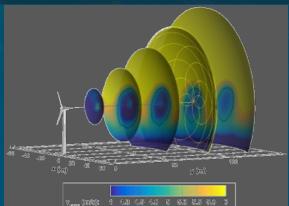




Sandia  
National  
Laboratories

# Effects of Lightning on Pultruded Carbon Fiber Wind Blades



*PRESENTED BY*

Michelle Williams

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Julia N. Tilles, Josh Paquette, Daniel Samborsky,  
Paul Clem



Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

## Motivation

**Problem:** Determine effect of lightning damage on pultruded carbon fiber laminates.

Ability of inspection equipment to find damage

- Fiberglass vs. Carbon Fiber



# Methodology



Vinylester (62% FVF)

Epoxy-matrixed (65% FVF)

## Pre-Test Inspection

- Immersion Ultrasonics (UT), Pulse Echo UT, Thermography

## Lightning Impulse Testing

## Post-Test Inspection

- Immersion UT, Pulse Echo UT, Thermography, Computed Tomography

## Post-Test Structural Testing



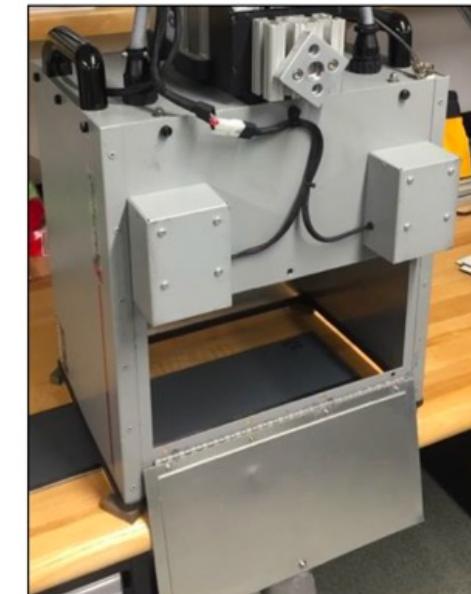
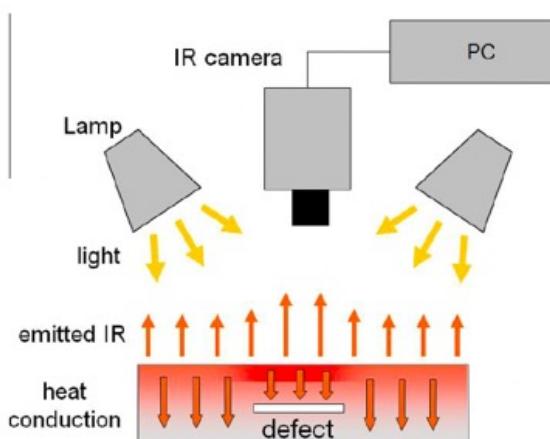
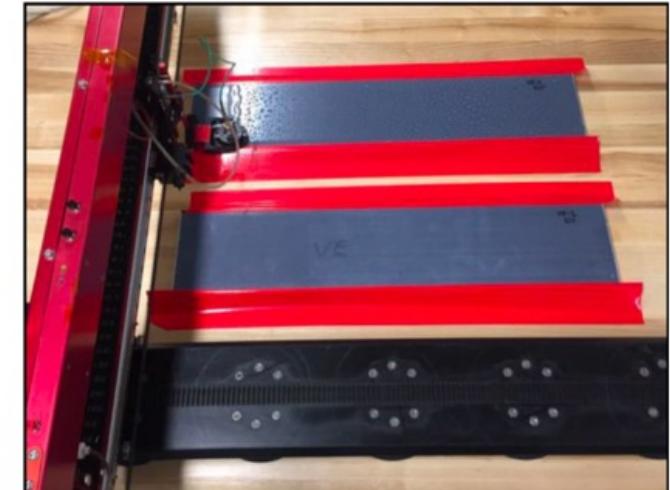
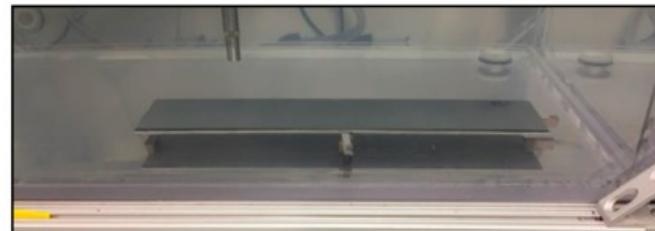
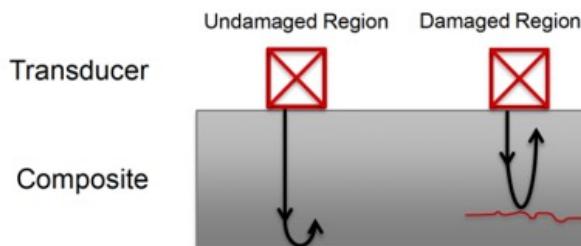
# Pre-Test Nondestructive Inspection



