The ODiSI with HD-FOS Sensing for Composites

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LUNA
DEFYING IMPOSSIBLE.

HOSKIN SCIENTIFIC

Products and Licensing segments – Ideas to Products

Fiber Optic Instruments:

- Sensing products - Aerospace, Automotive, and Energy markets
- Test & Measurement solutions - Telecommunications industry

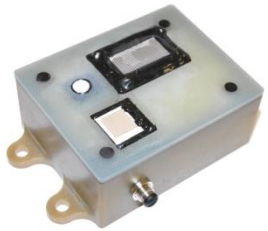
Terahertz solutions:

- Terahertz wave industrial systems for quality control, inspection, and process control
- Imaging through material, Spectroscopic measurements, thickness

Technology Development segment – New Technology/Applications

Applied research and development:

- Contract research - focused on commercialization
- Aircraft Corrosion Monitoring, 3D Shape Sensing, TrueClot etc.



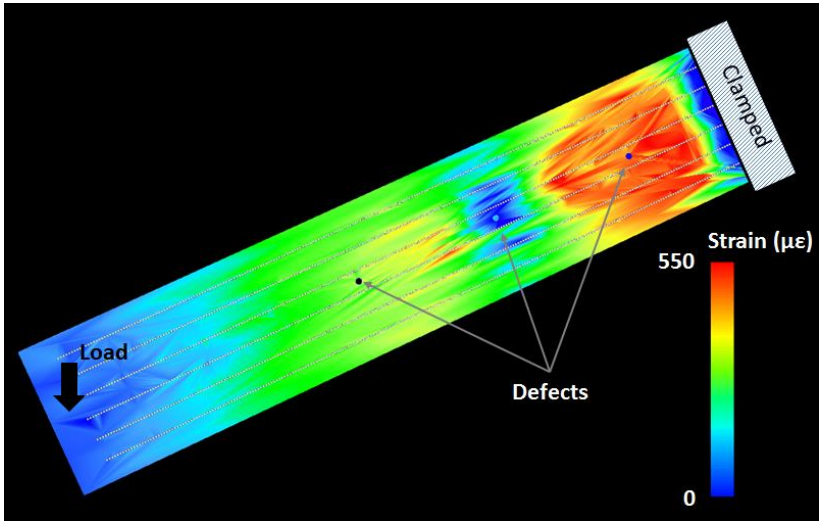
Introduction

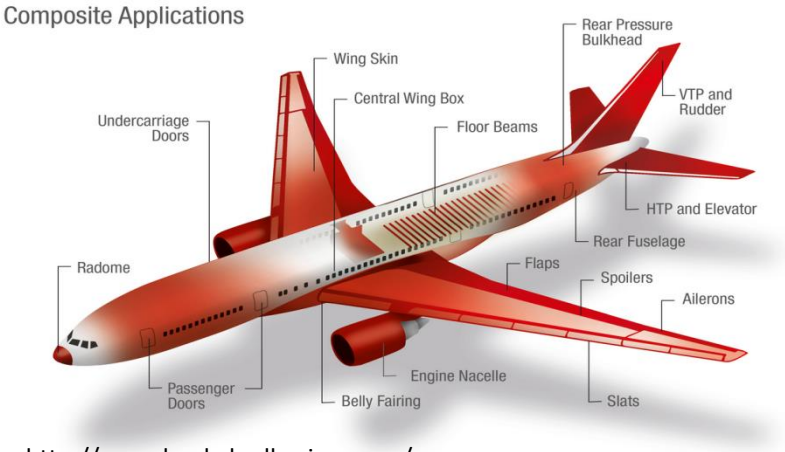
At Luna, we've developed a lightweight (nearly weightless), flexible, inexpensive, easy to install and ultra-high definition sensor technology.

We are addressing key challenges encountered in the automotive, aerospace and energy industries presented by the evolution towards more fuel efficient, lighter weight, higher strength and greener designs.

Today we will talk about:

- High-definition temperature and strain mapping using Luna's ODiSI Technology

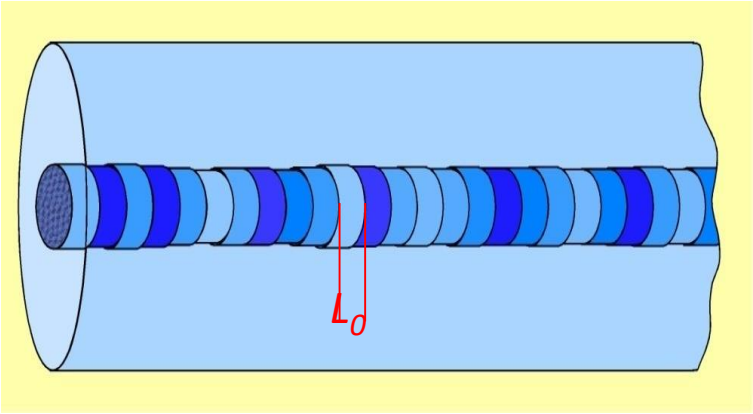




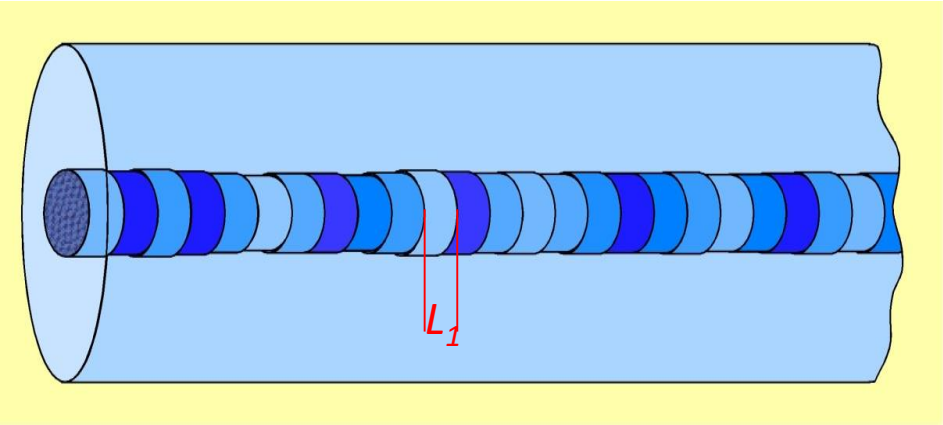
http://www.henkel-adhesives.com/

ODiSI – How it Works

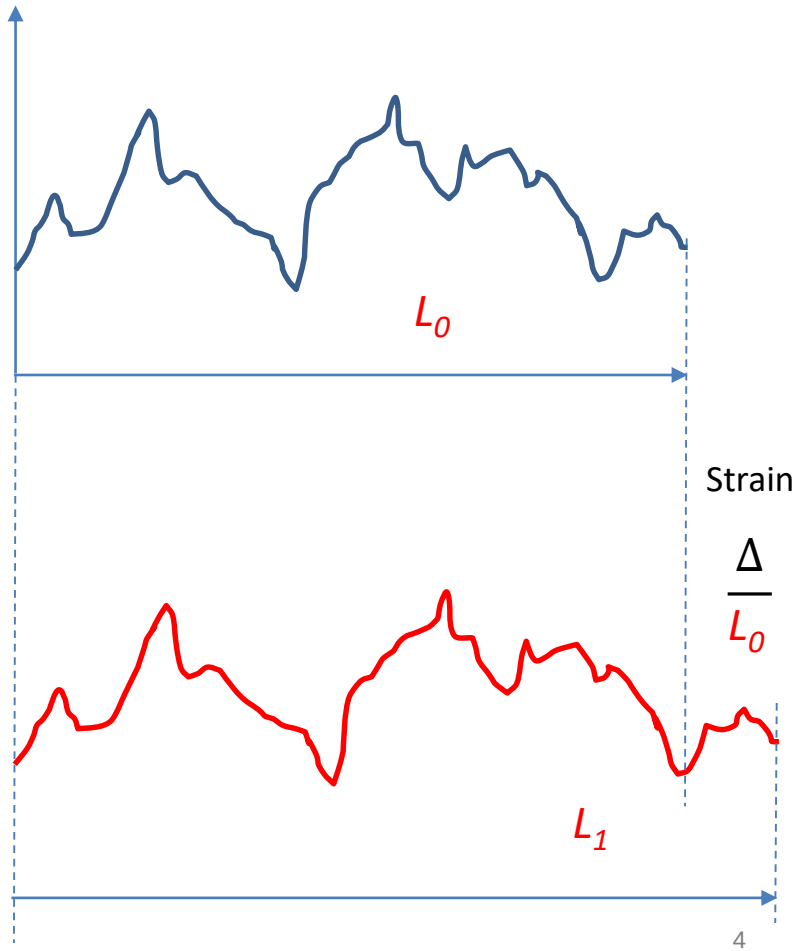
Microstructure in the fiber



Strained Microstructure in the fiber



Rayleigh Backscatter
(Reflections off the microstructure in the fiber)



