Comparison of Moiré Interferometry & Image Correlation Deformation Measurement Techniques

David Mollenhauer
Air Force Research Laboratory

John Tyson
Trilion Quality Systems

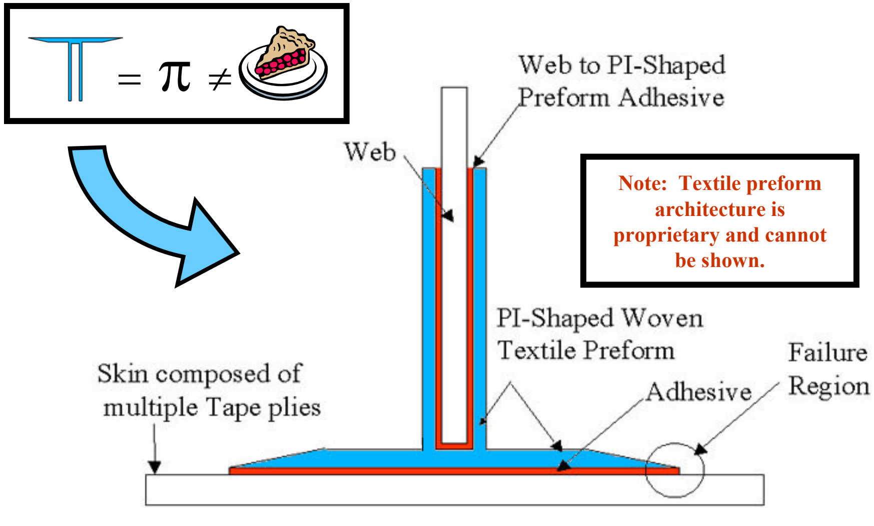
Background

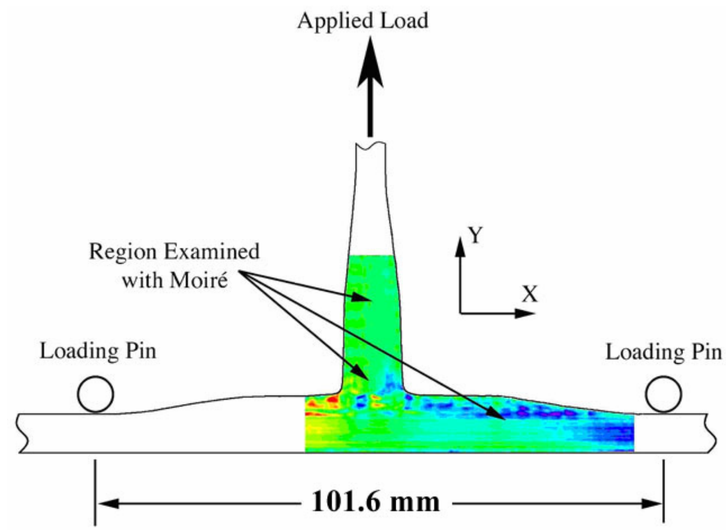
- **Increasingly complex fiber architectures are becoming a reality in aerospace composite structures of interest to the U.S. Air Force and DoD.**
- **Full-field experimental deformation data on a sub-bundle level of spatial resolution is …**
  - **necessary for understanding behavior of these material systems.**
  - **required for validation of bundle-level material modeling.**

Objective

- **Compare results from the relatively new image correlation method with the well established moiré interferometry technique.**

Specimen Configuration, Fiber Architecture, and Mechanical Loading



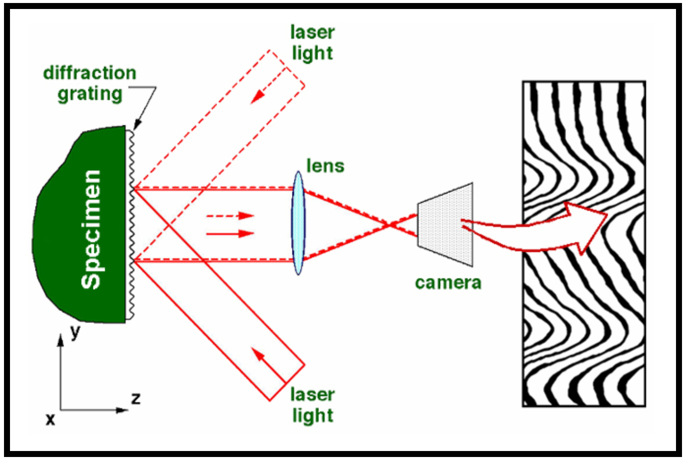


Comparison Procedure

- Moiré interferometry test conducted on extremely complex fiber architecture structural joint.
  - testing results in very high spatial resolution displacement data set.
- Digital image correlation (Trilion Quality System's "Aramis") test also conducted on the same specimen in the same loading fixture.
  - analysis results in less dense displacement data point distribution.
- Moiré data resampled to match the Aramis data point distribution for a "fair" comparison.

