Temporary Fiber Bragg Grating Sensors for Static and Dynamic Strain Measurements in Hypersonic Wind Tunnels

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Biography

- Research Associate – UNSW Canberra at ADFA | 2022 - Current
  - *Aerothermal vehicle shape distortion*

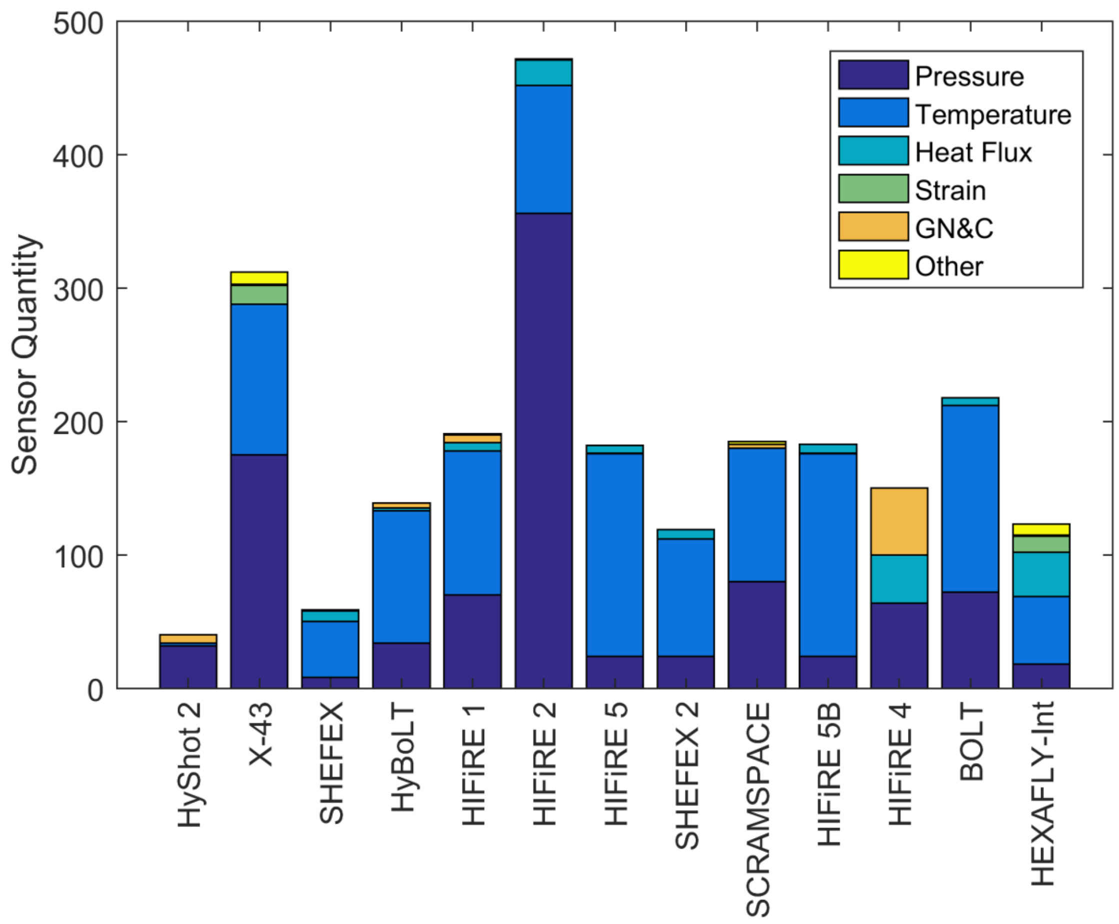
- Doctor of Philosophy Student (PhD Student) – UNSW Canberra at ADFA | 2021 - Current
  - *Non-destructive testing and structural health monitoring of hypersonic vehicles*

- Bachelor of Aerospace Engineering (Honours) – RMIT University | 2016 - 2020
  - *Acoustic phased arrays for structural passive health monitoring*

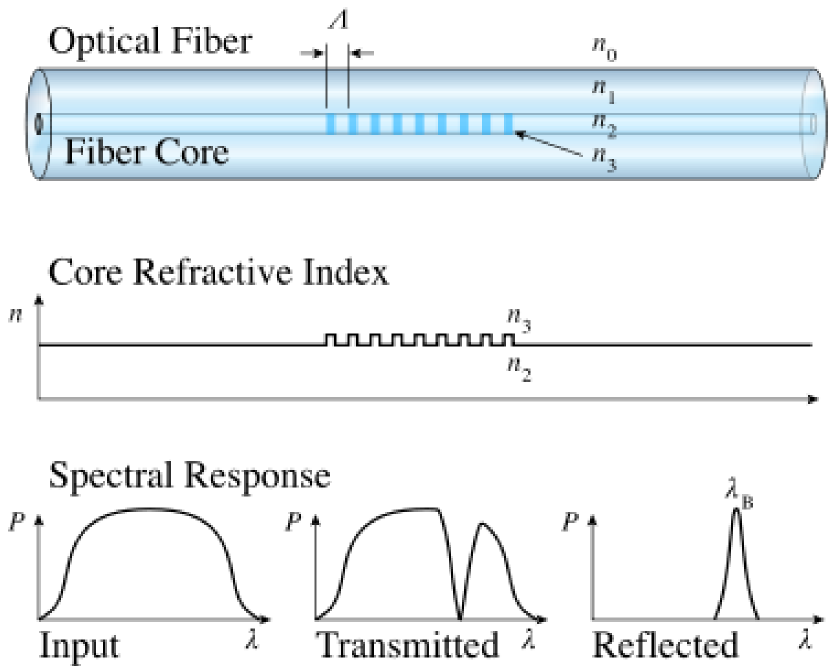
Hypersonic Instrumentation

- Hypersonic flight tests have limited instrumentation

- Wind tunnel technology focuses on “full-field” measurements but has poorer accuracy and sensitivity
  - DIC,
  - PSP,
  - etc.