Immersion UT (top left)

Pulse Echo UT (top right)

Thermography (bottom)



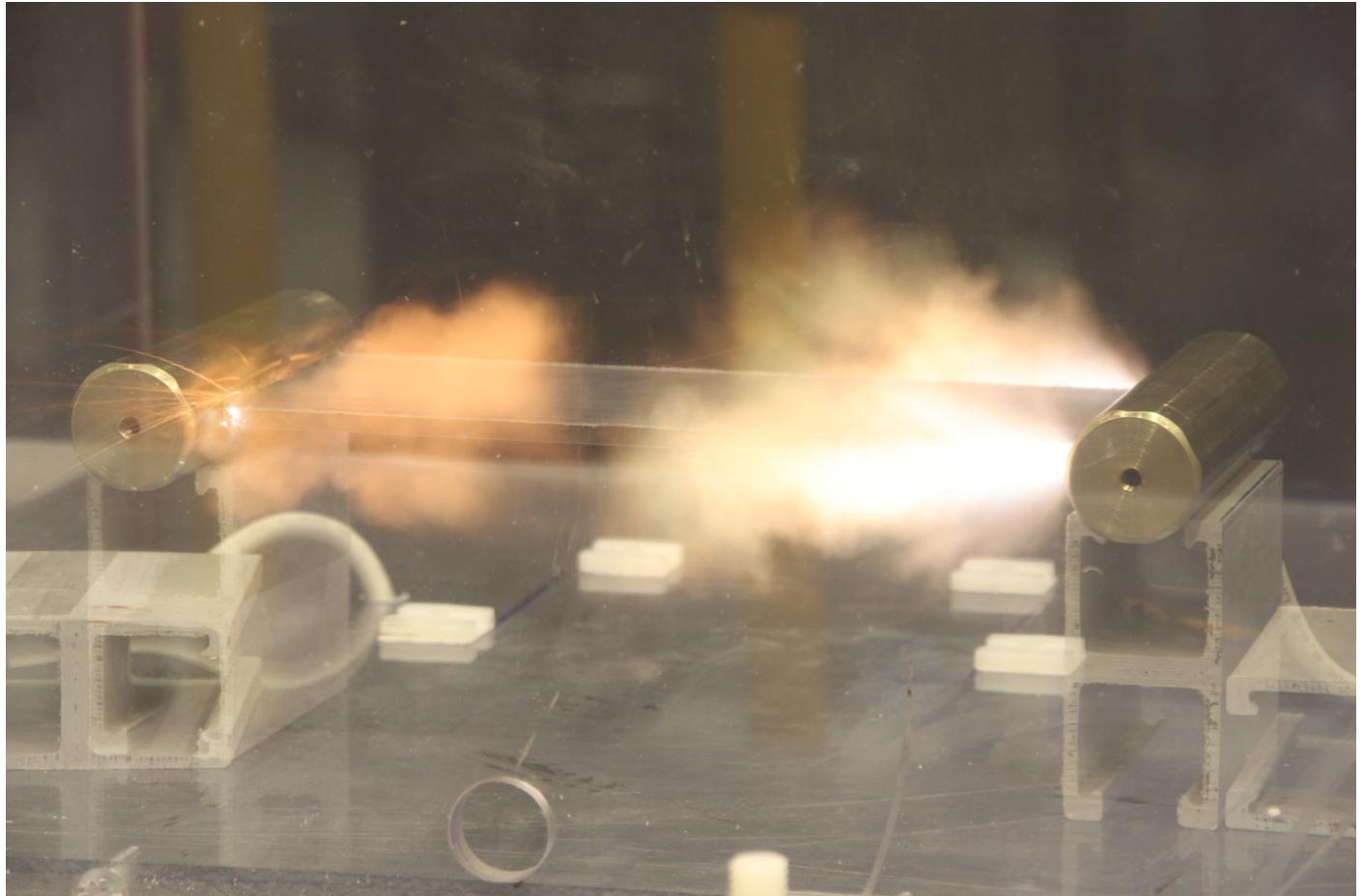
## Lightning Impulse