3-Dimensional Non-Contact Optical Strain Measurements for Structures Evaluation and Optimization

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Introduction

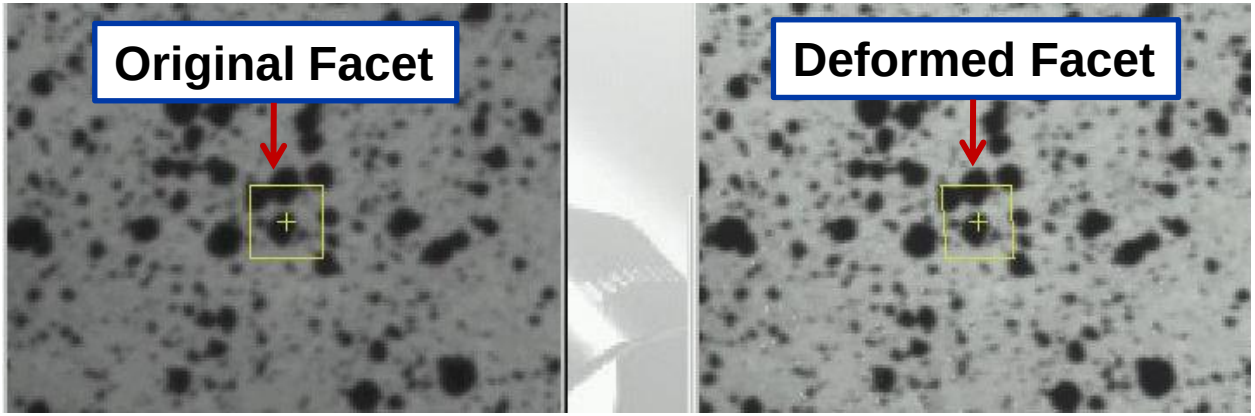
- **Introduce Aramis**
  - Aramis basics
  - Dot pattern application
  - Boeing Applied Physics Lab system
  - Operation modes and tests
- **When and how we use Aramis**
  - Micro-Aramis
  - Comparison to FEM
  - Strain gauge replacement
    - Extreme environments
    - Large test matrix
    - Modulus calculations
    - Large Notch Compression load balance
- **Conclusions**

Aramis introduction

- **Aramis is a 3D non-contact optical Digital Image Correlation (DIC) system**
- **Measures deformations, calculates strains.**
- **Useful for:**
  - structures testing
  - structural model and allowable development
  - advanced strain/deformation correlation algorithms

- **Extensively used by Boeing Research & Technology as part of Material State Awareness approach to NDE**
- **Flexible, portable system.**
- **Used on a wide variety of materials, sample sizes and environments for a variety of applications.**

Aramis basics



Photos courtesy of John Tyson, Trilion

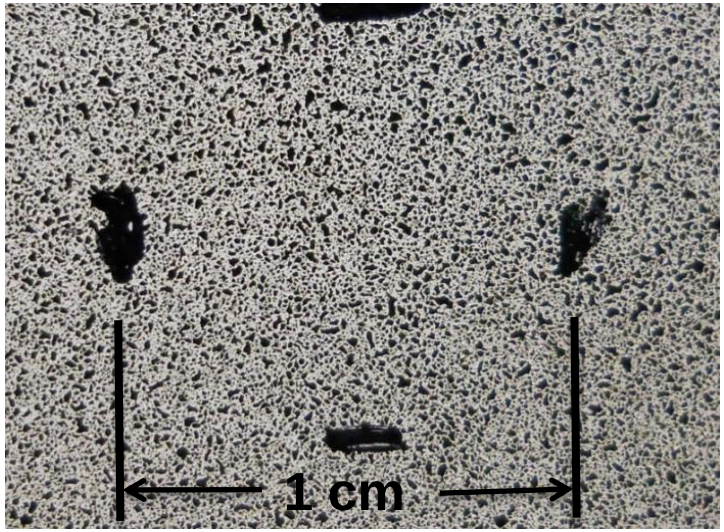
- **Aramis uses pattern recognition between original and deformed facets**
- **Calculates displacement and deformation based on facets**
- **Calculates strains based on the deformation**
- **Requires marking un-deformed specimens with a speckle pattern**
- **Scanned before, during, and after the deformation sequence.**

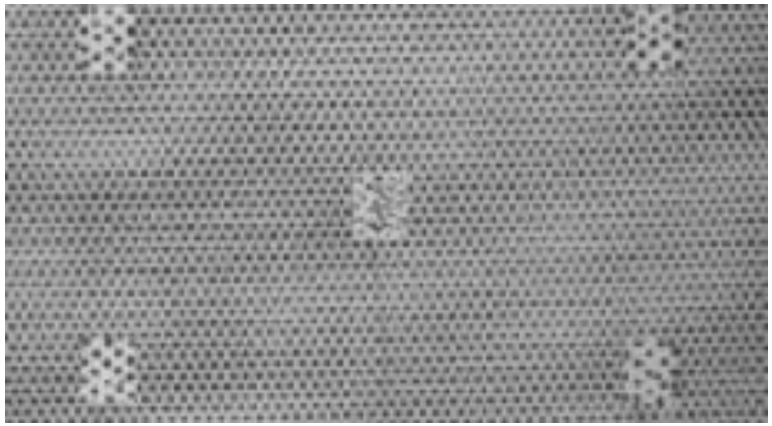
Basic calculations

- **Dot size calculation**
  - Dot size is a function of pixel size
  - Size of pixel = Field of View/# of camera pixels
  - Typically want ~5 pixels per dot
  - Typically want 5-7 dots per facet
- **Effective strain gauge length**
  - Essentially the area over which the strain is averaged.
  - depends on
    - size of a pixel
    - distance between facet centers
    - number of facets used in the average.
  - For a 30 cm sample with typical settings the gauge length is ~6 mm.

