Enhancing Finite Element Analysis with Digital Image Correlation Test Data

2018 Space Symposium

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Agenda

- Introduction
  - How do you evaluate the structural mechanics and material response of complex aerospace structures
- What is Digital Image Correlation
- Industry Uses (NASA Shell Buckling Knockdown Factor)
- 3 Case Studies
  - Aluminum Coupon Tensile Test
  - Carbon Fiber Composite Tube with Cutout Under Bending
  - Additive Manufactured Complex Geometry under Compression
- Summary

Introduction

- Optimized Shapes are Complex
  - Need to be analyzed with Finite Element Models
- How Conservative / Un-Conservative is it?
- Modeling Assumptions
  - Modulus, Anisotropic, Boundary Conditions
- Proper Validation is Needed

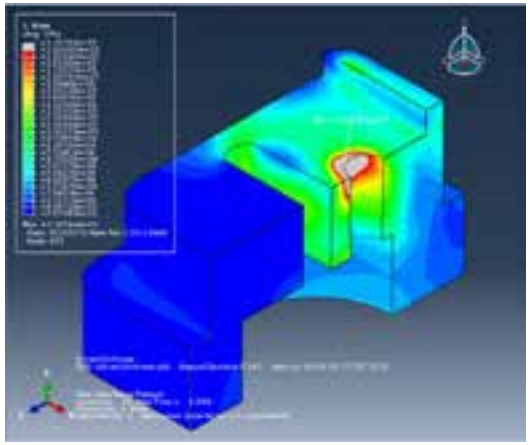


Image Courtesy of:
Raju, Ivatury S., Knight Jr., Norman F., Shivakumar, and Kunigal N.,
"Some Observations On The Current Status of Performing Finite Element Analysis,"
NF1676L-19037, NASA Technical Reports Server, April 29, 2015.

ASME

"Scientists and engineers [should] be aware that the computational models they develop and use are approximations of reality and that these models are subject to the limitations of available data, physical theory, mathematical representations, and numerical solutions."

American Society of Mechanical Engineers
Guide for the Verification and Validation of Computational Solid Mechanics, ASME-V&V-10-2006, New York, 2006.

NASA

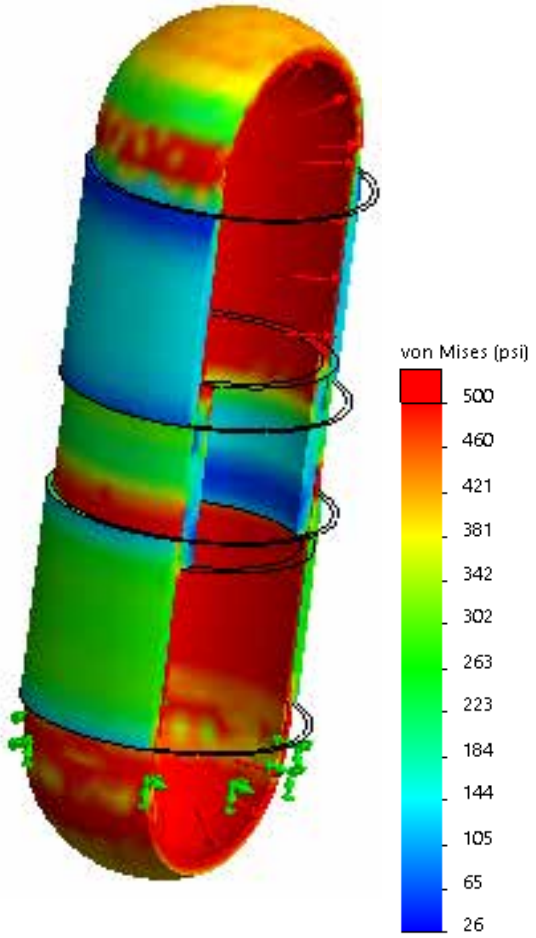
"Engineers are becoming increasingly efficient in building complex 3D models of complicated aerospace components. However, the current trends demonstrate blind acceptance of the results of the finite element analysis."

"Analysis of any physical problem needs to be subjected to Verification & Validation."

Raju, Ivatury S., Knight Jr., Norman F., Shivakumar, Kunigal N.,
"**Some Observations On The Current Status of Performing Finite Element Analysis**."
NF1676L-19037, NASA Technical Reports Server, April 29, 2015.