Experimental Displacement Measurement Techniques

Moiré Interferometry



Displacements

$$U(x,y)=\frac{1}{f}N_x(x,y)$$

$$V(x,y)=\frac{1}{f}N_y(x,y)$$

In-Plane Strains

$$\varepsilon_x=\frac{\partial U}{\partial x}=\frac{1}{f}\left[\frac{\partial N_x}{\partial x}\right]$$

$$\varepsilon_y=\frac{\partial V}{\partial y}=\frac{1}{f}\left[\frac{\partial N_y}{\partial y}\right]$$

$$\gamma_{xy}=\frac{\partial V}{\partial x}+\frac{\partial U}{\partial y}=\frac{1}{f}\left[\frac{\partial N_y}{\partial x}+\frac{\partial N_x}{\partial y}\right]$$

Phase-Shifting Analysis

$$I_1(i,j) = A(i,j) + B(i,j)\ \mathrm{Cos}(\Phi(i,j) + \Delta_1)$$

$$I_2(i,j) = A(i,j) + B(i,j)\ \mathrm{Cos}(\Phi(i,j) + \Delta_2)$$

•

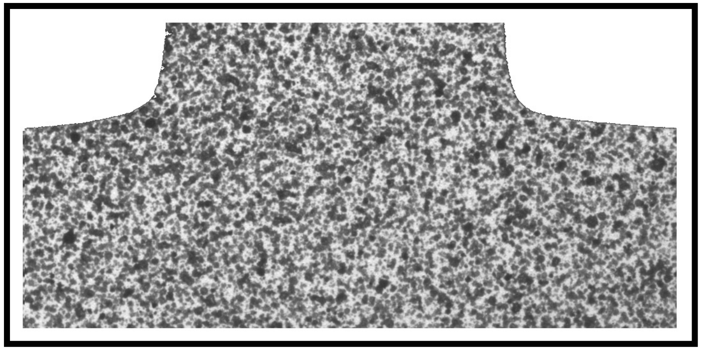
•

$$I_N(i,j) = A(i,j) + B(i,j)\ \mathrm{Cos}(\Phi(i,j) + \Delta_N)$$

Digital Image Correlation

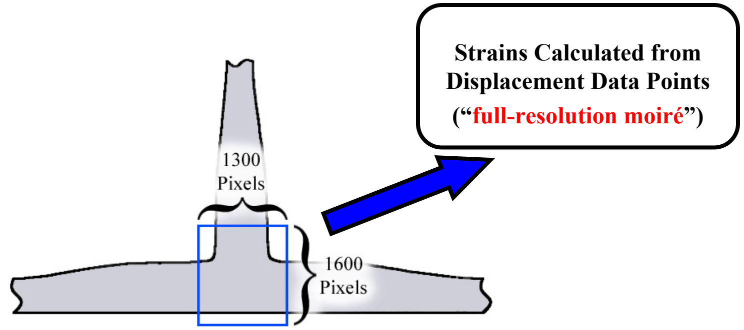
(Aramis from Trilion Quality Systems)

Speckle Pattern Correlation
(3-D Surface Deformation)



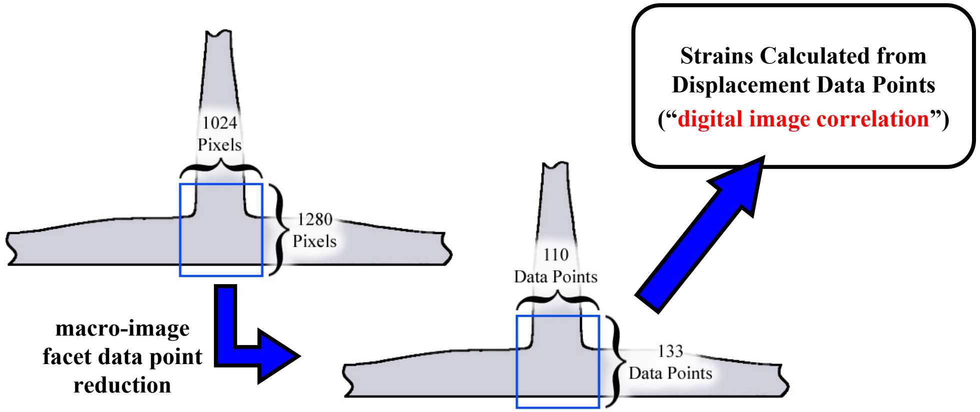
Camera Field of View (Moiré)

