Damage Evaluation & Analysis of Composite Pressure Vessels Using Fiber Bragg Gratings to Determine Structural Health

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Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **FEB 2005**	2. REPORT TYPE	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **Damage Evaluation and Analysis of Composite Pressure Vessels Using Fiber Bragg Gratings to Determine Structural Health**	5a. CONTRACT NUMBER **F04611-02-C-0007**
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) **Marley Kunzler; Eric Udd; Stephen Kreger; Mont Johnson; Vaughn Henrie**	5d. PROJECT NUMBER **3005**
	5e. TASK NUMBER **02AG**
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Blue Road Research,Gresham,OR,93524-7680**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
N/A

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**		**60**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

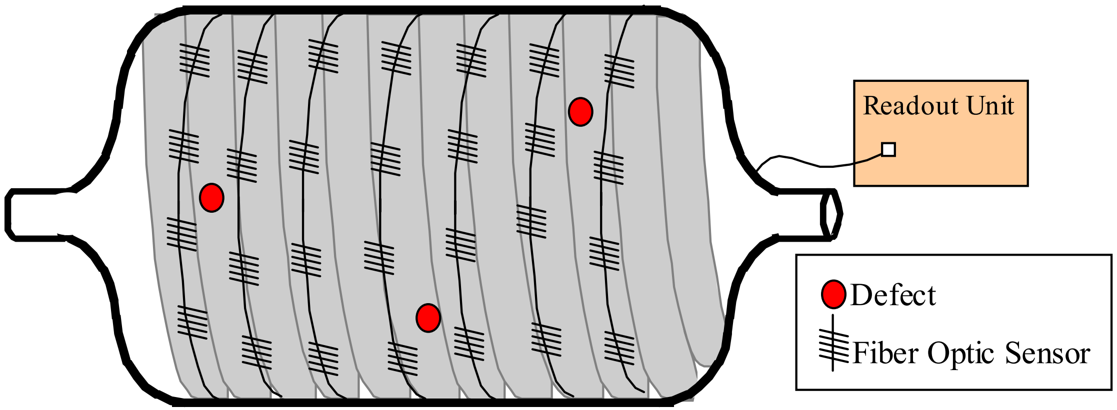
Acknowledgements

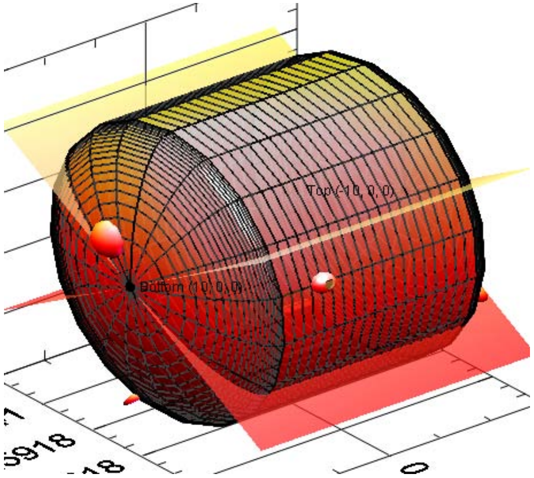
Blue Road Research would like to acknowledge funding support for this research effort from the SBIR Phase II Air Force Contract F04611-02-C-0007. Additional support was provided under the SBIR Phase II Air Force Contract F33615-02-C-5043

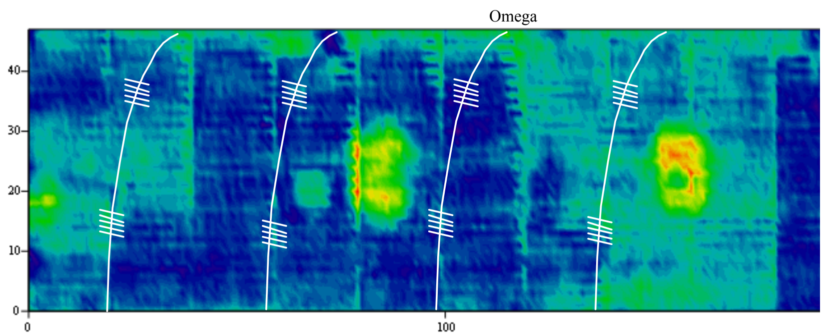
Overview

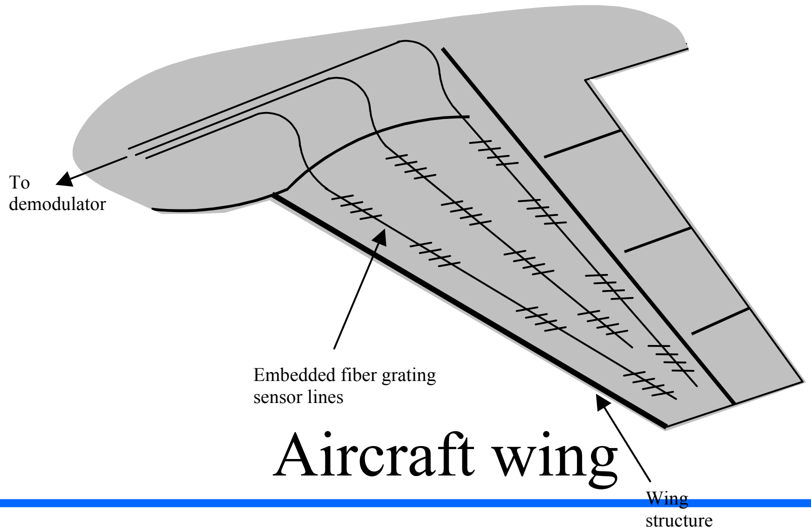
- Why Composites & Fiber Optics?
- Readout System Overview
- Experiments:
  1. Impact Quantification
  2. Manufacture/Cure
  3. Blind Impacts
  4. Dynamic ‘Strain Imaging’
- Conclusions & Future Work

Composite 'Smart Systems'









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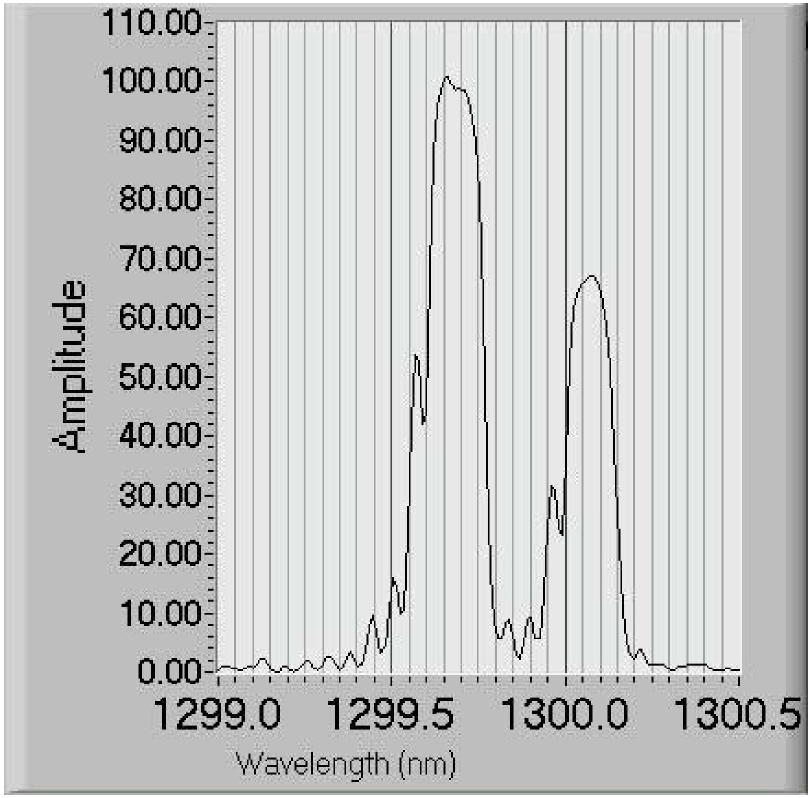
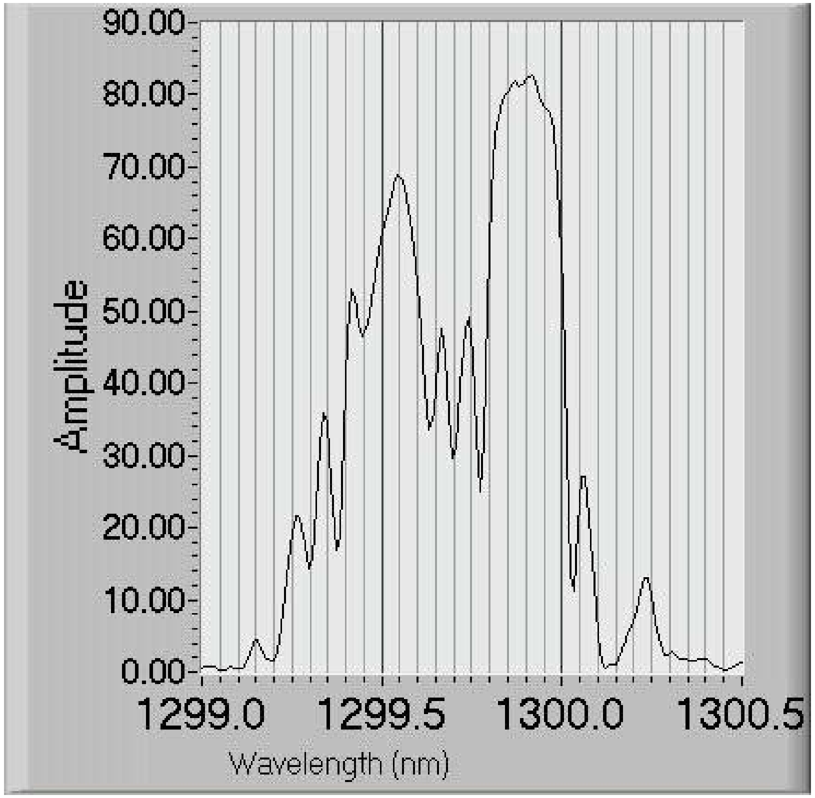
Multi-Axis Information