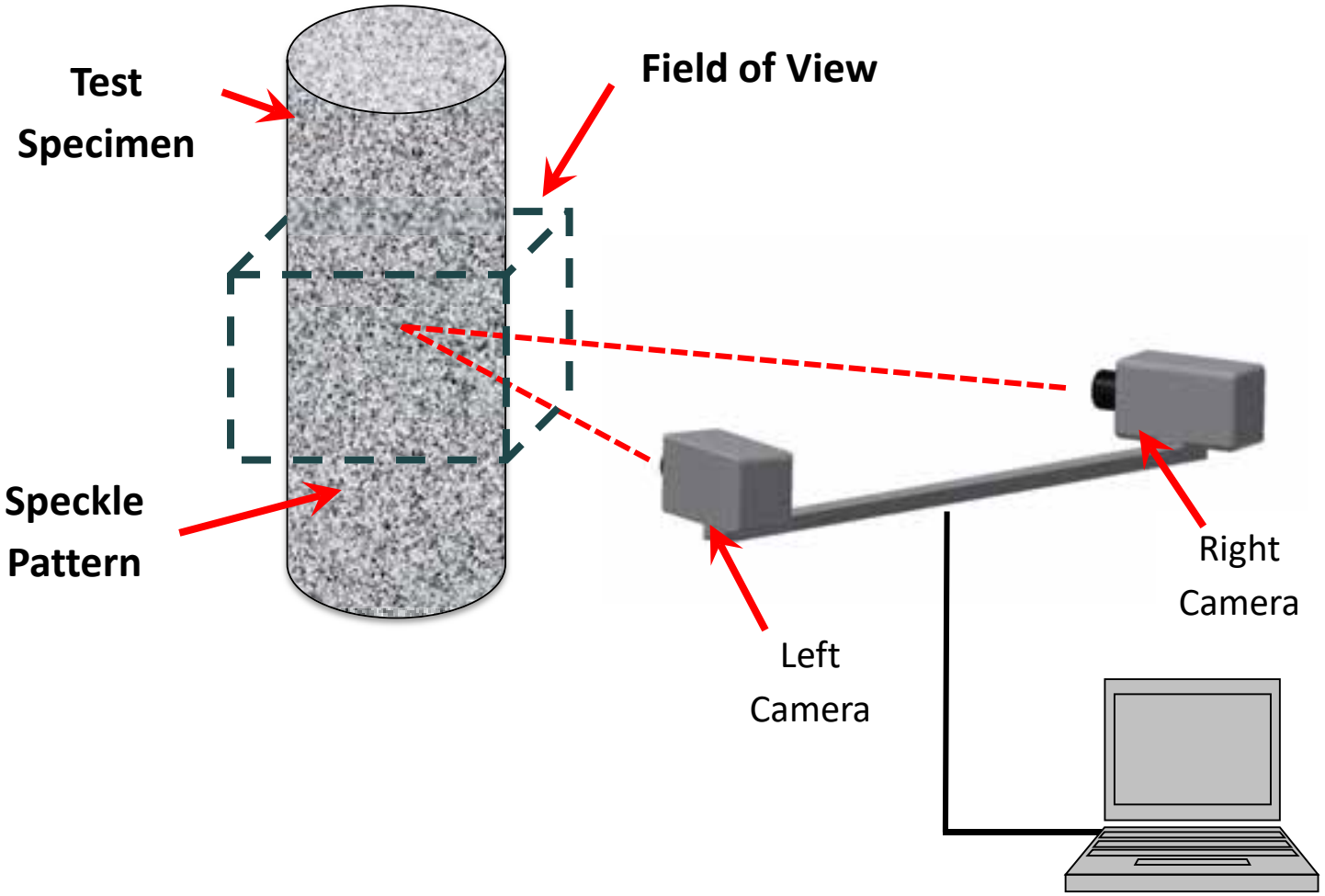
Empirical Test Data

- What do you compare to FEA?
- Measuring Material Structural Response
  - Foil Rosette, Fiber Optic, Extensometers
- Issues
  - Discrete measurements
  - Installation
    - Placement Accuracy
    - Principal Direction
    - Timely and Costly
  - Limitations
    - Range
    - Grid Length
    - Surface Contact