- Moiré interferometry test conducted as usual (several days for testing - including specimen preparation).
- Magnification chosen with enough spatial resolution to reveal sub-fiber bundle resolution (~13μm/pixel).
- Phase-shifting analysis gives 1-to-1 displacement point per pixel.



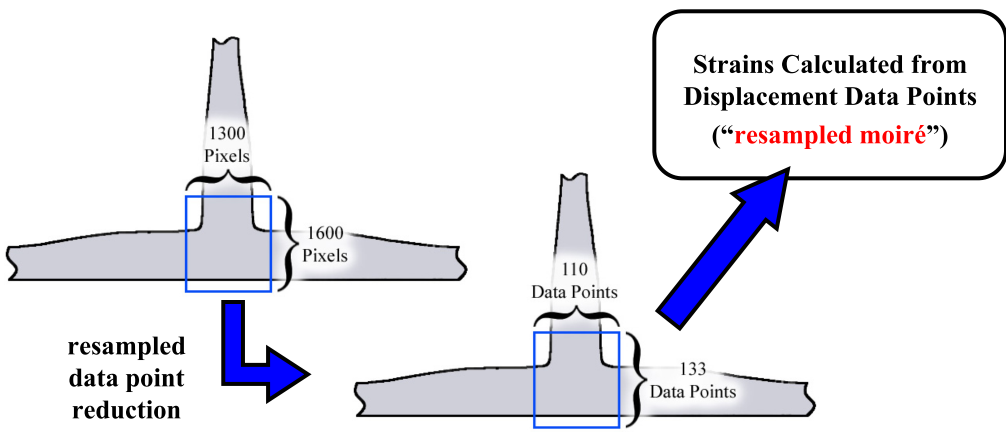
Camera Field of View (Aramis)

- Aramis test conducted as usual (several hours - including specimen preparation).
- Magnification chosen to cover central region of specimen.
- Overlapping macro-image facets give ~9.5 pixels per displacement point (~150 μm/data point).



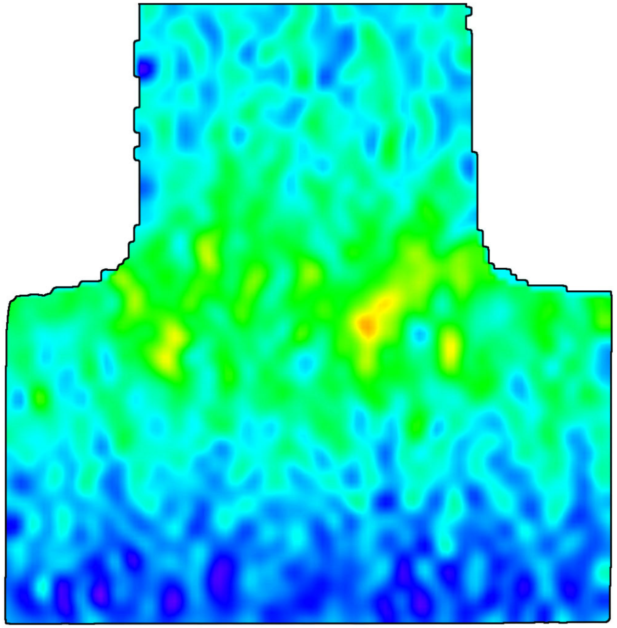
Data Points (Resampled Moiré)

- Full-resolution moiré displacement data resampled to match the digital image correlation data.
- Resampled data gives ~9.5 pixels per displacement point (~150 μm/data point).