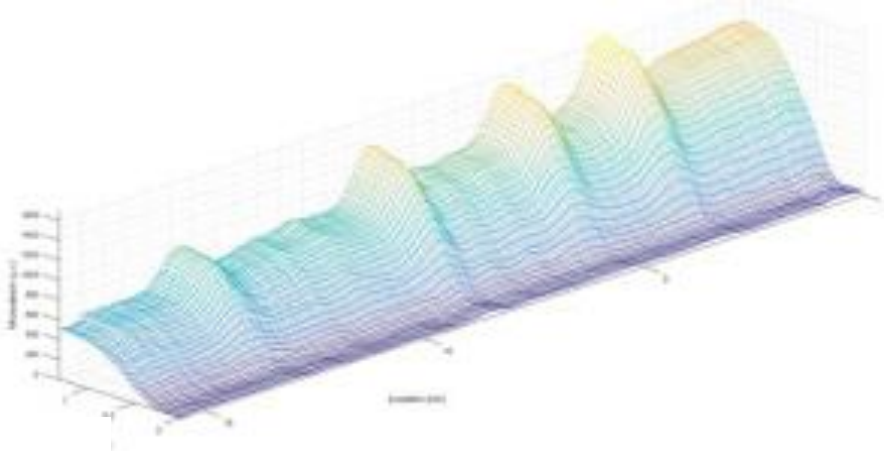
ODiSI – How it Works

Scanning the fiber, signal processing and converting to strain or temperature

- The laser, optical network and processing are housed in the interrogator
- The reflection pattern is measured and processed into a wavelength shift proportional to strain or temperature change

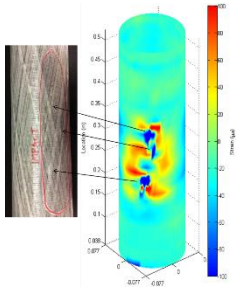
A user interface for data collection and analysis

- Displays strain or temperature over the length of sensor (or test article)
- Can show in as a 2D or 3D visualization in real time
- High density data ideal for detecting sharp gradients and validating models



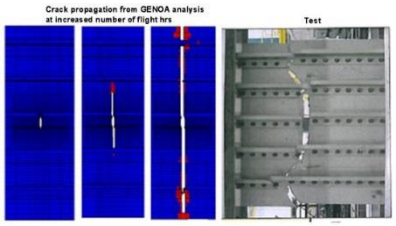
HD-FOS Addresses Key Challenges in Lightweighting

Composite Damage



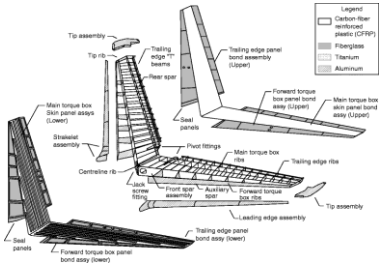
- Intrinsically small
- Very lightweight
- Low profile
- Measure residual strain
- Embed sensor inter-laminar
- “Smart Parts”

Crack Propagation



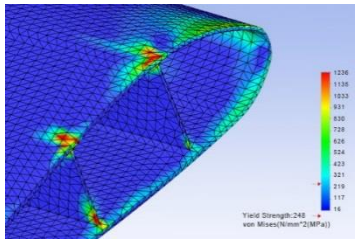
- Measure spatially continuous strain gradients
- Track crack growth through cyclic loading
- Verify probabilistic models

Multi-Material Joining



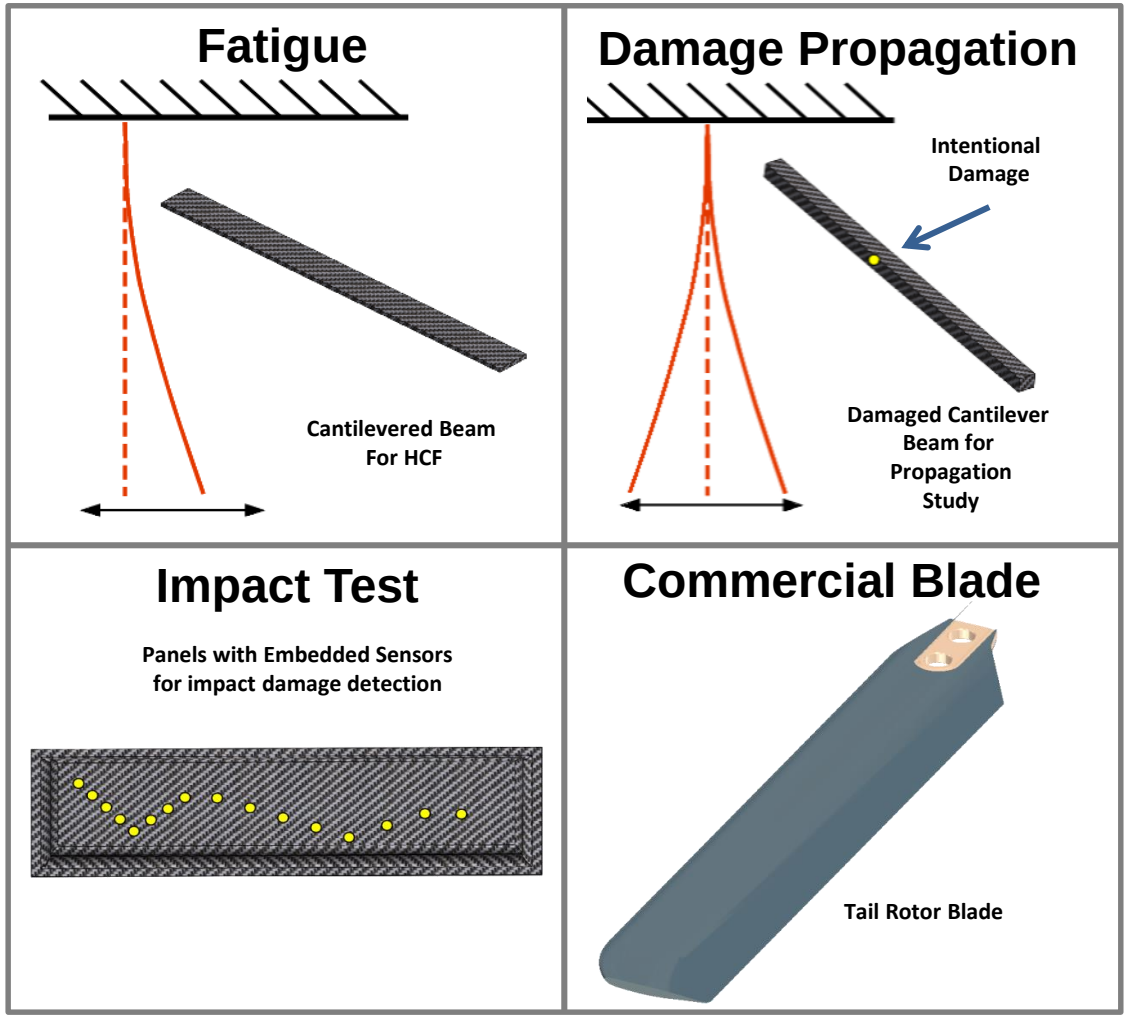
- Certify bond line temperature / strain during curing
- Routine adhesive bond lines
- Capture adhesive performance
- Weld quality

FEA Model Verification



- Calibrate FEA
- Verify model
- Measure complex geometries
- Measure inter-laminar
- Fatigue over millions of cycles
- 3D printing