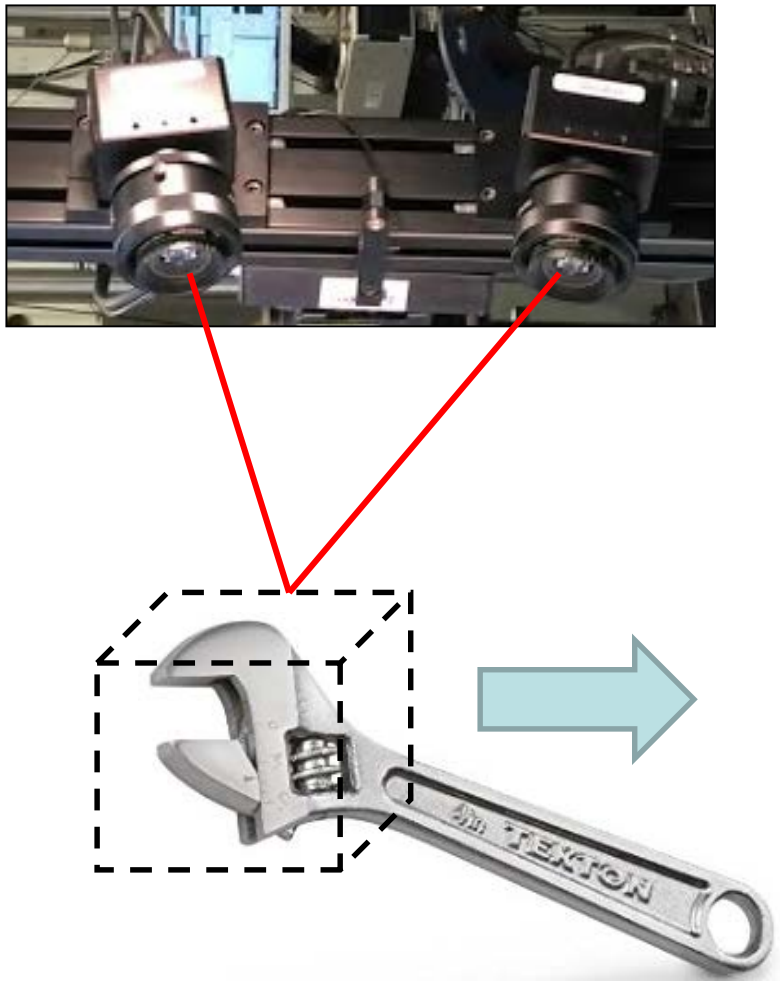


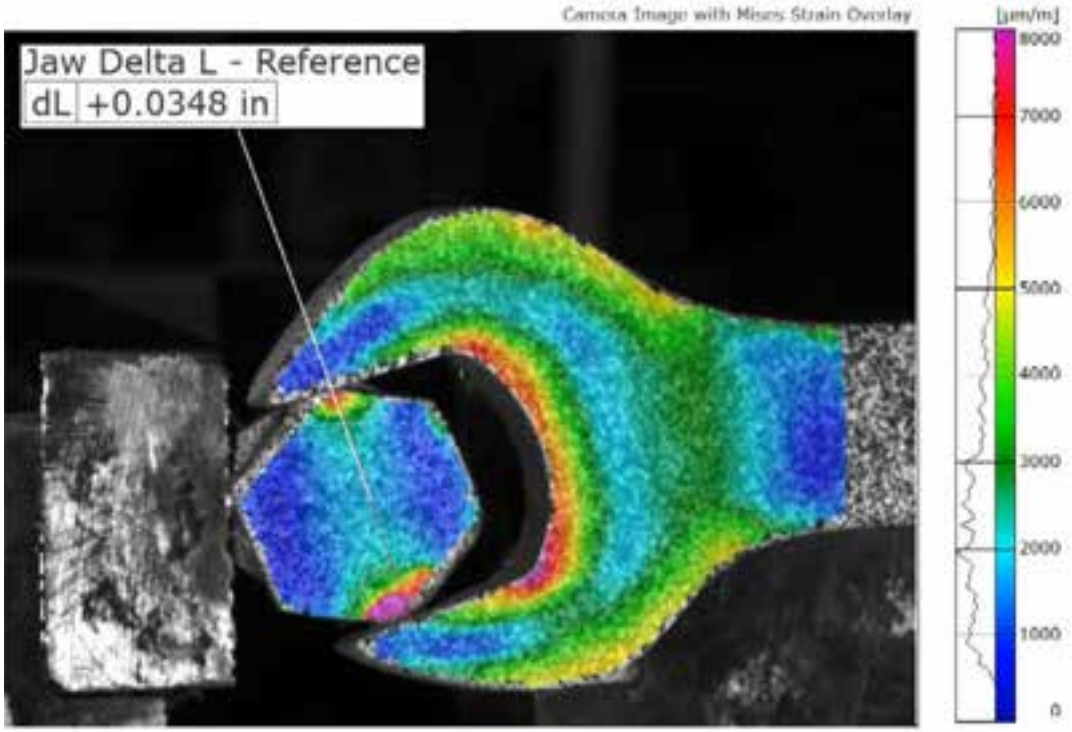
Foil Rosette: Vishay Micro Measurements
Fiber Optic: Micro Optics
Extensometer: MTS

