

INFRARED THERMOGRAPHY AND X-RAY COMPUTED TOMOGRAPHY AS COMPLEMENTARY TECHNIQUES FOR THE CHARACTERIZATION OF DAMAGE IN COMPOSITE SANDWICH STRUCTURE

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OUTLINE

- ✖ Background on Composite Crew Module (CCM)
- ✖ Overview of splice test article
- ✖ Thermography and CT Results
- ✖ Discussion



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CCM BACKGROUND



JANUARY 2007 NASA ADMINISTRATOR
CHARTERED THE NESC TO FORM AN
AGENCY TEAM TO...

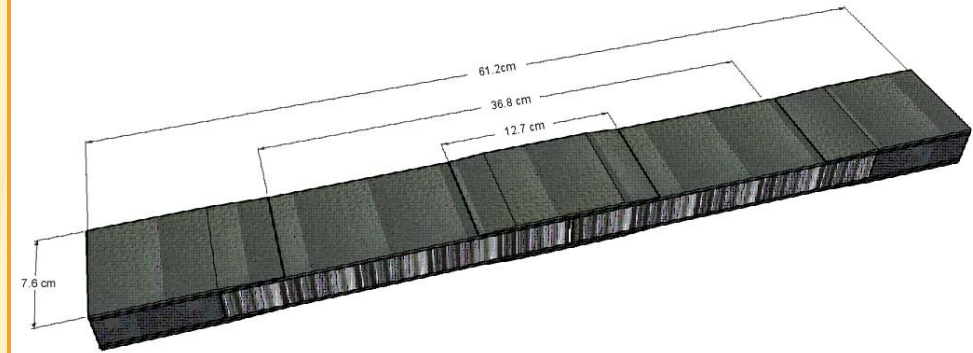
- design and build a composite crew module,
- gain hands-on design, build, and test experience,
- in anticipation that future exploration system may be made of composite materials.



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CCM TEST ARTICLE

Splice Region



61.2 cm Overall Length
7.6 cm Overall Width
12.7 cm Splice Region Length



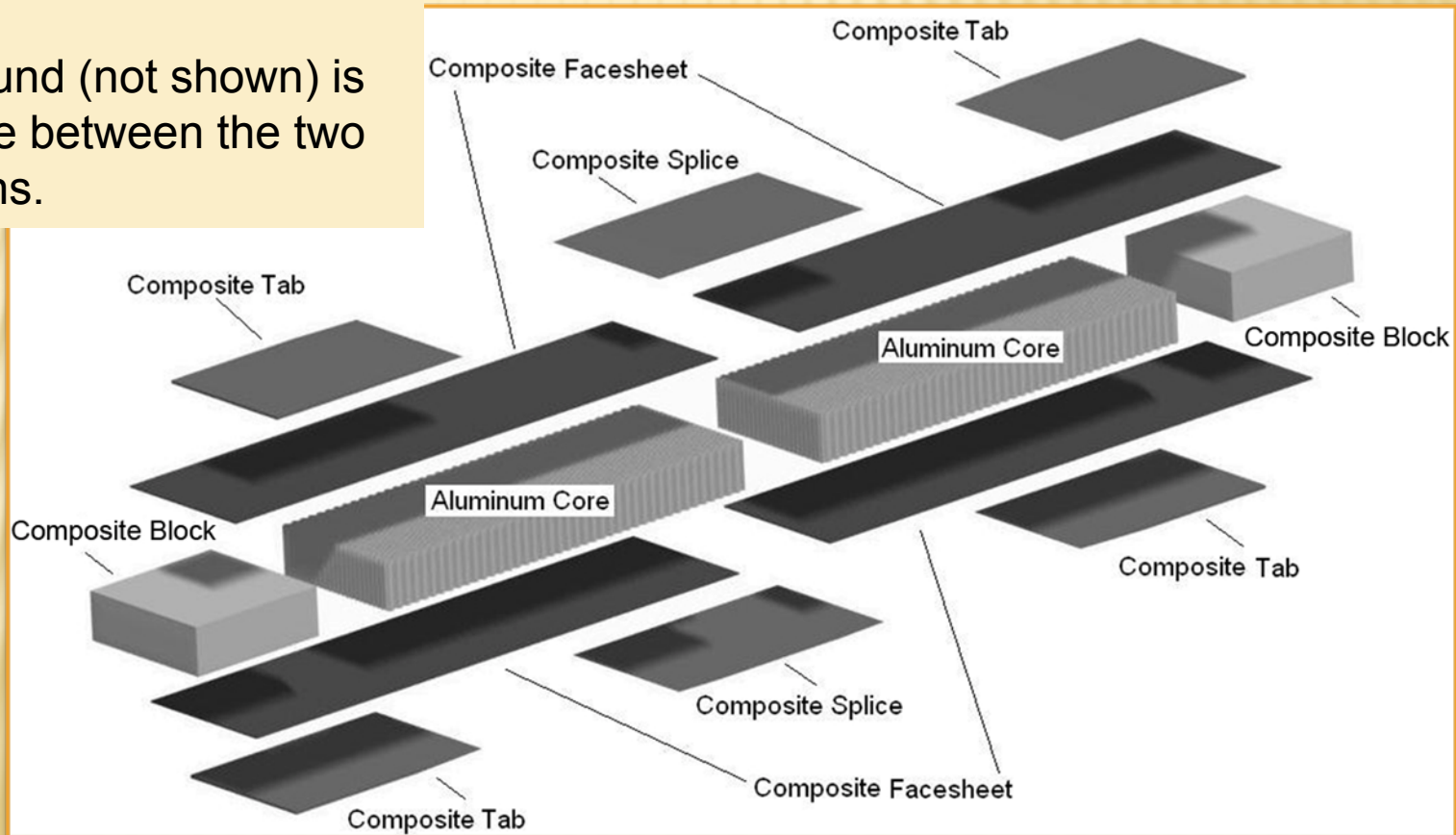
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CCM TEST ARTICLE - EXPLODED