Pattern application

- **Dot size depends on size of specimen**
- **For the 5M system:**
  - 1 cm FOV => ~20 μm dots
    - Inkjet toner (~10μm) suspended in alcohol
  - 1 m FOV => ~2 mm dots
- **Ideally ~35-50% coverage**
- **Multiple application methods depending on FOV.**
  - Airbrush – for sub 0.1 mm dots
  - Spray paint – ~ 2 mm dots
  - Templates – > 5 mm dots
  - Other custom application methods
  - Dot application is almost an art



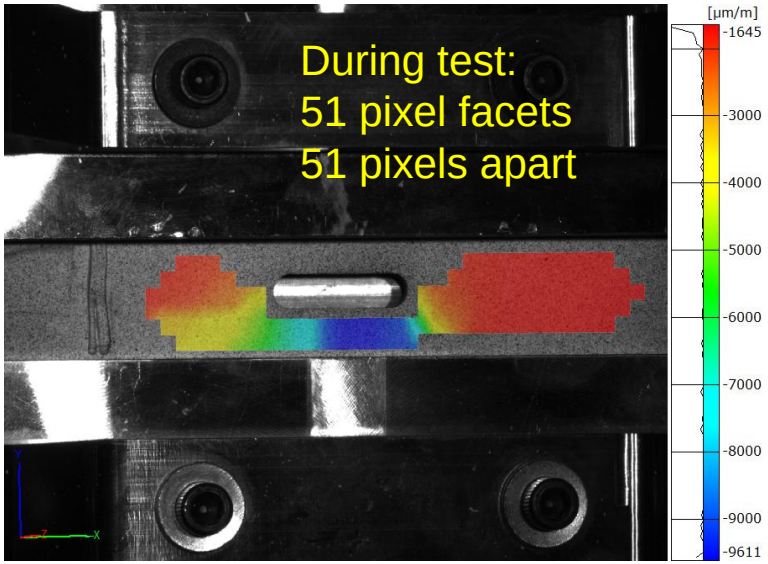


2 m FoV, template pattern, ~5mm dots

Methods of using Aramis

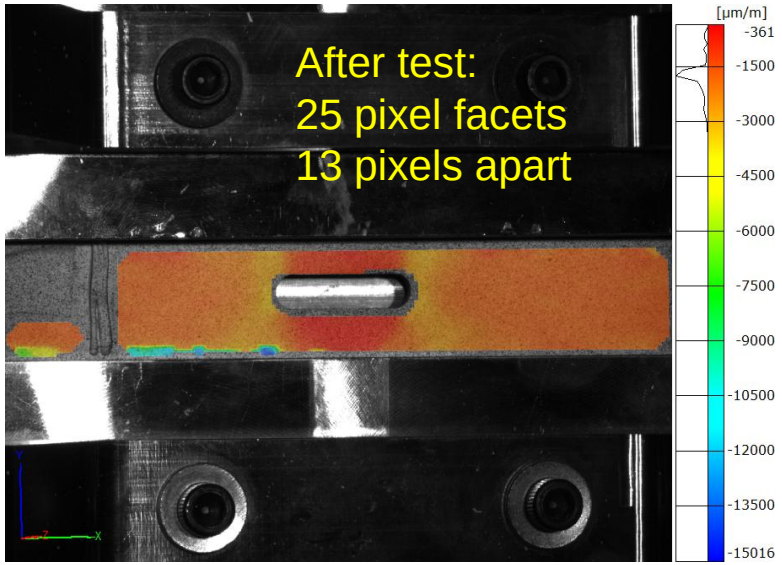
- **Used three operation modes:**
  - Real-time online
    - Scaled-down full-field strain view
    - calculated and displayed during test.
  - iView
    - real-time, monitors only a few facets
    - measures displacement between facets
    - does not calculate a strain, plots dx vs. time.
  - “normal”
    - frames taken before, during, and after test
    - data is calculated later.
- **Real-time online data can be recalculated later**

Real-time online mode



- **Real-time feedback of strain fields during test.**
- **Facets tend to be large and far apart (for calculation speed)**