Testing



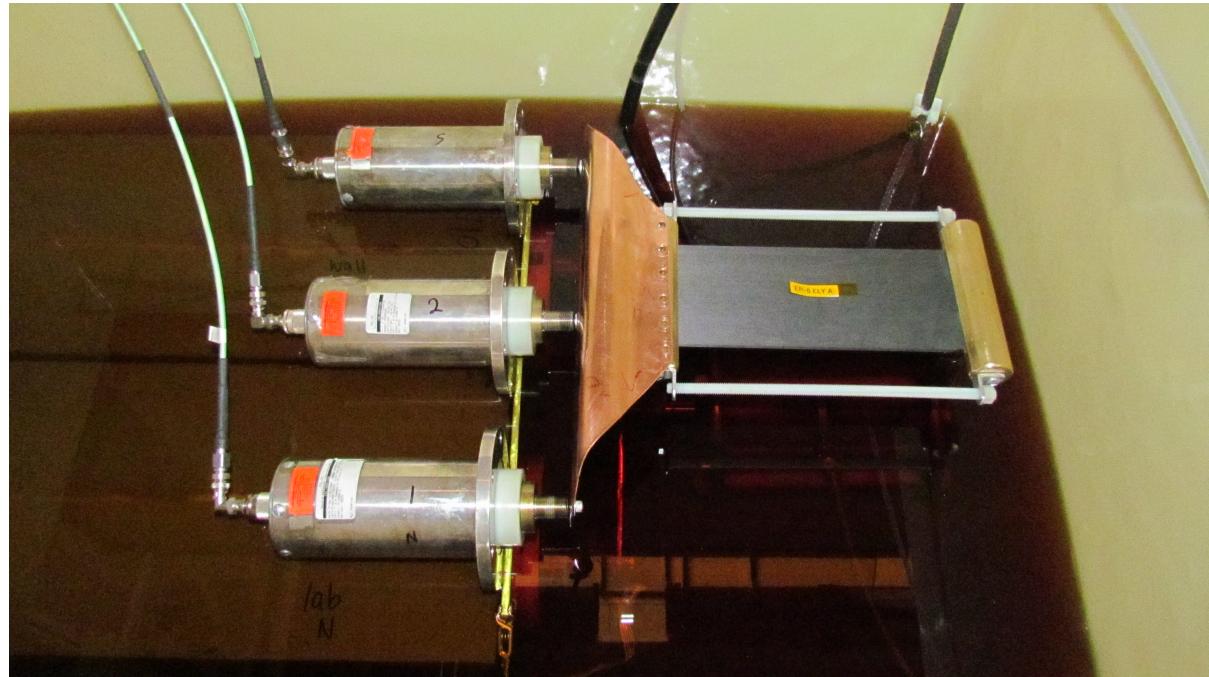
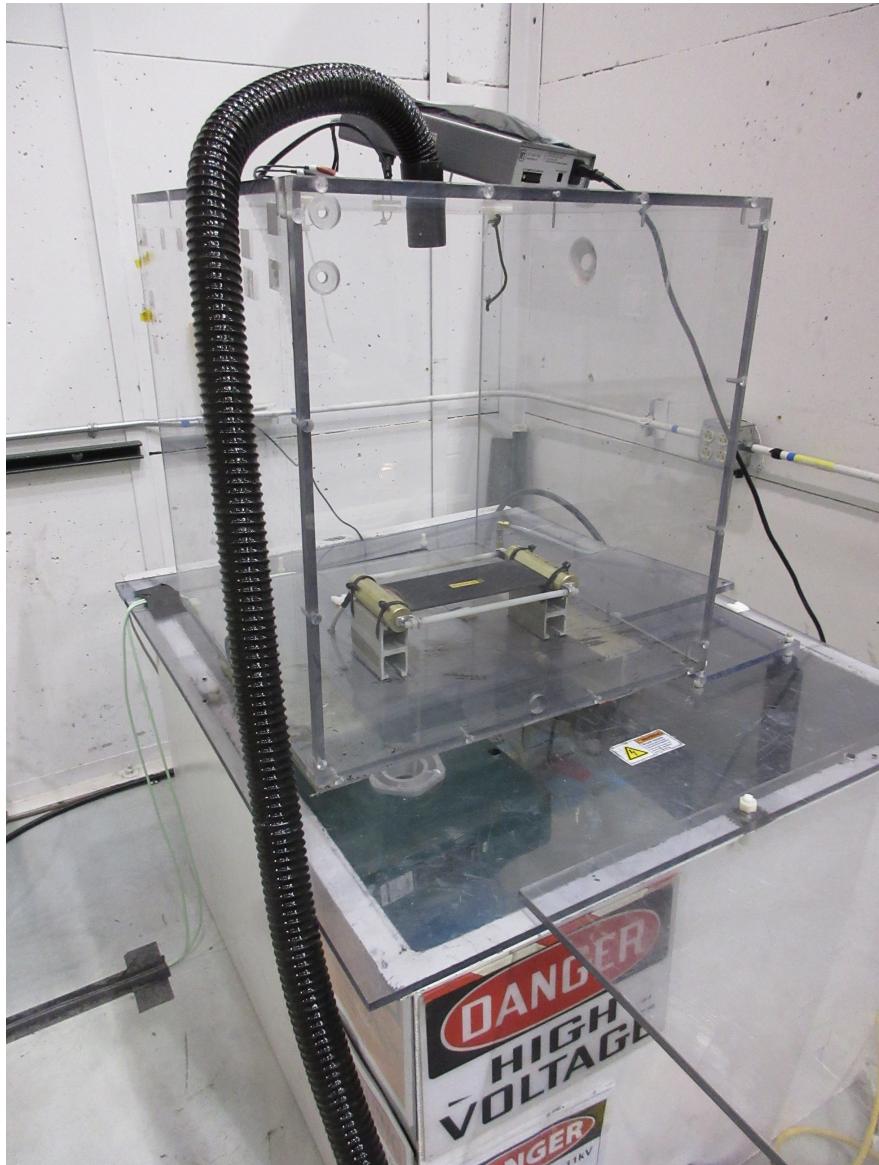
Pulsers: (200kV) 1 microsecond  
(22kV) 30 microsecond