Fiber Bragg Gratings



- Fiber Bragg Gratings (FBGs) are a distributed measurement technology that provide:
  - High sensitivity,
  - High accuracy,
  - Low cost,
  - Multiple measurands

- FBGs are an excellent alternative to traditional strain gauges and thermocouples

- Typically, are permanently fixed to the structure which limits reuse and increases cost

Fiber Bragg Gratings

- An FBG is composed of a series of periodically varying Bragg reflectors
- Acts as a dielectric mirror
- Variation in refractive index results in reflection of some wavelengths
  - Described by the Bragg wavelength

$$\lambda_B = 2\mathrm{n_e}\Lambda \tag{5.1}$$

$$\frac{\Delta\lambda_B}{\lambda_B} = k_\epsilon \epsilon + k_T \Delta T \tag{5.2}$$

$$k_\epsilon = 1 - \frac{1}{2} n^2 [p_{12} - \nu(p_{12} + p_{11})] \tag{5.3}$$

$$k_T = \left[1 - \frac{1}{2} n^2 (p_{11} + 2p_{12})\right] \alpha + \frac{\xi}{n} \tag{5.4}$$

Temporary Adhesive Tapes

- Exploration of temporary adhesives for wind tunnel tests to allow for reuse and lower cost

Japanese Washi

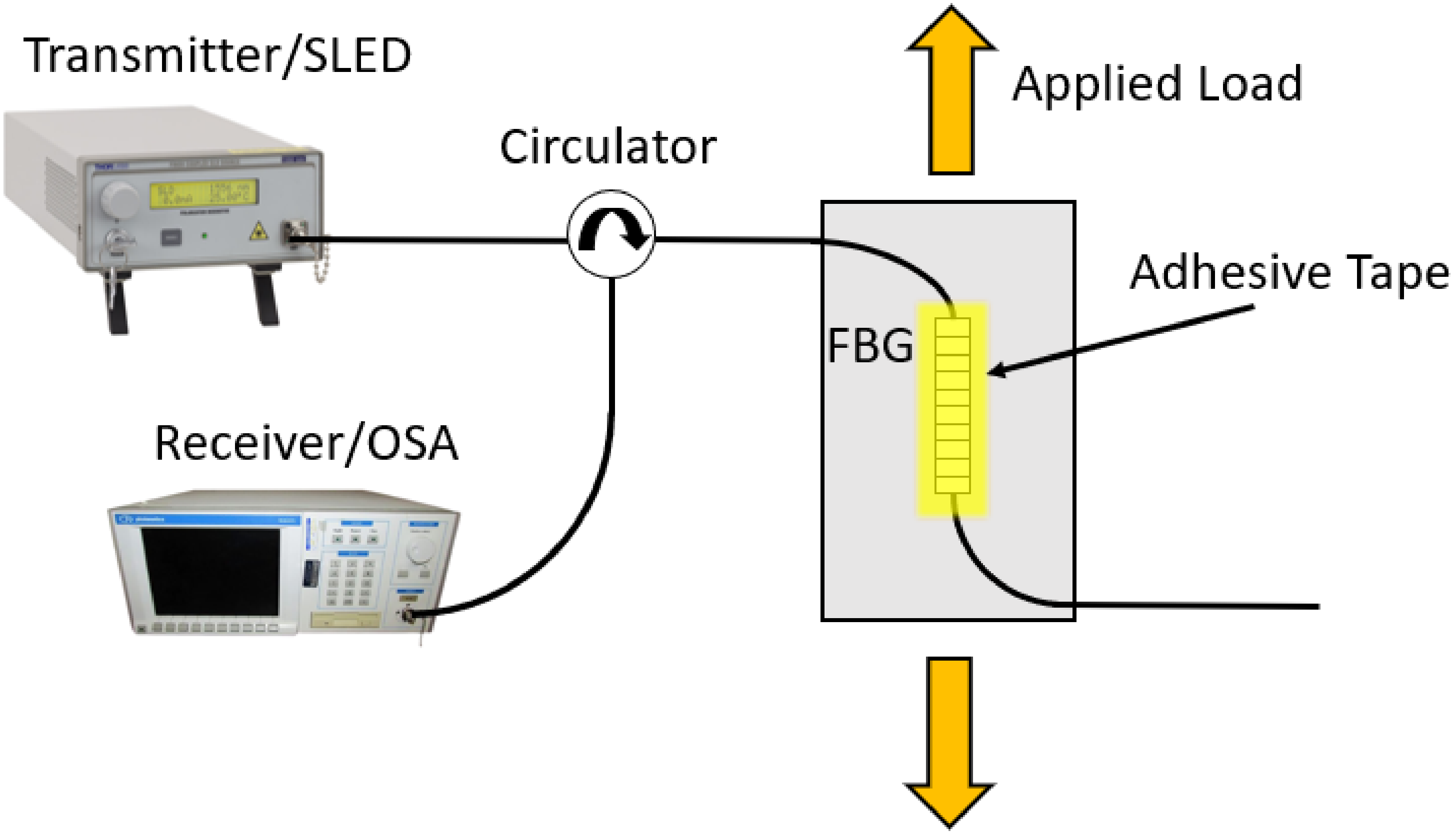
Fiberglass Backed Aluminium

Double-Sided Tissue

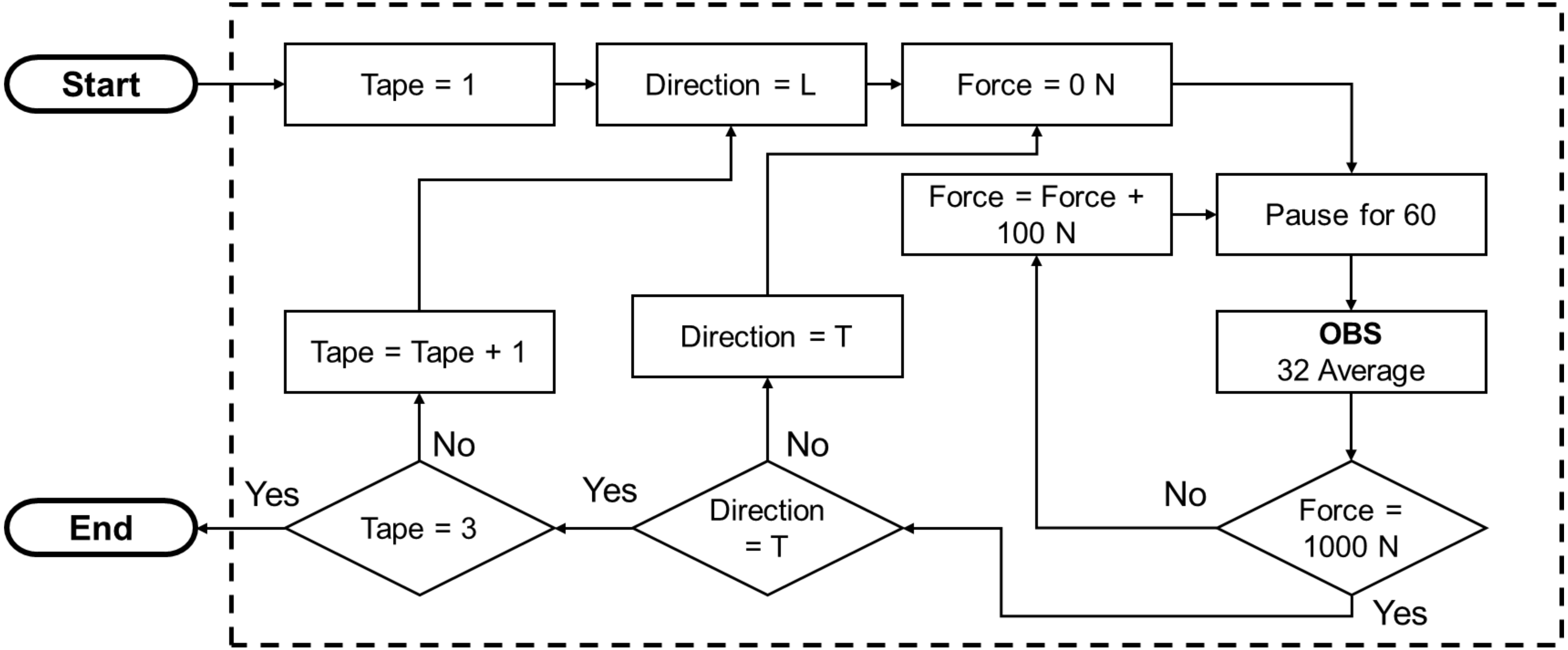
Methodology

- Broadband light source used to illuminate FBG which functions as a mirror

- Wavelength shift under strain is received by OSA



Experimental Flow Chart

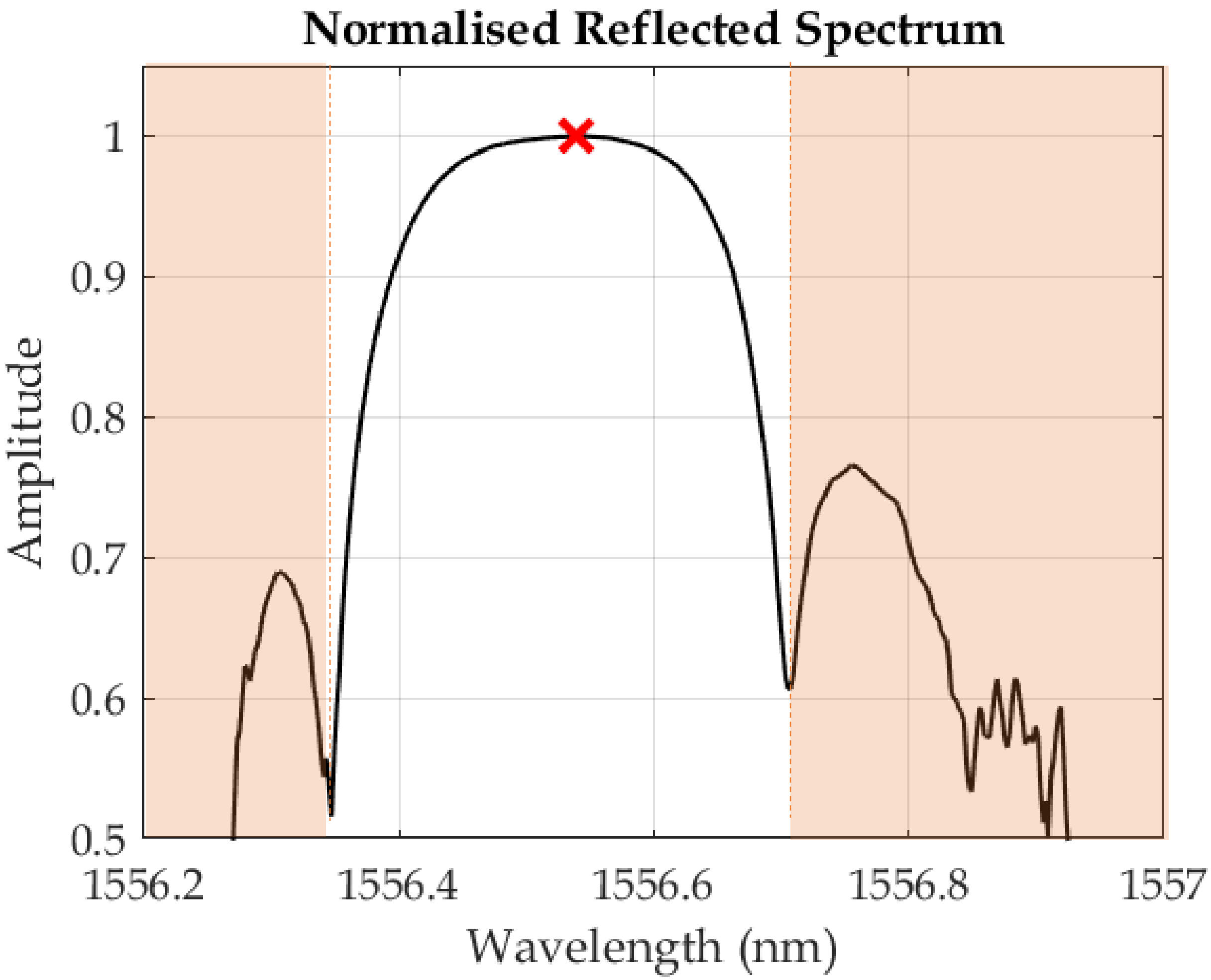


<u>Direction:</u>
L = Longitudinal
T = Transverse

<u>Tape:</u>
1 = Washi
2 = High-Temp
3 = Tissue

Raw Results

- FBG response was as expected, with visible side lobes
- Response exhibited flat peak which means simple maximum point tracking could not be used