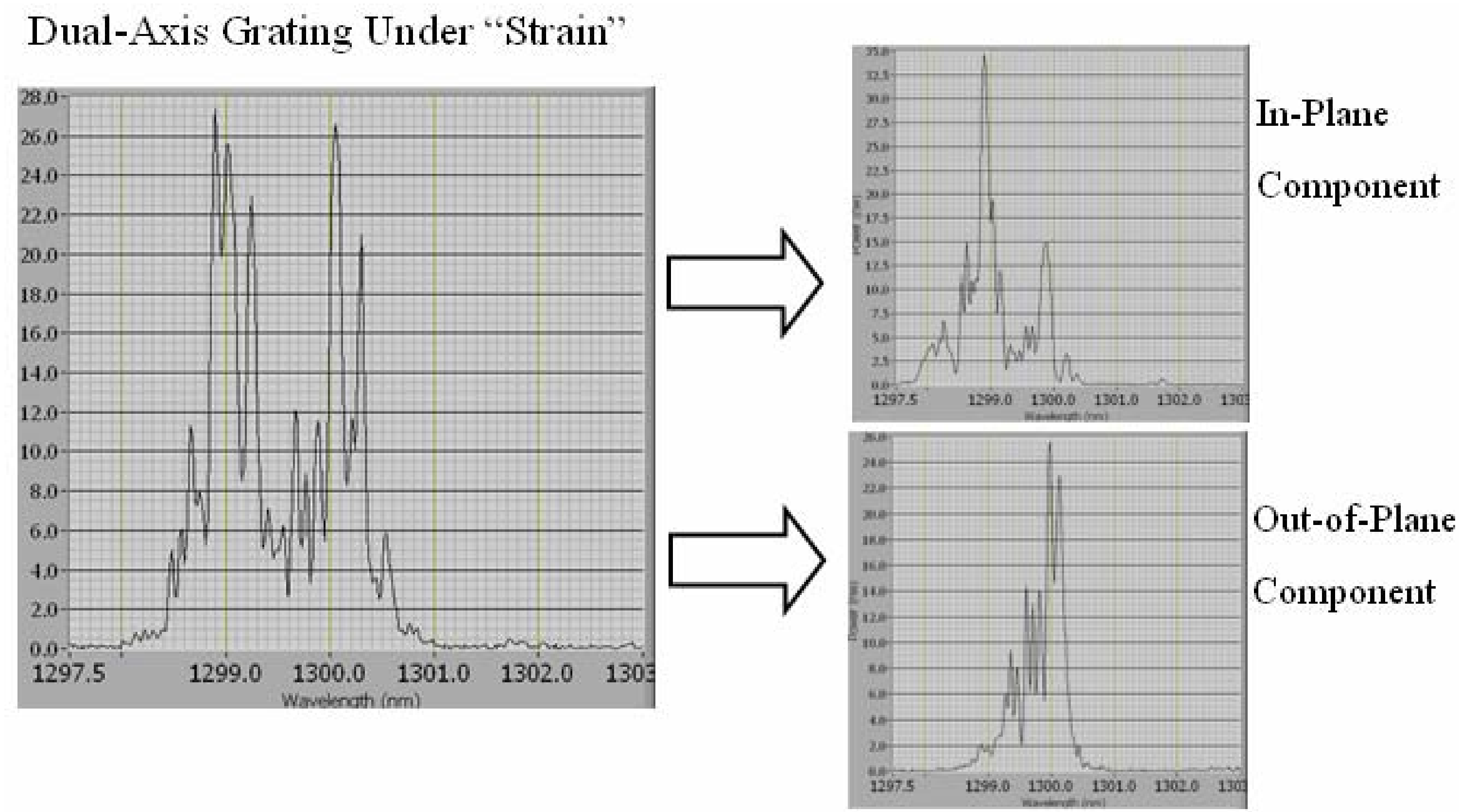


(a)
before

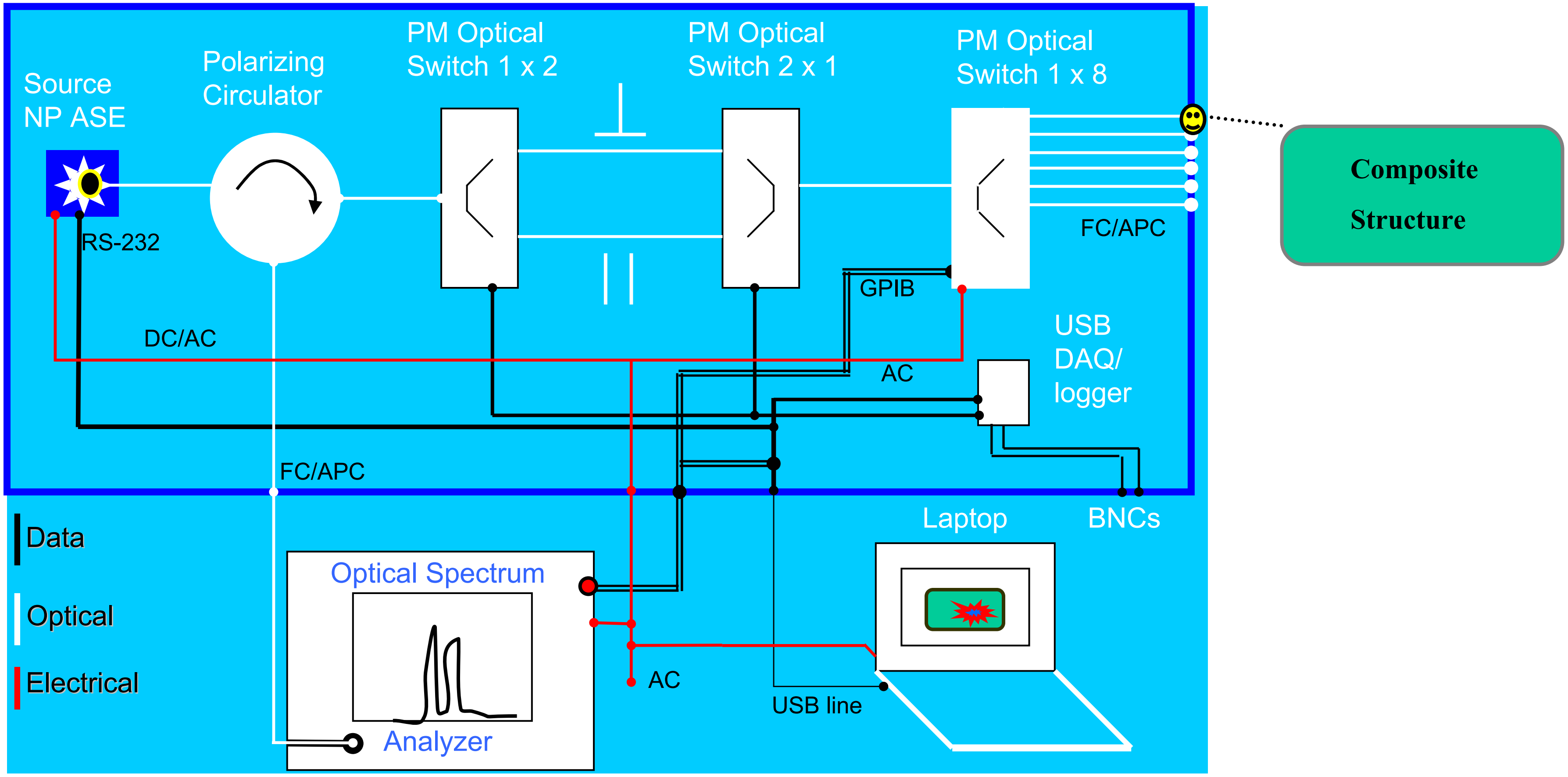


(b)
after

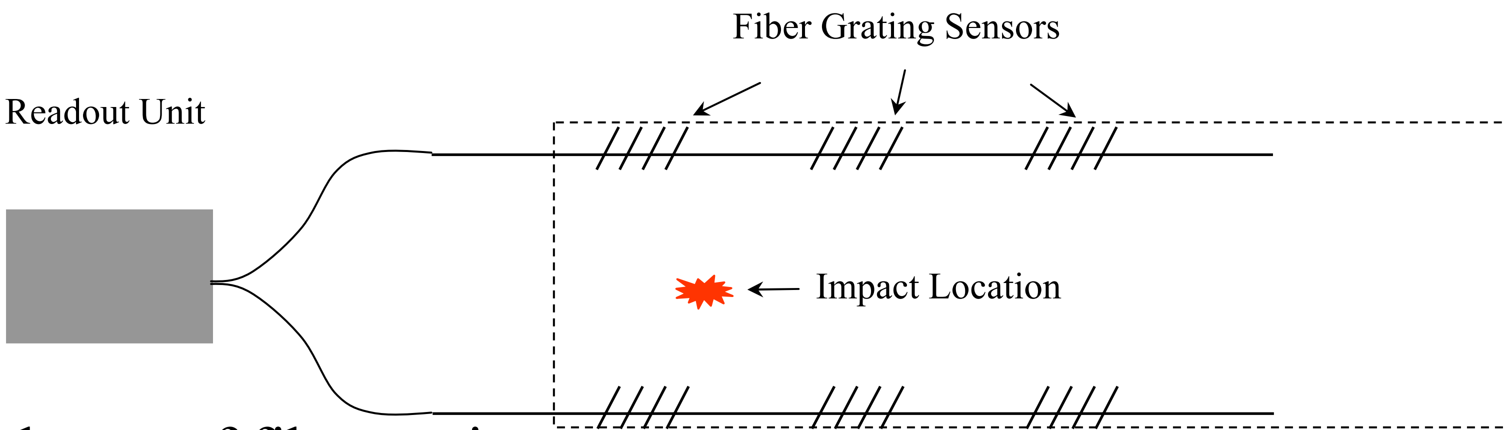
Multi-Axis Separation of Data



Composite Health Monitoring System

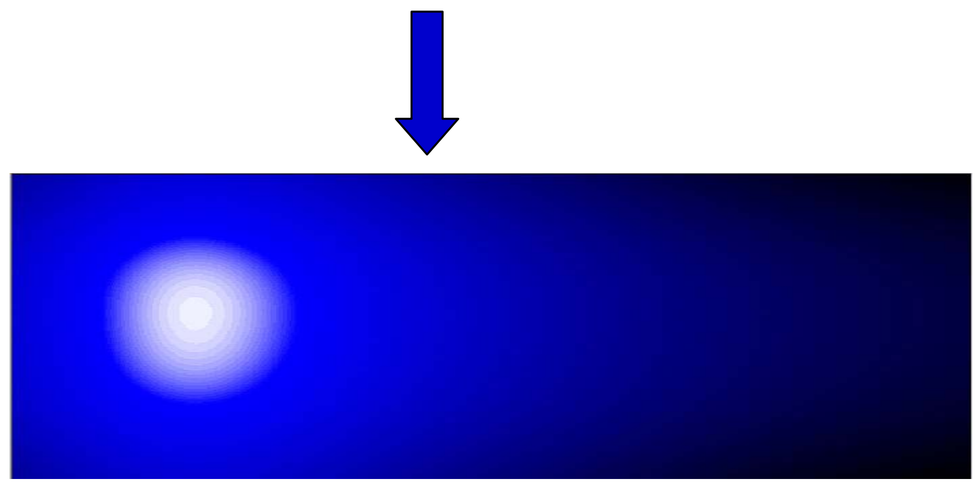


Composite 'Strain Image'

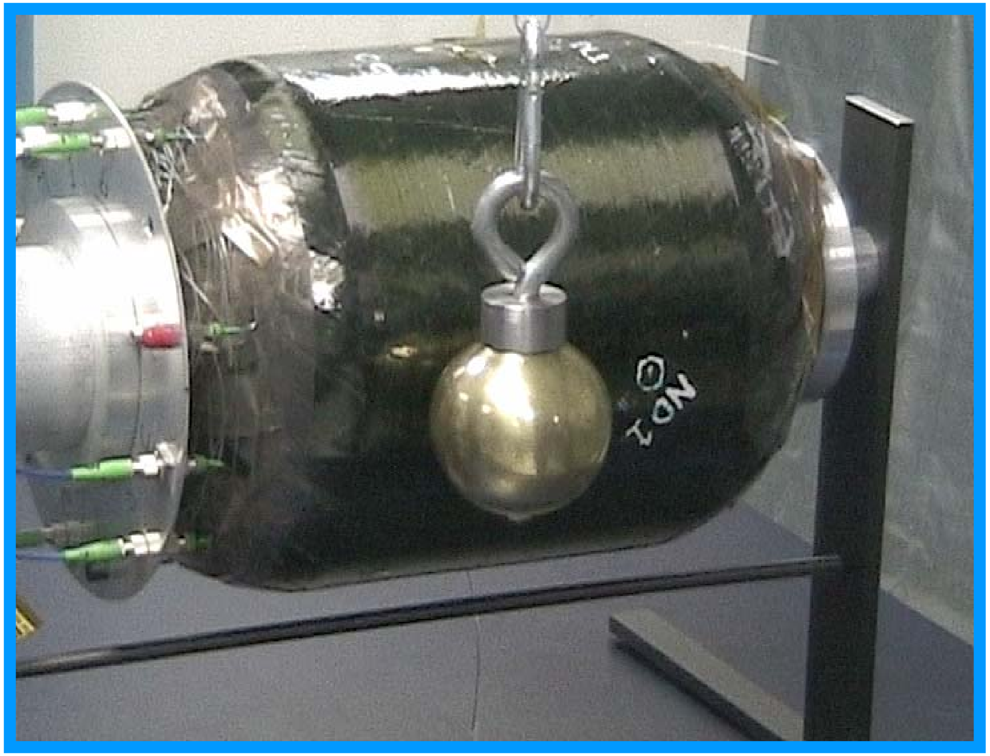


Embedment of fiber optics for damage/health evaluation

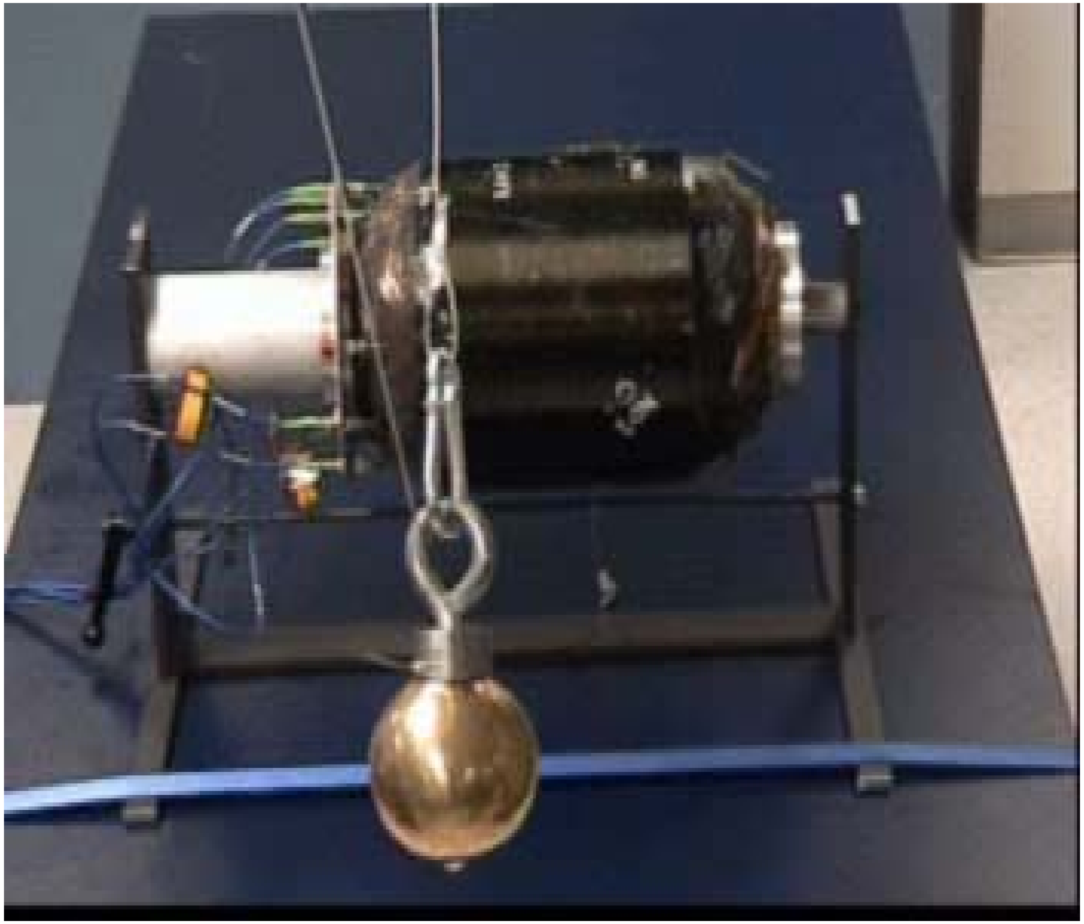
Composite Strain Image:



Experiment 1: Impact Quantification



5 ft-lbs Impact



10 ft-lbs Impact

15 ft-lbs Impact

Damage Output Before Impact

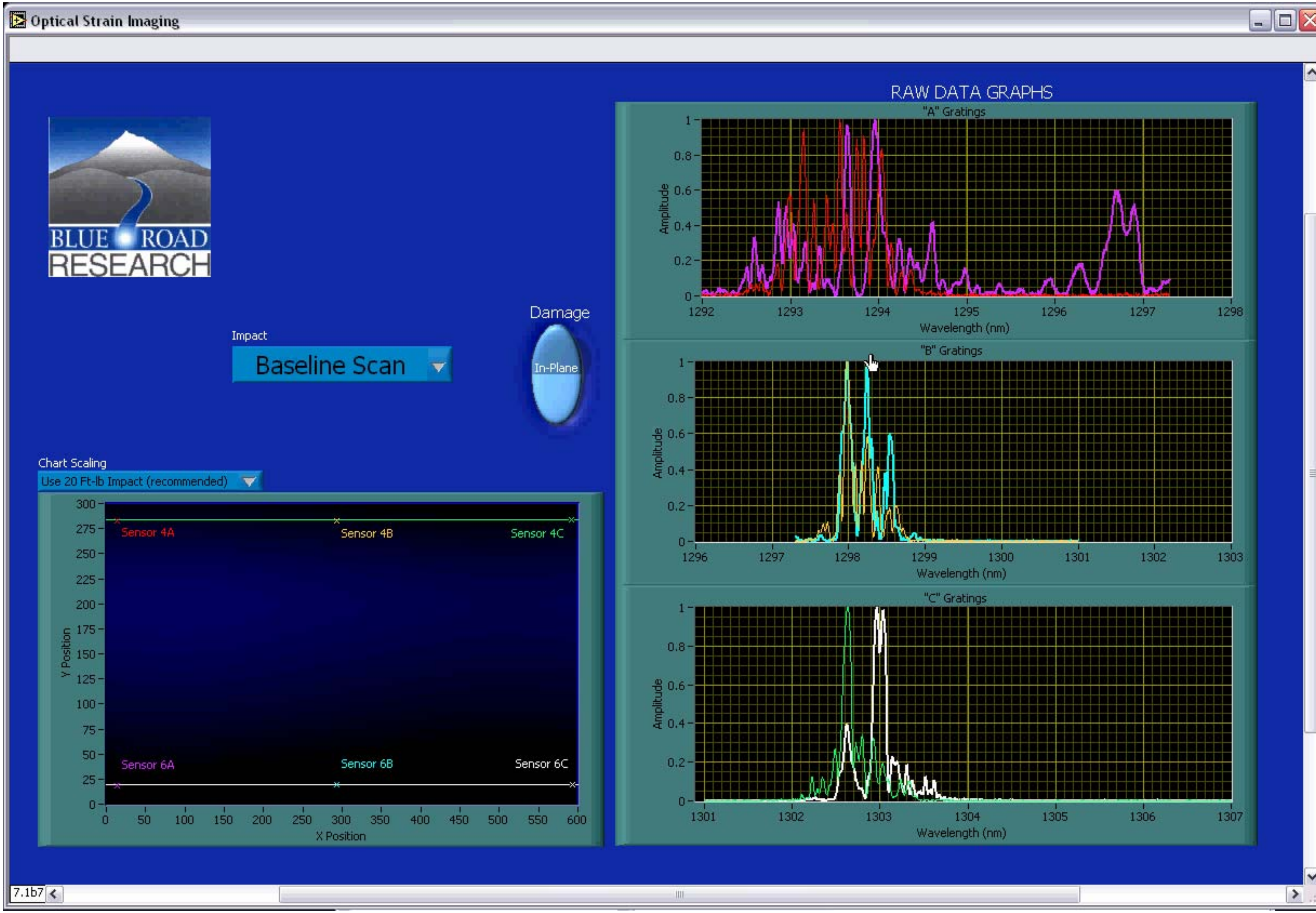
Damage Output After 5 ft-lb Impact

Damage Output After 10 ft-lb Impact

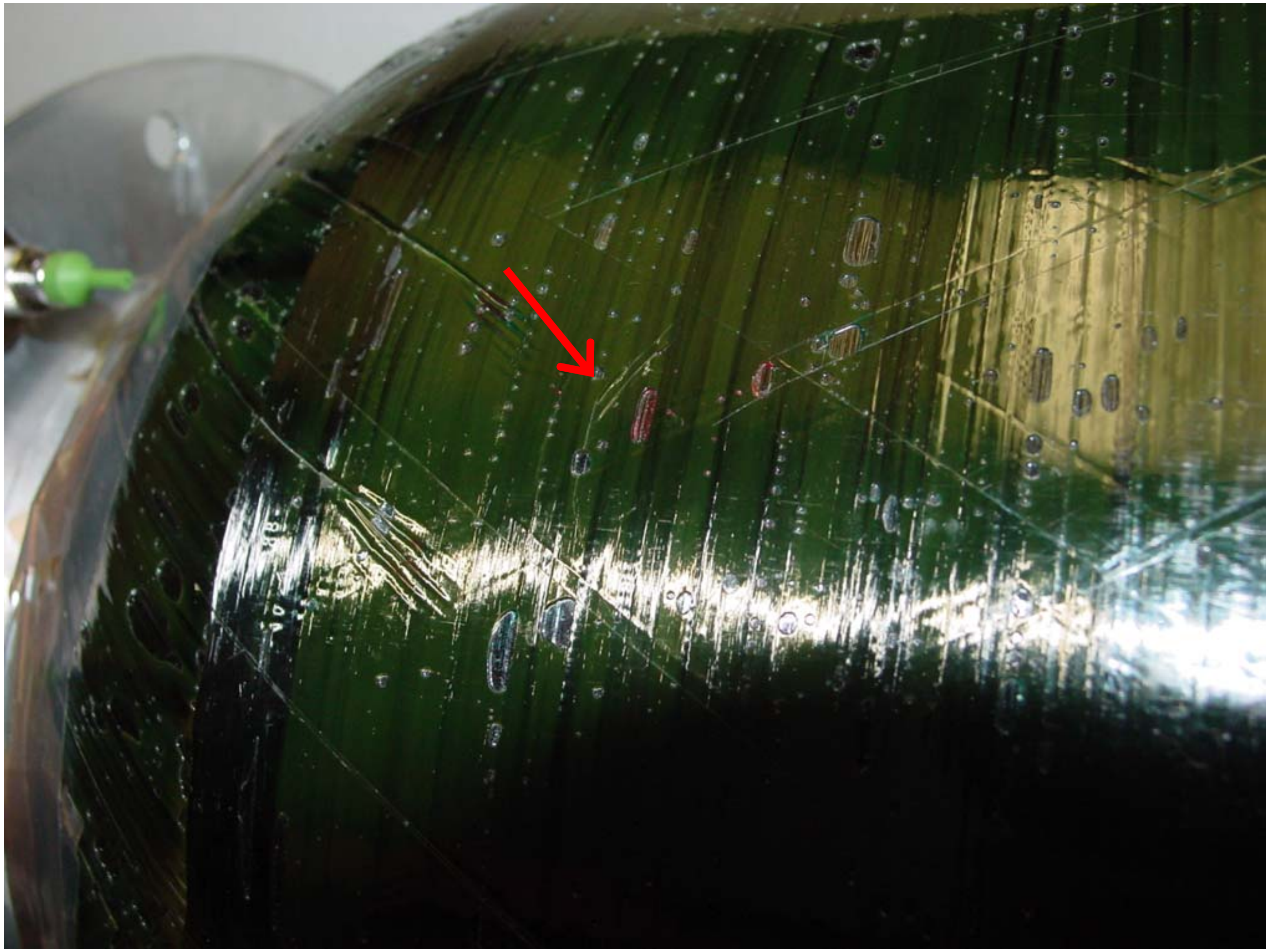
Damage Output After 15 ft-lb Impact

Damage Output After 20 ft-lb Impact

Strain Imaging Demonstration

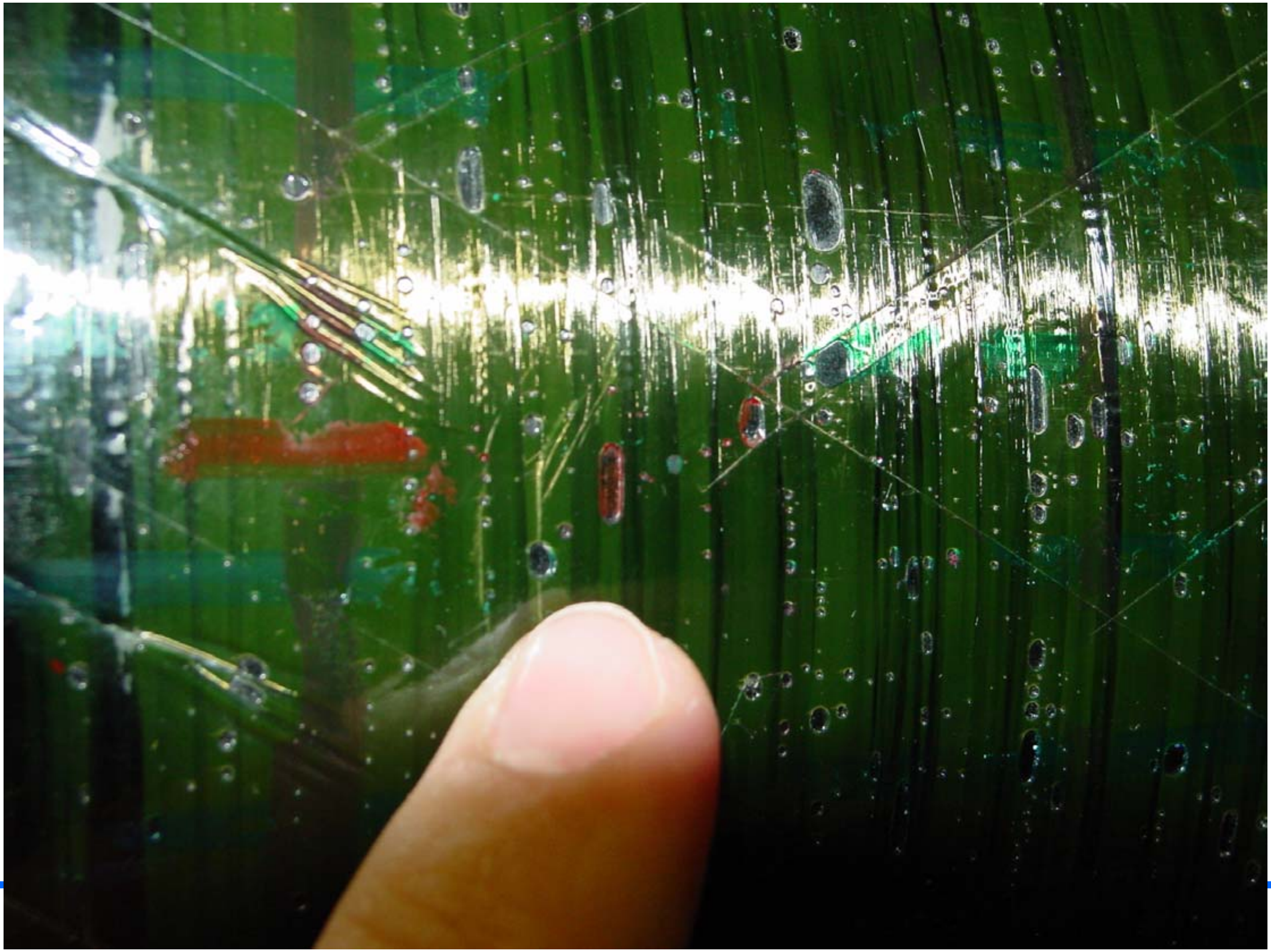


Strain Imaging Bottle Impact Test Damage Area After All Impacts

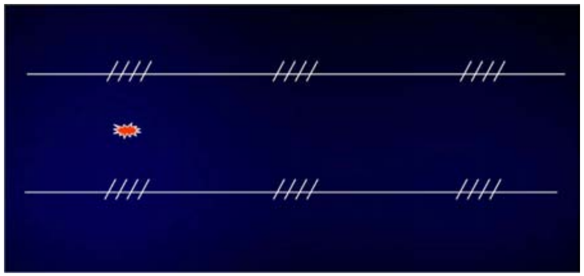


Strain Imaging Bottle Impact Test
Damage Area After All Impacts

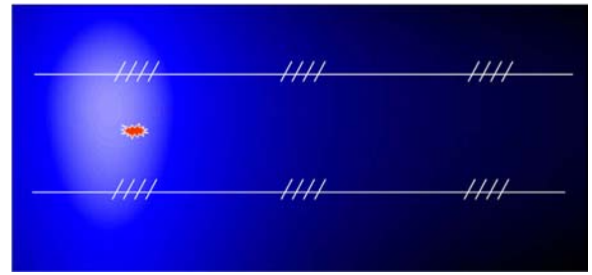
20 ft-lbs Impact



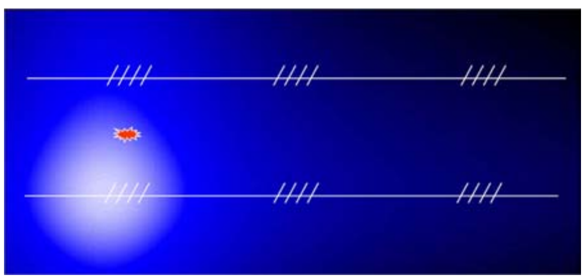
Reduction of Data:



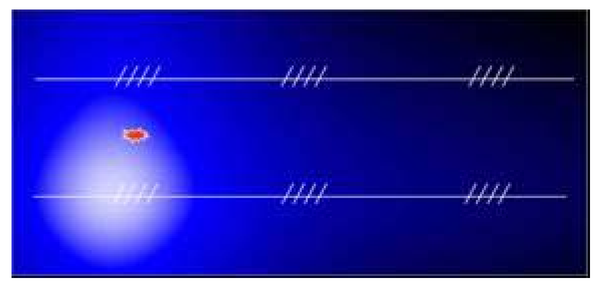
Before Impact



After 1st Impact

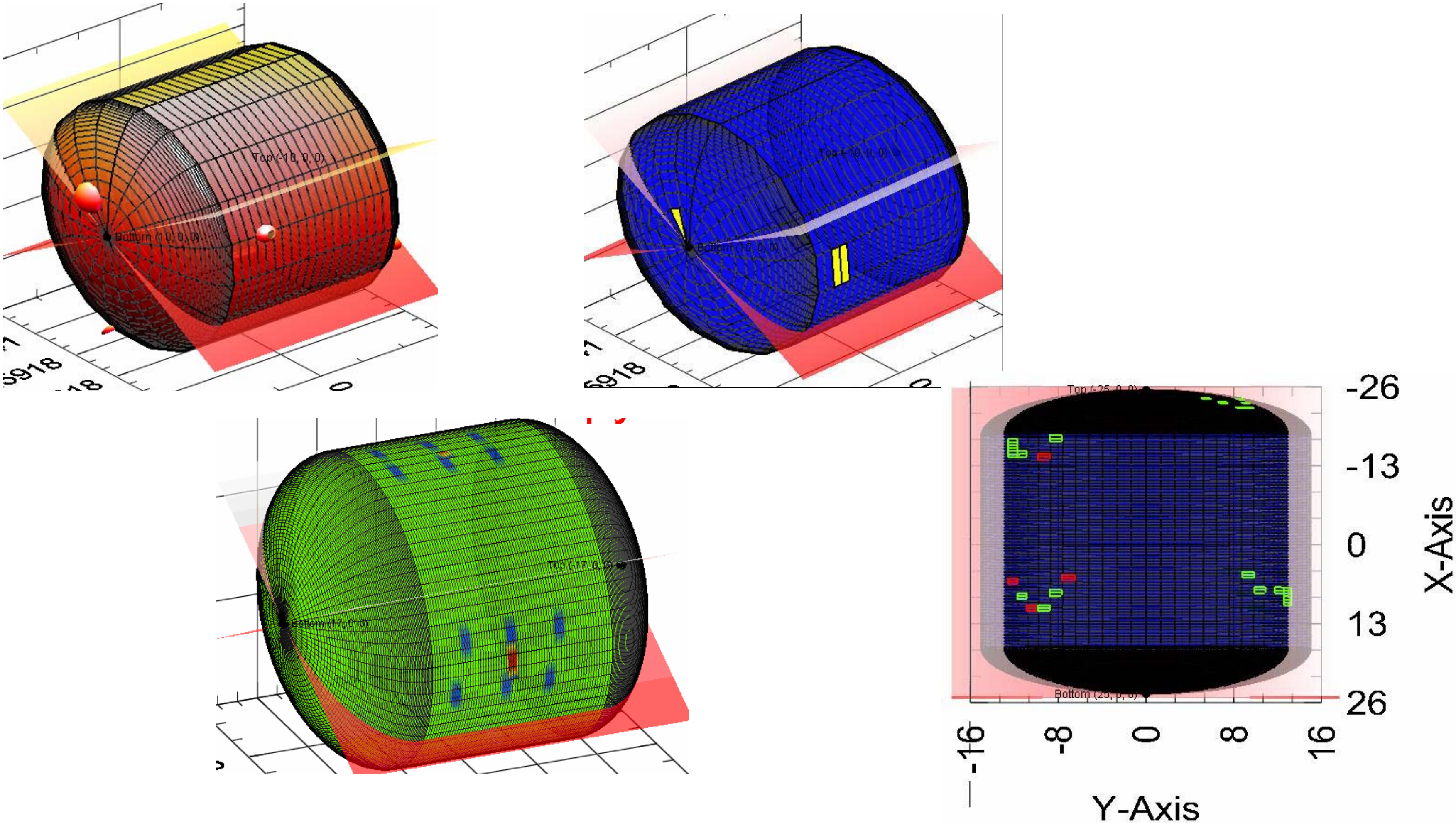


After 2nd Impact

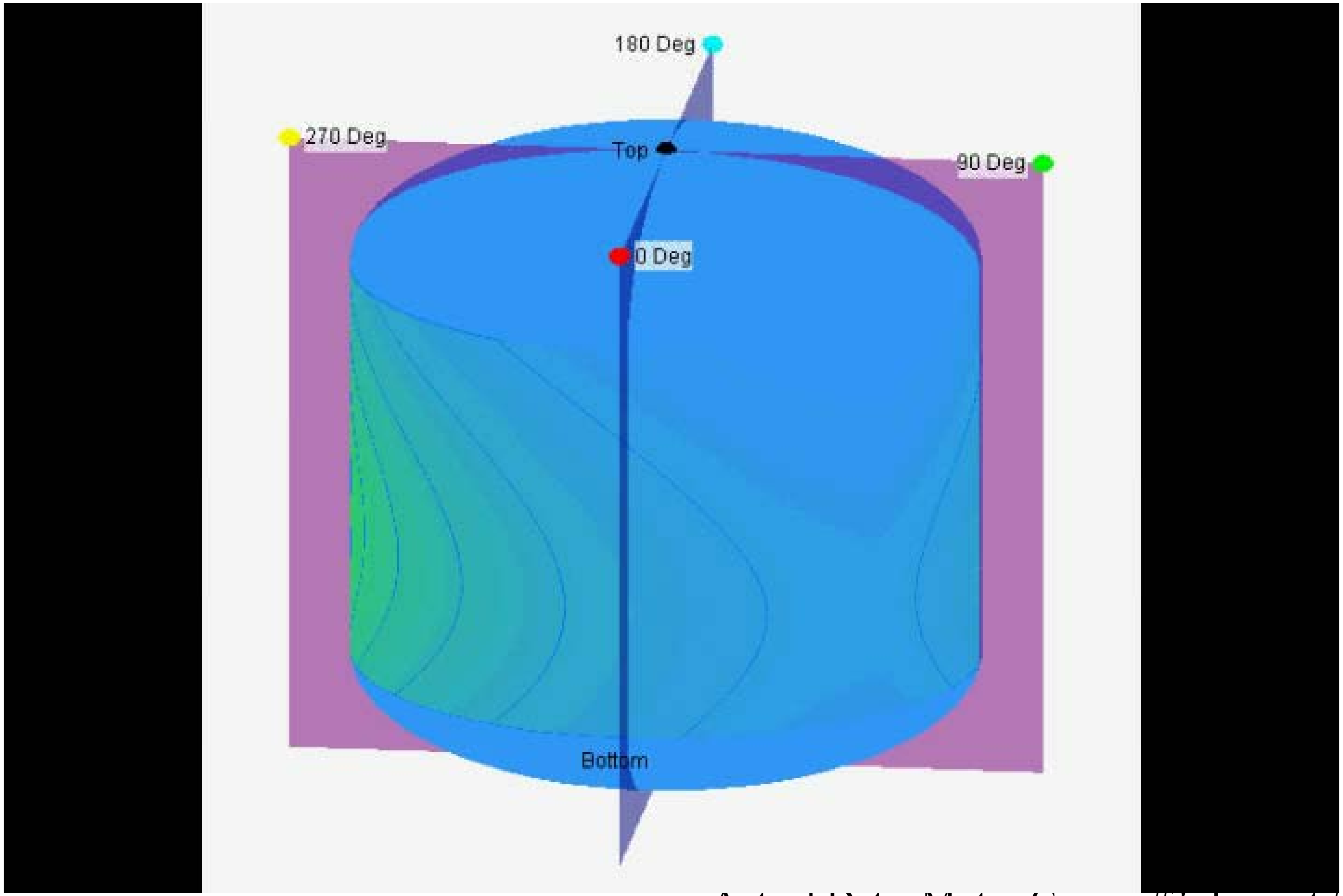


After 3rd Impact

Simplified Ideas to Show Damage

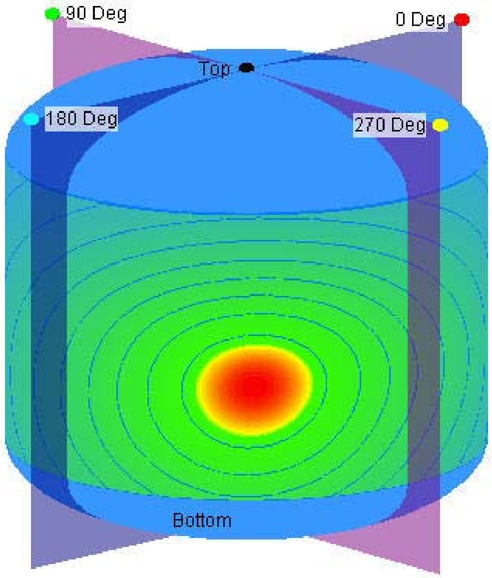


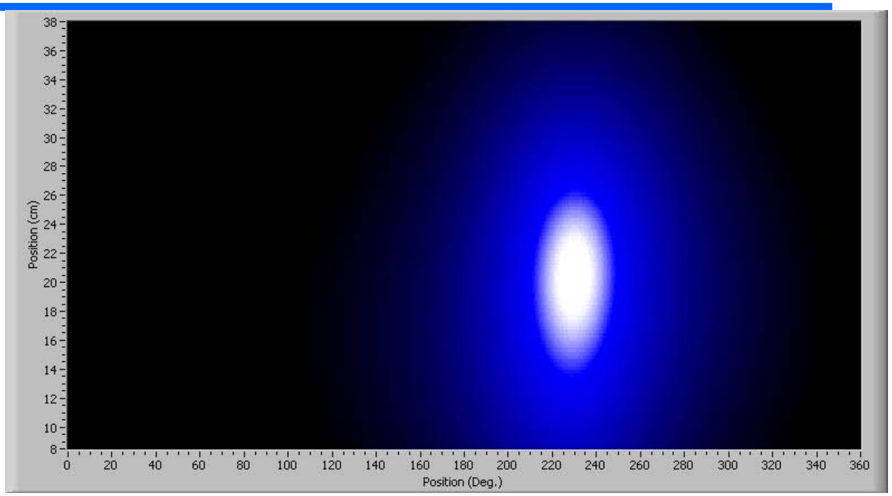
Simplified Display



Actual Data, Motor Casing #3, Impact #3

Simplified Display

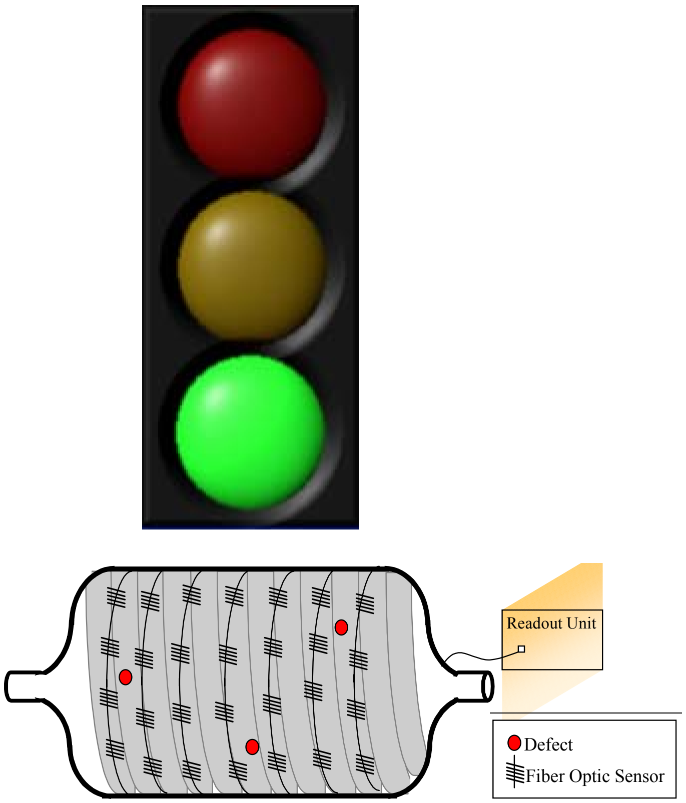


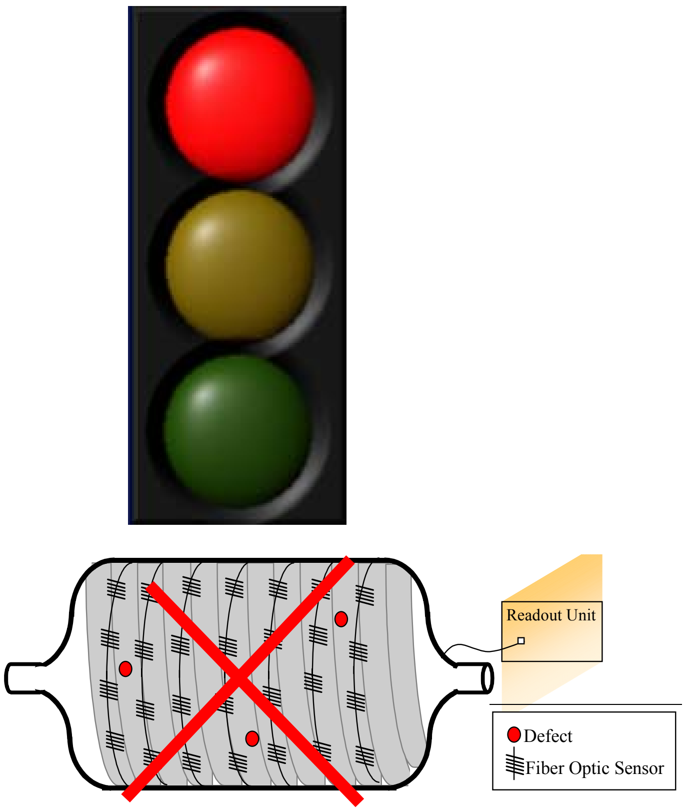


Force: 24.3 ft-lbs
15.0 cm Distance from Flange
47 cm Distance from 0 Degrees

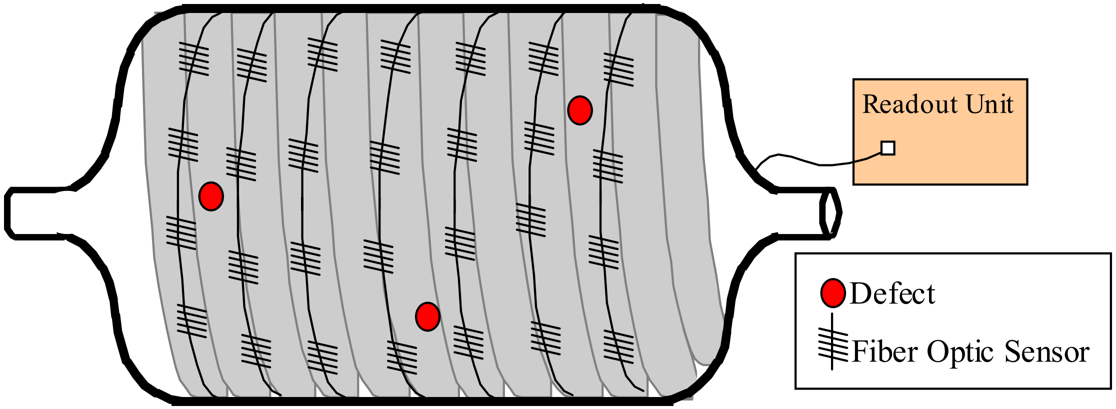
Degree Measurement: 222.6 °

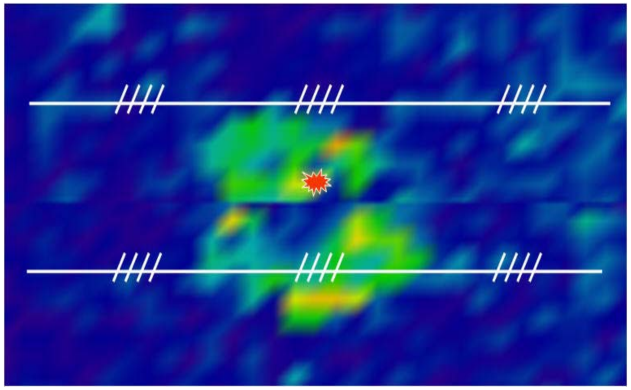
Goal – ‘Digital’ Analysis



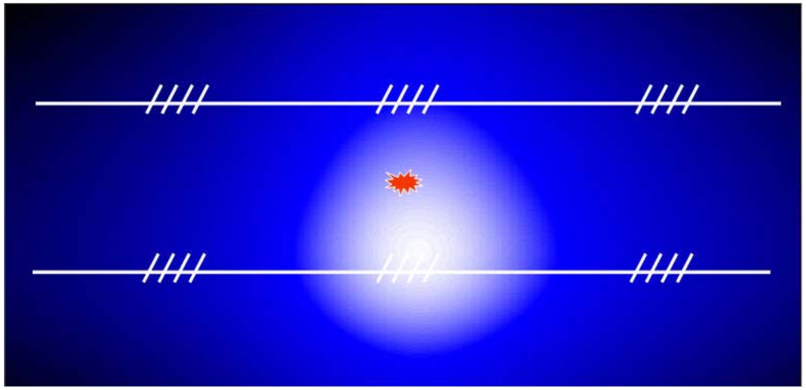


Strain Imaging, Ultrasonic and Eddy Current Scans-Impact Damage in a Composite

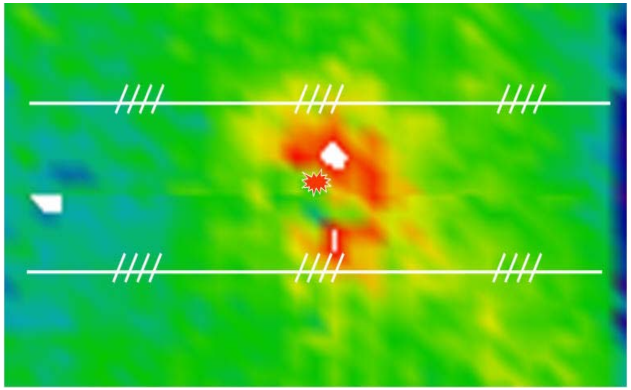




Ultrasound



FBG Strain Imaging



Eddy Current

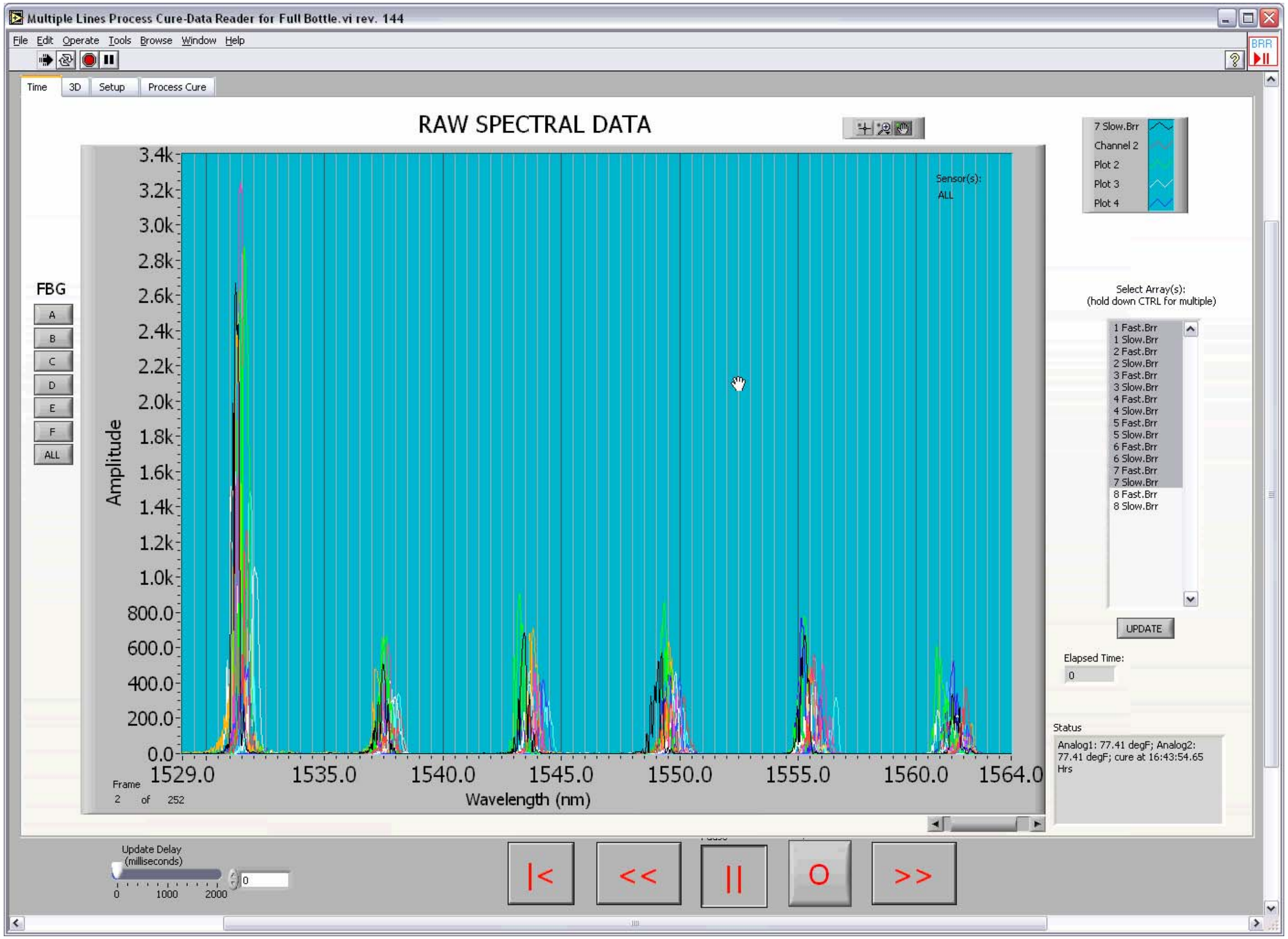
Recent Progress

BLUE ROAD RESEARCH

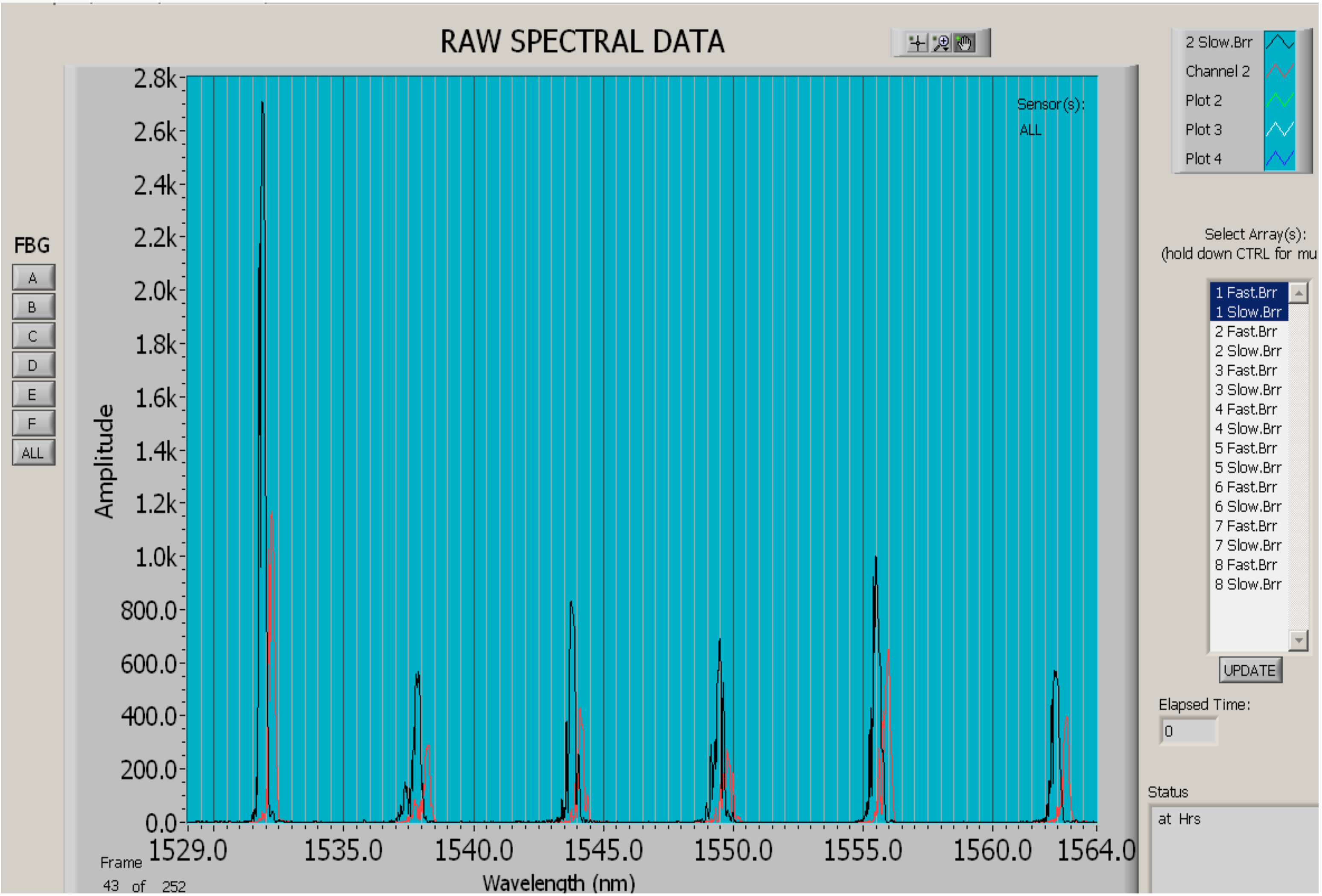
- Multi-axis fiber grating sensors may be used to perform "strain imaging" localizing and characterizing damage
- Optical signal processing has been improved to allow separation of in plane and out of plane "strain imaging" signals
- Evaluating & Applying new "strain imaging" algorithms