- **Calculated after test**
- **Smaller, closer facets for accuracy**

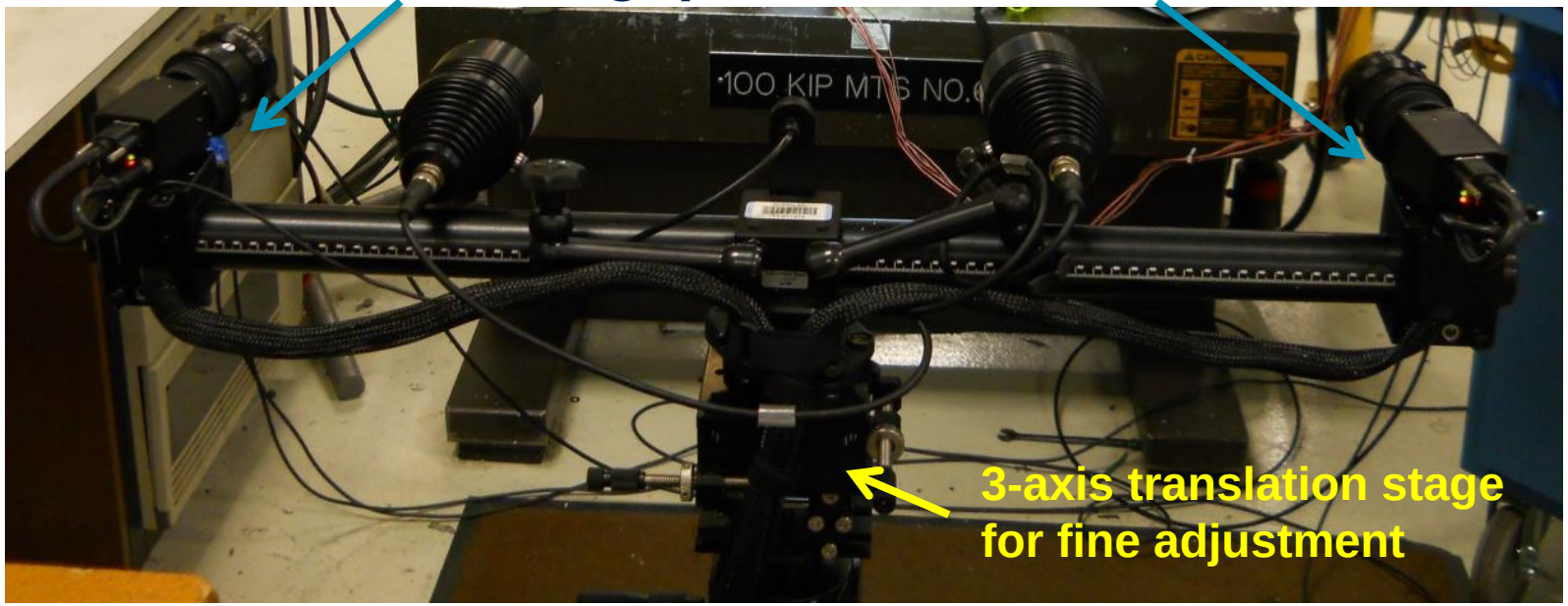


Tests are inexpensive

- **Part prepared day before test (a few minutes/part)**
- **Transported to test site and set up (< 1 hour)**
- **Focused and calibrated (~ 1 hour)**
- **Set up measurement and cameras each test (+ 2 minutes)**
  - Check measurement quality
  - Take baseline frames
- **Run test**
- **Stop cameras, download images (no added time)**
- **Optionally:**
  - Set start points (1-5 minutes)
  - Run calculations (5-30 minutes)
- **Repeat when next sample is ready to test**
- **May periodically require additional calibration**

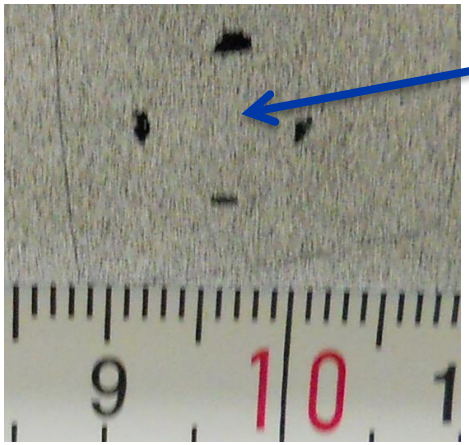
Boeing APL Aramis 5M system

Dual 5 Megapixel CCD cameras



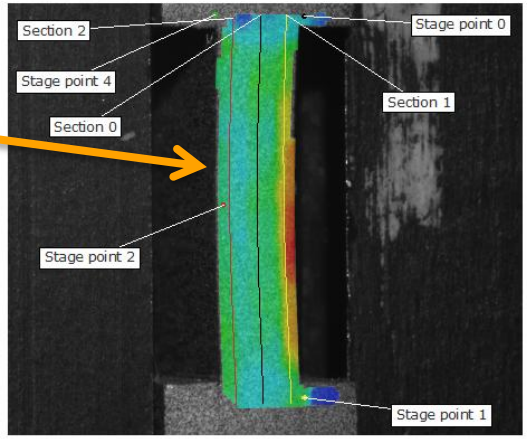
- **12mm, 17mm, 50mm, and 50mm micro lens sets available**
  - **Can test FOV from ~3 m down to 1 mm squares**
    - **BAPL also has an Aramis 2M system**