Composite Damage Detection



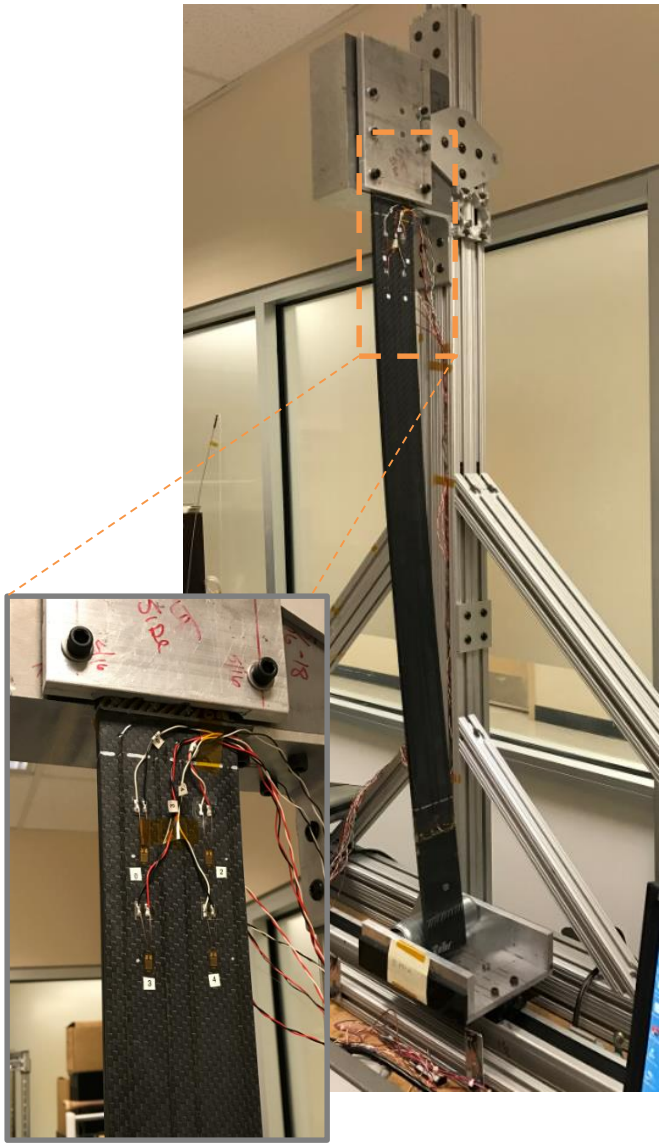
- Four test article designs
- Each design met the needs of a specific mechanism being tested

1) Fatigue
2) Damage Propagation
3) Impact Test
4) Commercial Composite Tail Rotor Blade

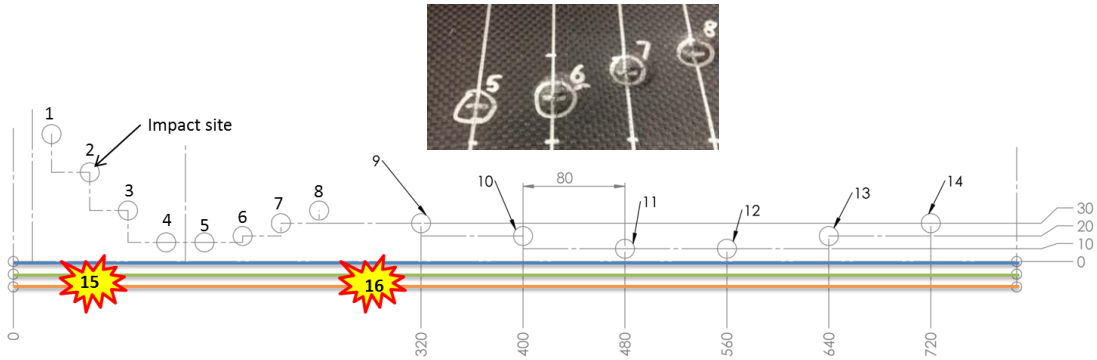
Kominsky et. al. Extracting Information from Damaged Carbon Fiber Composites Using High Definition Fiber Optic Sensing (HD-FOS). CAMX 2017

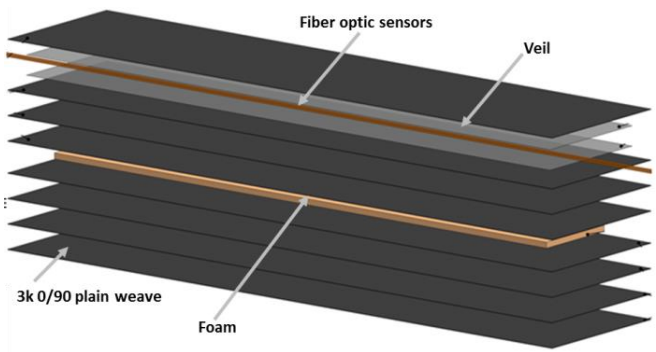
High Cycle Fatigue

- Externally instrumented beam has been flexing for 21 months (4.05 million cycles) sampled at 2 Hz
- Co-instrumented with 8 foil strain gages
- Foil gages have started showing drift, and some failures (~36% of readings have a correlation of less than 0.99)
- HD-FOS readings between matched locations have 0.019% of readings with correlations below 0.99

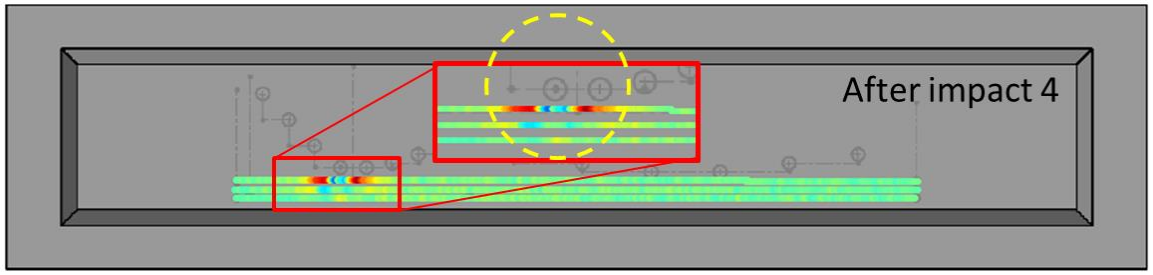


Impact Test: ASTM D7136





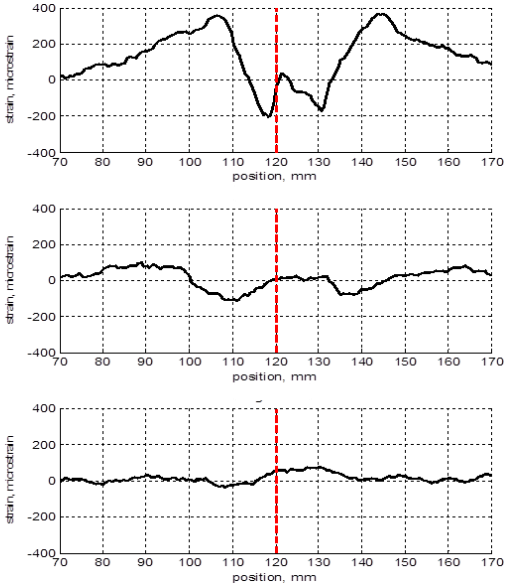
- Impact 4 and those following, consistently present a pattern of alternating regions of tension and compression with relatively minimal strain directly aligned with the point of impact
- Significant residual strain up to 5 cm away from the impact location