Experiment 2:
Process Cure

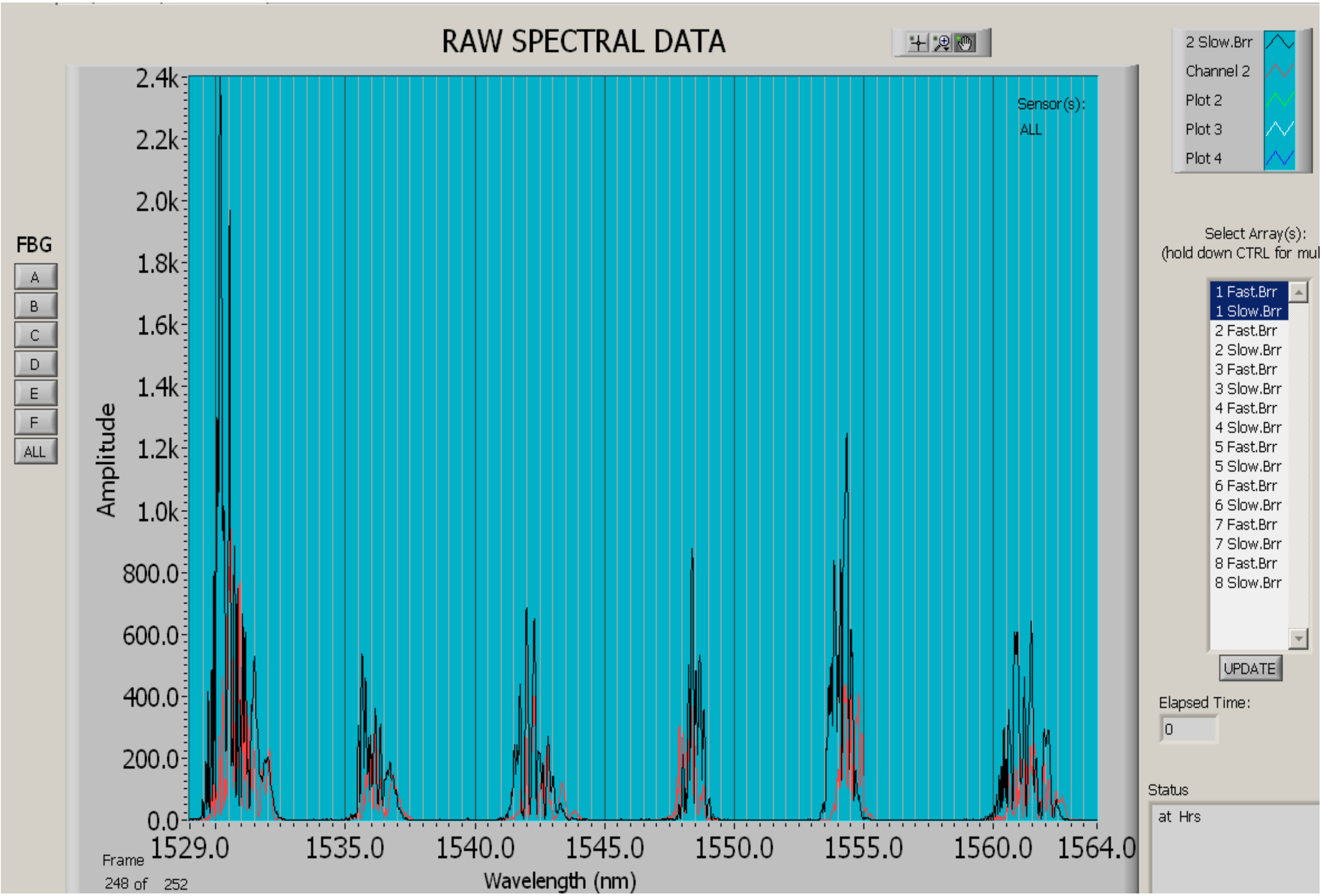
Watching Composites Cure



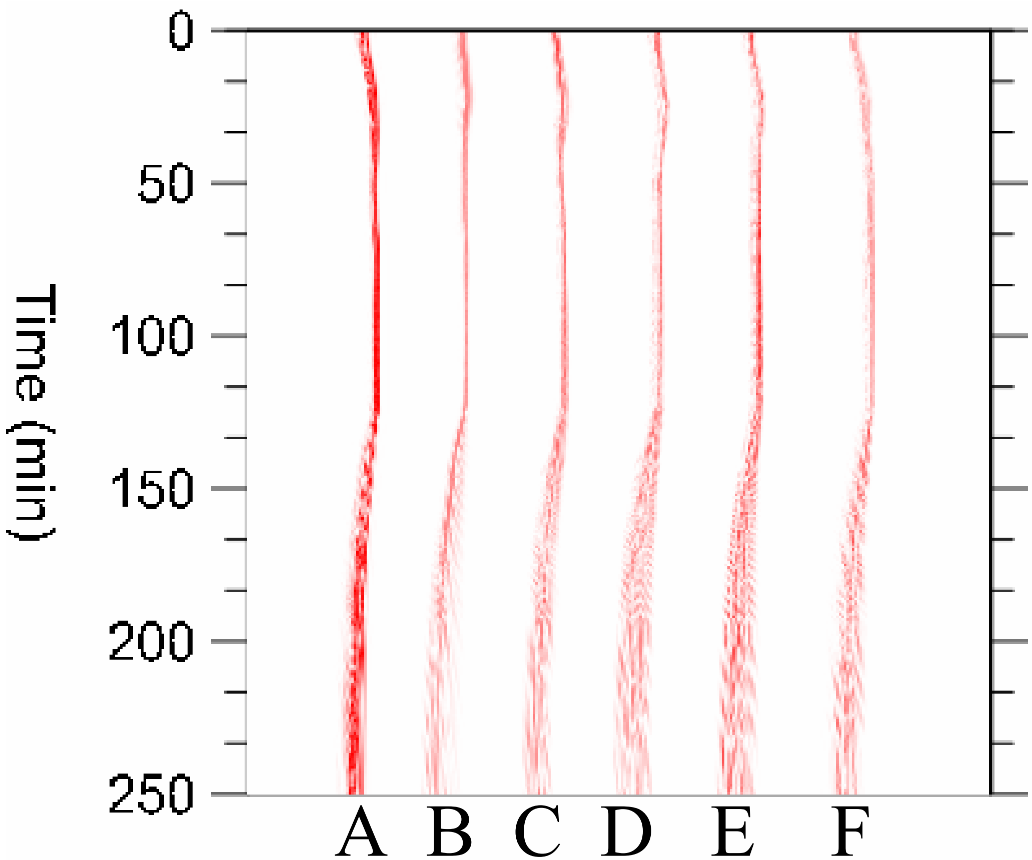
6 Sensors (Dual-Axis) as Cure Starts



6 Sensors (Dual-Axis) as Cure Finishes



Cure Cycle Information



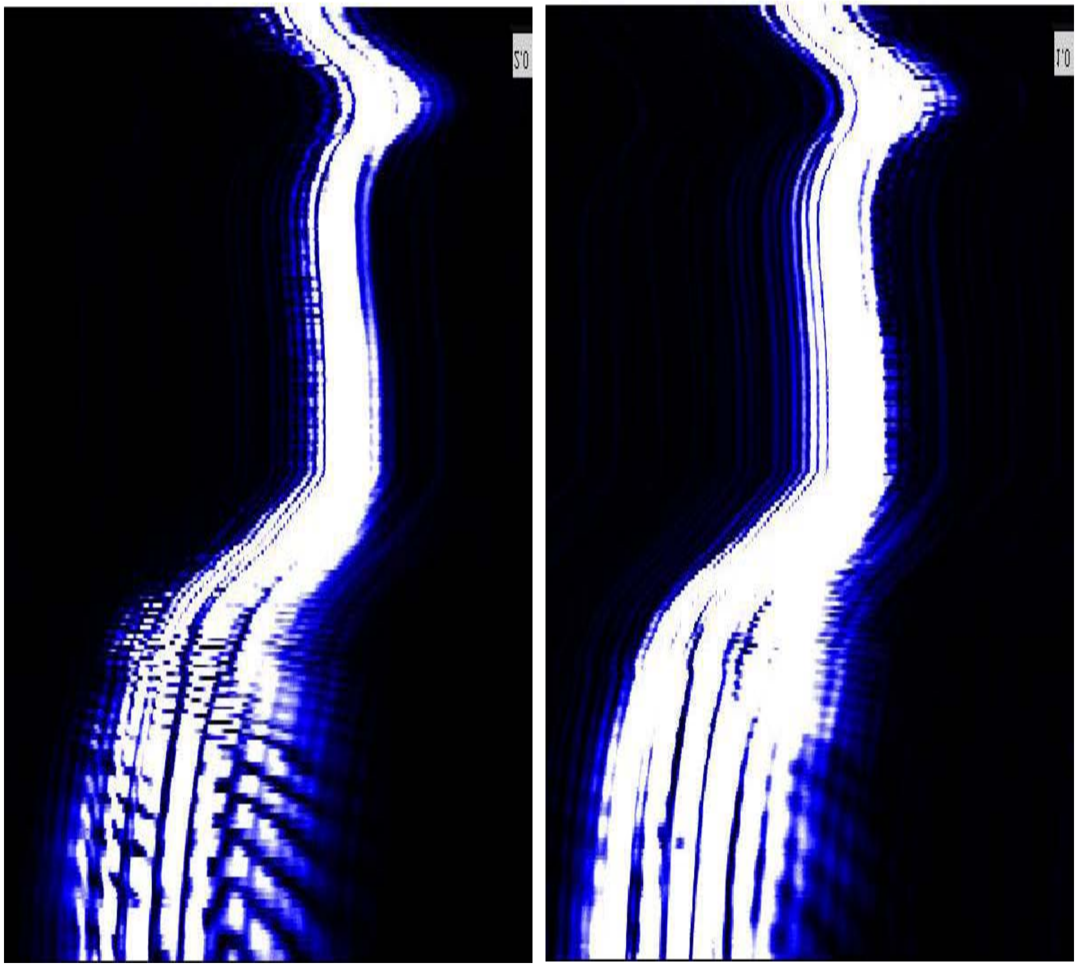
Array 1, Axis 1, Cure - EDW MC3

Array 1, Axis 1
Spectral data:

6 FBG Peaks widen as cross-linking occurs

Reduced Data (Cross-Linking)

↓ cure time



1A: In-Plane 1A: Out-of-Plane

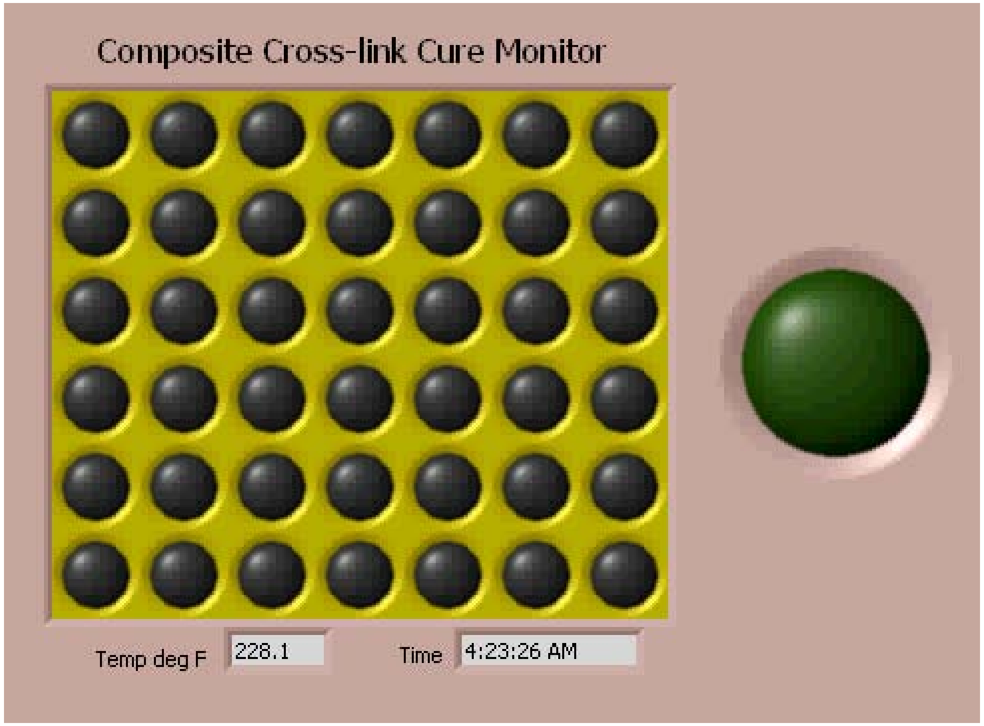
FBG 1A-
In-Plane/Out-of-Plane
Spectral data:

Close-up shows
FBG Peaks widen
as cross-linking occurs
during cure.

Cure & Process Verification Simulation

FBG Sensors/Discrete

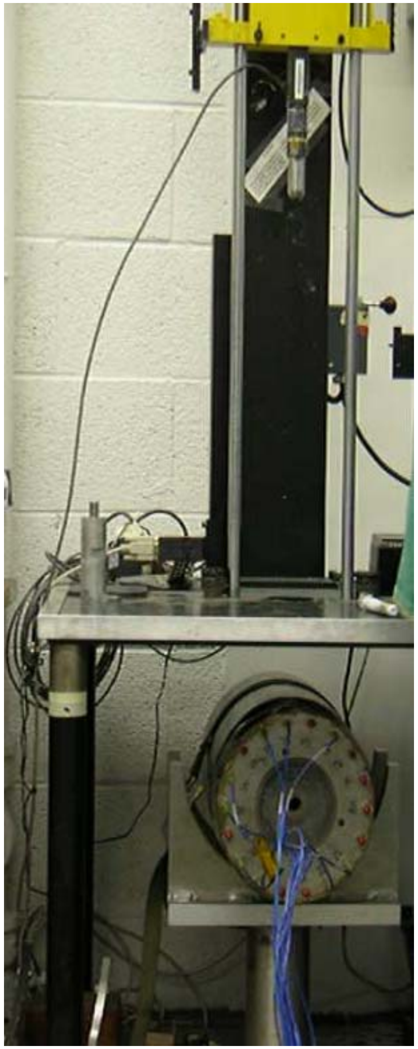
Points inside Composite

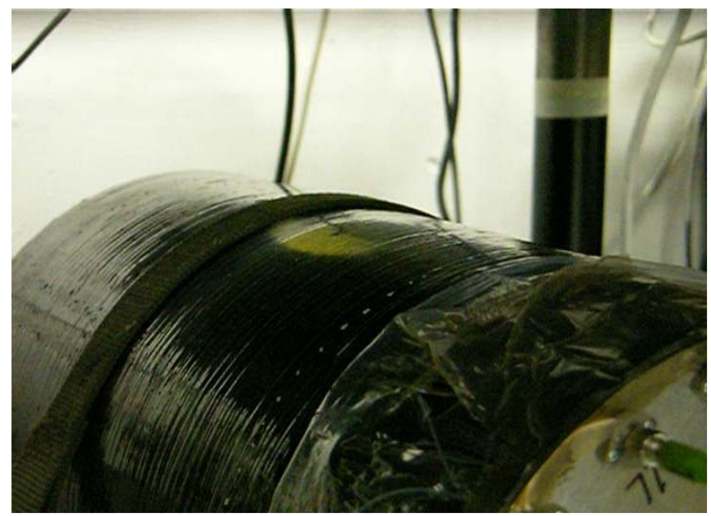


Manufactured Composite

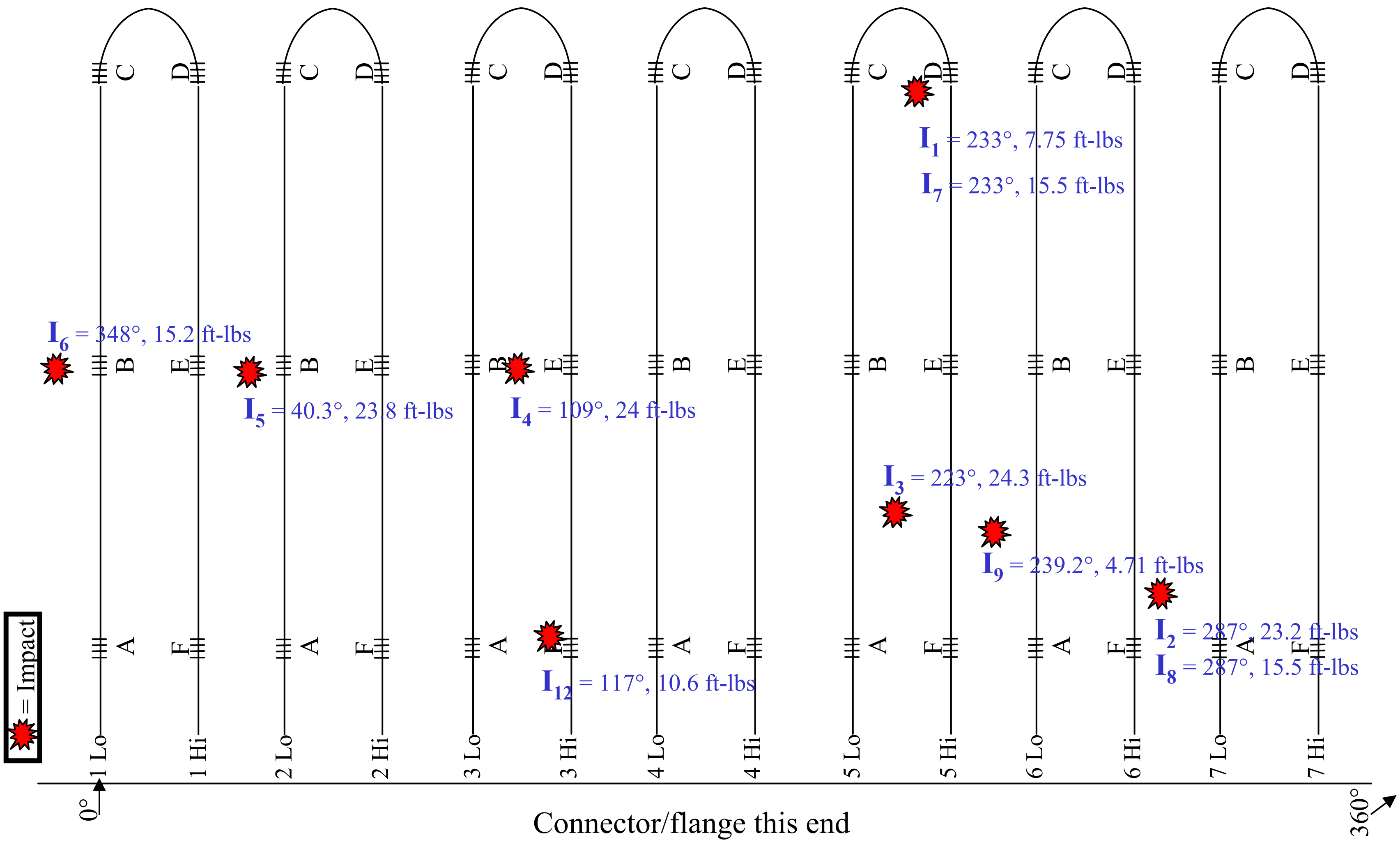
100% of 48 FBG sensors
Survived winding,
cure, casting, and handling