Facesheets: Four layers of IM7/977-2 4-harness satin fabric [(0/90)/±45/±45/(0/90)] layup.

Splice: Both IM7/977-2 tape and fabric.

A potting compound (not shown) is used at the splice between the two sandwich sections.





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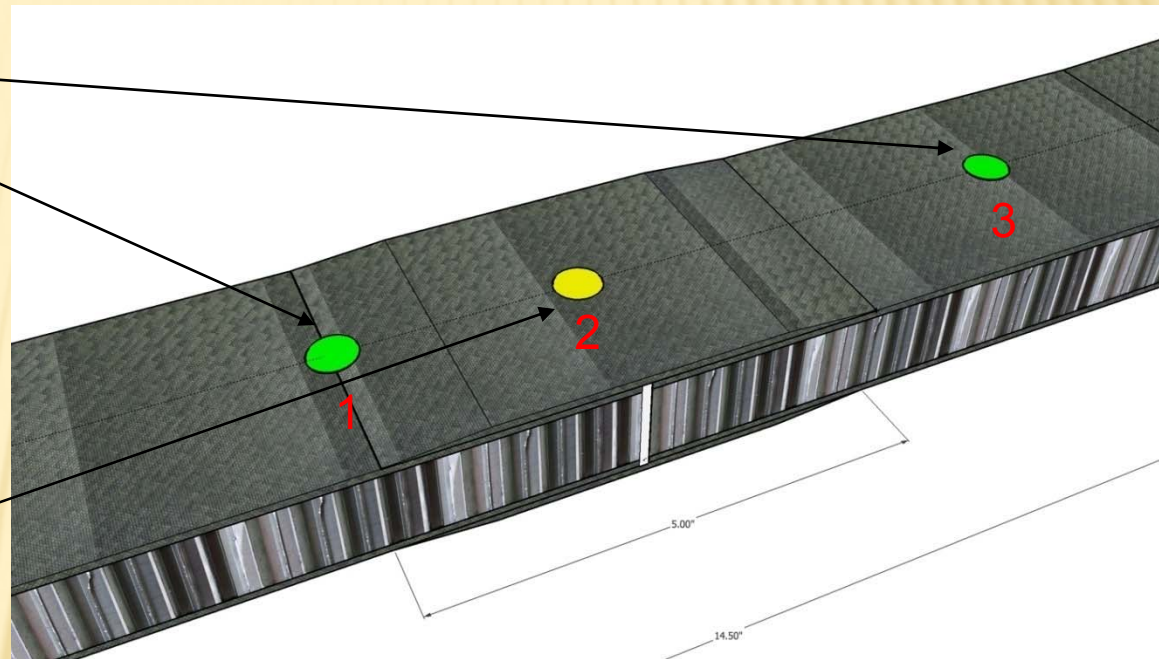
CCM TEST ARTICLE – IMPACT LOCATIONS

Impact Locations

Front Face

Impact Locations

Rear Face



Location	Energy, J	Dent Depth, mm	Max Force, kN	Indenter Disp, mm
Splice Center	7.6	0.48	7.65	1.83
Splice Tip	1.7	0.71	1.72	1.75
Facesheet	2.4	0.99	1.97	2.24



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CCM TEST ARTICLE - FATIGUE

- Cyclic loading was applied to the damaged article in accordance with the Mission Load Spectrum.
- The loading sequence started with the highest loads and progressed to the lowest.
- Each cycle was between specified tensile and compressive load levels with a loading frequency of 1.0 Hz.
- At the maximum tensile load, measured strains were approximately 1150 $\mu\epsilon$ on the facesheet and 450 $\mu\epsilon$ on the splice material.
- At the maximum compressive load, measured strains were approximately -1250 $\mu\epsilon$ on the facesheet and -500 $\mu\epsilon$ on the splice material.
- After 1 lifetime spectrum NDE was performed
- After 4 lifetime spectrums NDE was performed