Peak Currents: 30kA, 200kA

Average 50% and worst 1%



## 6 Lightning Impulse Testing setup



(22kV) 30 microsecond rise-time pulser (left)

(200kV) 1 microsecond rise-time pulser (top right)

# Lightning Impulse Testing



		30 kA peak current		200 kA peak current																																																																
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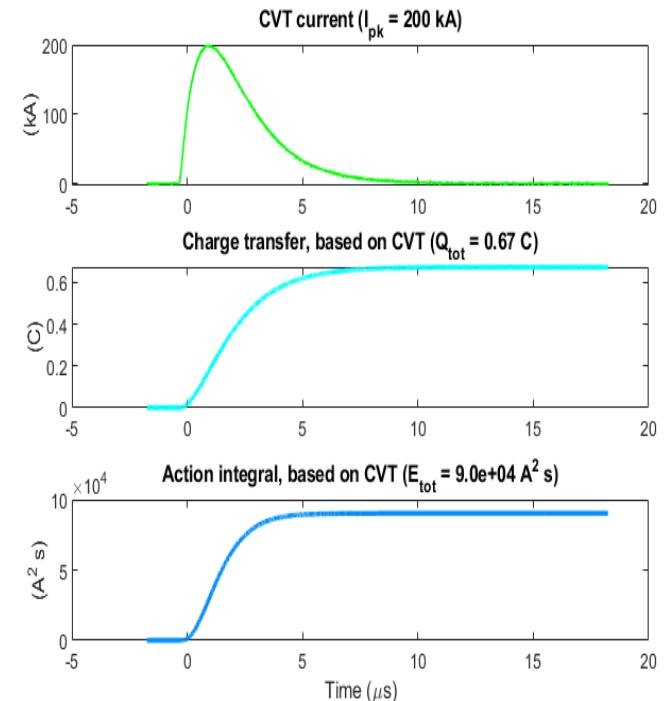
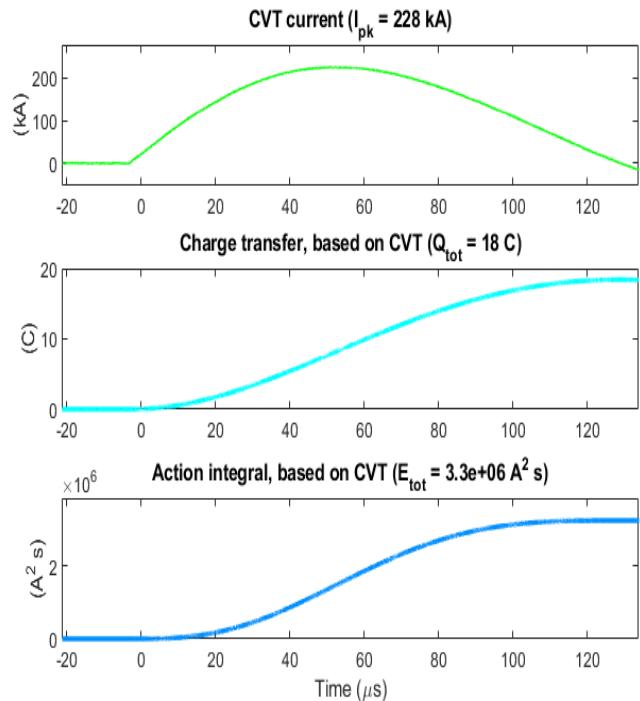
<sup>1</sup>The entire cloud-to-ground discharge may be comprised of multiple individual major current pulses. These are known as return strokes or, simply strokes.