Experiment 3: Blind Impacts

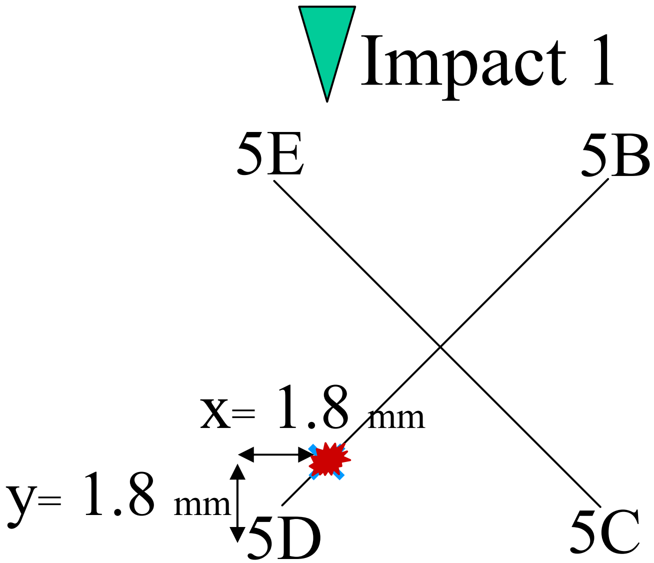


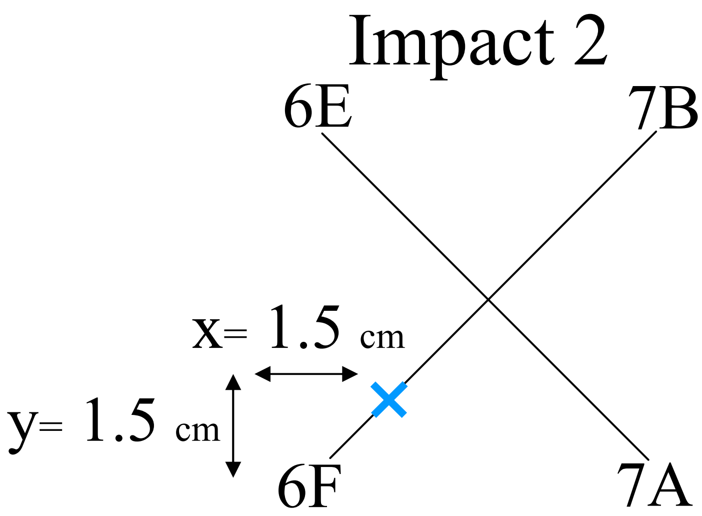


Sensor & Impact Layout on Bottle



Impacts 1 & 2



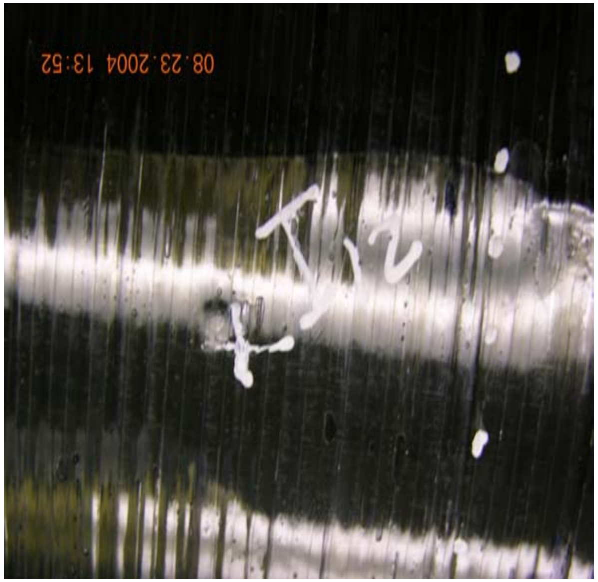


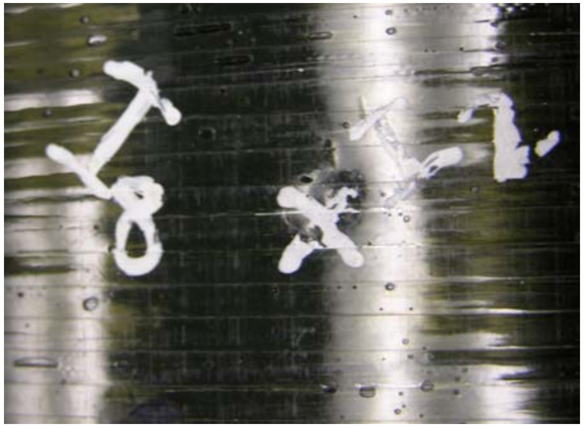
Force: 7.75 ft-lbs
Physical Measurement: 233.5°
26.8 cm Distance from Flange
49.3 cm from 0 Degrees

Force: 23.2 ft-lbs
Physical Measurement: 286.58 °
13 cm Distance from Flange
60.5 cm Distance from 0 Degrees

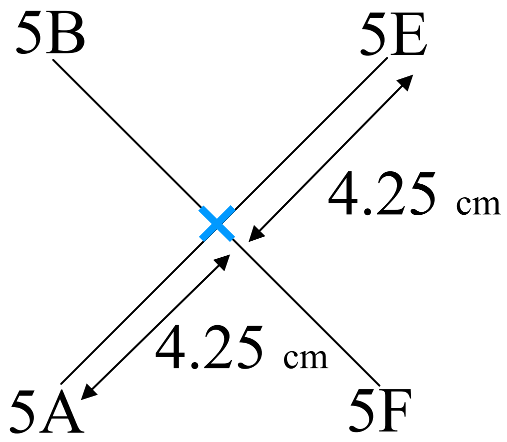
Impact Forces

Impact	Force (ft-lbs)
1	7.75
2	23.2
3	24.3
4	24
5	23.8
6	15.2
7	15.5
8	15.5
9	4.71
10	dome-15.76
11	dome-16.77
12	10.62





Impact 3



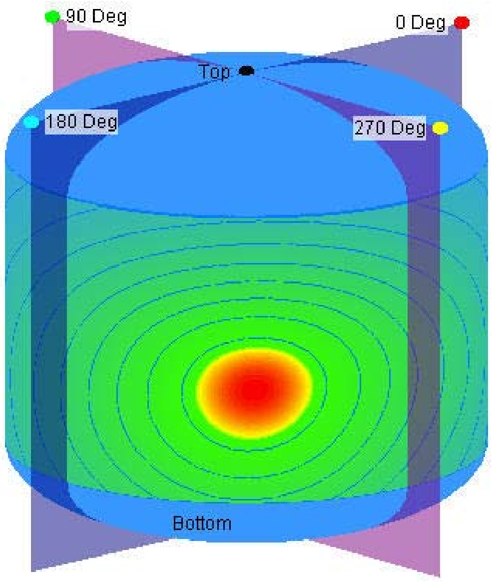
Force: 24.3 ft-lbs

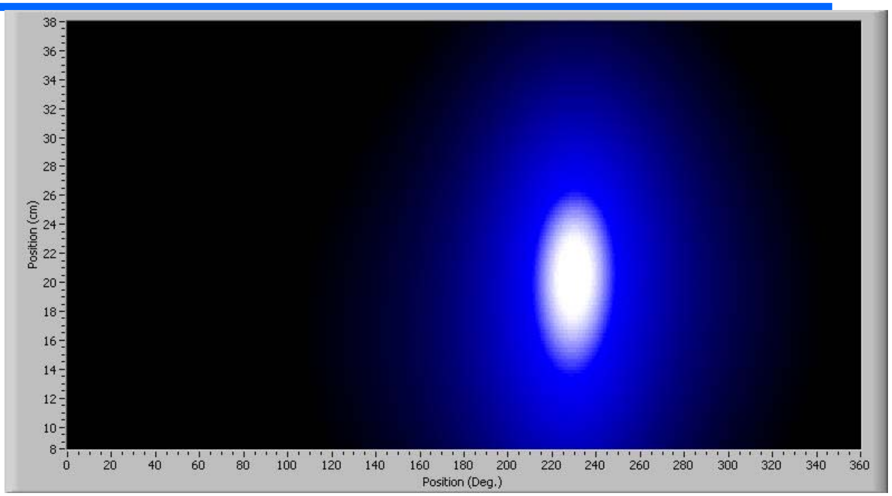
Physical Measurement: 222.6 °

15.0 cm Distance from Flange

47 cm Distance from 0 Degrees

Impact 3

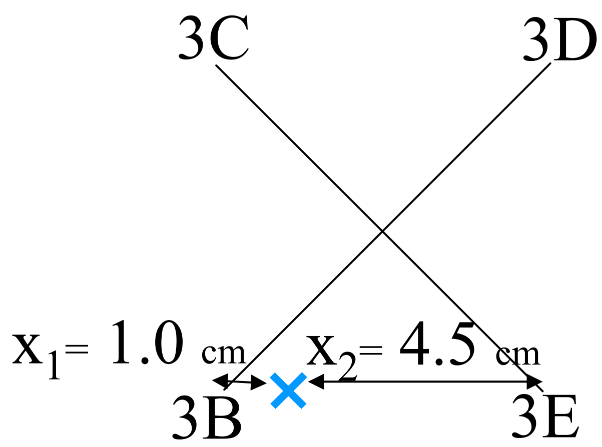




Force: 24.3 ft-lbs
15.0 cm Distance from Flange
47 cm Distance from 0 Degrees

Physical Measurement: 222.6 °

Impact 4



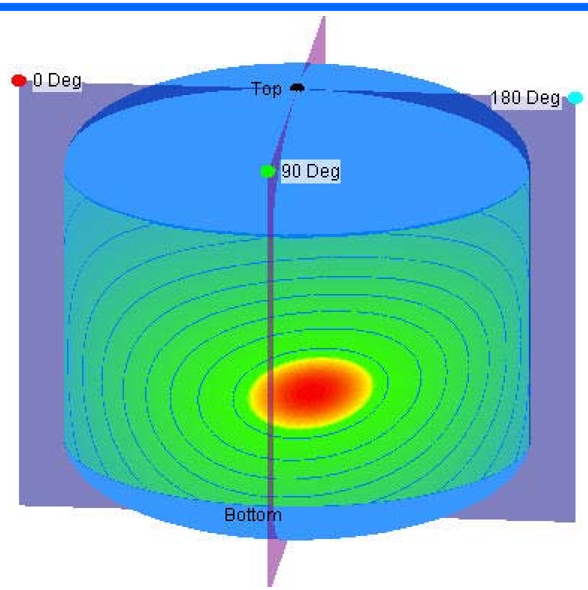
Force: 24 ft-lbs: Physical

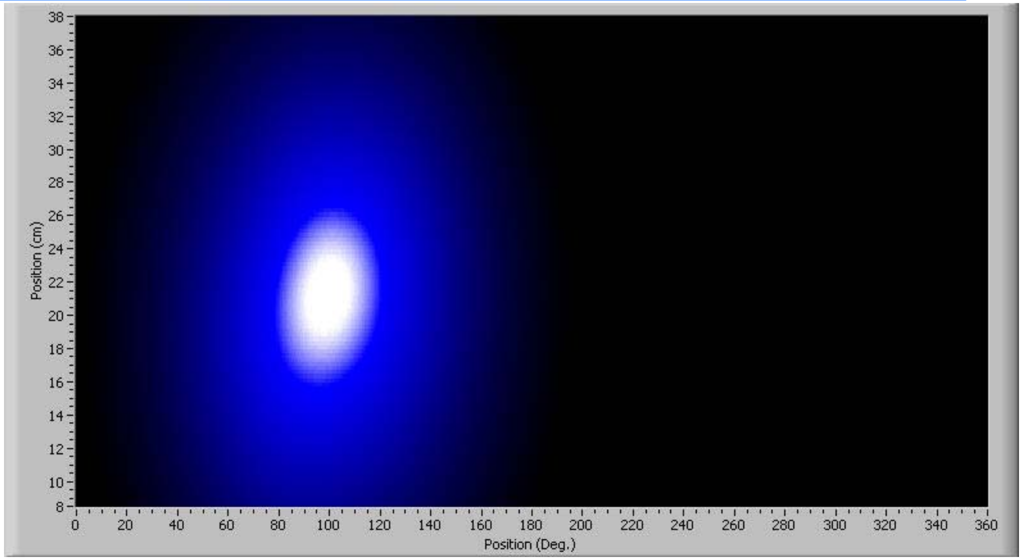
Measurement: 108.9 °

18.2 cm Distance from Flange

23 cm Distance from 0 Degrees

Impact 4

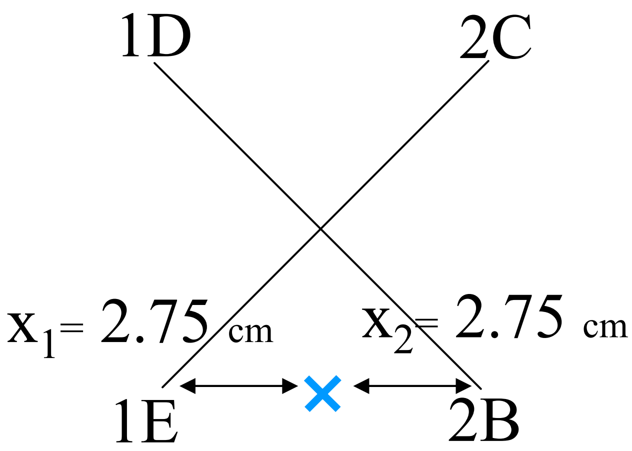




Force: 24 ft-lbs
18.2 cm Distance from Flange
23 cm Distance from 0 Degrees

Physical Measurement: 108.9 °

Impact 5



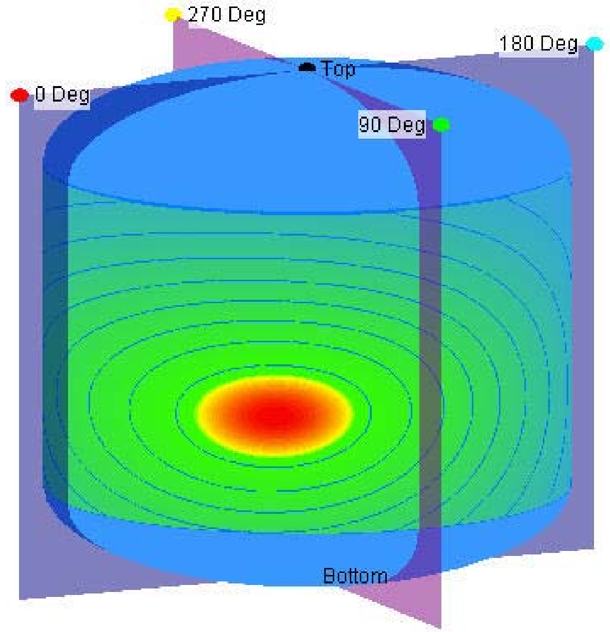
Force: 23.86 ft-lbs

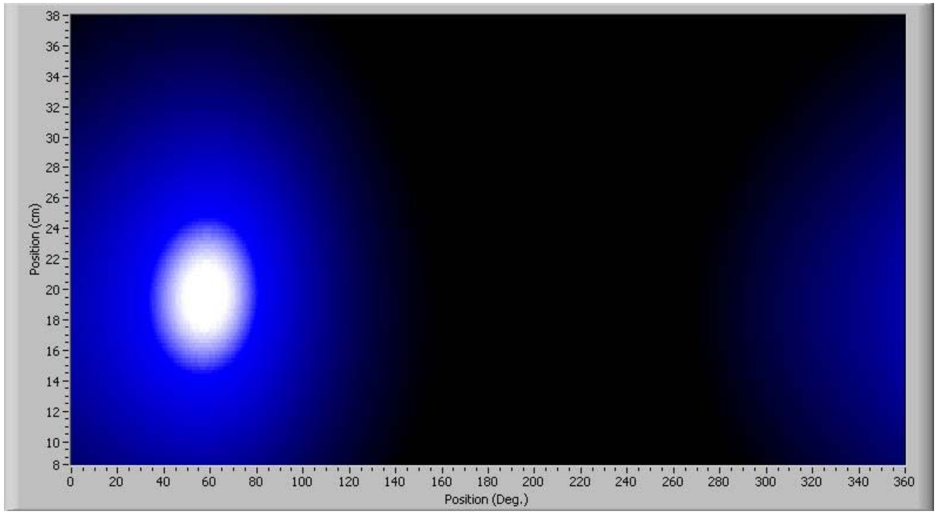
Physical Measurement: 40.3 °

18.0 cm Distance from Flange

8.5 cm Distance from 0 Degrees

Impact 5



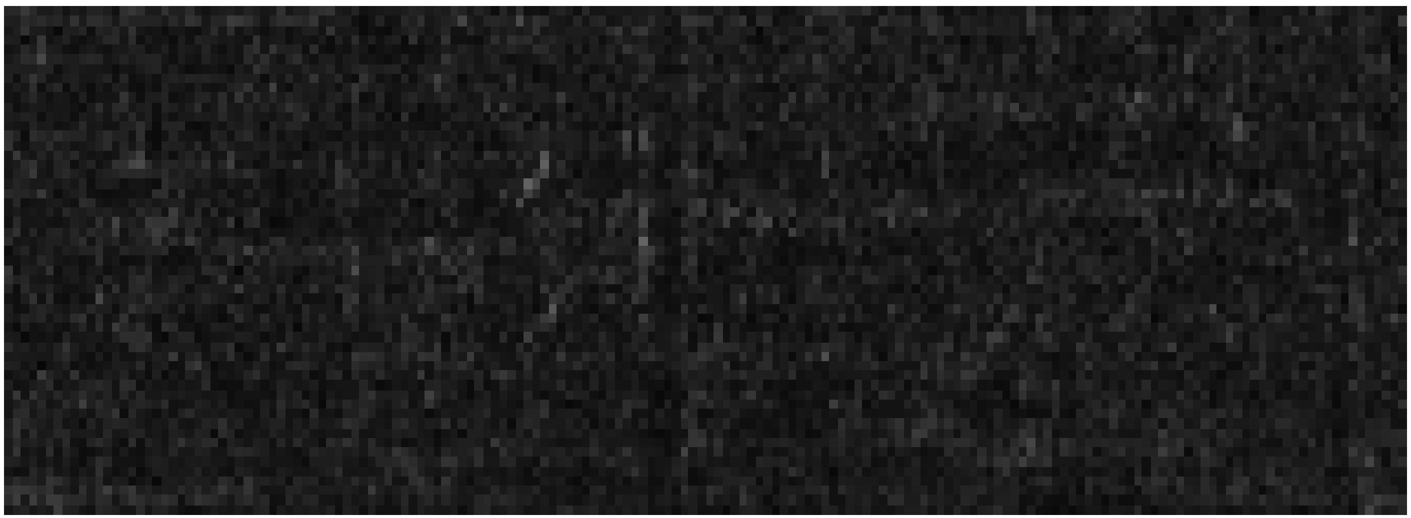


Physical Measurement: 40.3°

Comparing Strain Imaging Results:

Ultrasonic Baseline

Before Impact



Edge of cylinder (connector end)