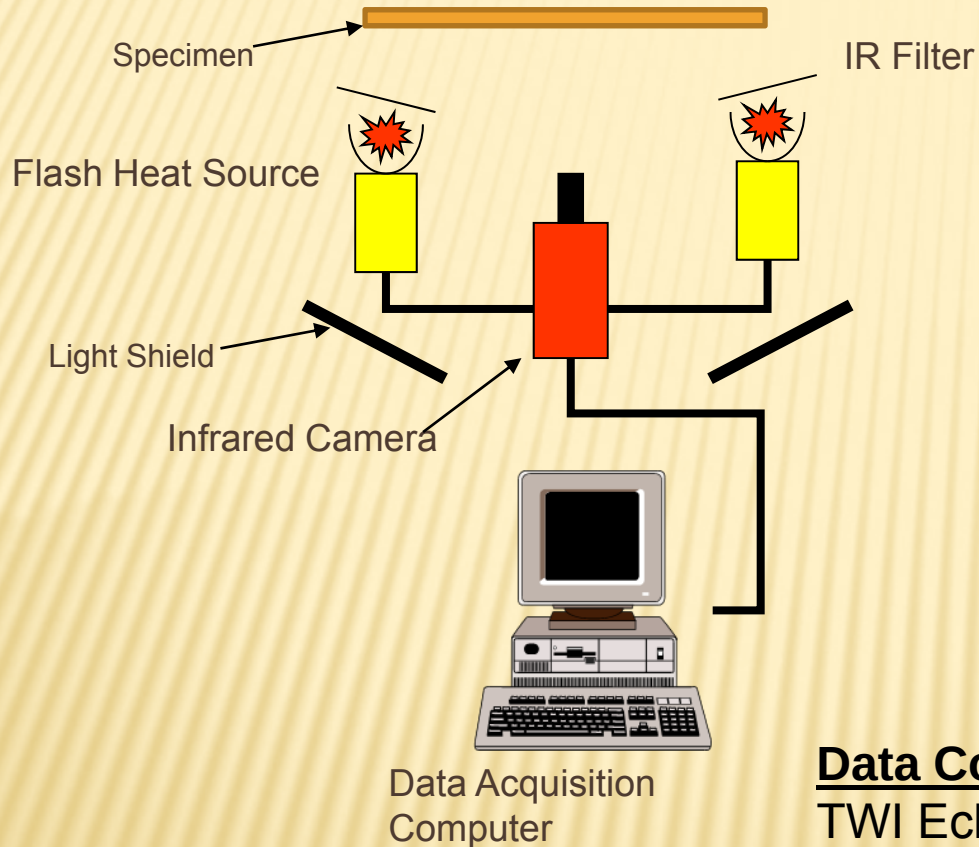
Load Spectrum

% Min/Max Load	Total cycles
90-100	13
80-90	18
70-80	22
60-70	30
50-60	36
40-50	58
30-40	82
20-30	108
10-20	198



THERMOGRAPHY HARDWARE

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Data Collection:

TWI Echotherm System

FLIR Phoenix® infrared imager

640 x 512 element array

3-5 μm wavelength range

120 fps acquisition speed



THERMOGRAPHY DATA PROCESSING

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- ✗ Reformatting data from a three dimensional array to a two dimensional array: $T(x,y,t) \rightarrow A(n,m)$ where:
$$n = N_x * N_y \text{ and } m = N_t$$
- ✗ Singular Value Decomposition of A to yield the eigen functions and eigen values that describe the spatial and temporal variations in the original data.
$$A^T A = U * \Lambda * V^T$$
 - + Where U contains the eigen functions and Λ contains the eigen values or principal components.
- ✗ Discard all but the largest eigen vectors (typically 2 or 3) that describe the data.
- ✗ Final PCA Images formed by calculating the dot product of the measured temperature response, pixel by pixel, with the eigen vectors of interest



X-RAY CT

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- **5 μm Focal Spot Reflection Target X-Ray Source or 25 to 225 kV**