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# Lightning Impulse Testing



	30 kA peak current	200 kA peak current
1- $\mu$ s pulser	<p>50% lightning peak current 1% lightning time to peak</p> <p>Current = <math>(Ch1 + Ch2 + Ch3) * Calibration</math> Calibration = 4,000</p> <p>Test day: 5/25/2021 File no. 1 → VE-7A File no. 2 → VE-8A File no. 3 → EP-9A File no. 4 → VE-9A File no. 5 → EP-10A</p> <p>Test day: 5/26/2021 File no. 6 → EP-11A</p>	<p>1% lightning peak current 1% lightning time to peak 50% lightning action integral</p> <p>Current = <math>(Ch1 + Ch2 + Ch3) * Calibration</math> Calibration = 20,000</p> <p>Test day: 5/4/2021 File no. 0 → EP-5A</p> <p>Test day: 5/5/2021 File no. 1 → VE-5A File no. 2 → EP-6A File no. 3 → VE-6A File no. 4 → EP-7A File no. 5 → EP-8A</p> <p>Test day: 5/26/2021 File no. 8 → VE-10A</p>
30- $\mu$ s pulser	<p>50% lightning peak current 50% lightning action integral</p> <p>Current = <math>Ch3 * Calibration</math> Calibration = 50,000</p> <p>Test day: 5/20/2021 File no. 0 → VE-6B File no. 1 → EP-7B File no. 2 → VE-7B File no. 3 → EP-9B File no. 4 → VE-10B File no. 5 → EP-10B</p>	<p>1% lightning peak current 50% lightning charge transfer 1% lightning action integral</p> <p>Current = <math>Ch3 * Calibration</math> Calibration = 50,000</p> <p>Test day: 5/13/2021 File no. 0 → EP-5B File no. 1 → VE-5B File no. 2 → EP-6B File no. 3 → VE-8B File no. 4 → EP-8B File no. 5 → VE-9B</p>



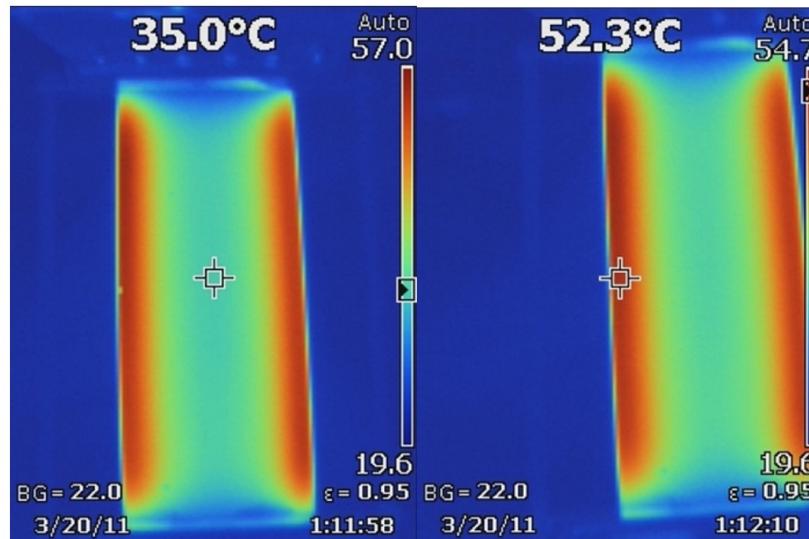
Current Viewing Transformer (CVT) (top plots)

Charge Transfer (middle plots)

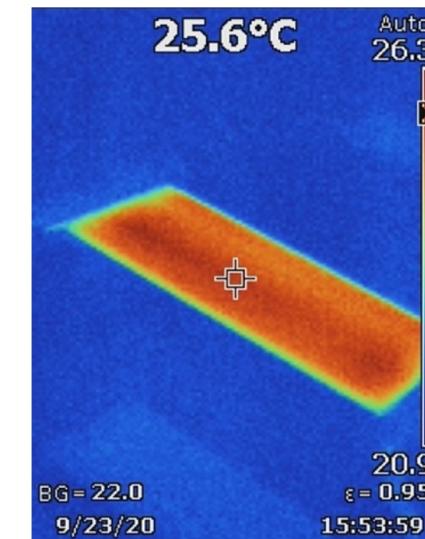
Action Integral (bottom plots)