Digital Image Correlation

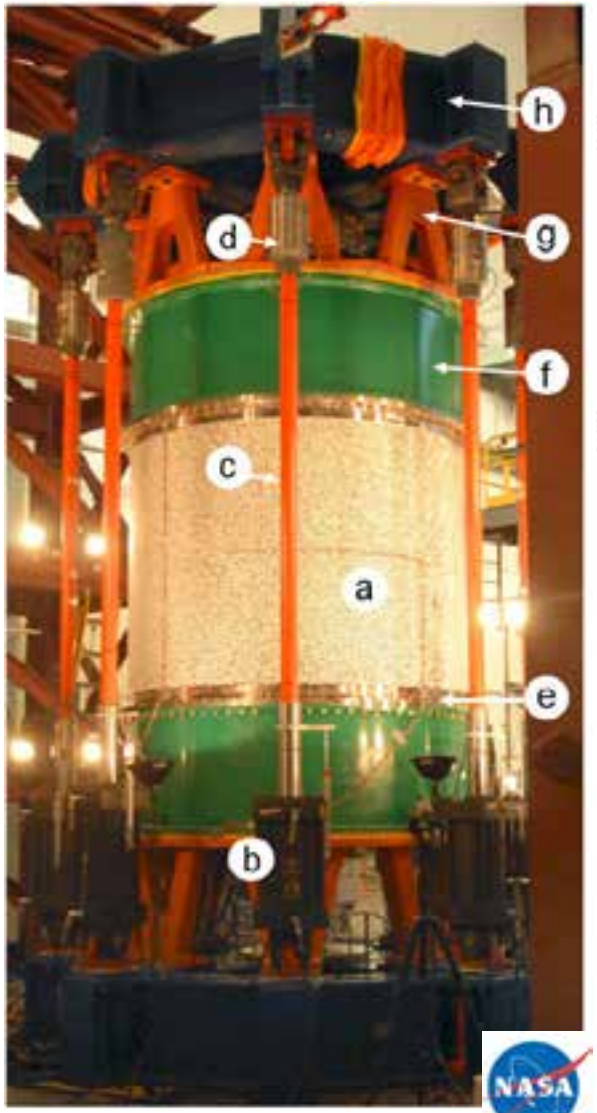


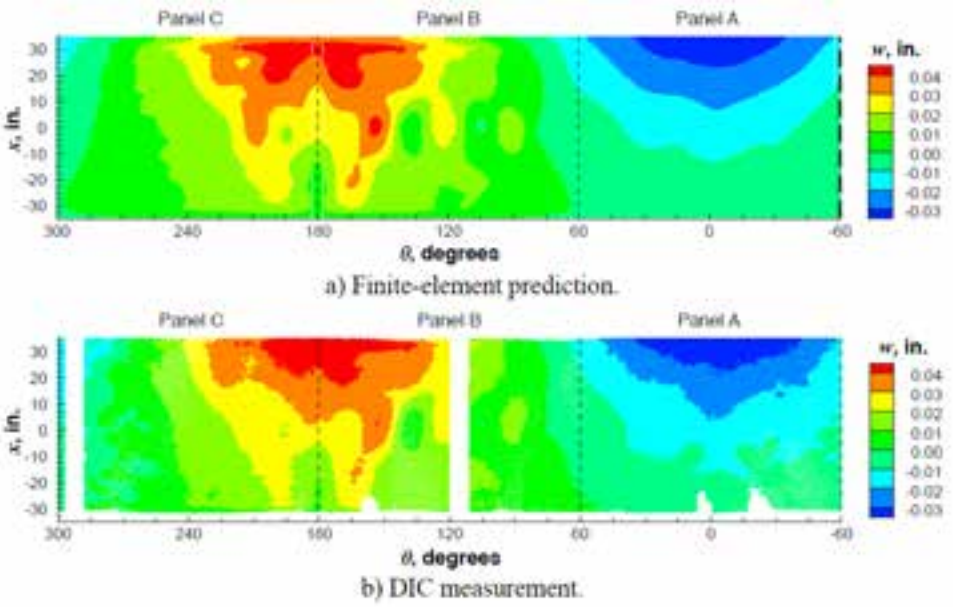
Digital Image Correlation



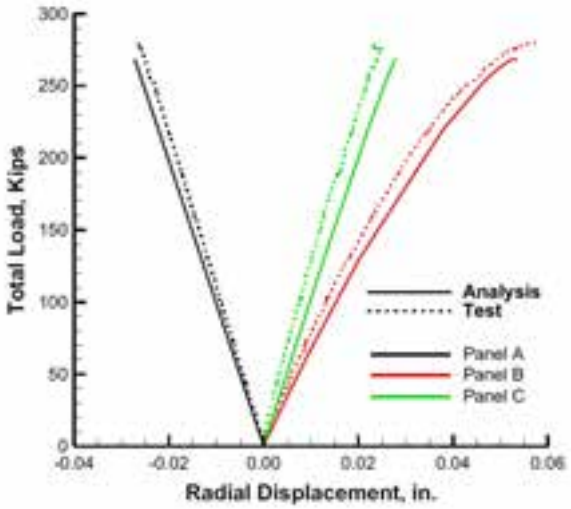


DIC with FEA Example-NASA SBKF





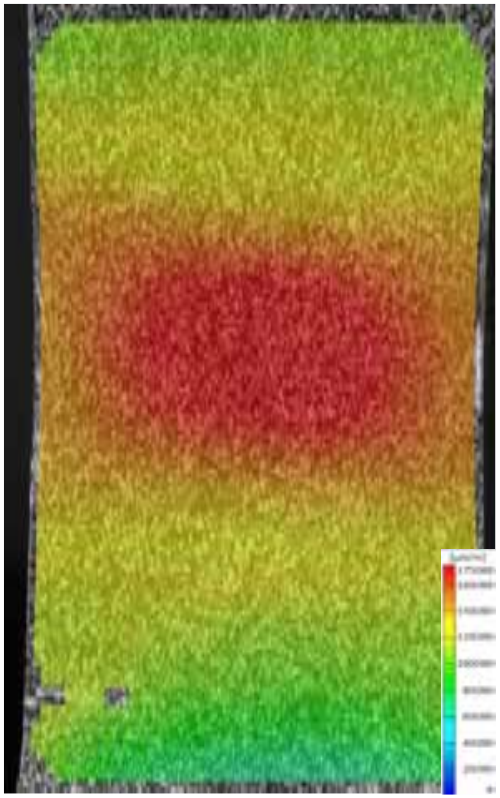