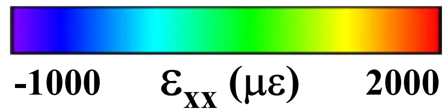


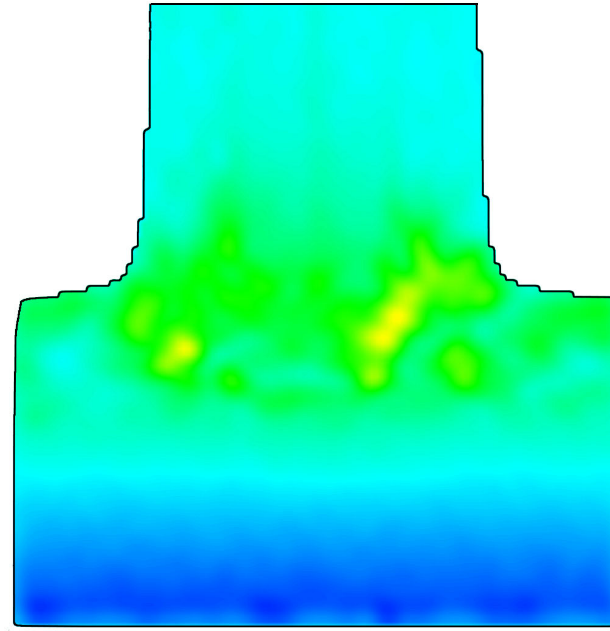
Comparison of Strain Results

(ε_{xx} Strain Component)

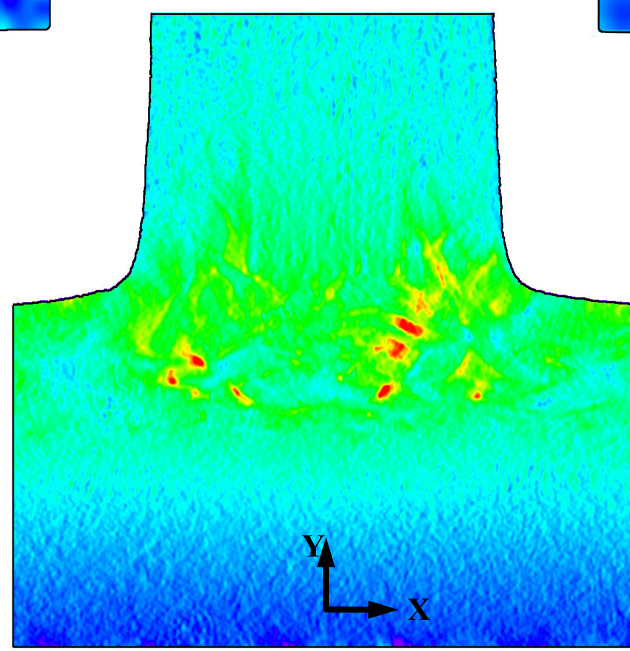


Digital Image Correlation





Resampled Moiré Interferometry



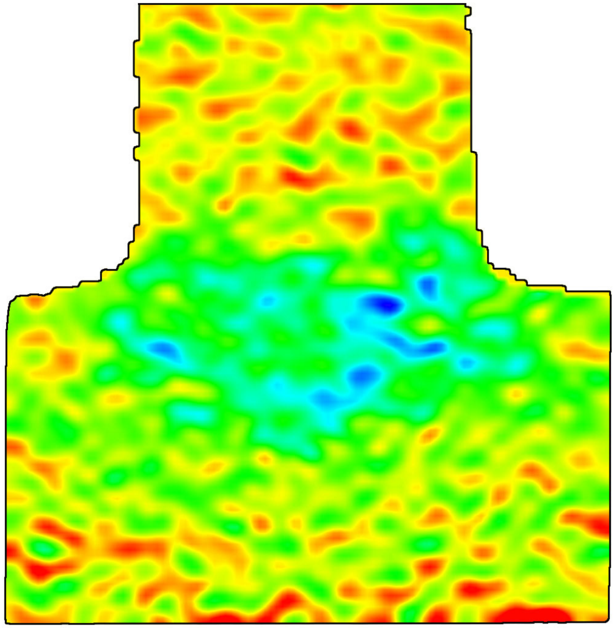
Moiré Interferometry

- **All strain distributions resulting from *digital image correlation* compare closely in overall magnitude with *resampled moiré* and *full-resolution moiré*.**