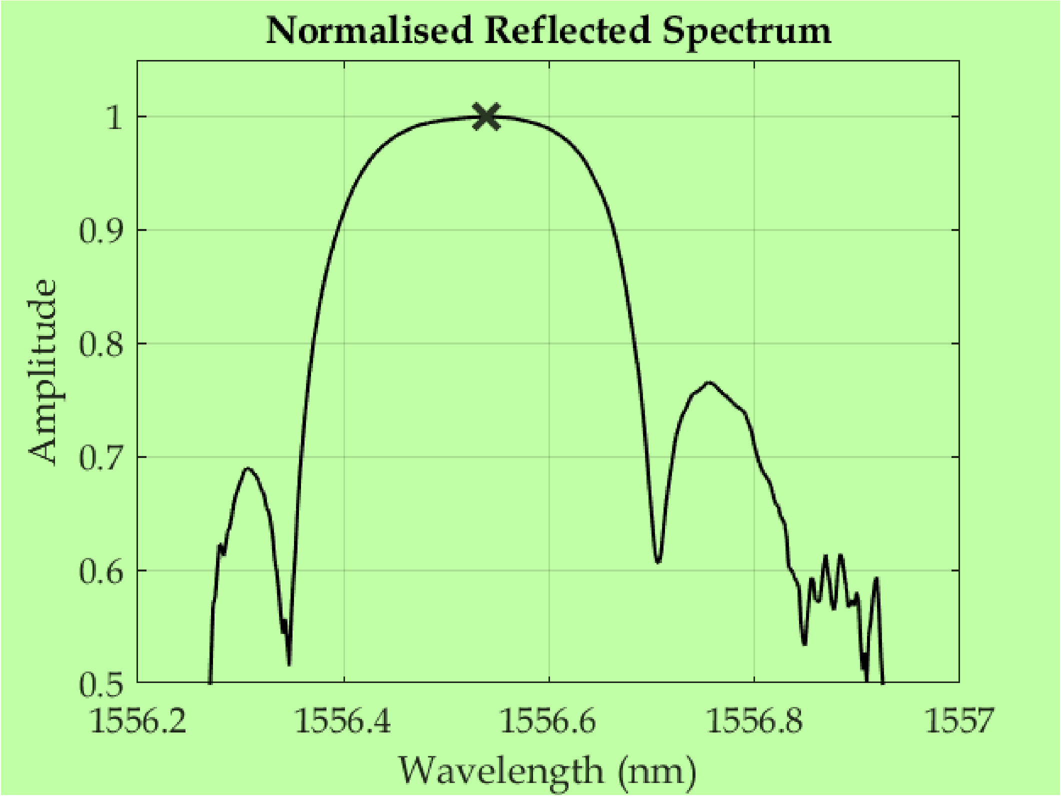
Cross-Correlation

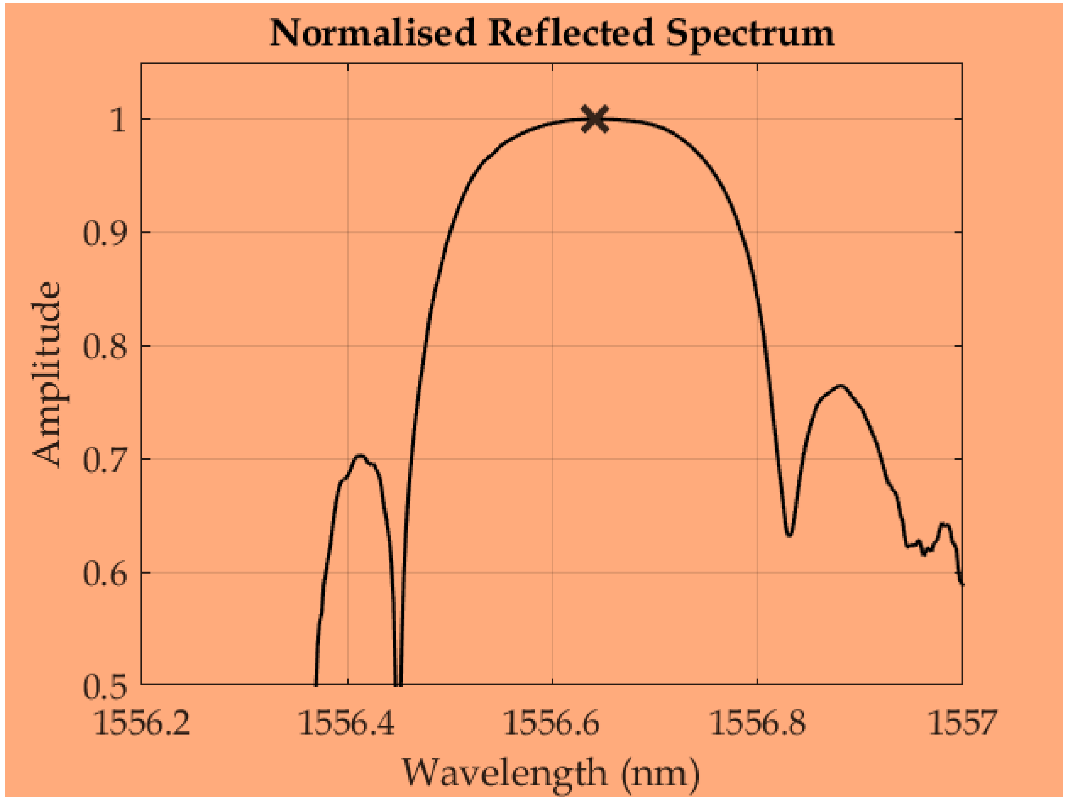
- Cross-correlation function was applied to successive spectra to estimate strain wavelength shift
- Main lobe were cropped out for analysis
- Spectrum broadening would be minimal, resulting in a mostly linear shift

$$(a_i \star a_j)[n] \triangleq \lim_{N\to\infty} \sum_{\lambda=-N}^{N} \overline{a_i[\lambda]} a_j[\Delta\lambda + \lambda]$$

$$\Delta\lambda = \max \mathbf{IFFT} \left| \overline{A_i[\lambda]} \cdot A_j[\lambda] \right| \; (4)$$