Close fiber:
4 cm away

Middle fiber:
5 cm away

Far fiber:
6 cm away

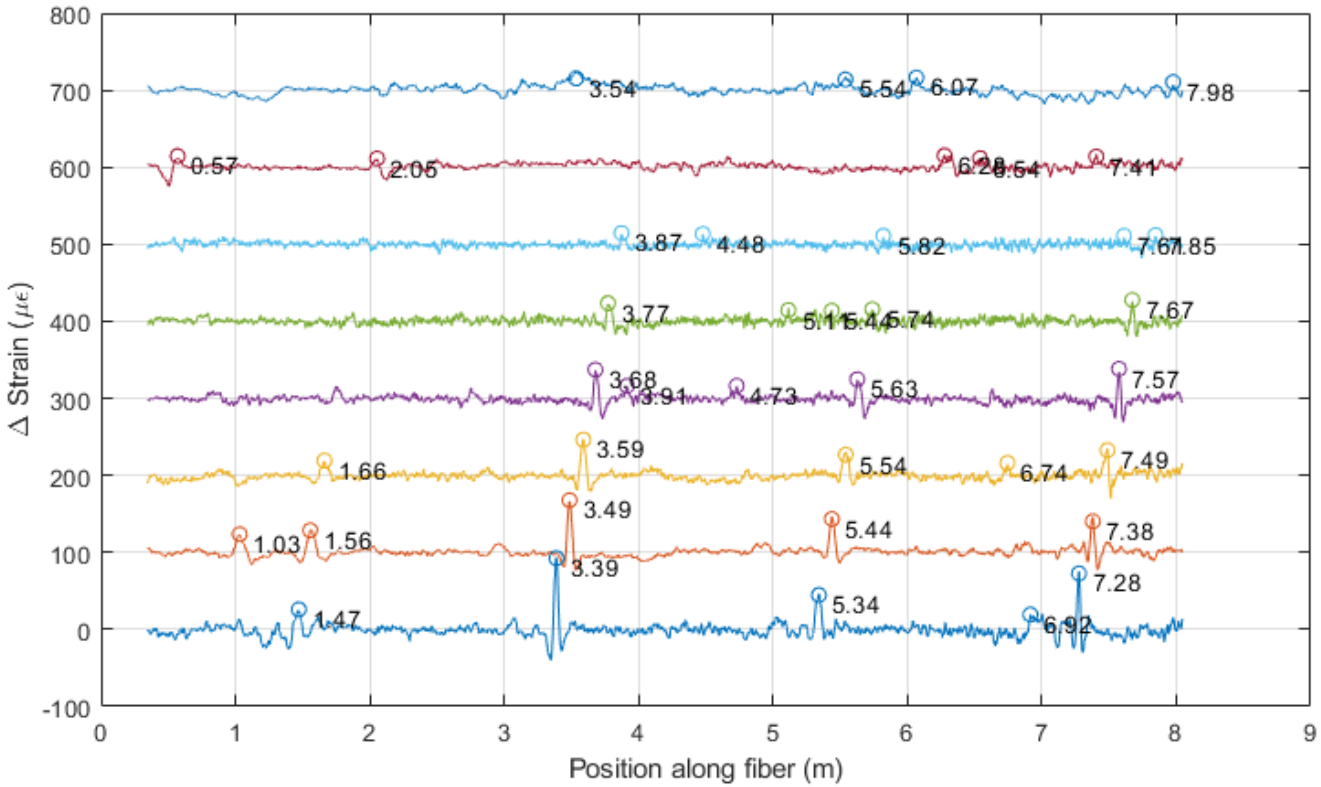


Impact 4

Kominsky et. al. Extracting Information from Damaged Carbon Fiber Composites Using High Definition Fiber Optic Sensing (HD-FOS). CAMX 2017

Impact Testing/Damage Localization

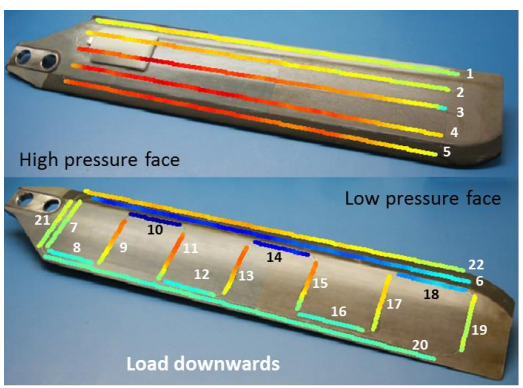
- Fiber is routed at 4 different depths within the panel
- Series of 8 impacts with decreasing impact energy
- Impact damage is seen with a “W” profile in strain
- Fully automated analysis reporting the 5 most significant signals for each impact

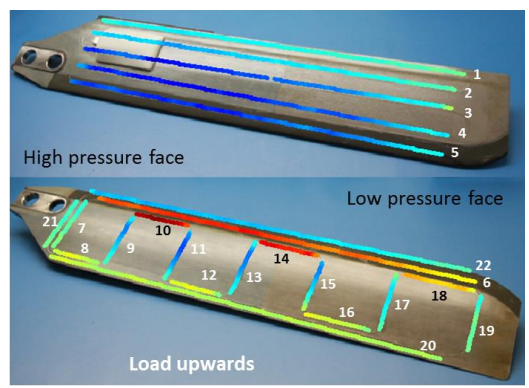


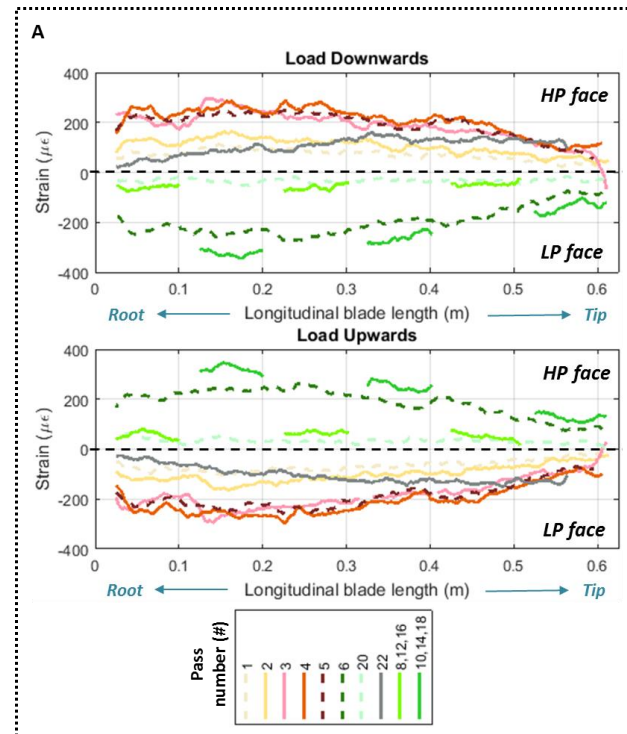
Commercial Composite Rotor Blade

- A 70 cm long tail rotor blade was instrumented with a 7 m fiber optic sensor
- Blade is fabricated using unidirectional carbon/epoxy tape with a rigid cell structural foam core
- Bending applied in the upward and downward directions
- Data viewed both numerically in the form of plots or as a color map superimposed onto the blade

- Representative of how the technology could be implemented in a maintenance and inspection capacity