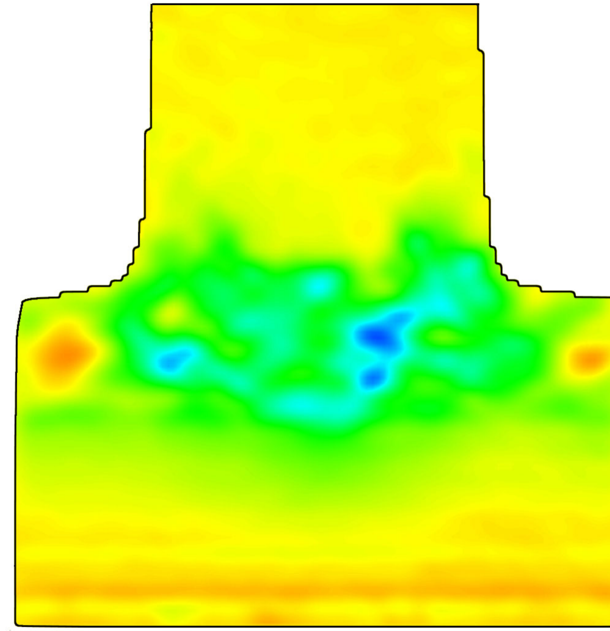
- ***Digital image correlation* strain distributions contain larger scale "noise" than *moiré*.**
- **"Hot spots" in *digital image correlation* data generally match well in location with *resampled moiré* and, to a lesser extent, with *full-resolution moiré*.**

Comparison of Strain Results

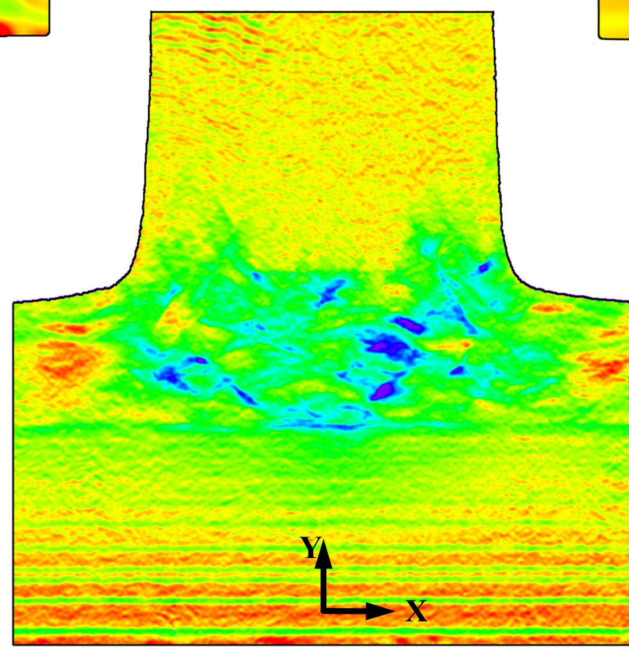
(ε_{yy} Strain Component)



Digital Image Correlation



Resampled Moiré Interferometry



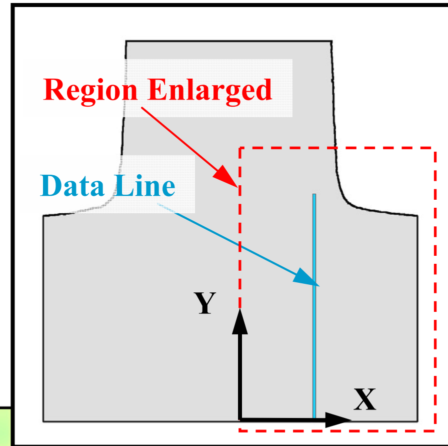
Moiré Interferometry

- **All strain distributions resulting from *digital image correlation* compare closely in overall magnitude with *resampled moiré* and *full-resolution moiré*.**