NASA Shell Buckling Knockdown Factor Project



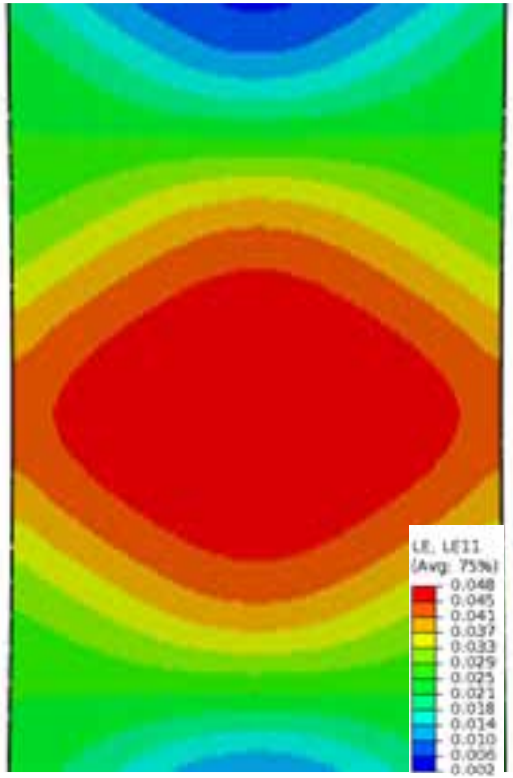
Reference: NASA/TP-2017-219587
Mark W. Hilburger, W. Allen Waters, Jr. Waddy T. Haynie, Robert P. Thornburgh
NASA Langley Research Center, U.S. Army Research Laboratory