- **15 or 30kg Capacity 5 axis fully programmable manipulator.**

- **Detector is 2000x2000 pixels with 200 micron pitch**

- **10 micron spatial resolution for specimens 1.5 cm wide**

- **Thin panels 10"x10" – full volume 200 micron spatial resolution**





THERMAL RESULTS LOCATION #1

After Impact

8mm

After 1 Lifetime

25mm

After 4 Lifetimes

25mm



THERMAL RESULTS LOCATION #2

After Impact

15mm

After 1 Lifetime

15mm

After 4 Lifetimes

15mm

Magnified

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THERMAL RESULTS LOCATION #3

After Impact

8mm

After 1 Lifetime

25mm

After 7 Lifetimes

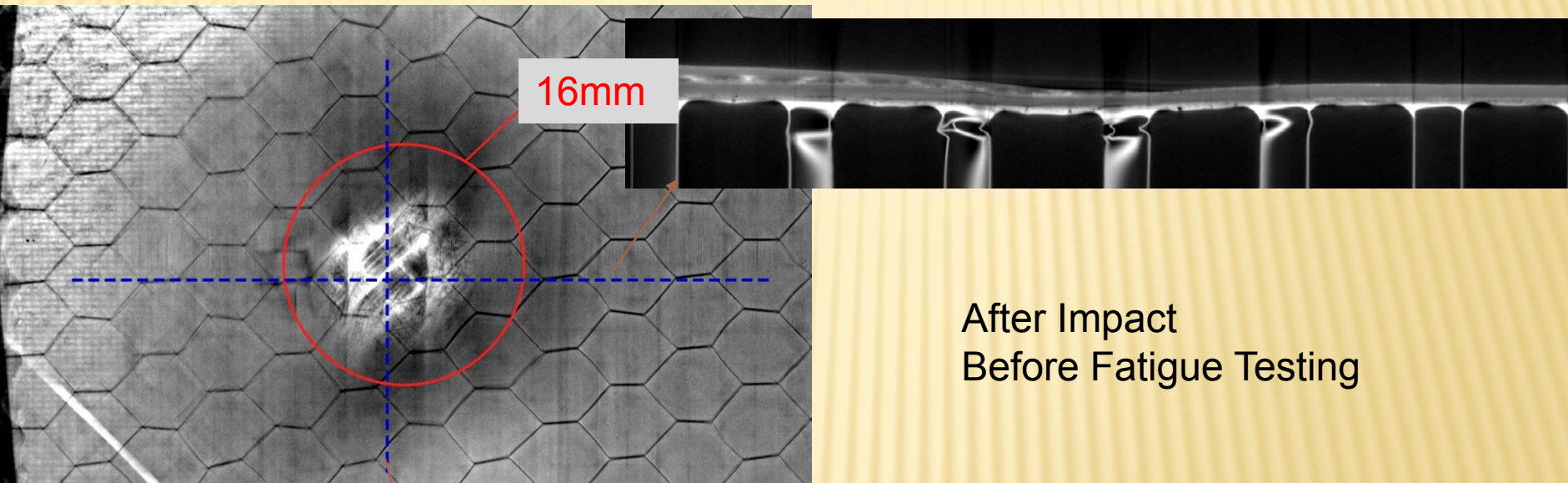
25mm

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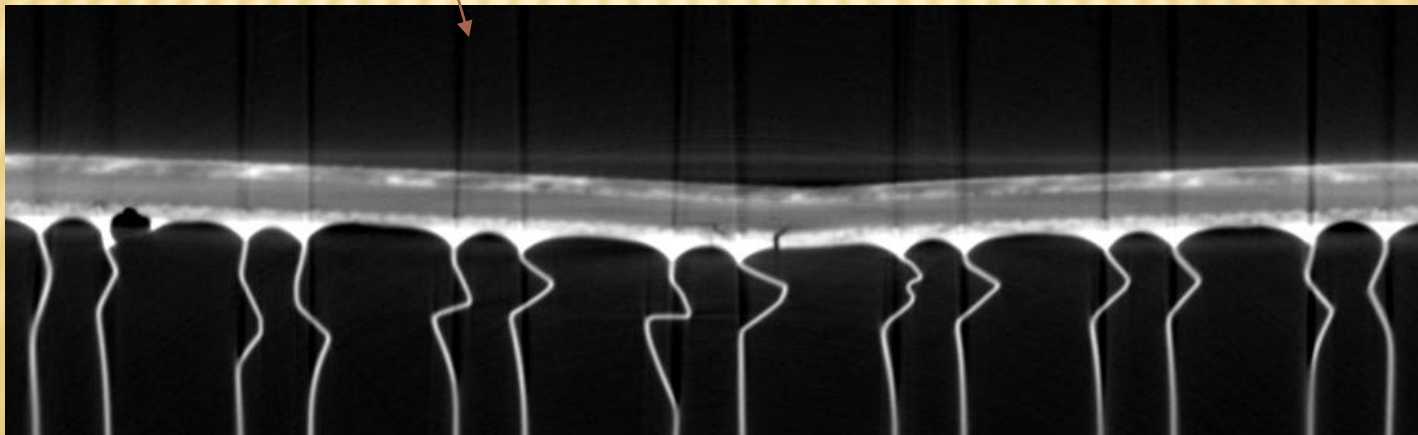