Micro-Aramis

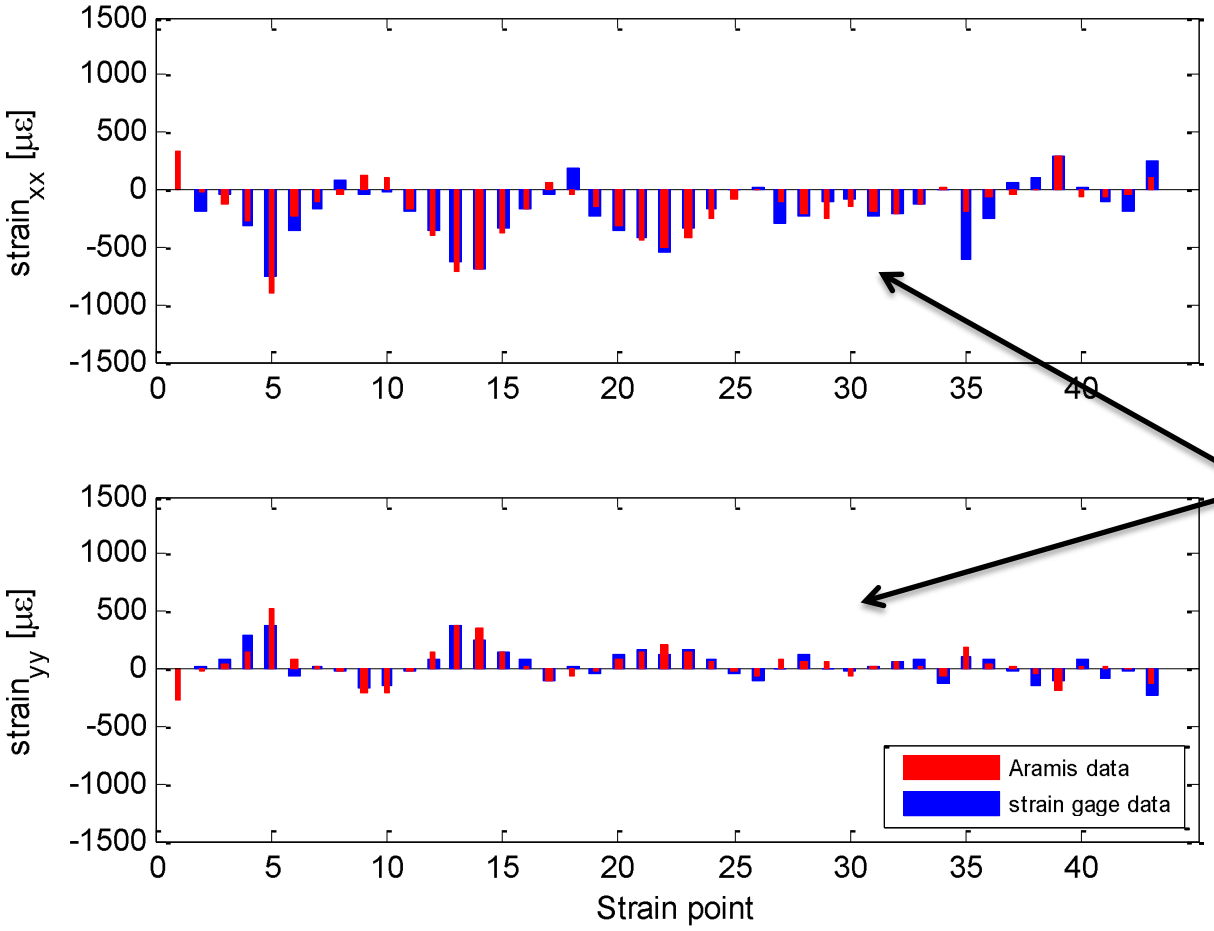


- **1 cm² area**
  - each pixel ~4 μm.
  - Sub-μm displacements can be resolved.
- **1 mm² area**
  - nm displacements can be resolved.

- **Calculate strain fields at high resolution on:**
  - Areas of damage initiation
  - notch edges
  - corners
  - delamination points
  - Small coupons
  - Edges of coupons



Aramis compares well to strain gauges



- **Aramis gives good match to strain gauges**
- **Better at higher strain**

44 strain gauges compared with Aramis strain field, ε_{xx}, ε_{yy}

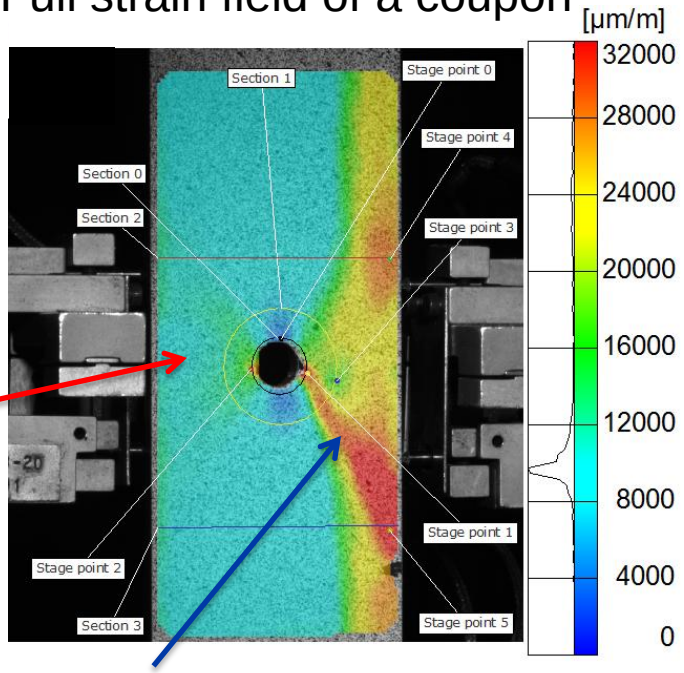
Aramis instead of strain gauges

- **Aramis is well suited for applications where standard strain gauges are impractical or cannot be used.**
  - Measuring strain fields of an entire sample for FEM comparison
  - Extreme environments, such as high heat
  - Very large deformations
  - Large test matrices
- **Can be used to calculate the modulus of a material.**
- **Can be used as a supplement to strain gauges**