Case Study 1: Uniaxial Tensile Test

DIC

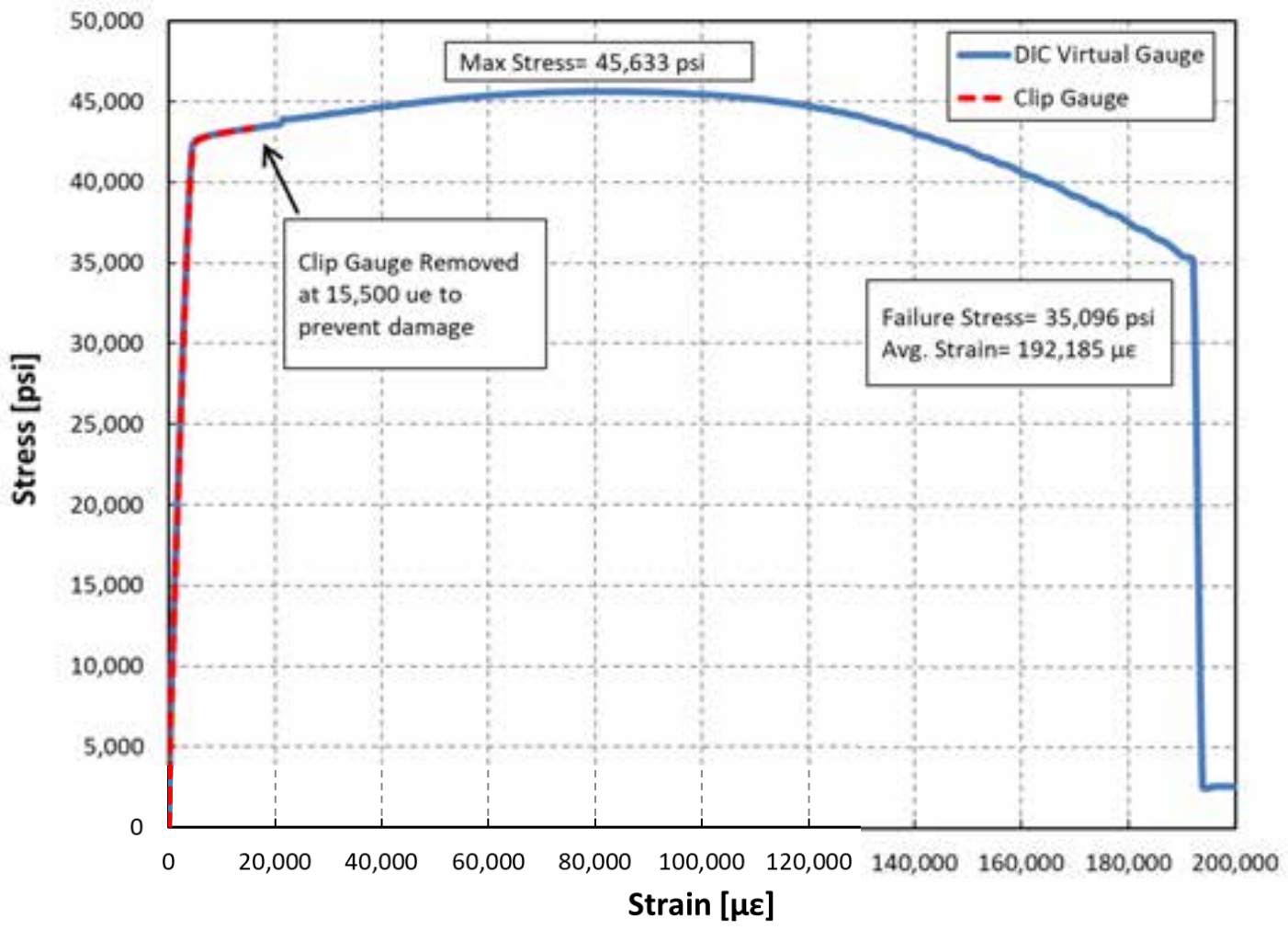


FEA

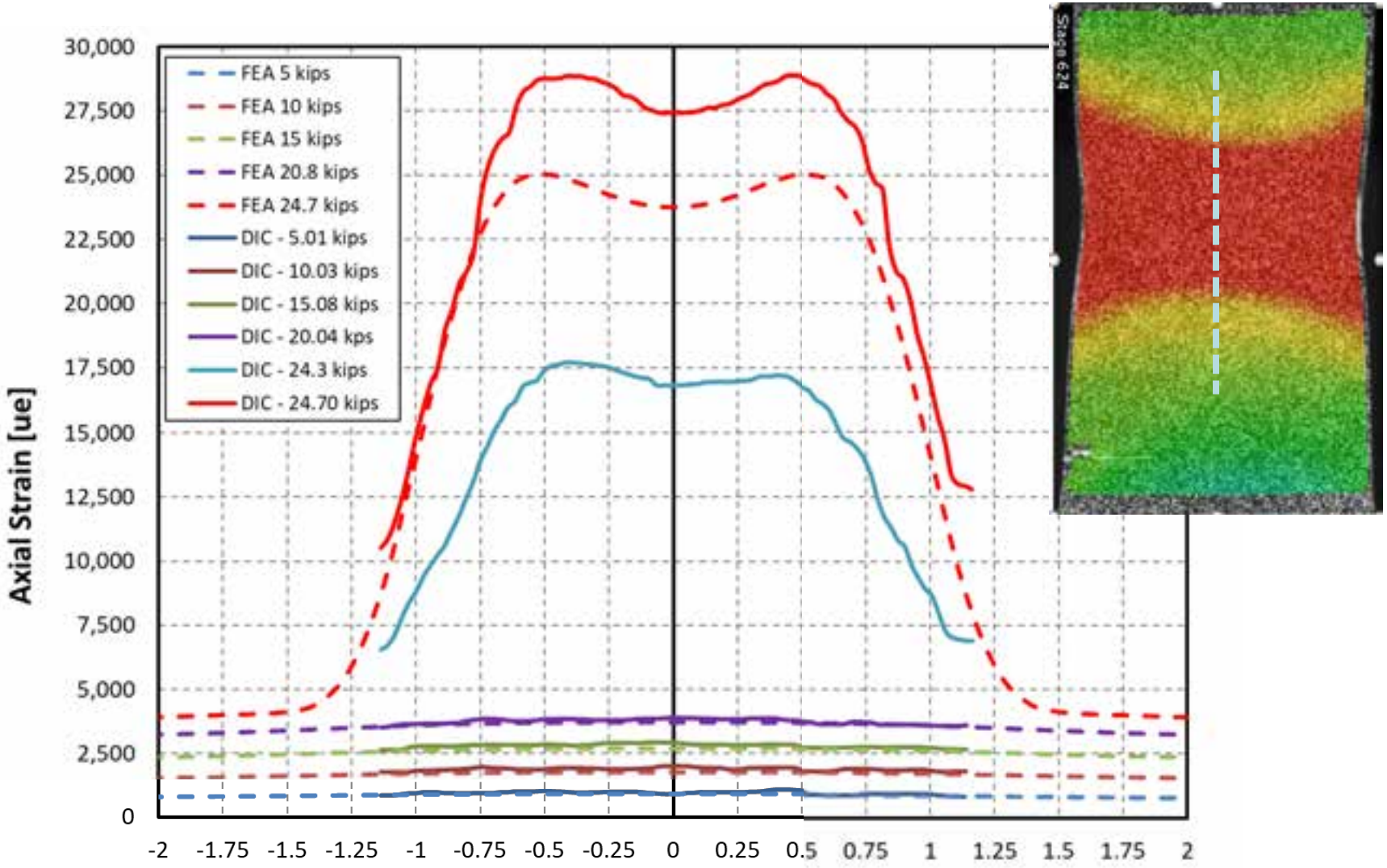