Cross-Correlation

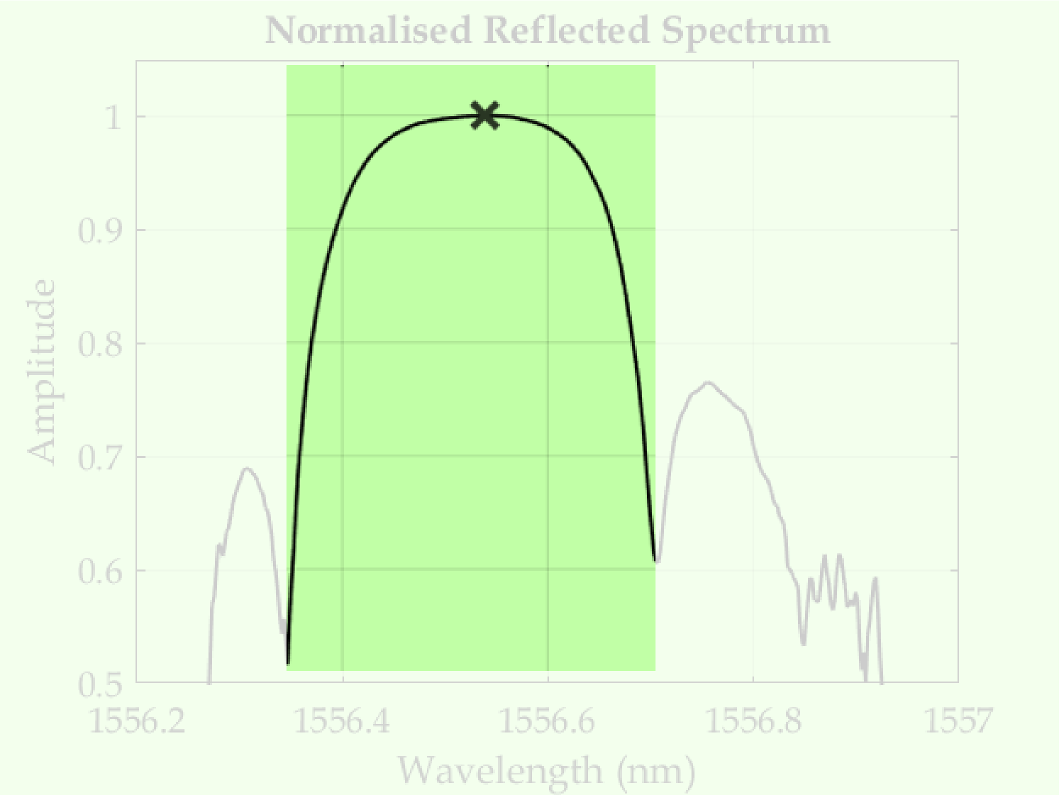


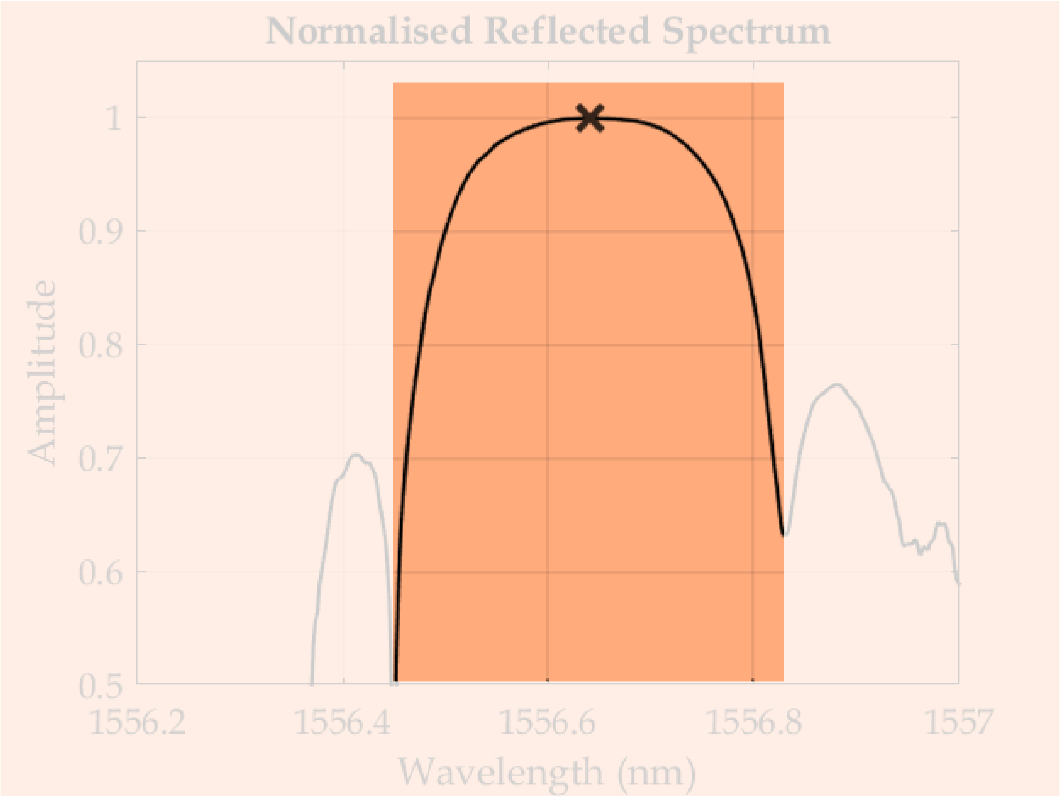


Spectra 1

Spectra 2

Cross-Correlation



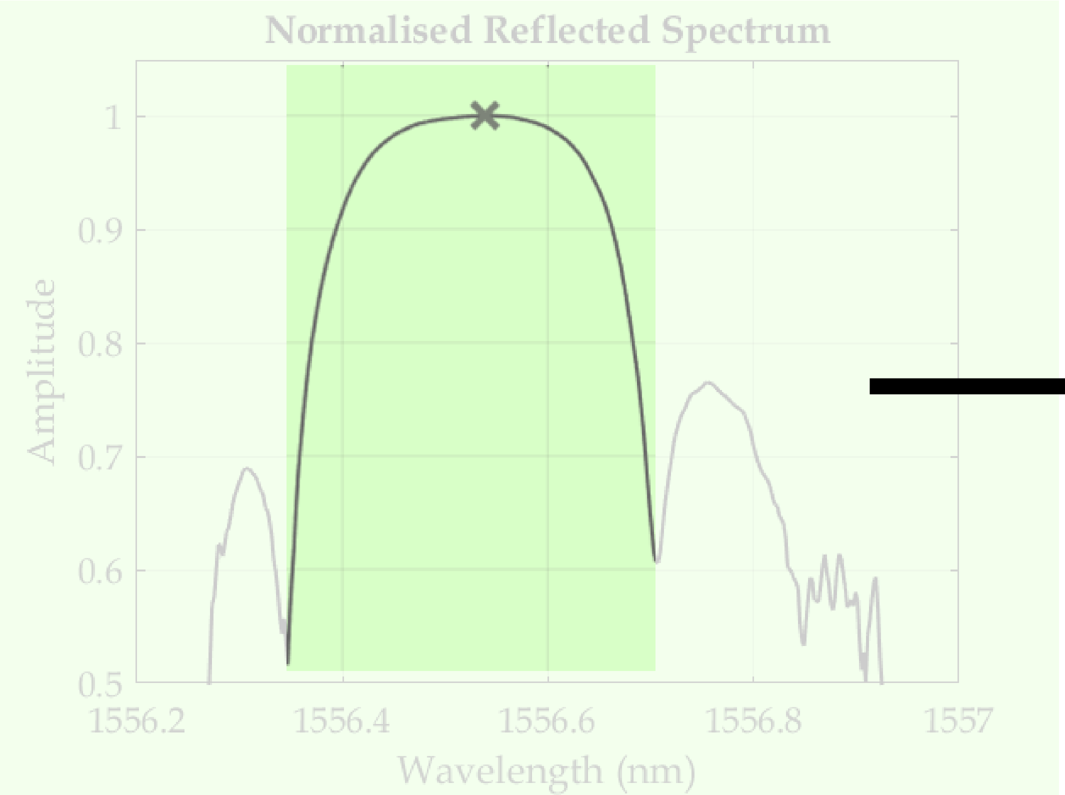


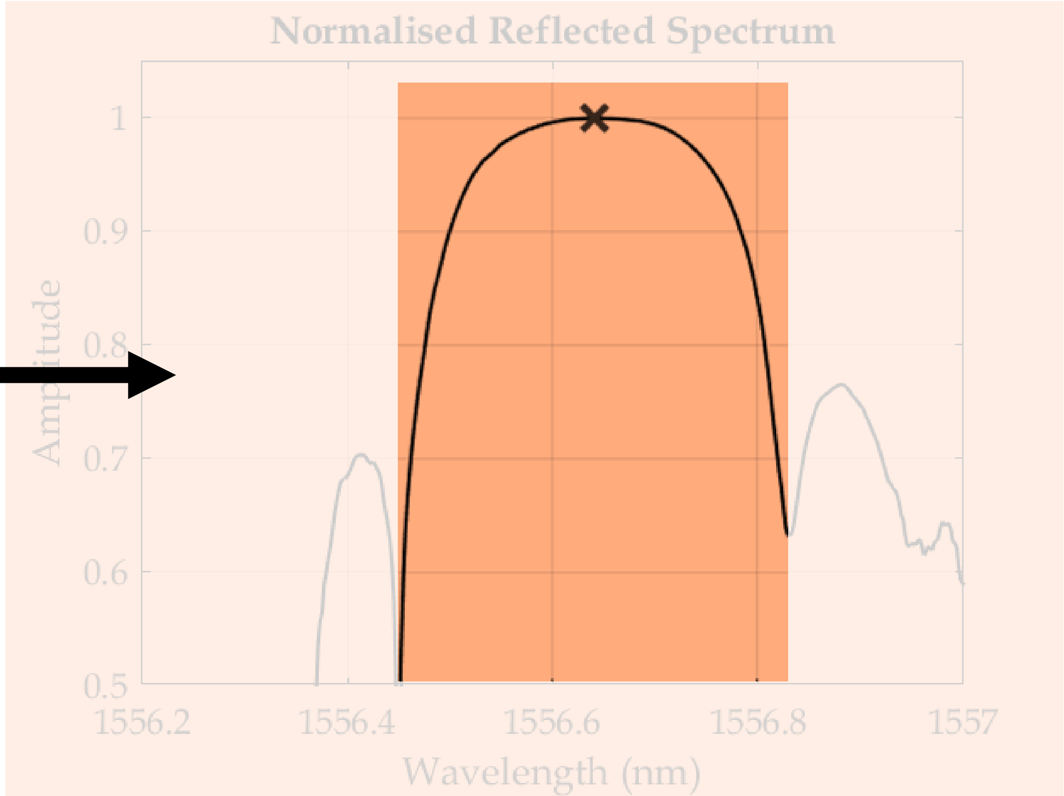