Comparison to FEM

- **Aramis calculates strain fields over an entire test coupon**
- **Calculates strain around failure points during test**
- **Full strain field can be directly compared to computer models**
- **This cannot be replicated by strain gauges**

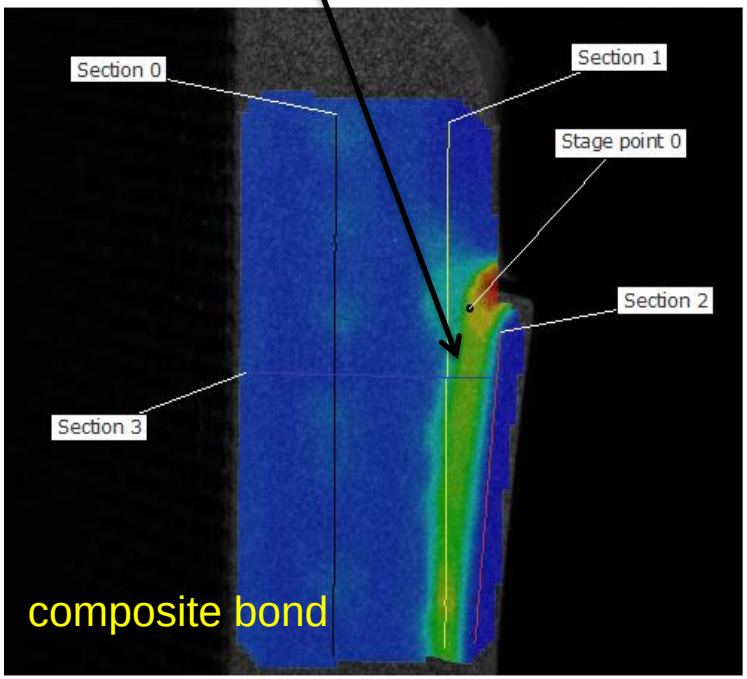
Full strain field of a coupon



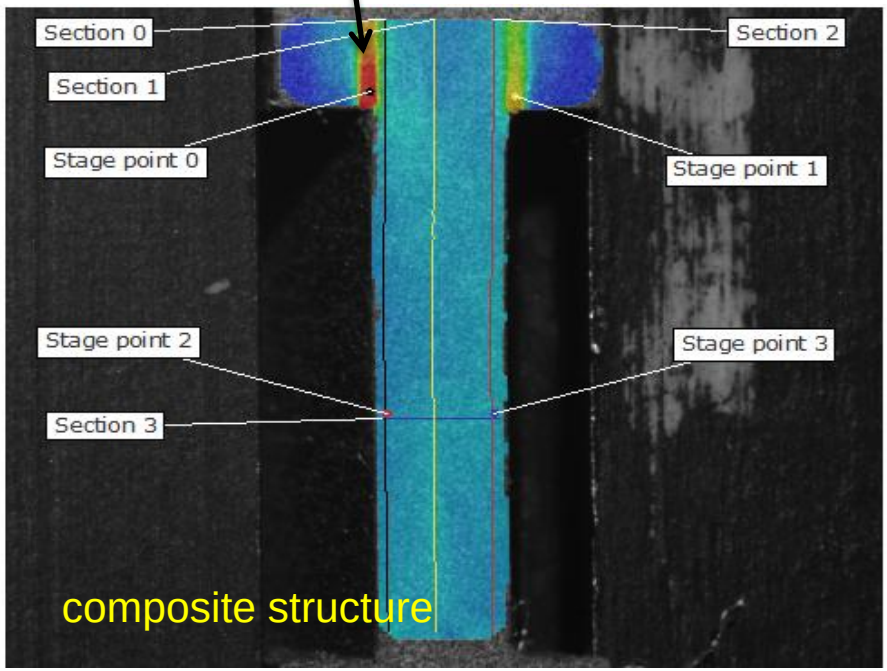
Damage propagation

Comparison to FEM