1.5” x 0.375” flat bar Aluminum 6061 Coupon

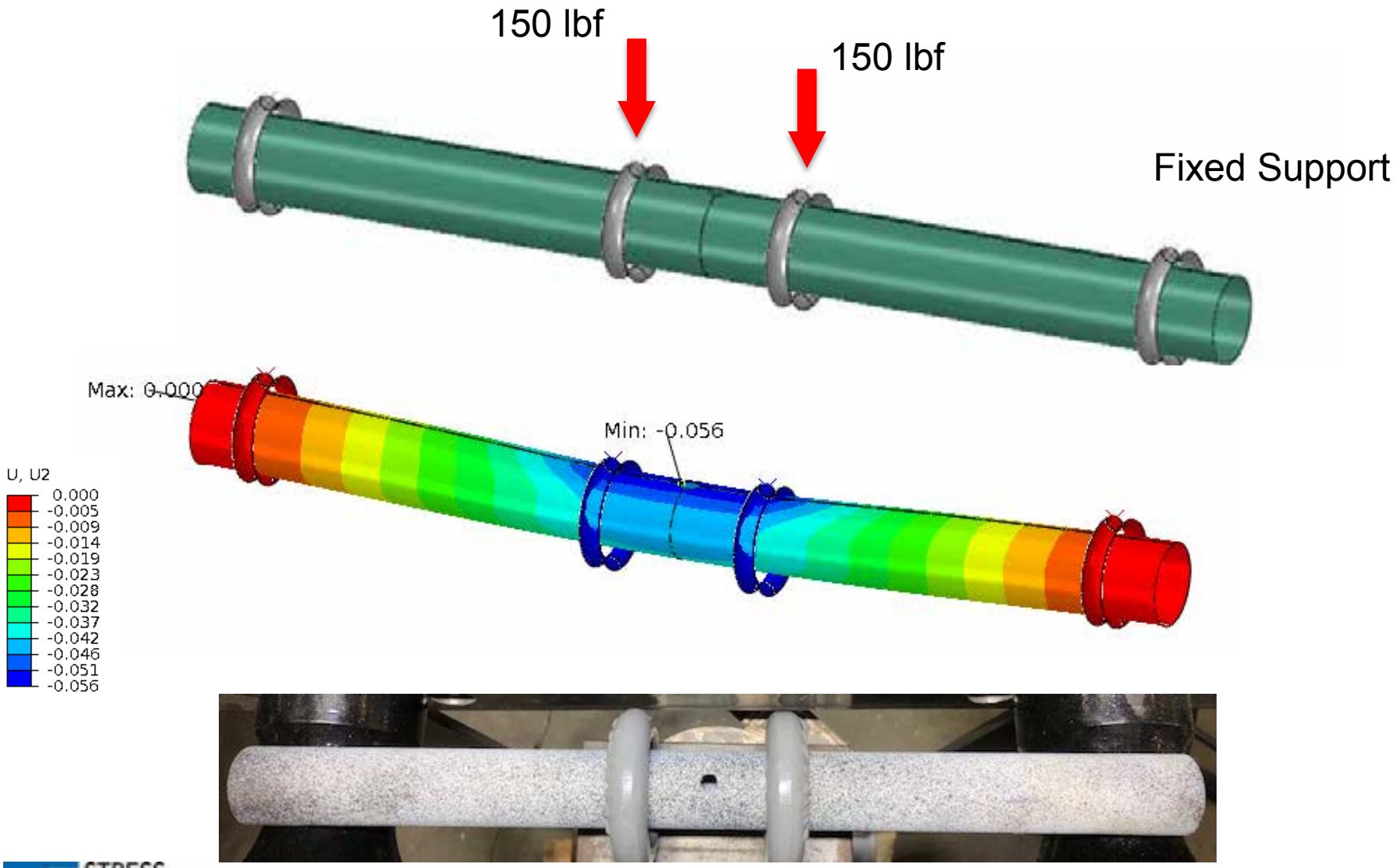
Non-Linear Material Response



Non-Linear Material Response