- energy deposition

# Investigation of Edge Effects



'2/3' test, 179.2 kA peak current

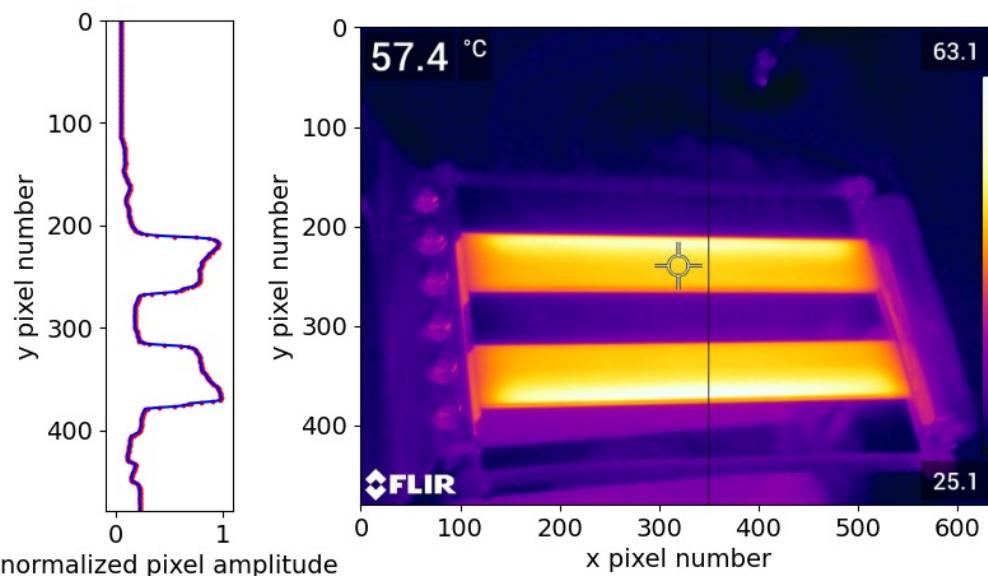


## Infrared images

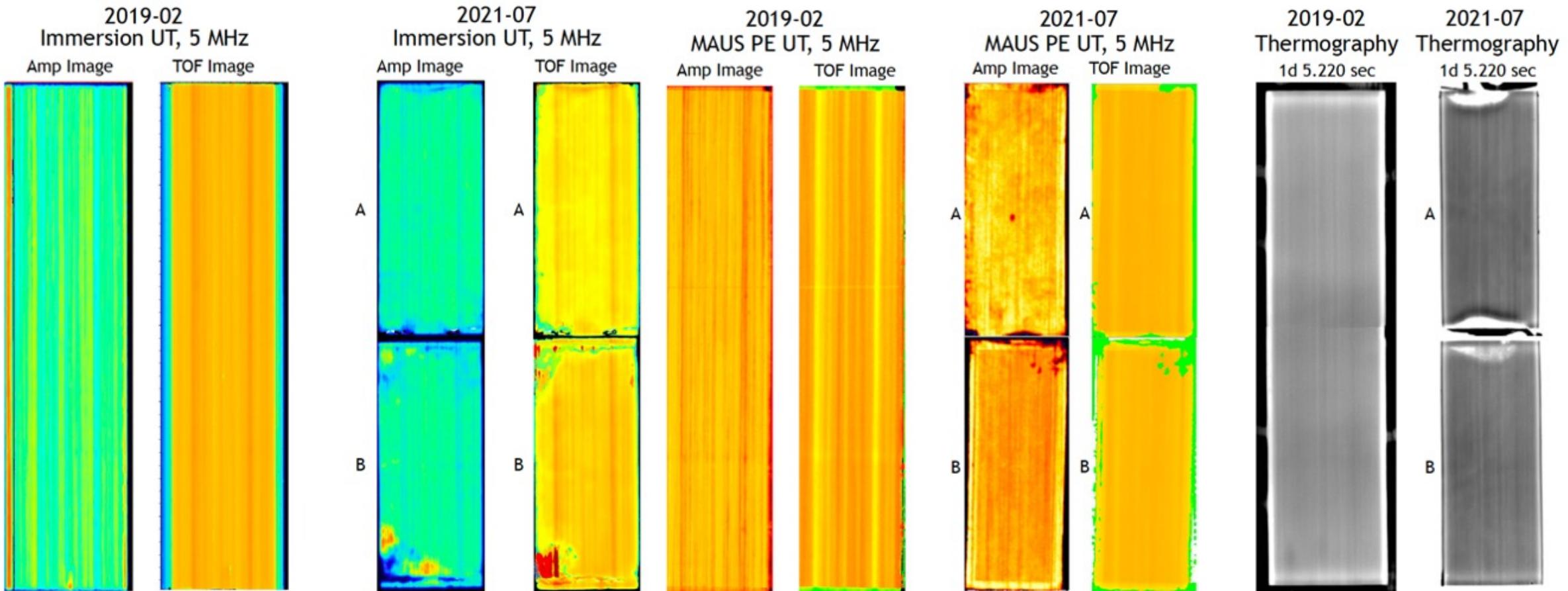
~200kA, 1microsecond rise time tests  
(top right, top center)

30microsecond rise time test (top right) uniform temperature.