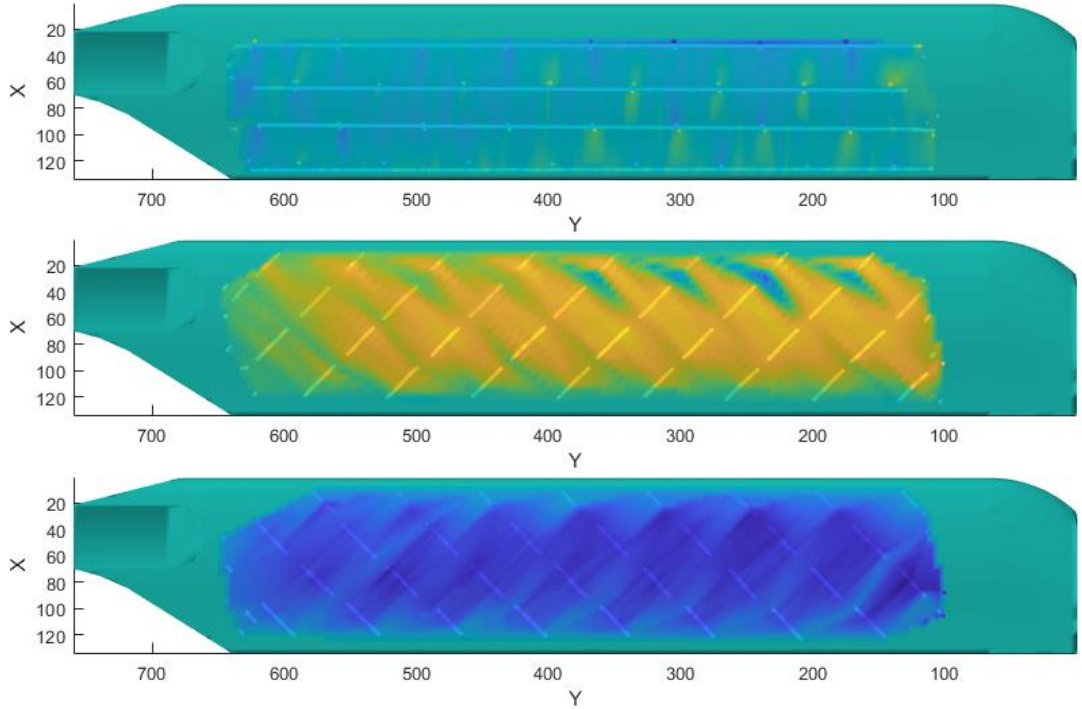


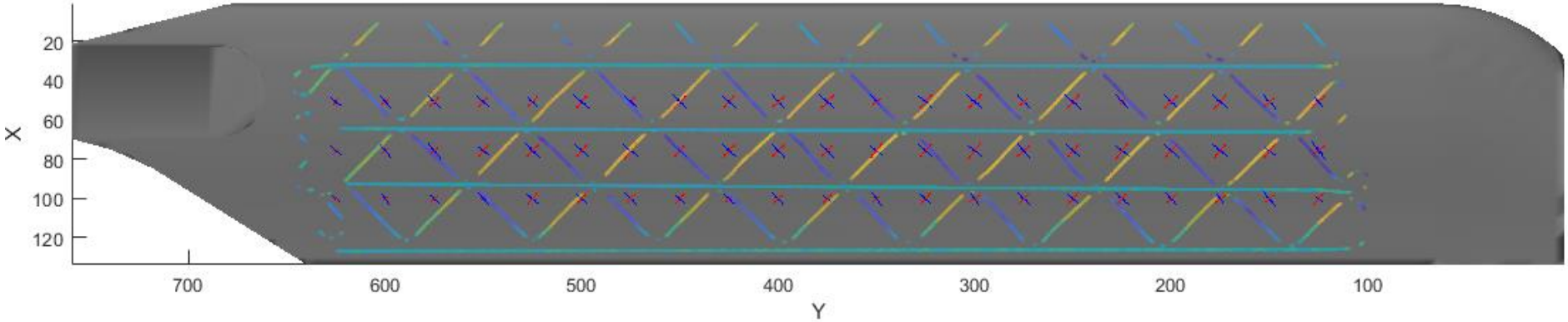




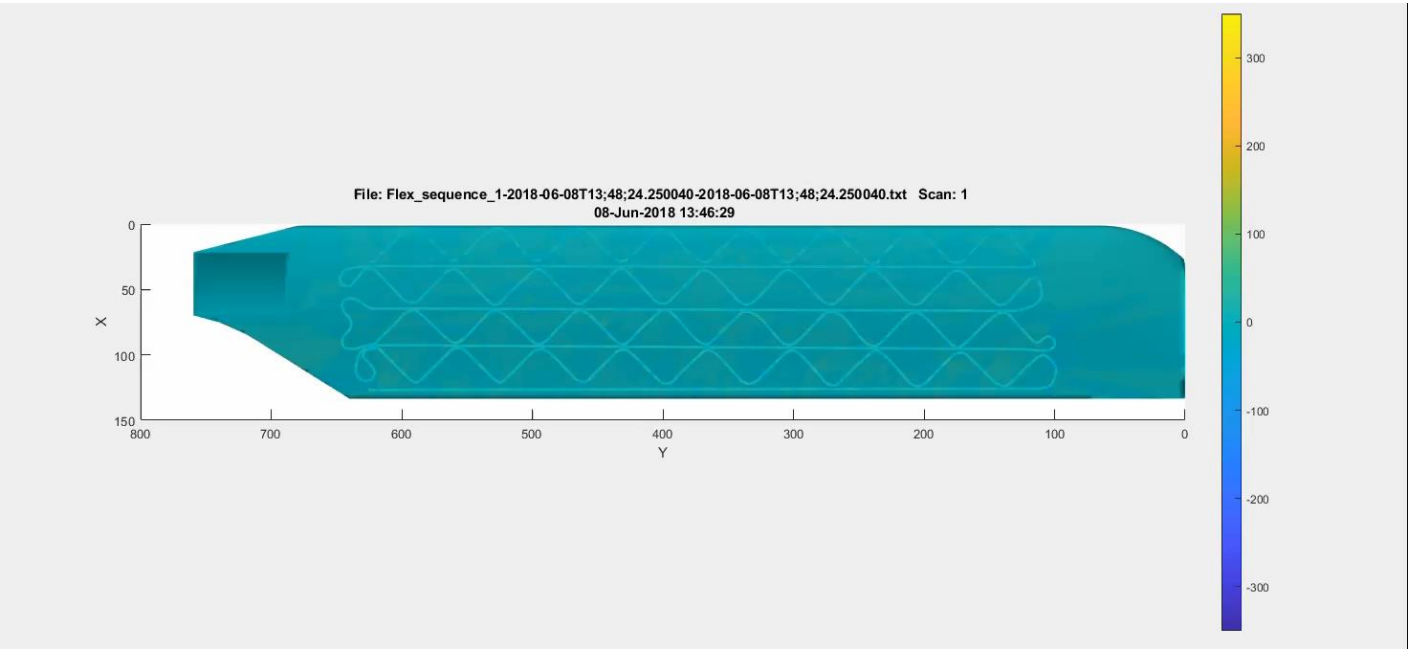
Interpolation Of Uniaxial Data → 2D Strain Map

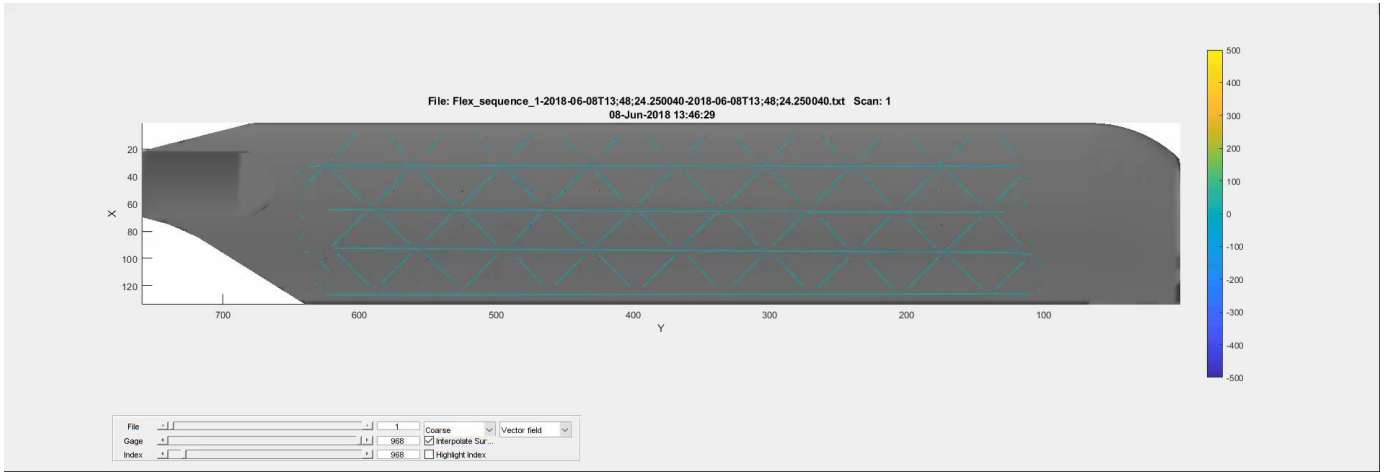
- Combine the individual interpolated values at any given location to determine the strain's principal axes