High resolution edge measurement compared to model at disbond

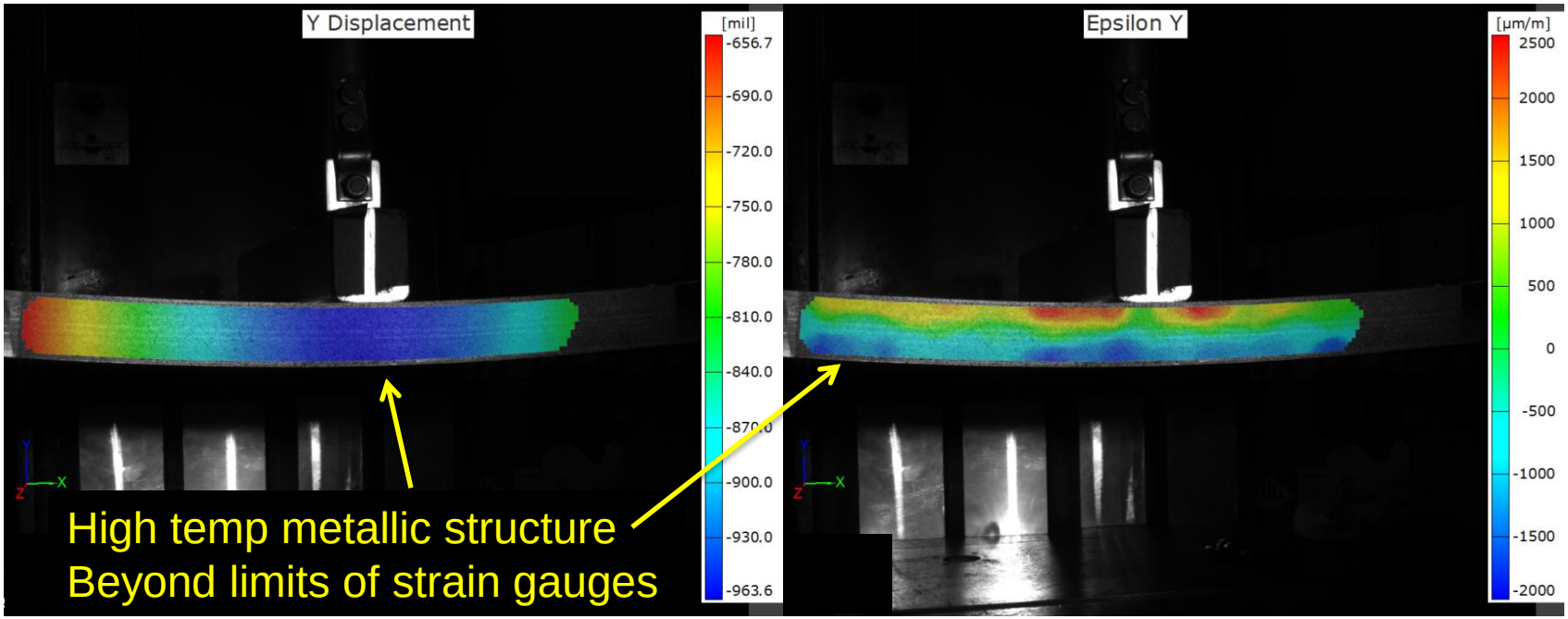


High resolution micro-Aramis strain compared to model at corners and edges



Extreme environments

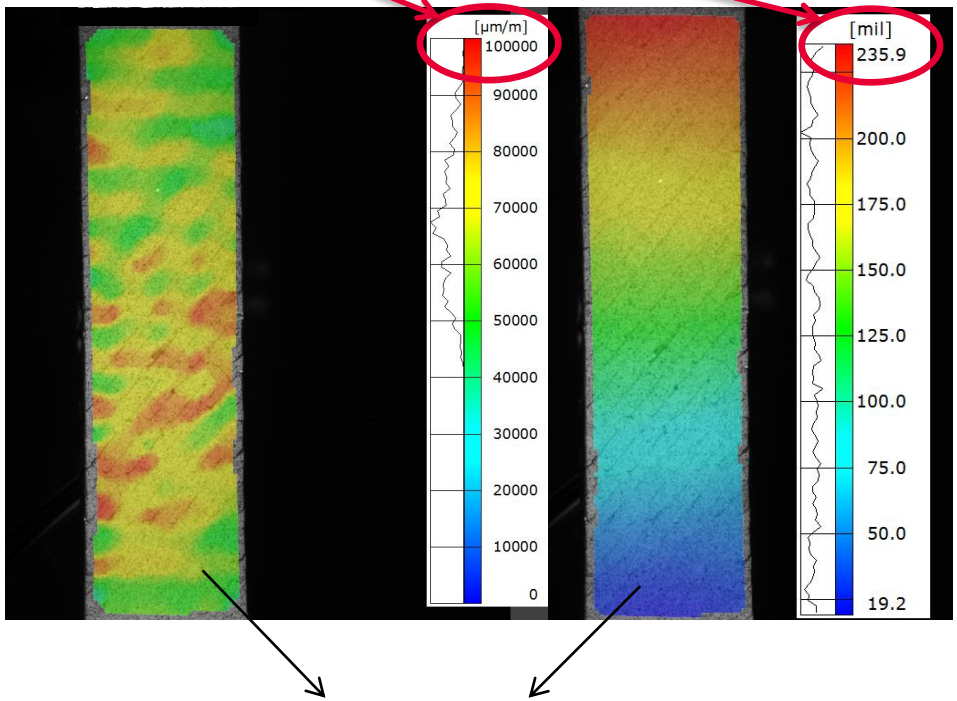
- **Well-suited for testing where standoff is necessary**
  - Extreme temperature
  - Vacuum



Large deformations

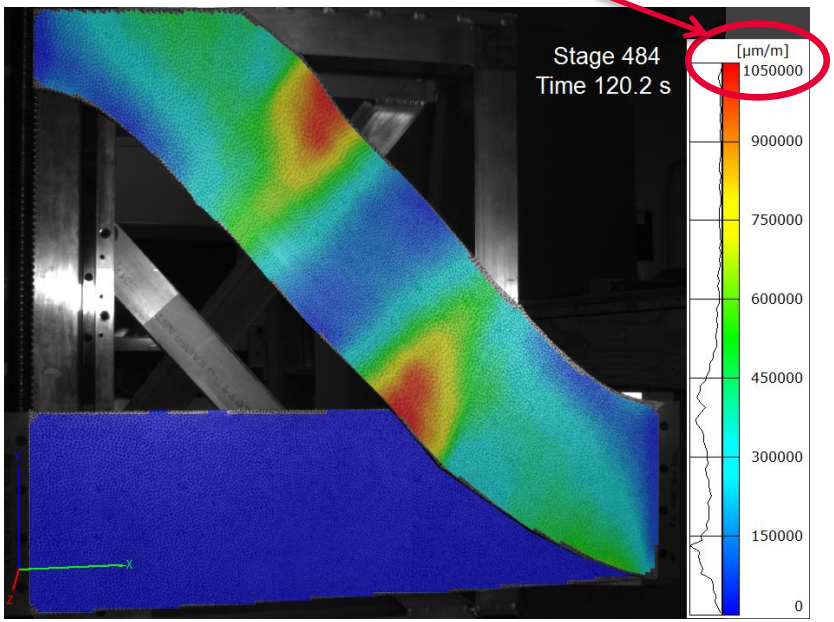
- **Aramis is excellent for large deformations**