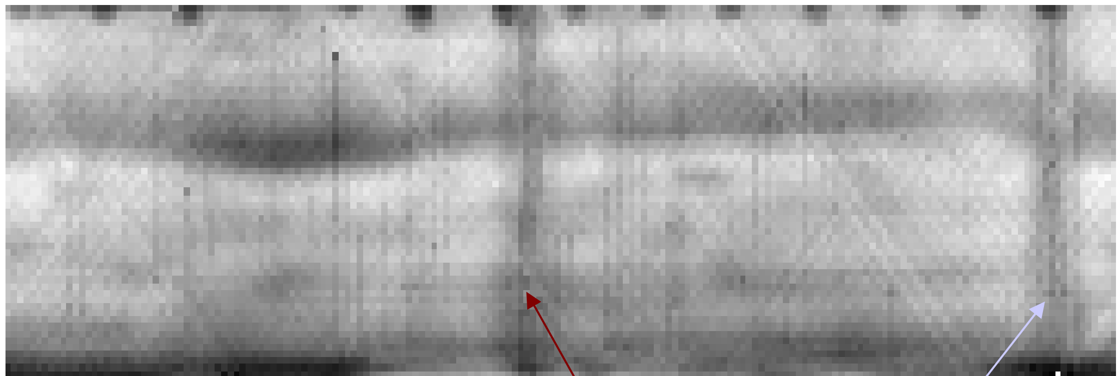
Edge of cylinder

0 deg

360 deg

Eddy Current Baseline (Before Impact)

Blue Road Bottle Axial EC scan First Impact "alpha"

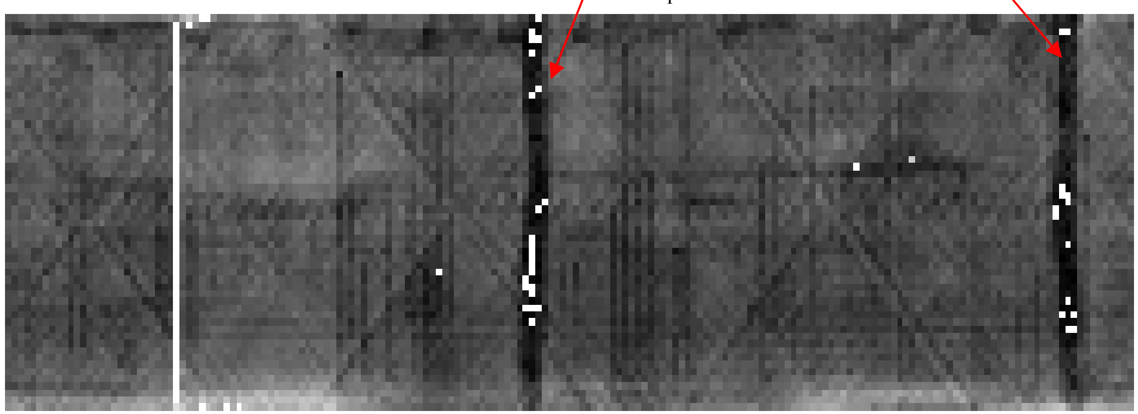


Edge of cylinder (connector end)

Edge of cylinder

Teflon tubing to dome sensor

Blue Road Bottle Axial EC scan Before Impact "Tau" 8-11-04



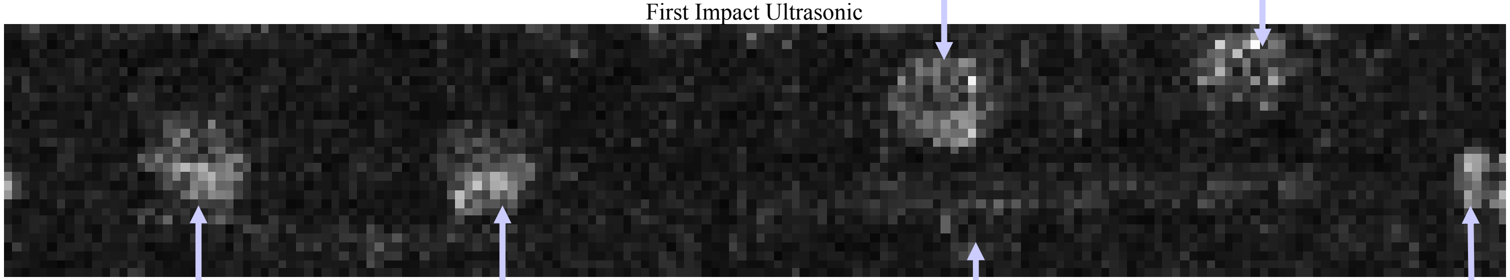
Edge of cylinder (connector end)