2/3 test, ~180kA, 1microsecond rise time (bottom)



# Post-Test Nondestructive Inspection

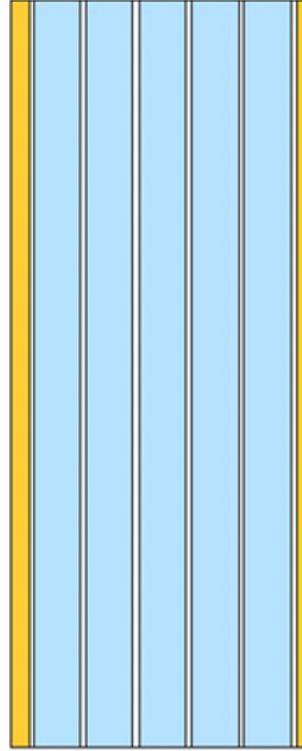


Immersion UT, Pulse Echo UT, Thermography, Computed Tomography (CT)

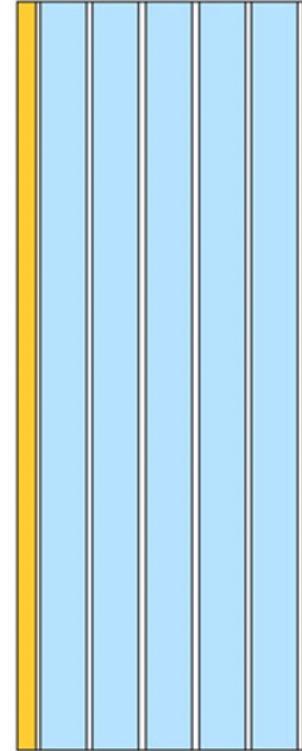
# Post-Test Structural Testing



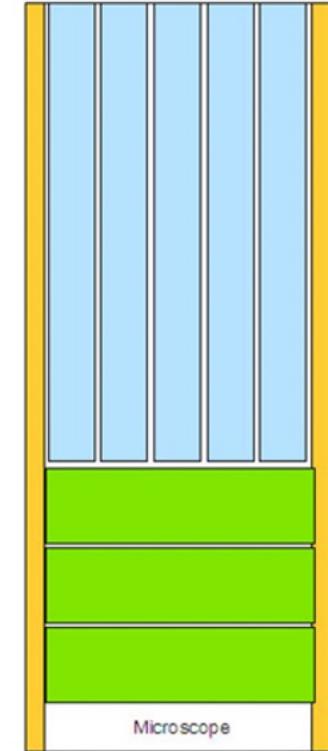
Tensile 0.5" x 9.8"  
1/4 edge trim



Fatigue 0.5" x 9.8"  
1/4 edge trim

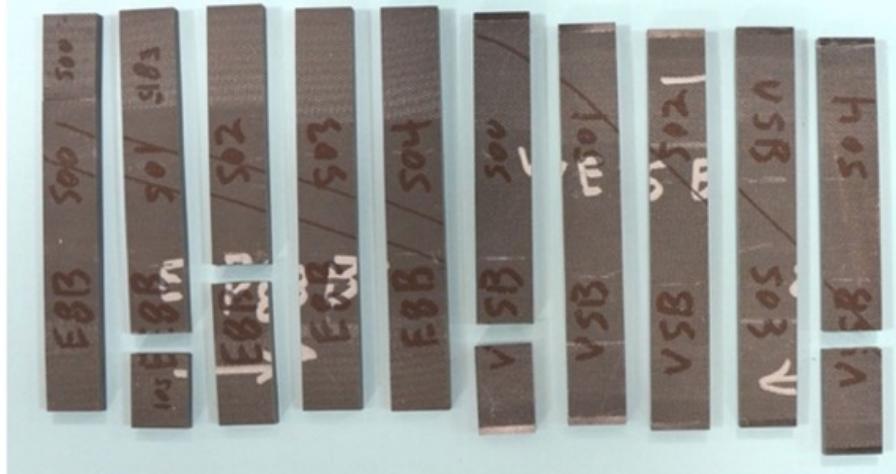


Compression 0.5" x 6"  
1/4 edge trim  
transverse tension  
1" x panel width



MSU's structural load frames:

(L-R) Instron 8562 (100kN capacity) and  
Instron 8802 (250kN capacity)