Composite structure
~100k μstrain @ 0.24” deformation



Strain gauge also used
failed well before end of test

flexible sheet, over 1M μstrain

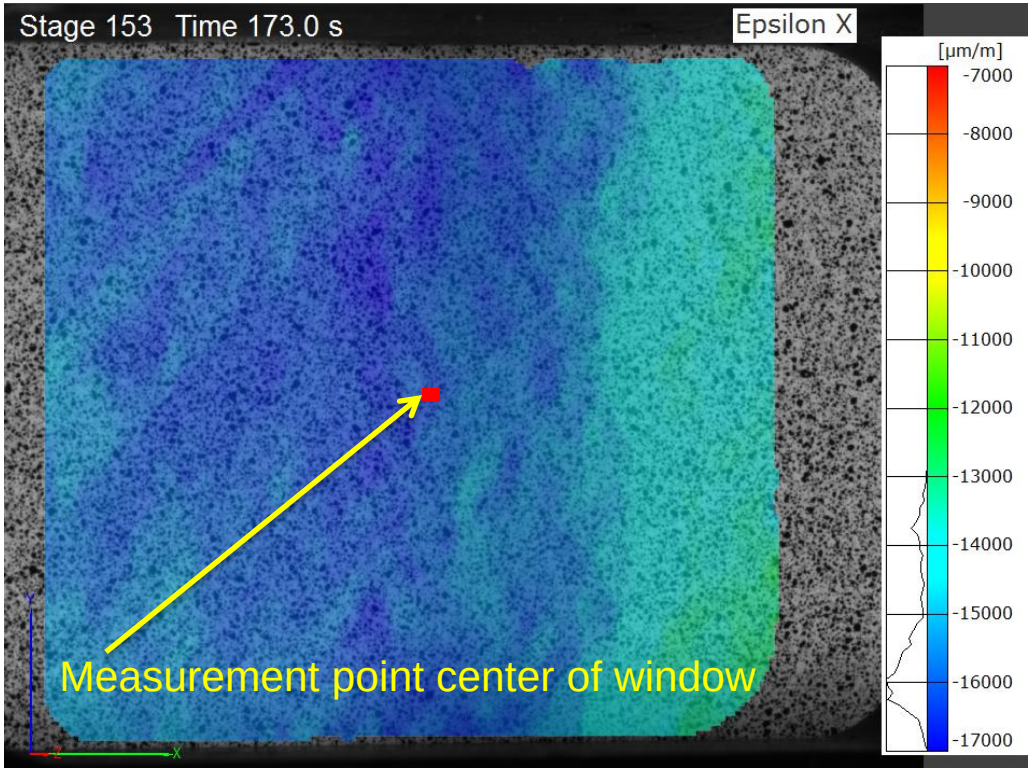


Large test matrices

- **Occasionally there are large test matrices where strain and load data is needed.**
- **Strain gauges can be prohibitively expensive.**
- **Often an extensometer can be used in these cases.**
- **In the cases of compression testing or large deformations Aramis can be used.**
- **Application of the speckle pattern, even for large numbers of samples, takes only minutes.**
- **Modulus calculation using Aramis takes only slightly more time than calculations using strain gauge data.**
- **This results in a large overall cost savings.**

Aramis to calculate modulus

- **160 sample matrix**
  - compression test
  - need - failure load
  - need - modulus data
- **Large number of samples**
  - strain gauging prohibitively expensive
  - no room for extensometer