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CT RESULTS LOCATION #1



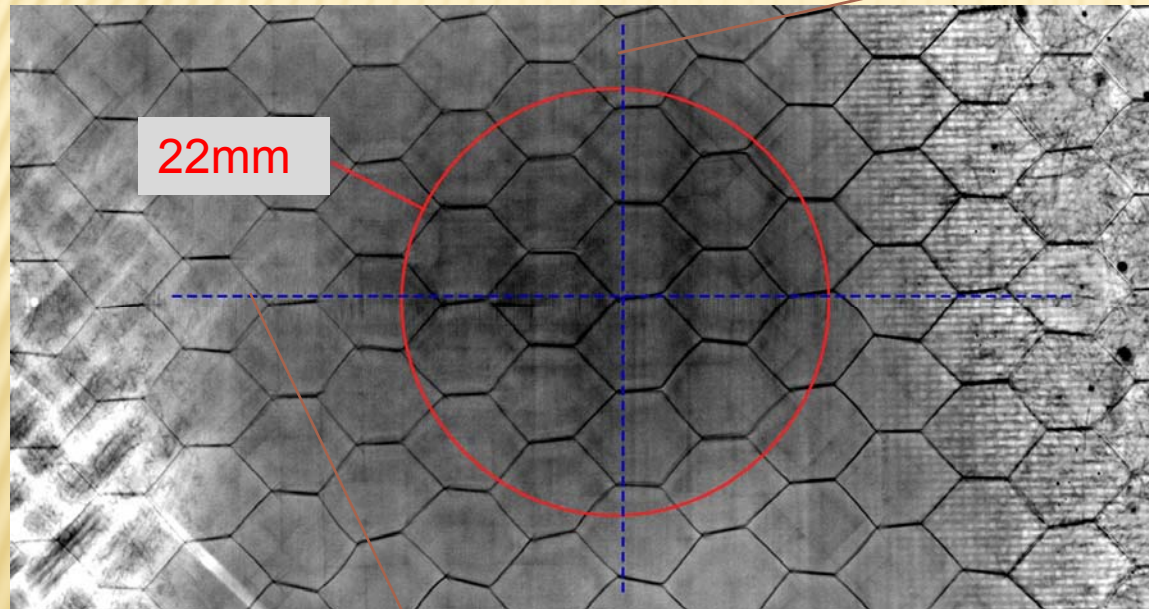
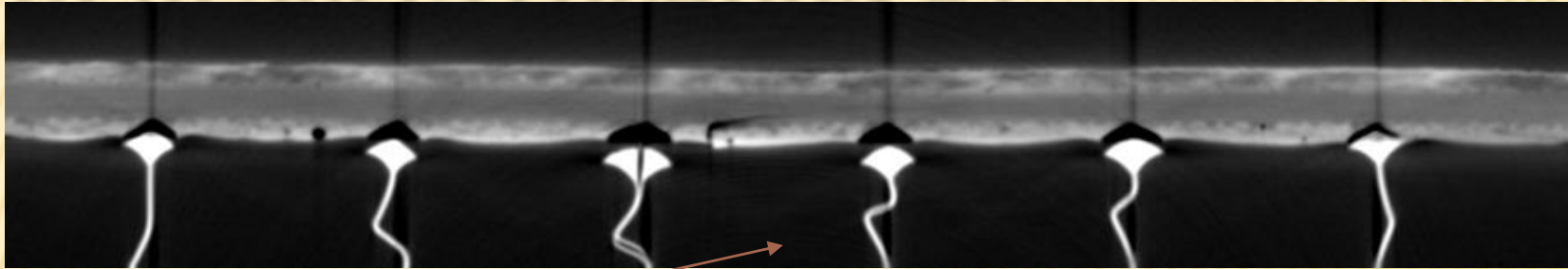
After Impact
Before Fatigue Testing