Spectra 1

Spectra 2

Extract main lobes

Cross-Correlation



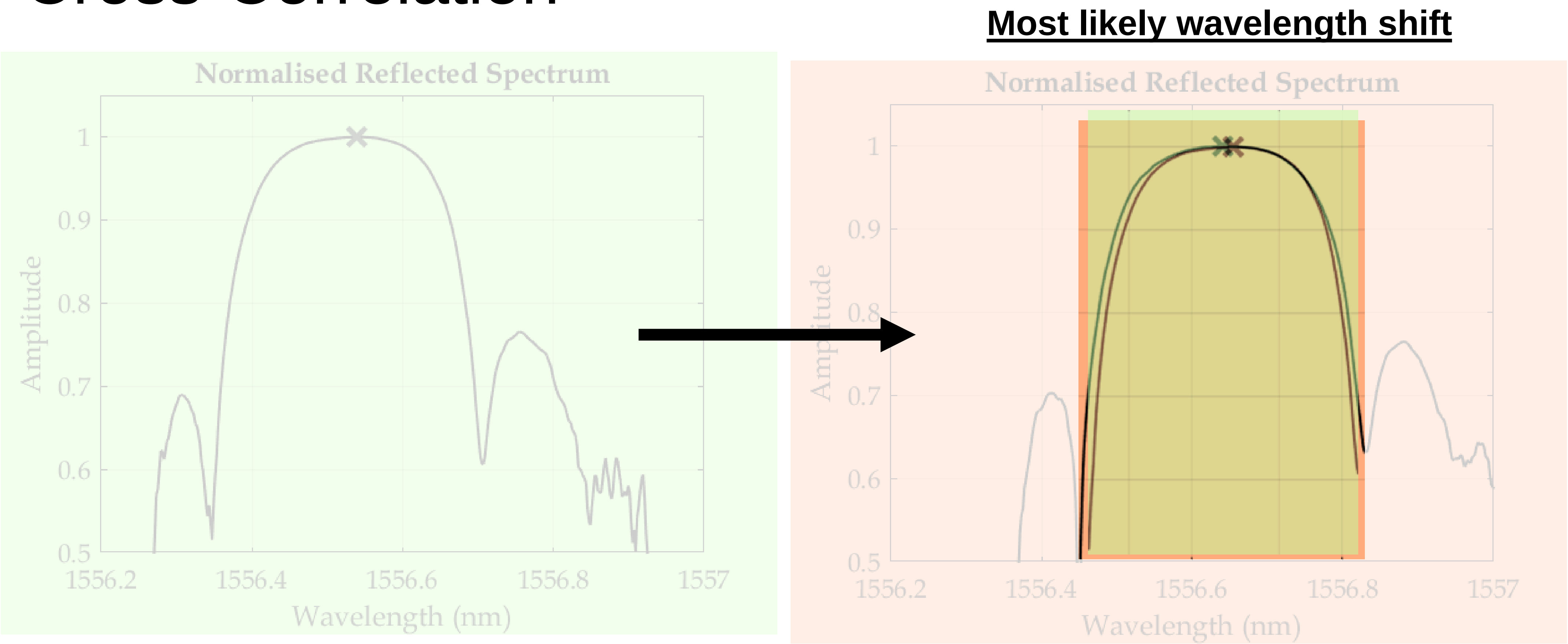


Spectra 1

Spectra 2

Shift spectra

Cross-Correlation



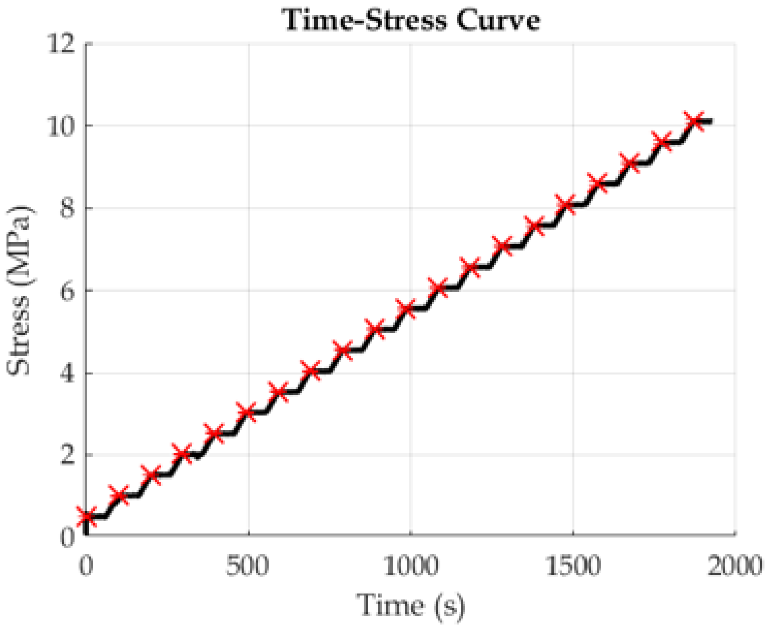
Spectra 1

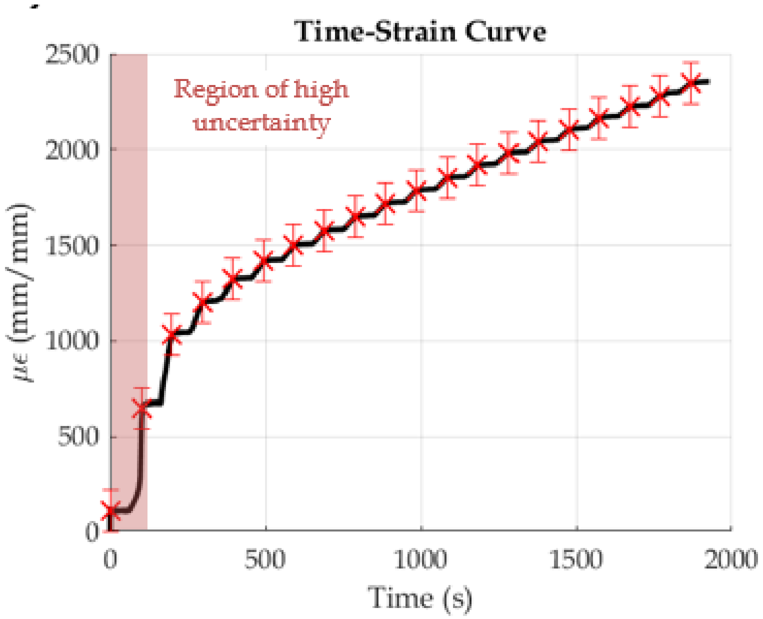