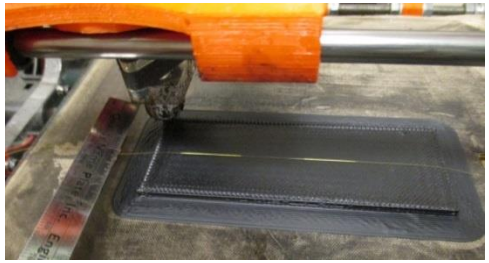


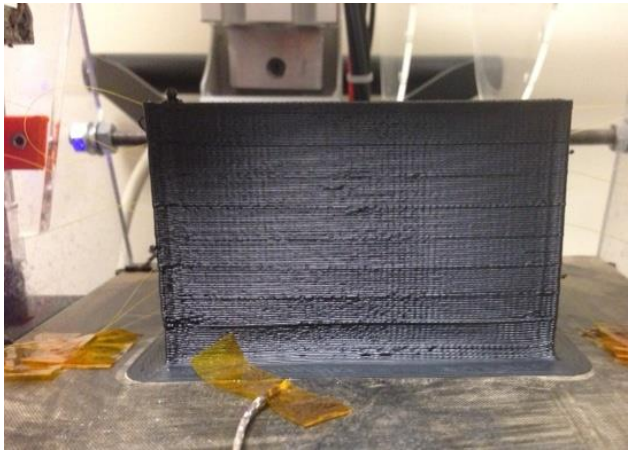
Blade Strain Rosette Video

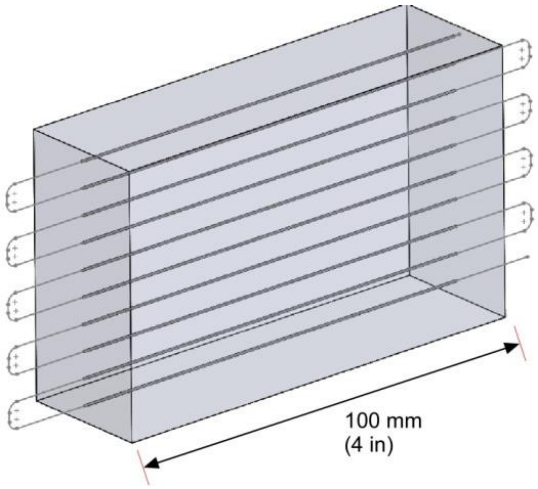


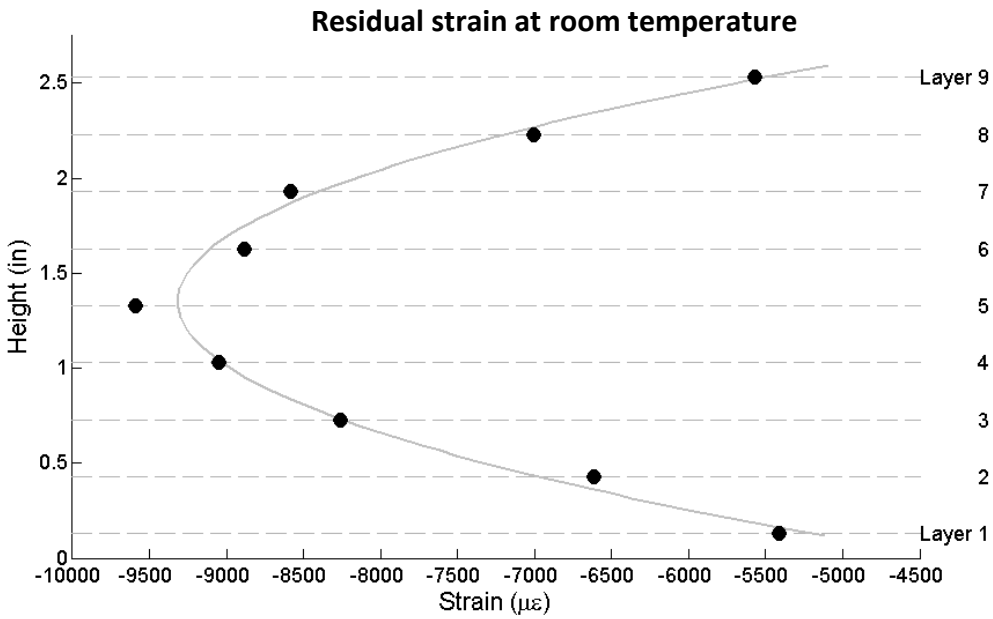


Additive Manufacturing



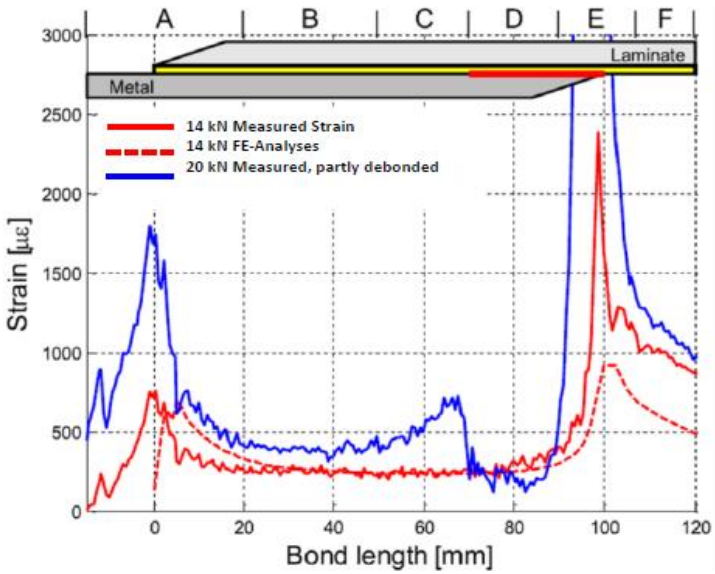




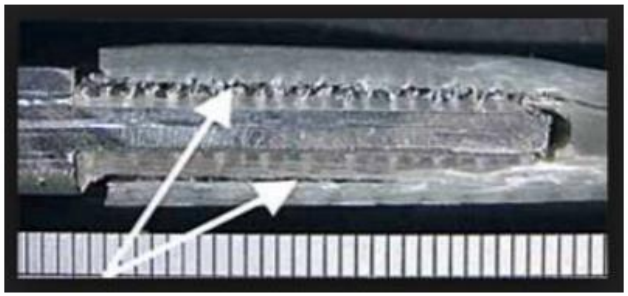


- Successfully embedded distributed strain sensor in 3D printed composite
- Residual strain show varying levels of strain through part, with maximum strain in mid-section

Bonded Joints



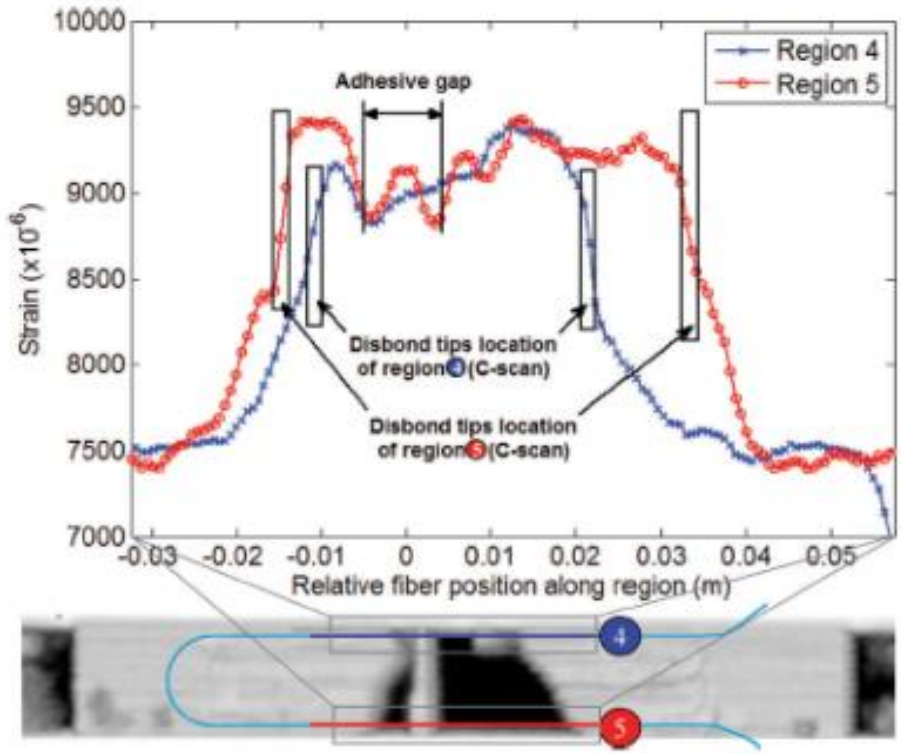
Data from embedded fiber sensor clearly showing a shifting strain concentration when damage develops within sample adhesive joint. The axial strain field calculated by Finite Element Analyses is shown for the undamaged specimen for comparison. (1)



Courtesy of TWI Ltd

Composite shear failure in a multi-material bonded joint

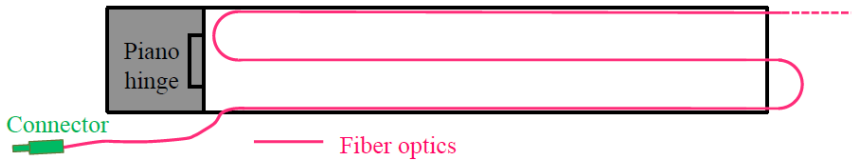
Develop a greater understanding of damage growth in bonded structures, to move away from chicken rivets



Reference 1: Figure 6. Strain distribution for regions 4 and 5 of the optical fiber after fatigue test and correlation with an image of C-scan inspection.