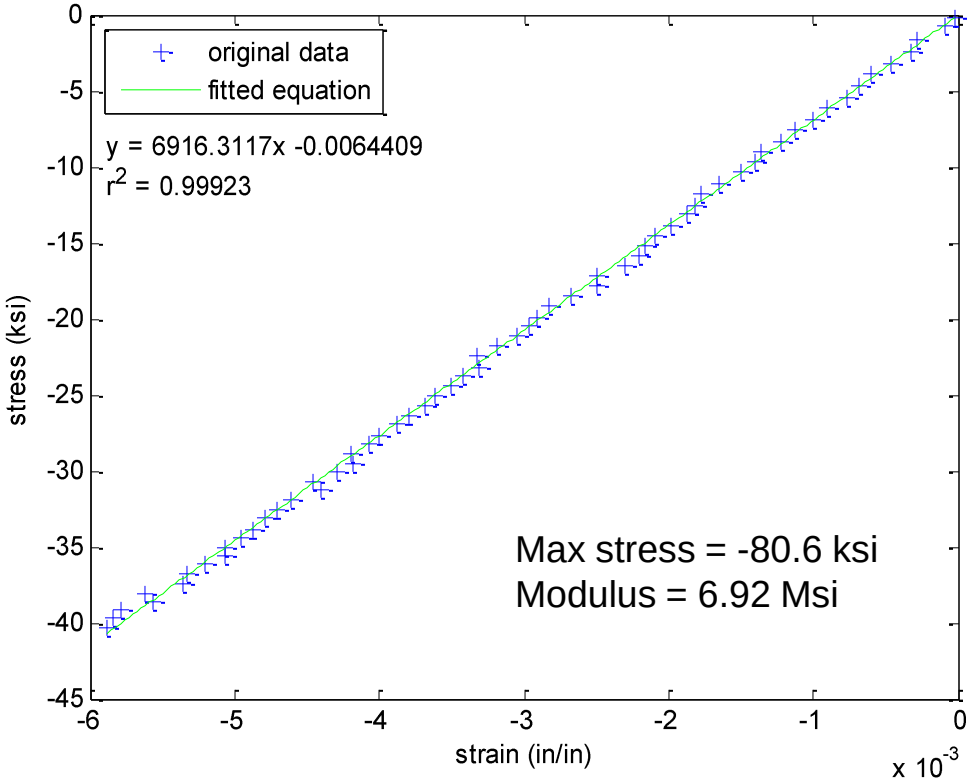


- **Aramis was as an inexpensive alternative**

Data for modulus calculations

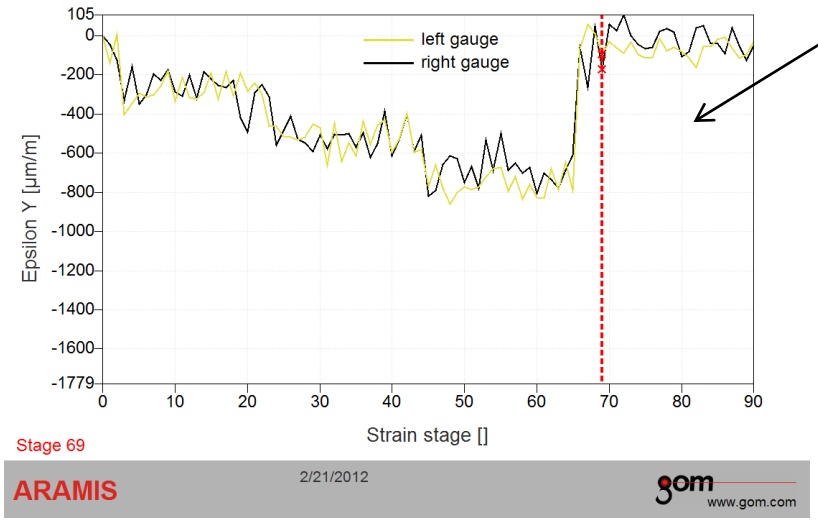
- **Aramis strain data from several points on sample read into model**
- **Load (stress) data recorded by Aramis from test fixture at time of test**
- **Stress-strain curve generated**
- **Linear regression fit made to calculate material modulus**
- **Results consistent with expected values for modulus on the control samples**

Stress-strain curve for point at center of viewing window.

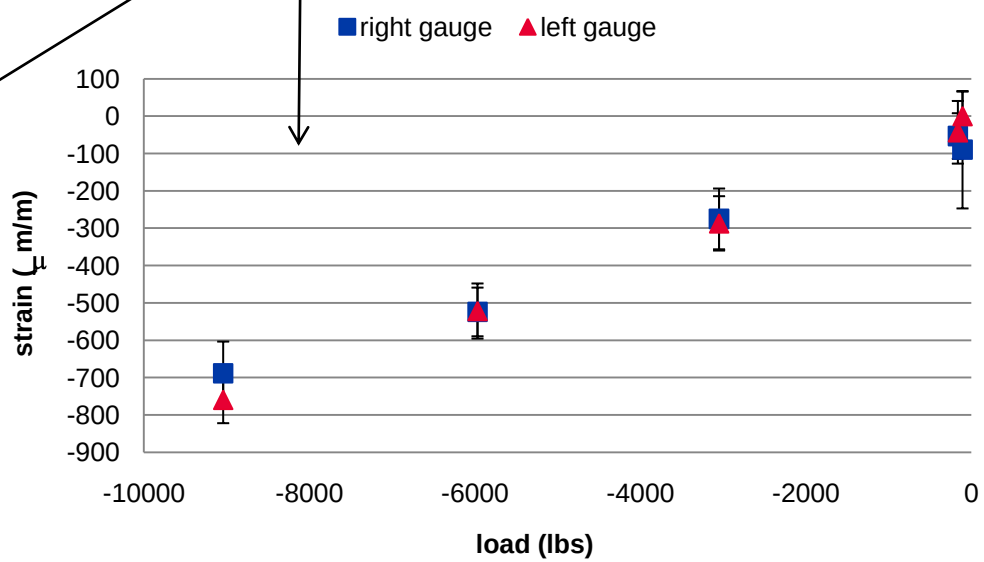


Aramis on LNC

- **Studying use of Aramis for load balancing on LNC tests**
- **Could eliminate costly strain gauges**
- **Successfully balanced right-left**
- **Confirmed with strain gauges**



Verified right-left balance
on ungauged test



Conclusions and next steps

- **Aramis has been used extensively at Boeing Applied Physics in a wide range of test scenarios.**
- **Tests have been done on fields of view as large as 2 m and as small as 4 mm.**
- **We have tested in high temperature environments where standard strain gauges were not applicable.**
- **Aramis allows us to test materials that are capable of extremely high strains before failure.**
- **Aramis allows a low cost method of testing large sample matrices when strain information is needed.**
- **Our next step is to incorporate high speed cameras into the system for damage propagation and impact physics studies.**