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CT RESULTS LOCATION #1



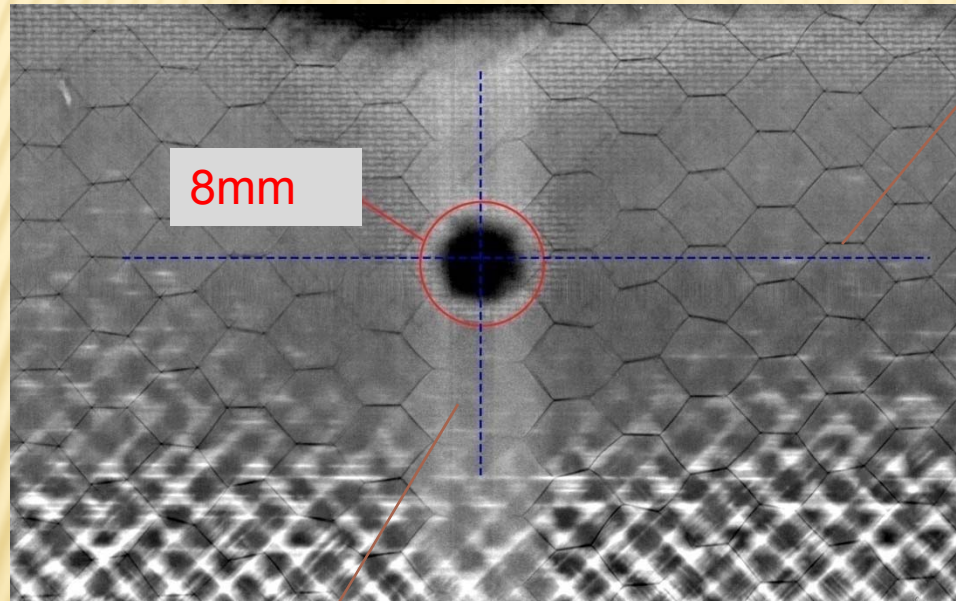
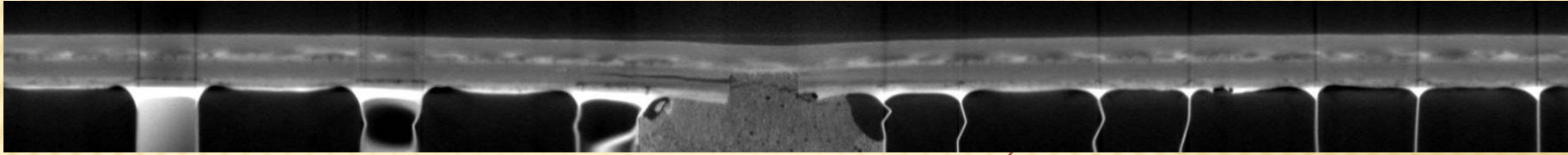
After 1 Lifetime Fatigue
Testing