Spectra 2

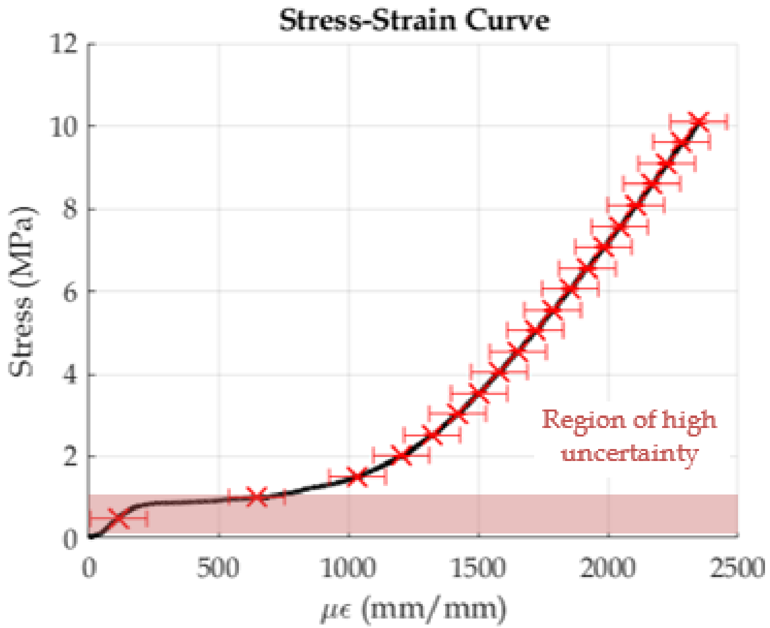
Find point of maximum correlation

Correlate with UTM Output

- Relate cross-correlated wavelength shifts with strain results from UTM to determine sensitivity