(1) Grave et al, Composites Part B 74 (2015) 138-146

Hybrid Composite-Metal Interfaces



A DCB specimen being tested at elevated temperature

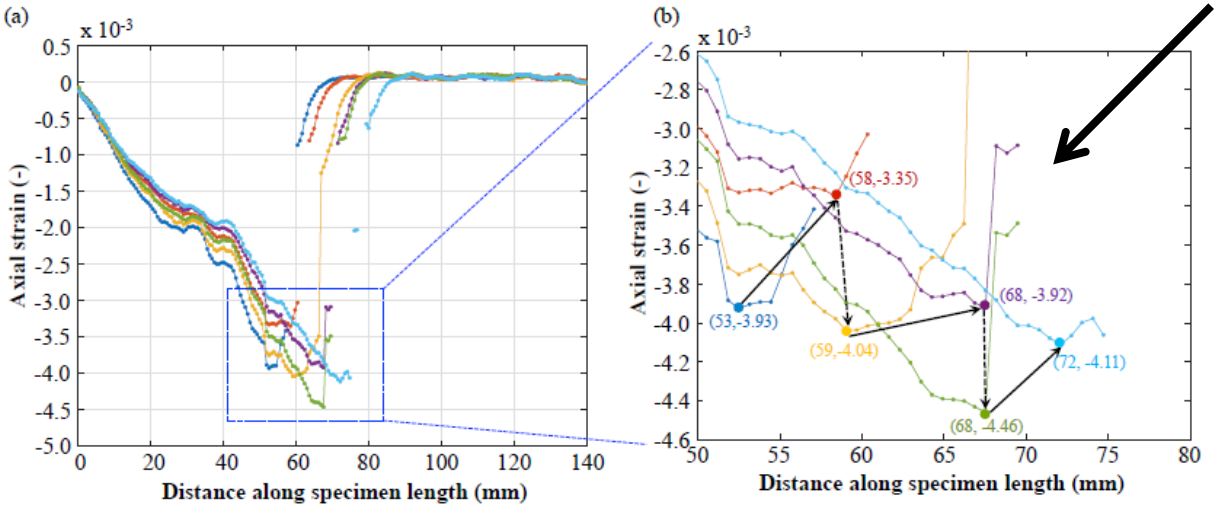


Figure 8: Distributed strain measured by fiber optics during a DCB test at 25°C.

- These tests looked at the crack propagation when the joint was pulled apart
- The test was set up per ASTM standard D5528
- The fiber sensor was surface-mounted
- The high density of fiber measurement points allowed them to see the <u>jagged advance-arrest</u> behavior of the crack growth

Truong, H., Martinez, M., Ochoa, O., Lagoudas, D. C. "An investigation on hybrid interface using on-line monitoring experiment and finite element analysis." 20th International Conference on Composite Materials, Copenhagen, July 19-24 2015.

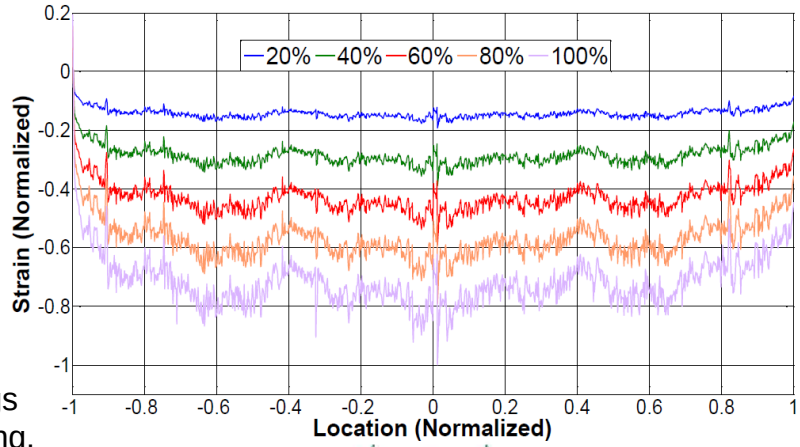
Structural Health Monitoring – Composite UAV

High Density Strain Measurements Used to Determine Structural Health

- A HD-FOS fiber is permanently installed in the wing of a UAV
- The wing is progressively loaded to 100% of maximum with data taken in 20% increments
- The data is analyzed with numerical techniques and compared to baseline data from a known good condition
- Through this comparison of data, degradation of structural integrity can be determined

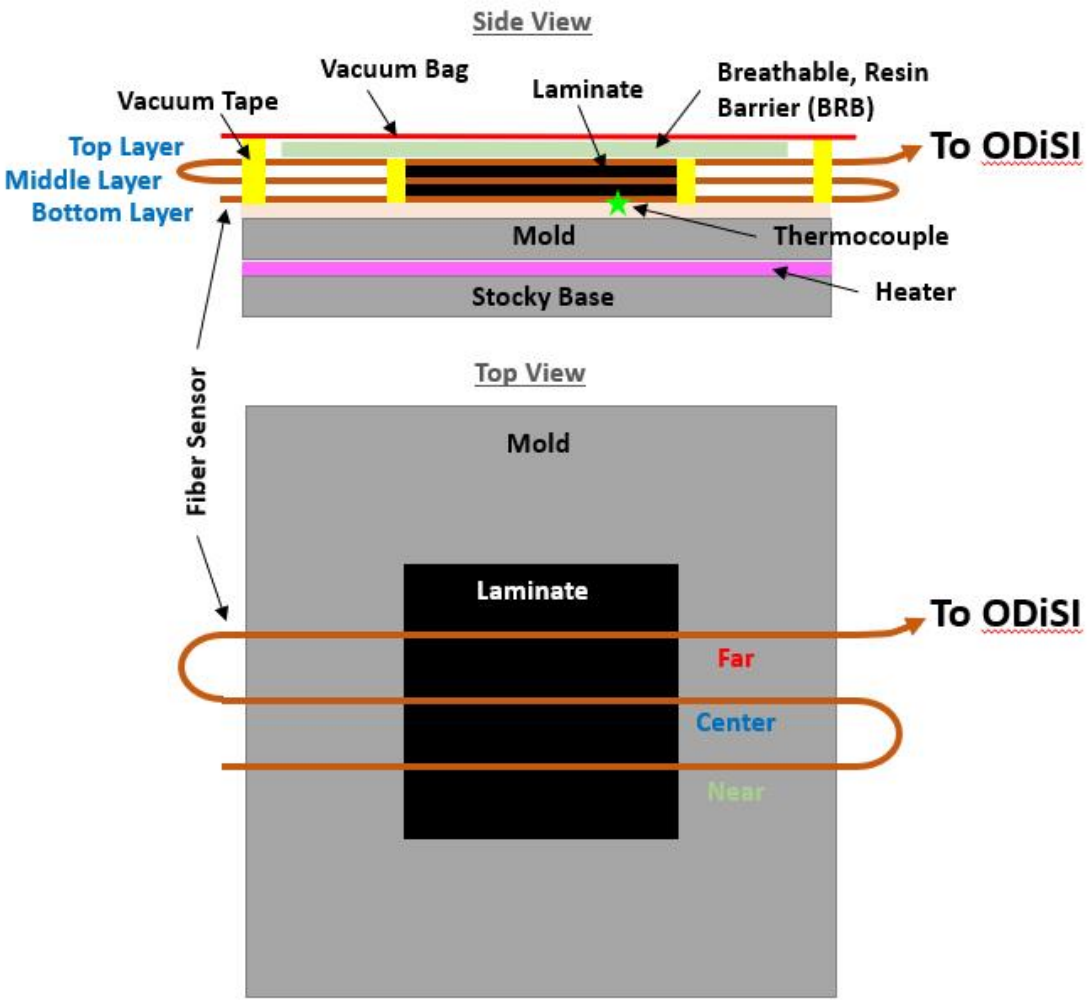
HD-FOS Sensors are Embedded in UAV Wing
In use over 5 years so far