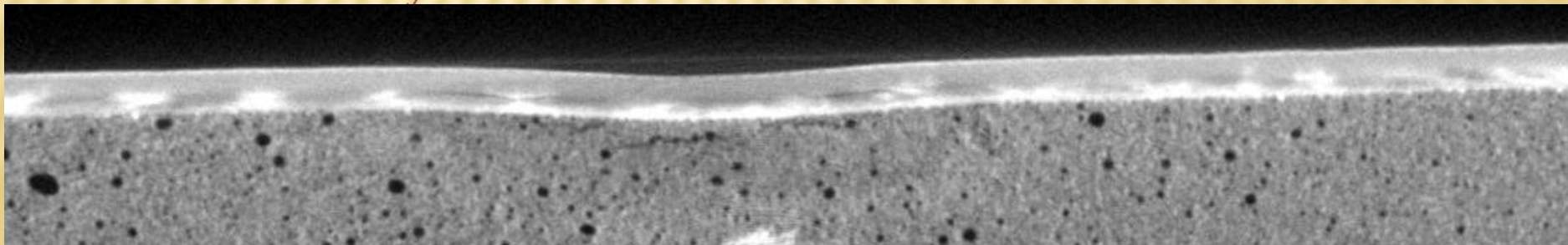


CT RESULTS LOCATION #2

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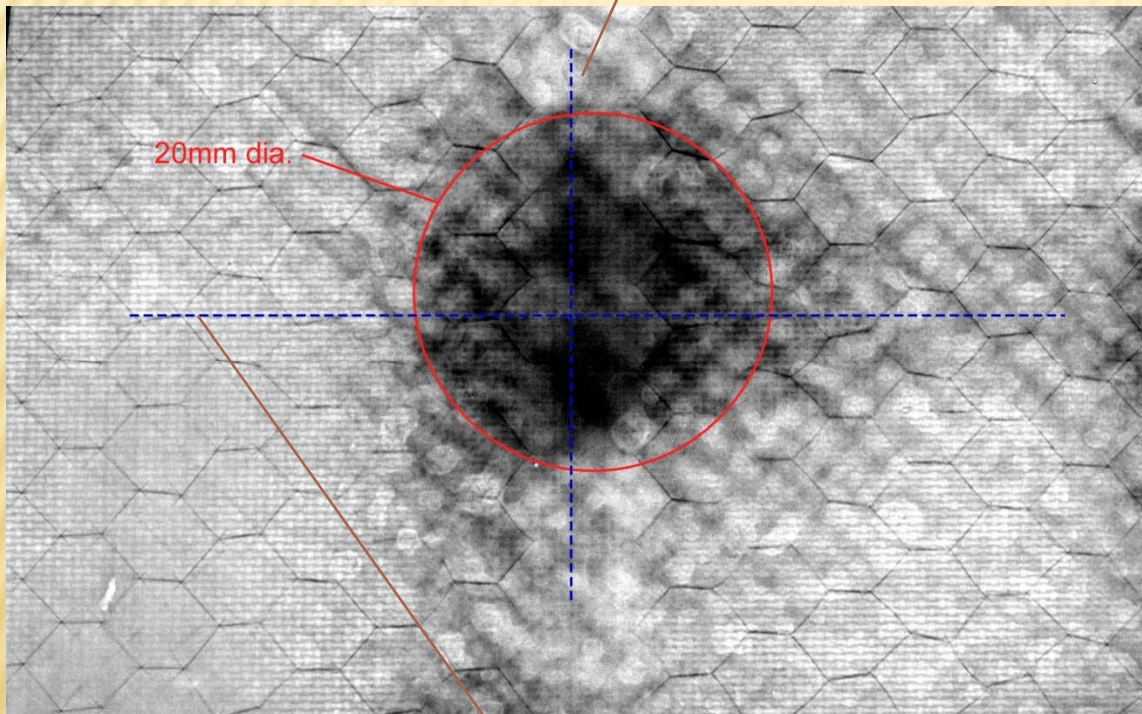
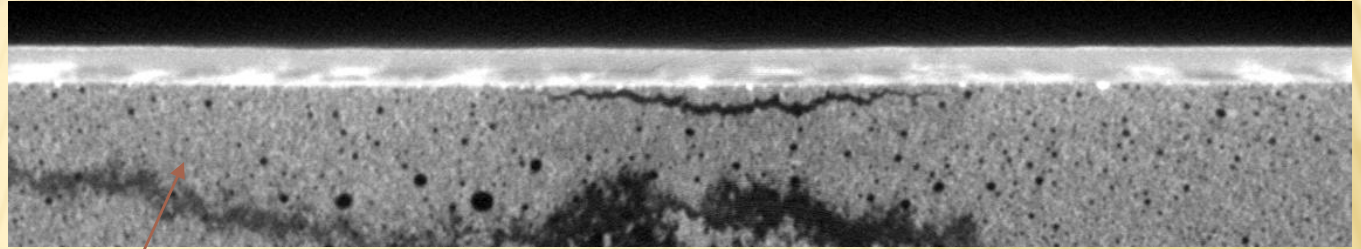
After Impact
Before Fatigue Testing



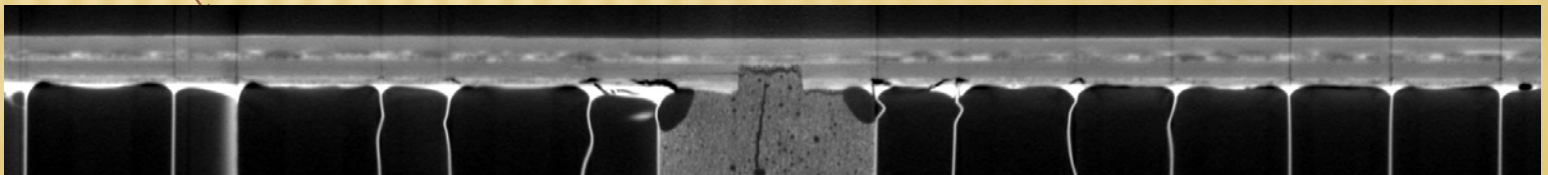


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CT RESULTS LOCATION #2



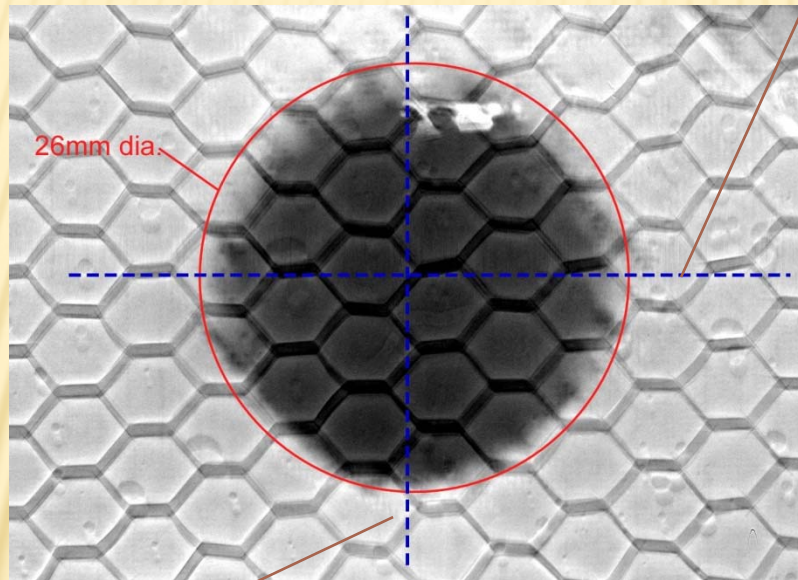
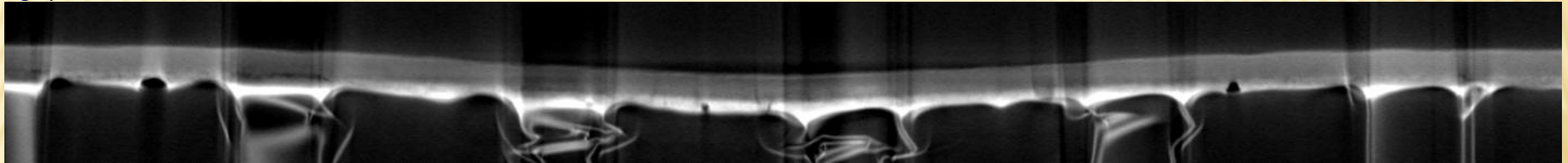
After 1 Lifetime Fatigue
Testing



