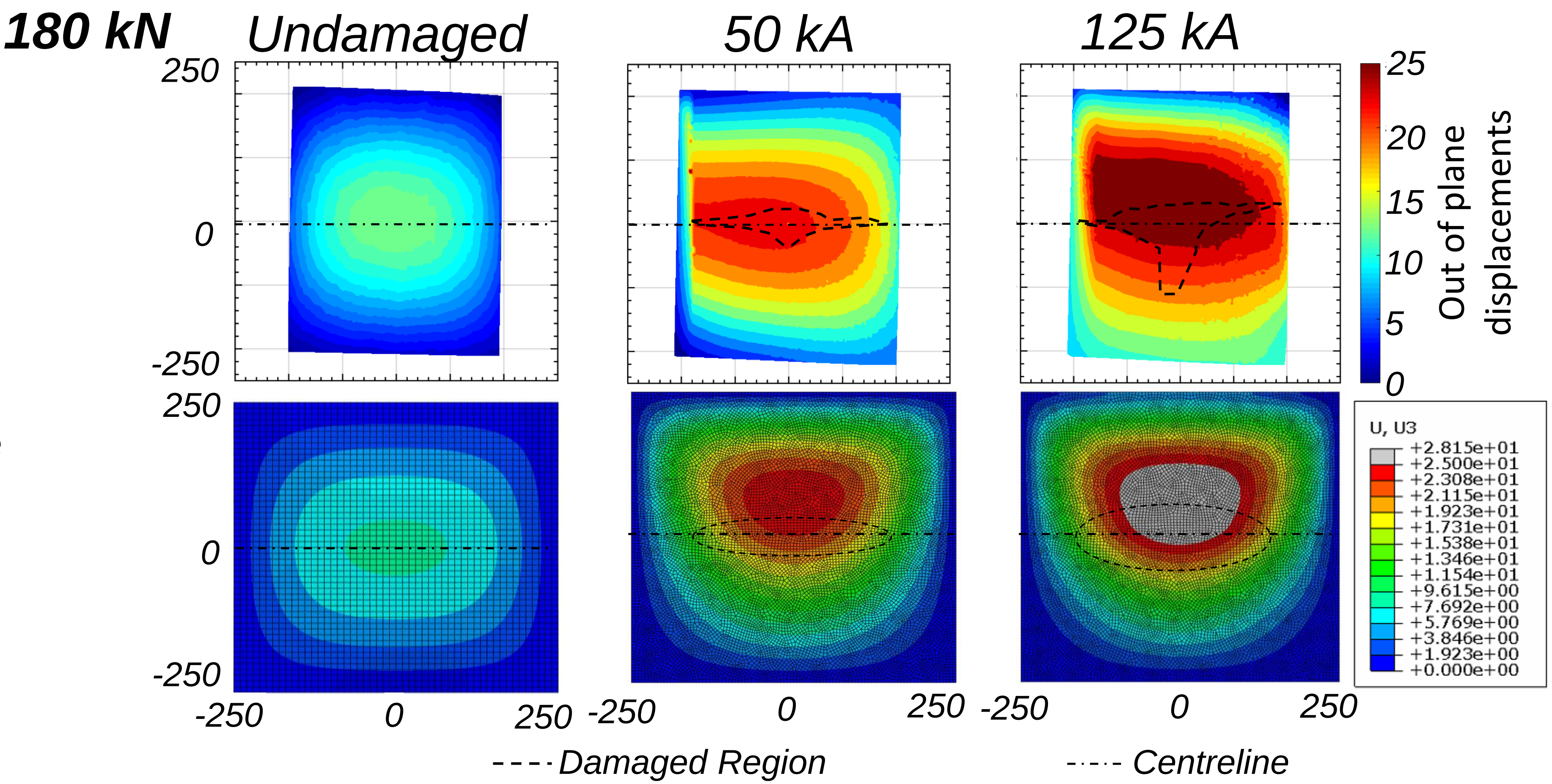
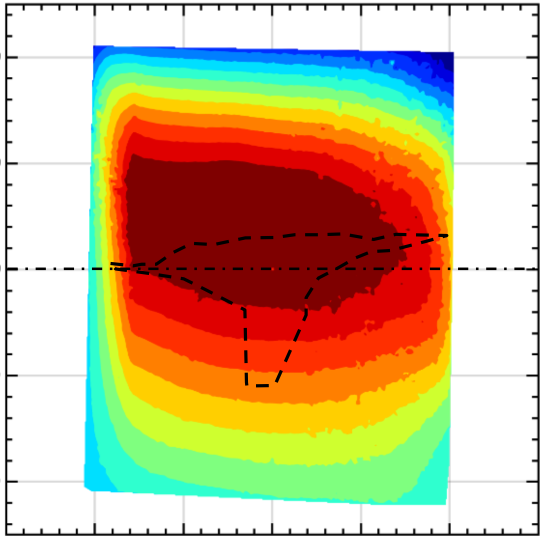
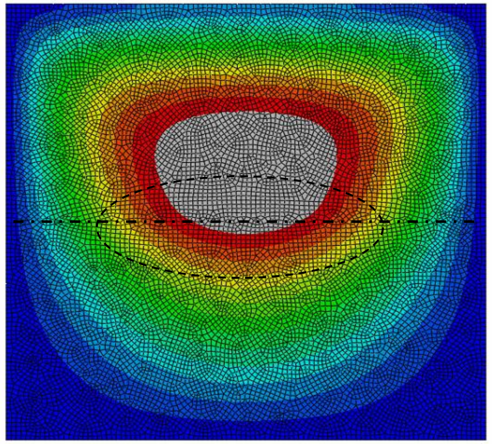


Conclusions

- Designed and manufactured novel CALS rig to include structural scale effects on CFRP materials damaged by lighting
- DIC enables capture of the redistribution away from the damaged region
- Damage induced is representative of lightning and able to quantify the buckling and post-buckling response
- The validation of the FEM creates opportunity to study other damage scenarios.





Thank You for your attention

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[4] International Electrotechnical Commission, “IEC61400: Wind turbine standard,” 2014.