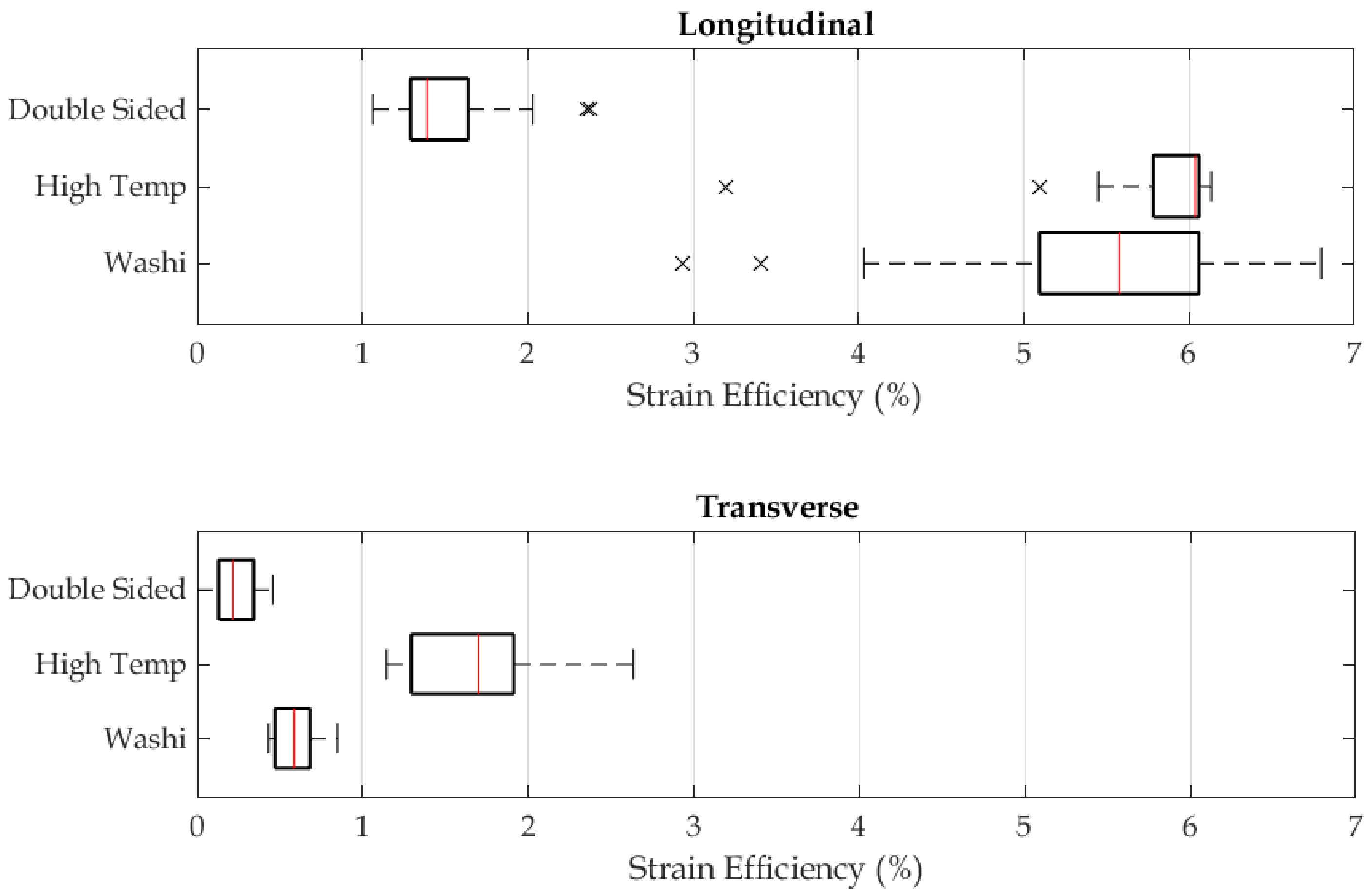
Processed Results

- Linearity of results is correlated to amount of slippage of the fiber
- Longitudinal results showed greater levels of linearity
- Double-sided tape (being pressure sensitive) showed poorest linearity

	Longitudinal			Transverse		
Tape	Linearity (R^2)	RSME	Sensitivity (pm/με)	Linearity (R^2)	RSME	Sensitivity (pm/με)
Washi	91.4 %	15.09	0.0834	71.2 %	4.314	0.0027
High Temp	98.5 %	5.364	0.0780	54.5 %	17.59	0.0091
Double-Sided	68.9 %	6.155	0.0163	41.4 %	3.661	0.0014

Strain Efficiencies

- High temperature tape showed greatest strain efficiency
- Washi tape also showed good efficiency and is a good lower cost alternative



Comparison

- All tapes showed very poor strain efficiency compared to permanent bonding
- Tape bonding, however, was successful
- Better methodologies and materials could be developed but this is a promising method for temporary bonding

	Longitudinal Strain Efficiency			Transverse Strain Efficiency		
Tape	Median	Maximum	Minimum	Median	Maximum	Minimum
Washi	5.577 %	6.799 %	4.034 %	0.5844 %	0.8468 %	0 %
High Temp	6.036 %	6.134 %	5.449 %	1.670 %	2.635 %	0 %
Double Sided	1.391 %	2.379 %	1.062 %	0.2158 %	0.4559 %	0 %
Adhesive						
Epoxy	99.20 %	NA	NA	NA	NA	NA
AB (Polyurethane)	93.80 %	NA	NA	NA	NA	NA
502 (Cyanoacrylate)	96.50 %	NA	NA	NA	NA	NA

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Conclusion

- Study can be expanded to a wider range of adhesives - thermoplastics
- More instrumentation to reduce measurement uncertainty (laser extensometers)
- Tape bonding of FBGs proves suitable

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