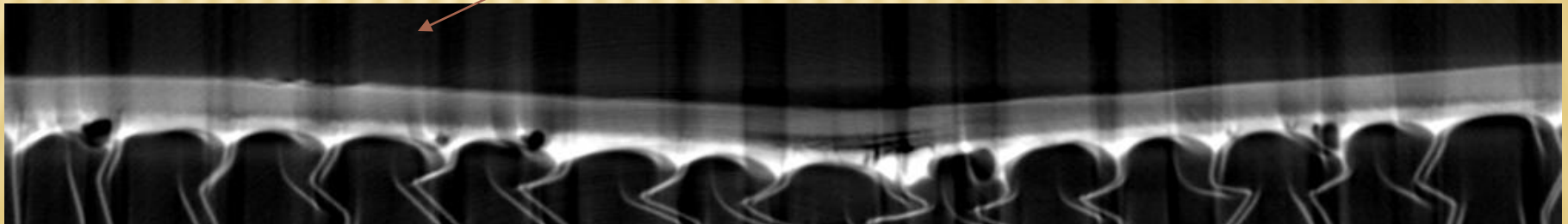


CT RESULTS LOCATION #3

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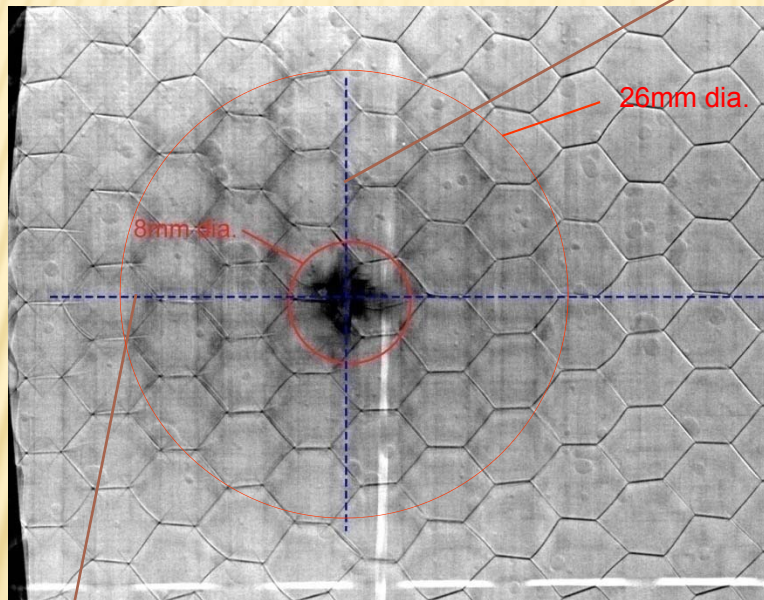
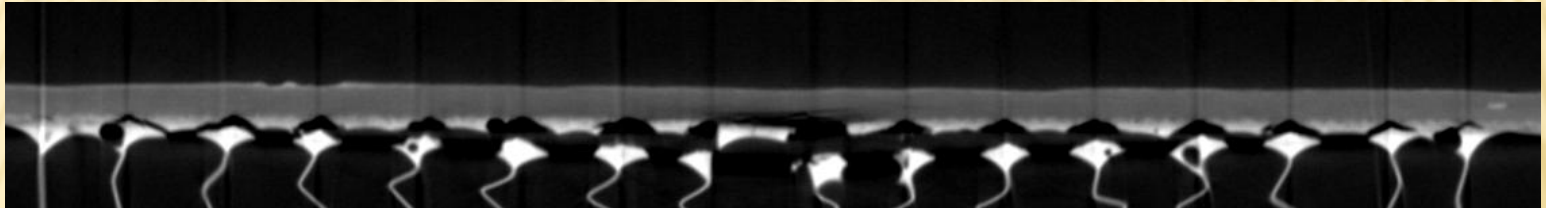
After Impact
Before Fatigue Testing





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CT RESULTS LOCATION #3



After 1 Lifetime Fatigue
Testing





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DISCUSSION / CONCLUSIONS

- ✖ Thermography is excellent at rapid detection of delaminations in composite sandwich structure
- ✖ Interpretation of the results can be difficult – Especially for complex geometries
 - + The use of complementary techniques such as X-ray CT or ultrasound may be necessary to get the complete picture