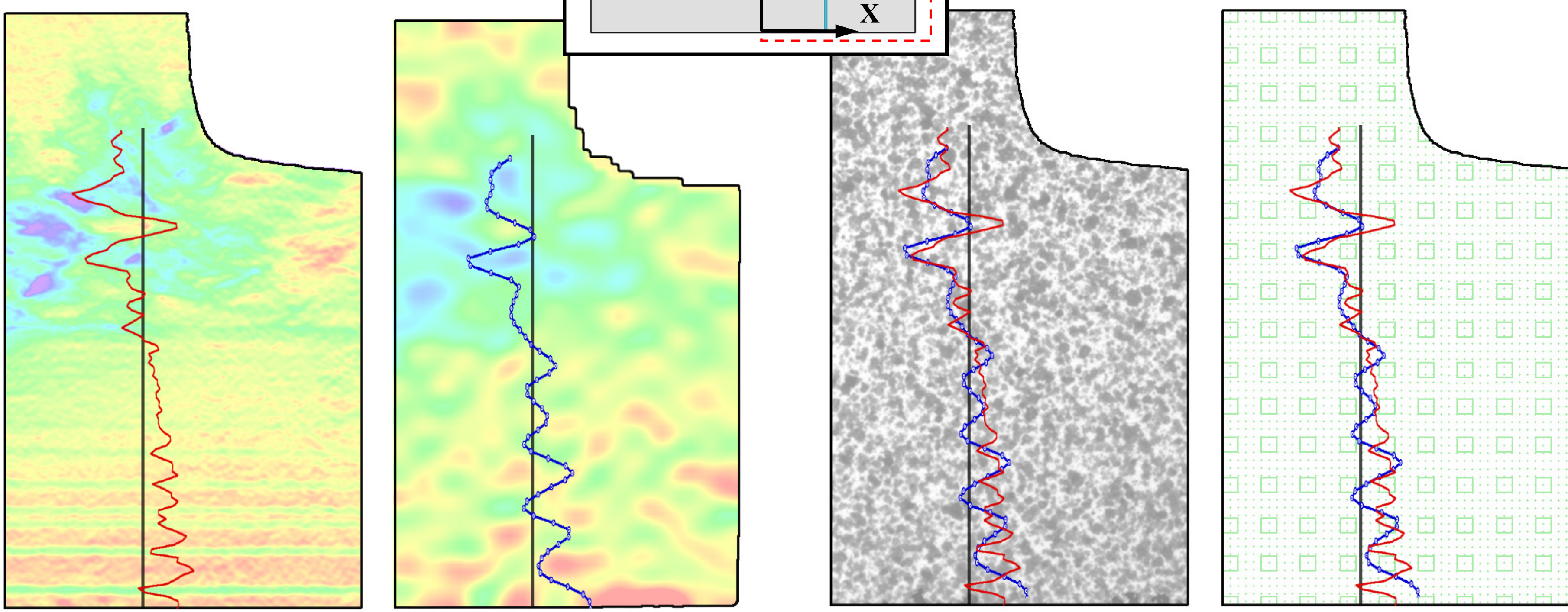
- ***Digital image correlation* strain distributions contain larger scale "noise" than *moiré*.**
- **"Hot spots" in *digital image correlation* data generally match well in location with *resampled moiré* and, to a lesser extent, with *full-resolution moiré*.**

Comparison of Aramis & Full-Resolution Moiré

- Comparisons of digital image correlation with full-resolution moiré data revealed some local differences in the measurements at a geometric scale on the order of a ply thickness.



- Likely causes include…
  - too coarse speckle pattern
  - macro-image facet effects (size and overlap)

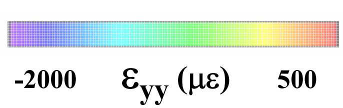


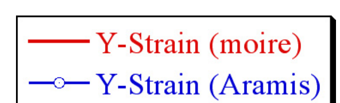
ε_{yy} - Moiré Results

ε_{yy} - Aramis Results

ε_{yy} - Results with Speckle Pattern

Data Points & Representative Facets





Discussion of Results

- **From an overall qualitative perspective, digital image correlation produced results very similar to the resampled moiré interferometry data.**
  - **Local variations in strain due to the fiber architecture, shown in the moiré data, were found in the Aramis data.**
  - **The Aramis data contained additional variations that were not associated with the underlying fiber architecture.**
- **Comparisons of digital image correlation with full-resolution moiré data revealed some local differences in the measurements at a geometric scale on the order of a ply thickness.**
  - **Likely causes include…**
    - **too coarse speckle pattern**
    - **macro-image facet effects (size and overlap)**

Summary / Conclusions

- **Comparison between digital image correlation and moiré interferometry was conducted using a composite T-joint with extremely complex fiber architecture.**
- **Overall, the digital image correlation results were comparable to the moiré results with a bit more noise and local variations missed.**
- **Moiré interferometry provides extremely fine spatial resolution deformation results…**
  - **Limited to flat (or singly curved) specimens**
  - **In-plane displacements only**
  - **Relatively skill/time intensive**
- **Digital image correlation provides full-field deformation results at a reduced spatial resolution..**
  - **Not limited by specimen shape**
  - **Provides 3 components of displacement**
  - **Relatively easy and quick to use**