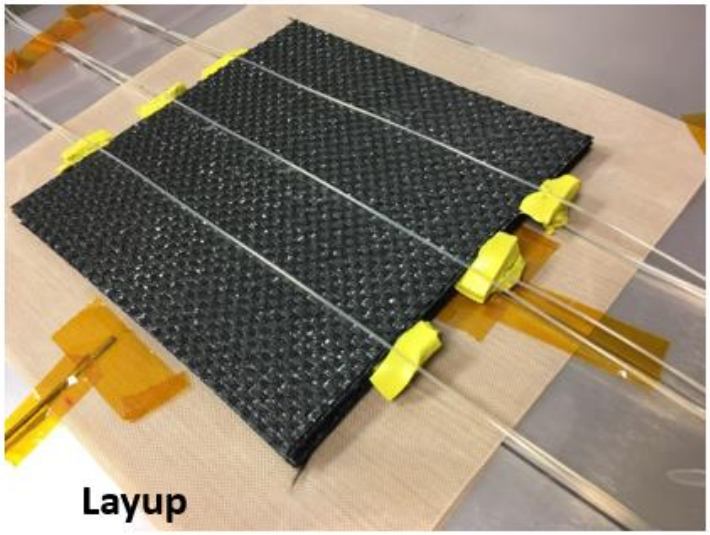
High Density Measurements are Taken as the Applied Load is Incremented

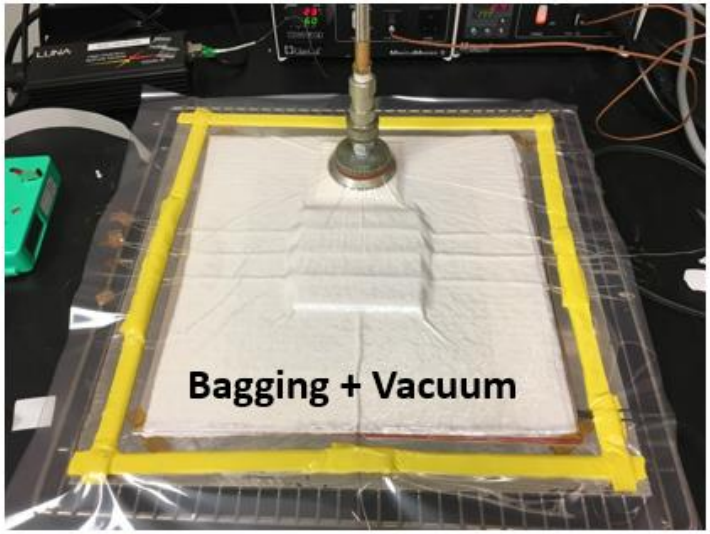


Kressel et. Al. Airworthiness Monitoring of the Wings of a UAV Fleet Using Fiber Optic Distributed Sensing. International Committee on Aeronautical Fatigue and Structural Integrity (ICAF) 2017

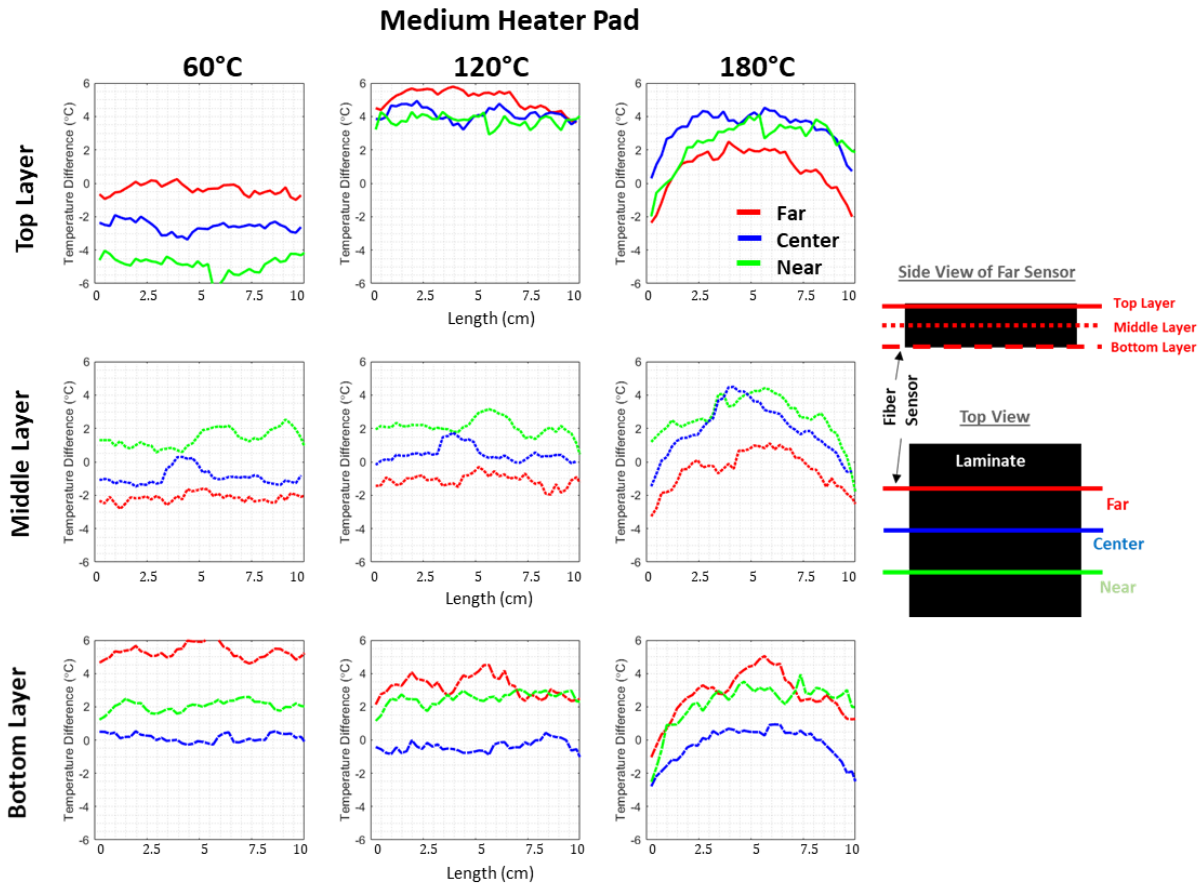
Measuring Uniformity of Cure Temperature







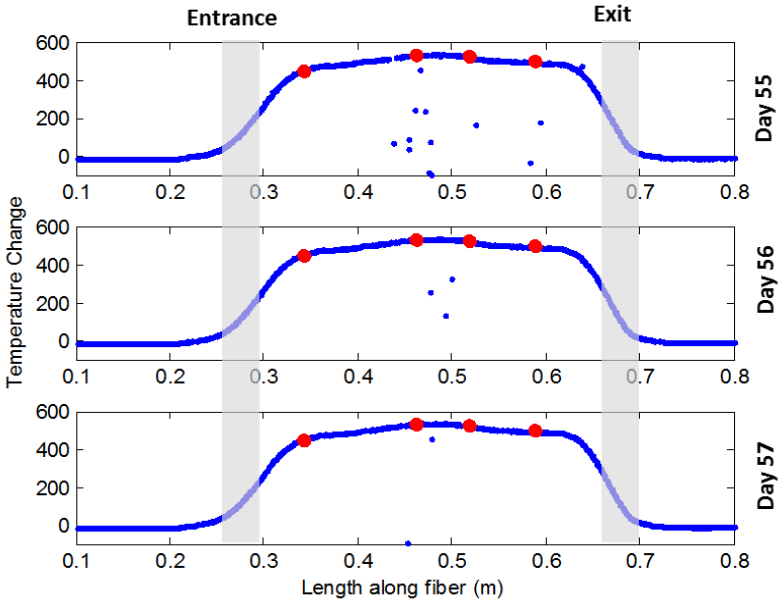
Measuring Uniformity of Cure Temperature



Profile of temperature difference across the panel heated with a Medium heater pad, relative to the temperature at the thermocouple location, at each of the 3 temperature plateaus. The temperature distribution is relatively uniform across the Medium pad during the manufacturing process.

High Resolution Thermal Profiling

- Furnaces can have cooler zones between the elements
- Capture the profile of a furnace in a single scan in less than a second
- See gradients, which may affect processing
- Real time monitoring to improve the uniformity and efficiency



Blue curve – ODiSI Thermal measurement of profile within oven shown on the left, Red points - RTDs

Summary

Our breakthrough Strain Sensing solutions allow materials, structures and systems to be seen like never before

- Provides high definition distributed strain map
  - Hundreds of sensing points per meter of fiber
- More cost-effective
  - Uses low-cost optical fiber as the sensor
  - Offers a single channel solution vs. multiple channels for strain gages
  - Easier to install
  - Strain: Fiber applies with a standard epoxy; does not require soldering of leads
- Validate CAE
  - Can see details that point sensors would miss
  - Fully characterize material properties and structural performance

Contact

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