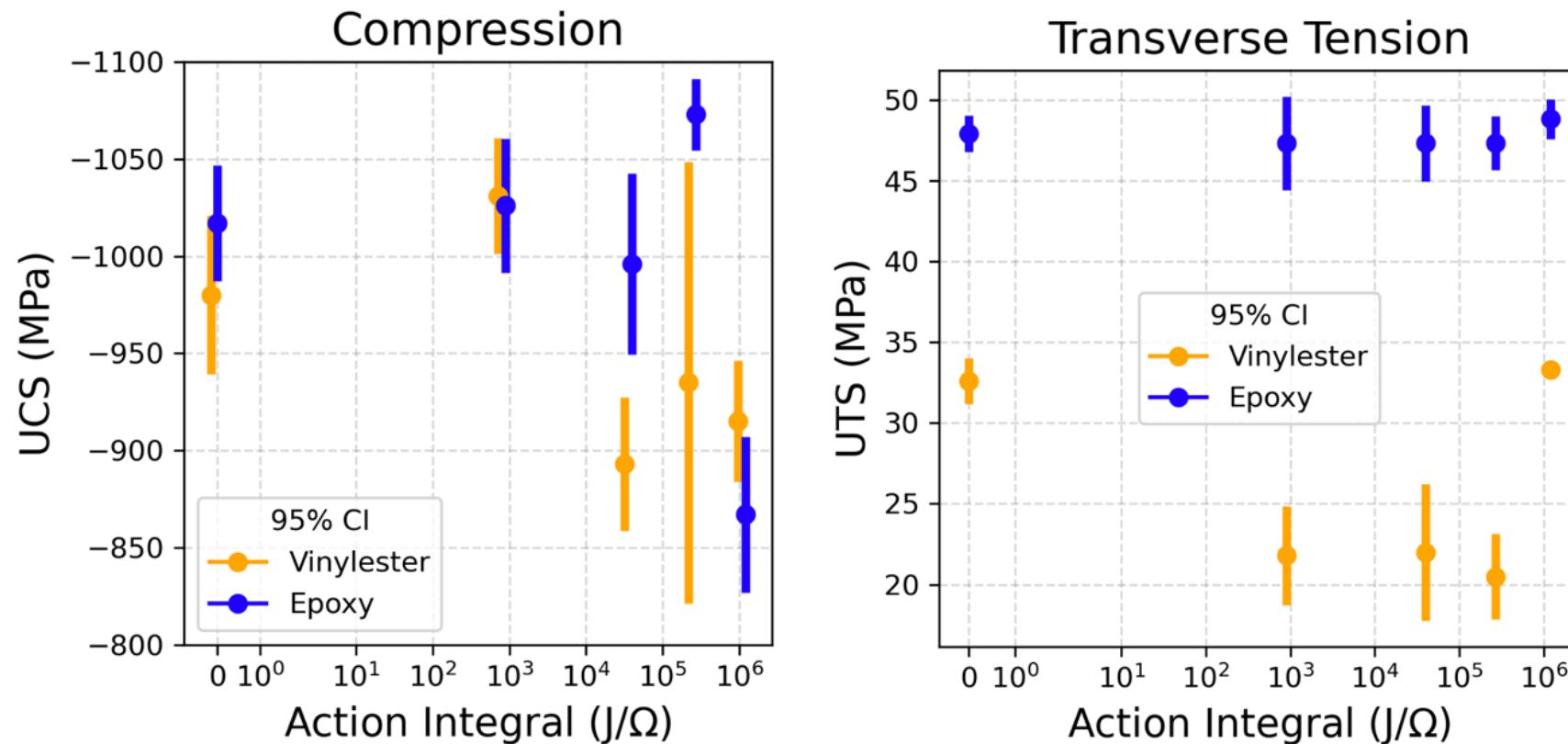
Compression (top left)

Transverse Tension (bottom left)

Longitudinal Tension (right)

Tensile Fatigue (in progress)

# Post-Test Structural Testing



Strength vs action integral (energy per unit resistance, 95% CI)

## Conclusions



Carbon fiber pultrusions withstand severe lightning currents, but with some ultimate strength degradation.

Preliminary results show that epoxy-matrixed specimens tests at 200 kA and a 30 microsecond rise-time had decreased compressive strength. Vinylester specimens also had decreased compressive strength at higher action integrals, but further testing is needed to confirm this conclusion.

Post-test structural results preliminary, more investigation required.

No recommendations can be made on NDI methods to be used for determining damage in a carbon fiber blade struck by lightning.



Repeat on thinner specimens for improved structural testing

Testing on adhered stacked plates

Multiple strike testing

Examine edge effects

## Acknowledgments



Department of Energy (DOE)– Wind Energy Technology Office (WETO)

Ray Martinez – Sandia National Labs, High Current Facility

References can be found in paper: “Effects of Lightning on Pultruded Carbon Fiber Wind Blades”.

**Contact:** Michelle Williams, Sandia National Laboratories, Wind Technology Design, [mwilli9@sandia.gov](mailto:mwilli9@sandia.gov)