Edge of cylinder

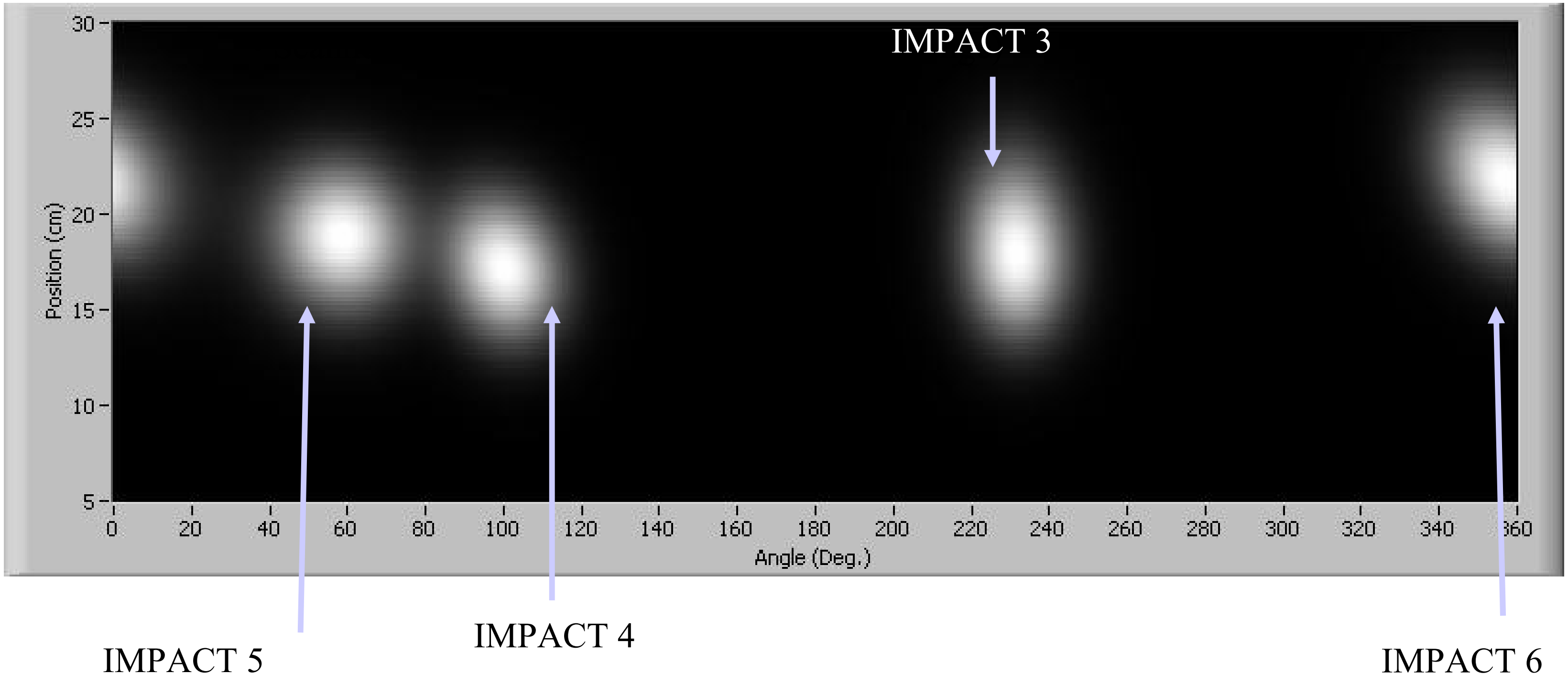
0 deg

360 deg

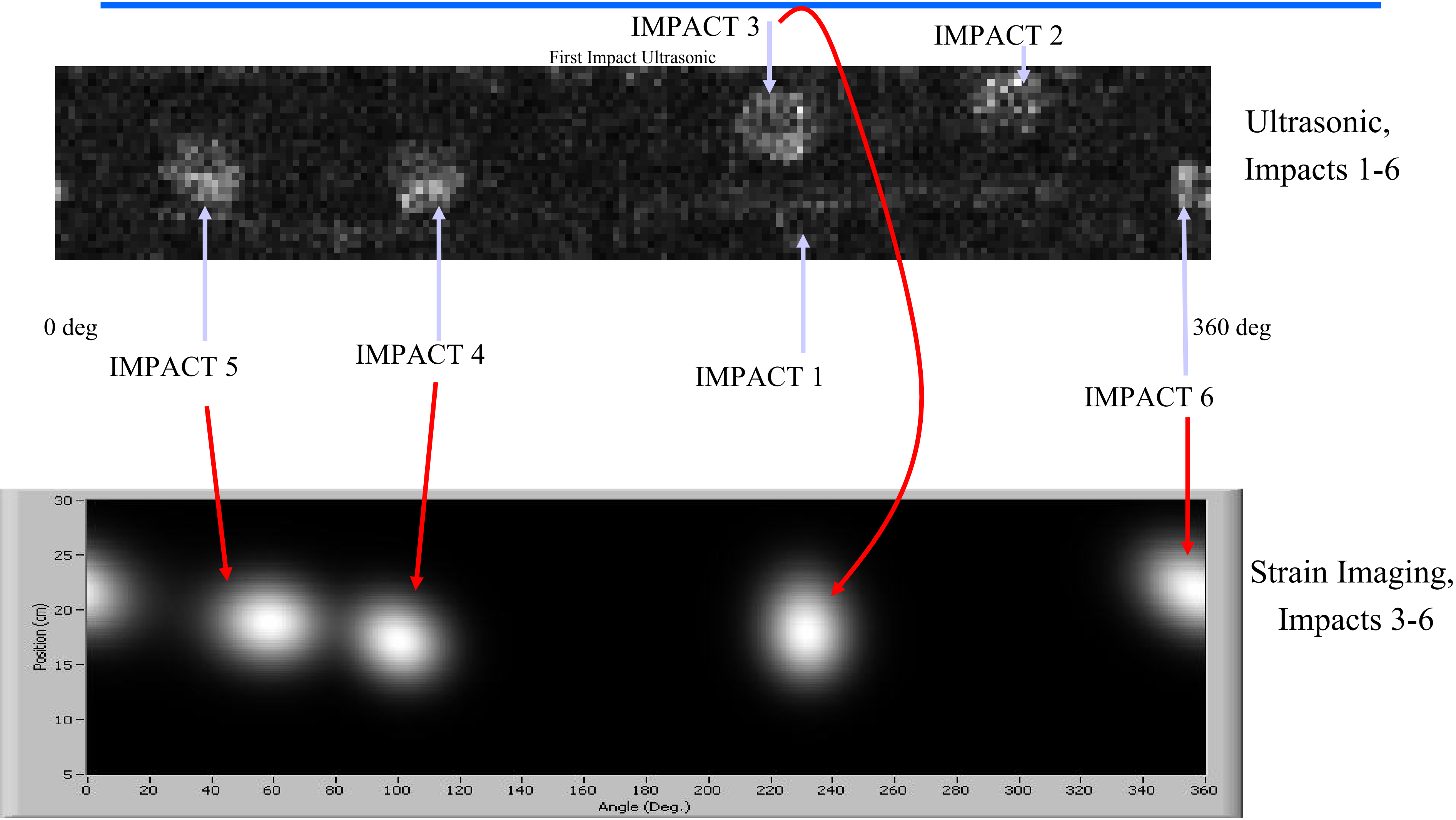
Ultrasonic, Impacts 1-6



Strain Imaging, Impacts 3-6

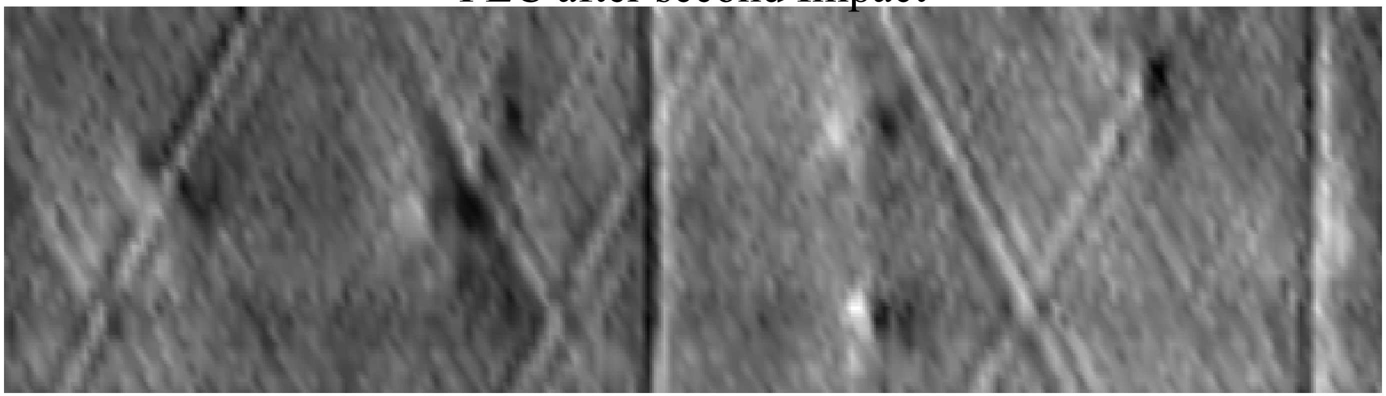


Comparison of NDE Scans



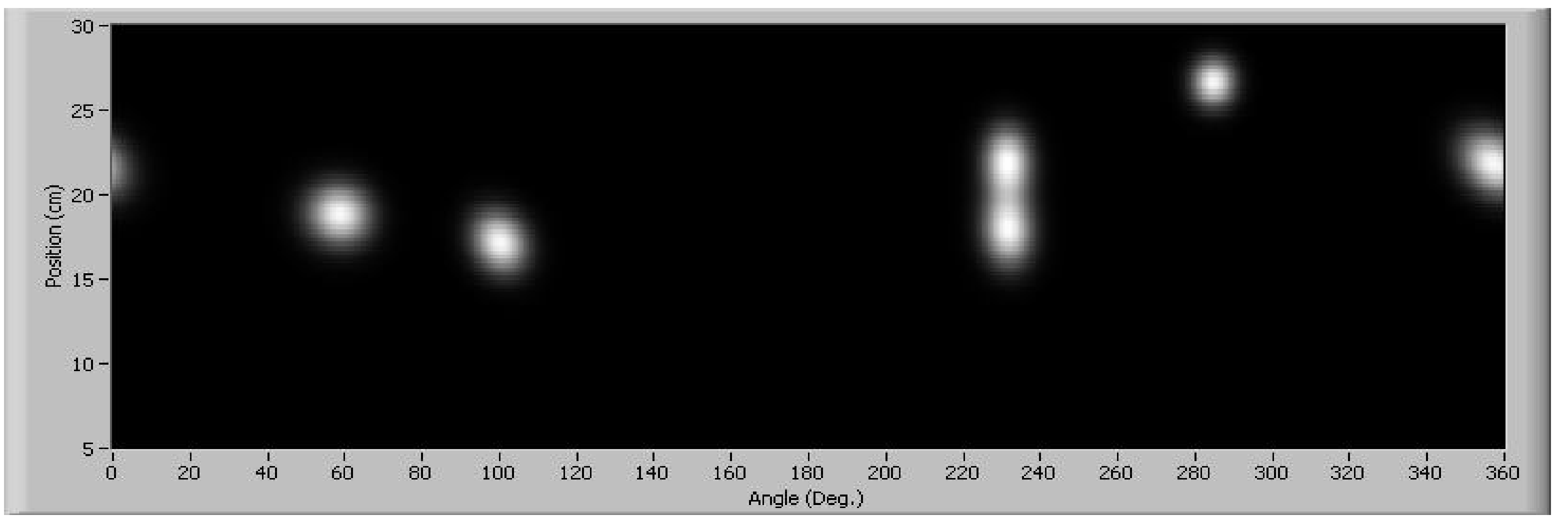
Pulse Eddy Current, Impacts 1-9, 12

PEC after second Impact



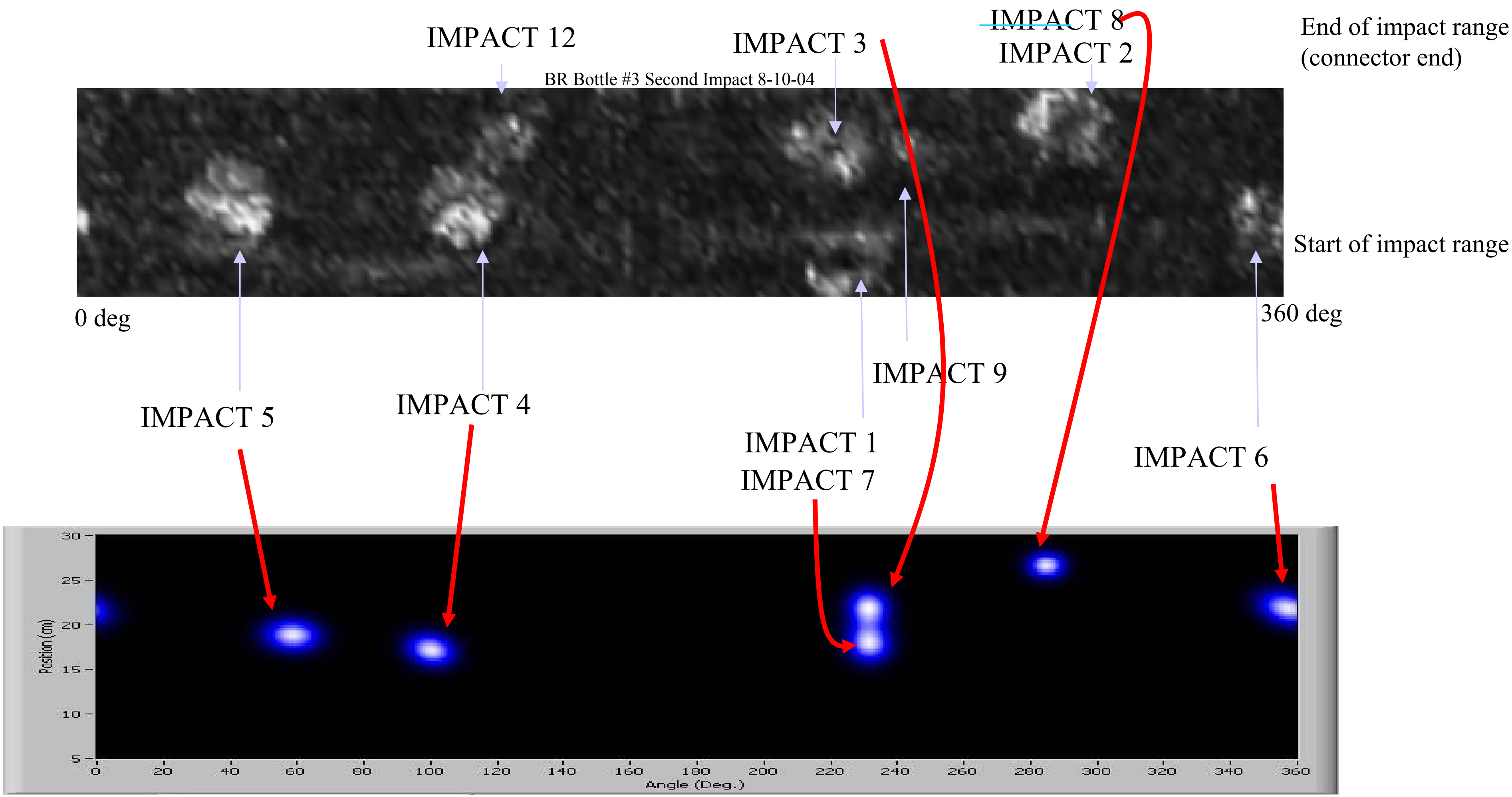
Pulse Eddy Current, Impacts 1-9, 12

0 deg 360 deg

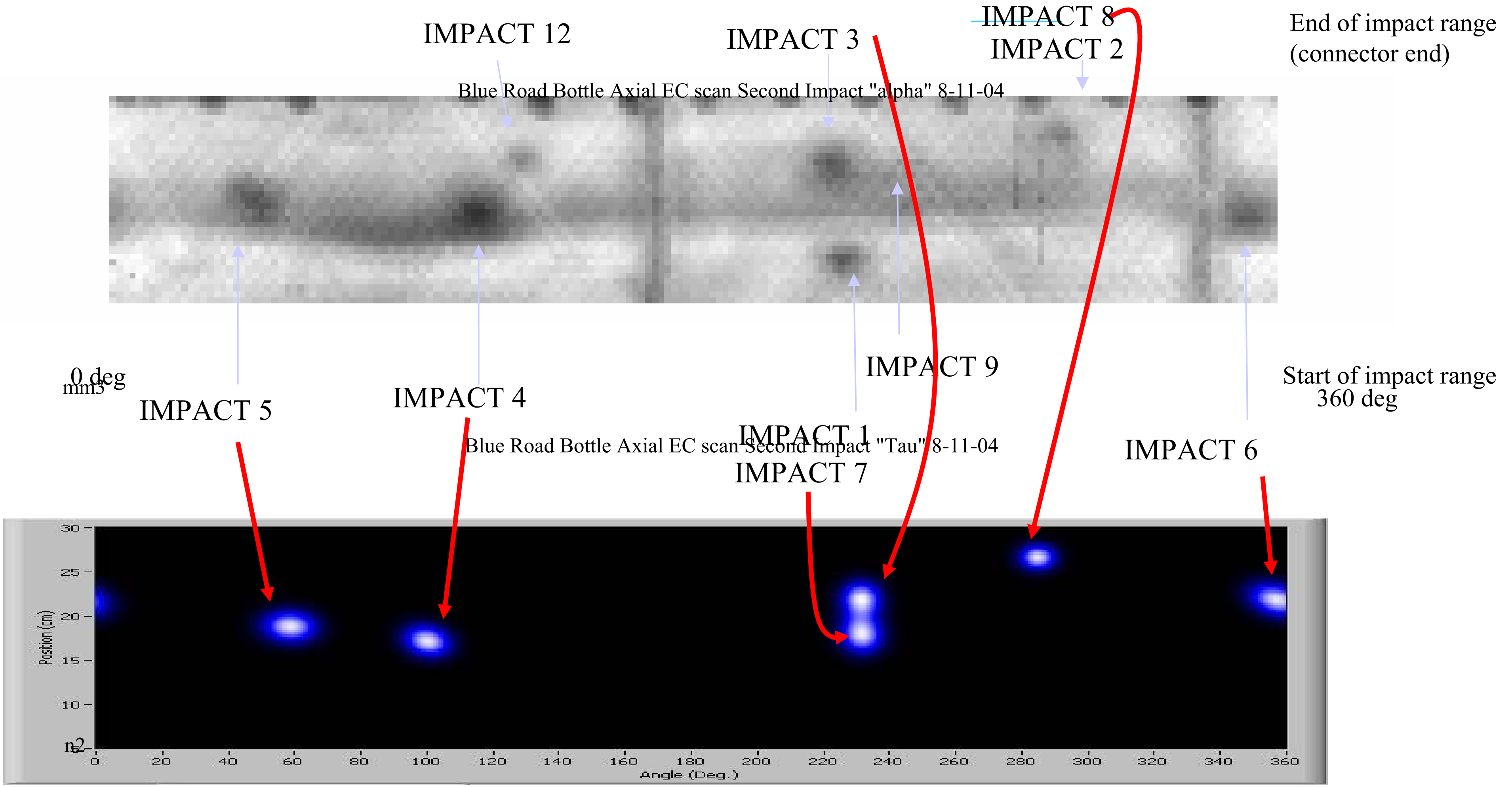


Strain Imaging, Impacts 3-8

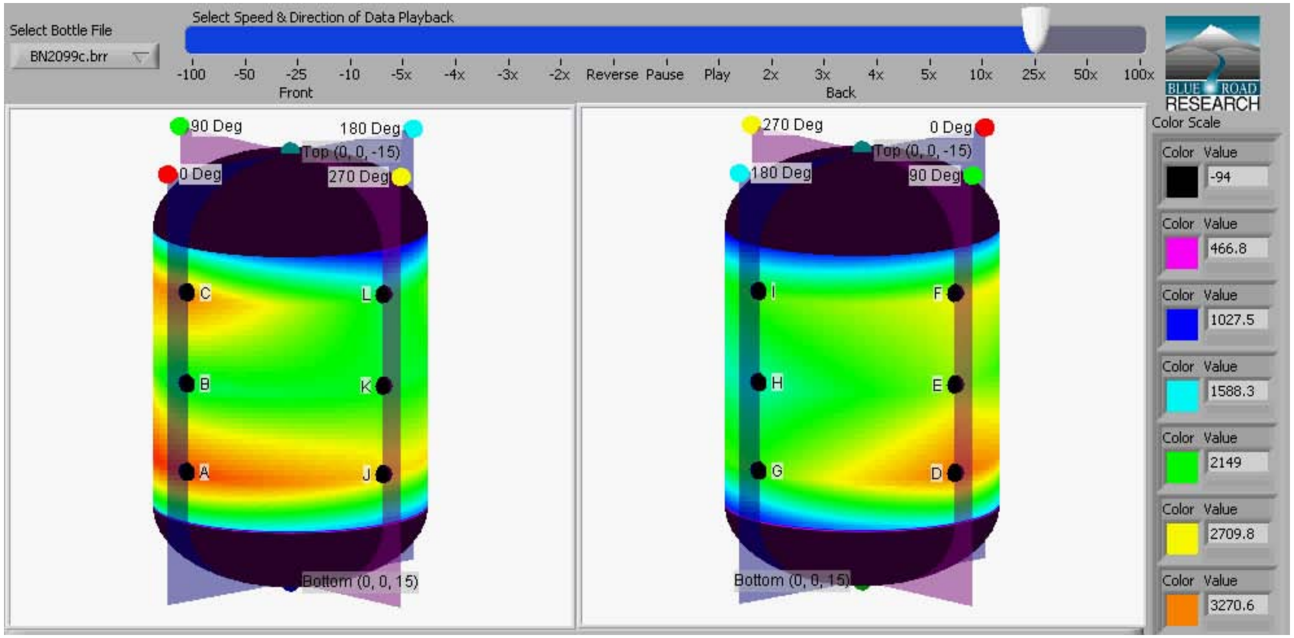
Ultrasonic: Impacts 1-9, 12
& Strain Imaging: Impacts 3-8



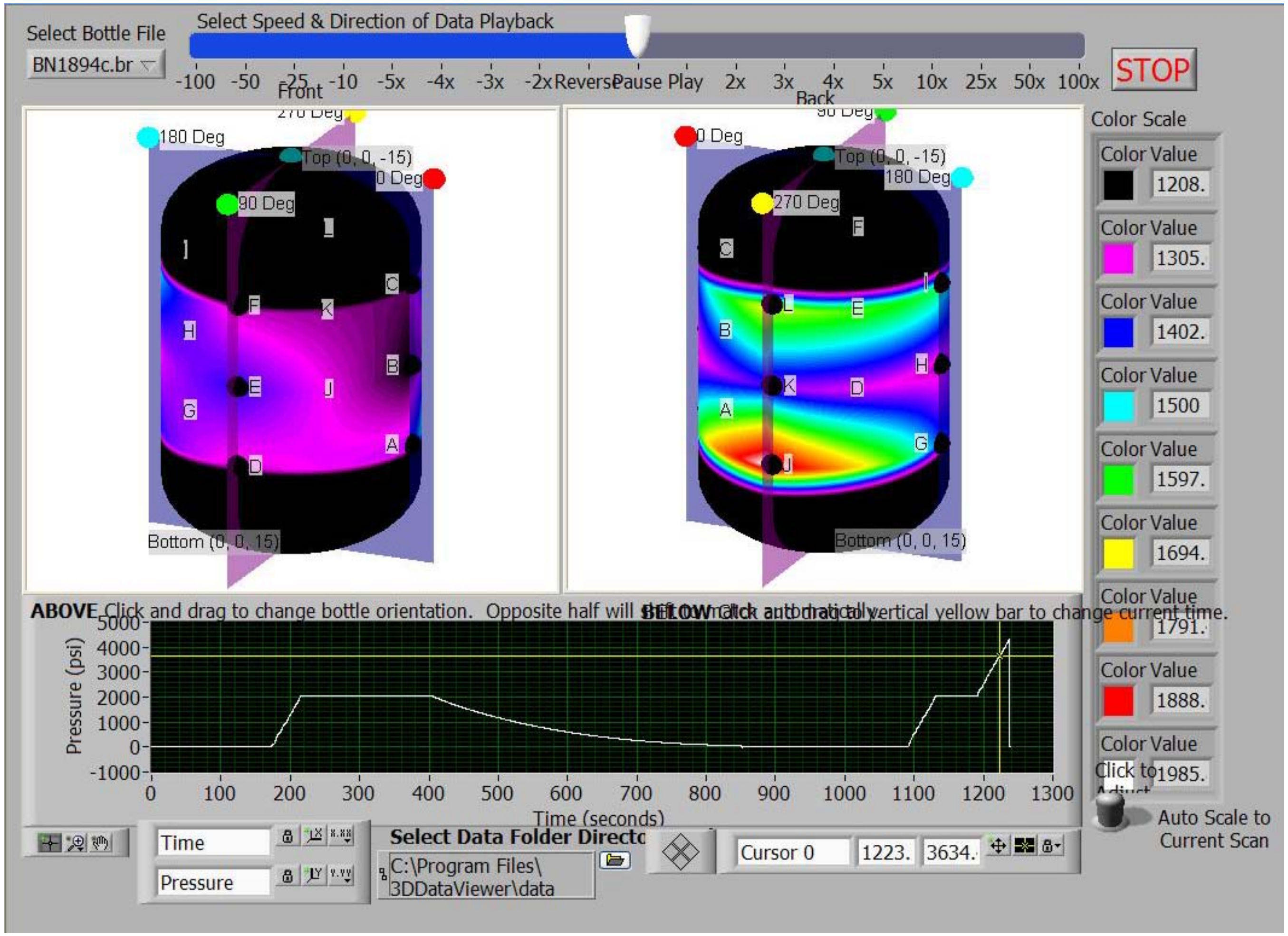
FBG overlaid – Eddy Current: Impacts 1-9, 12 & Strain Imaging: Impacts 3-8



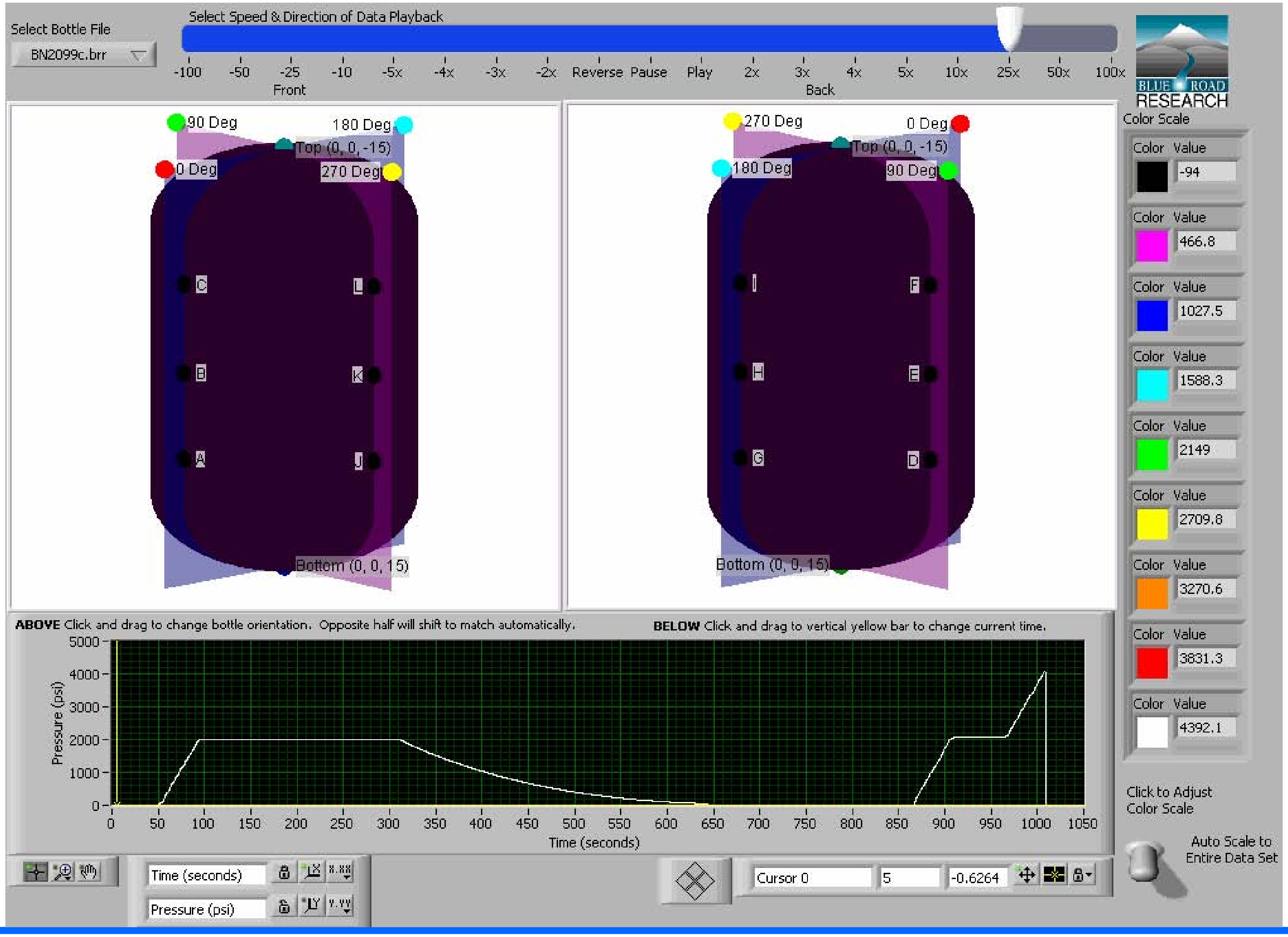
Dynamic Strain 'Imaging'



Dynamic Strain Imaging Interface



Dynamic Strain Imaging Concept



Conclusions

Strain Imaging offers the following:

- complementary to ultrasonic & eddy current NDE methods
- 'On-demand' monitoring capabilities
- Rapid (<1/10th the time of UT & EC) scanning
- Ability to catalog/compare composite health history over time
- Real-time feedback during manufacturing (process cure + FEA model verification)
- Ability to differentiate transverse and axial damage to 10 microstrain & 3 microstrain, respectively
- Locate damage in 8 out of 9 impacts to usually no greater than 2 cm

Future Work

- >20-40 Hz - kHz dynamic strain
- Wizard interface, allowing dynamic configuration of any composite geometry
- Label damage by type
- Calibrated output values
- Data viewable by multiple formats in real-time (includes raw spectral format, strain values, FEA export, etc.)
- Manufacturing Process Cure/FEA Verification
- Continue to build database of damage signatures
- Hardware improvements in speed, size, & resolution