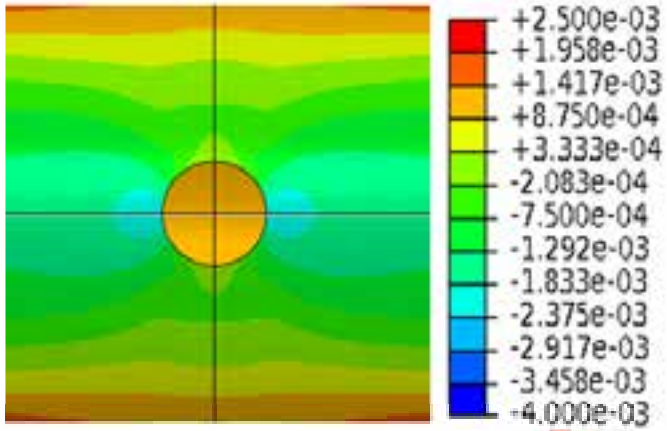
Case Study 2: Carbon Fiber Composite Tube with Cutout

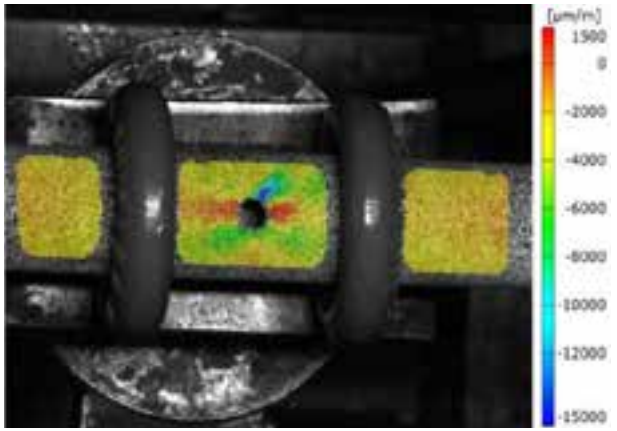


FEA to DIC Comparison

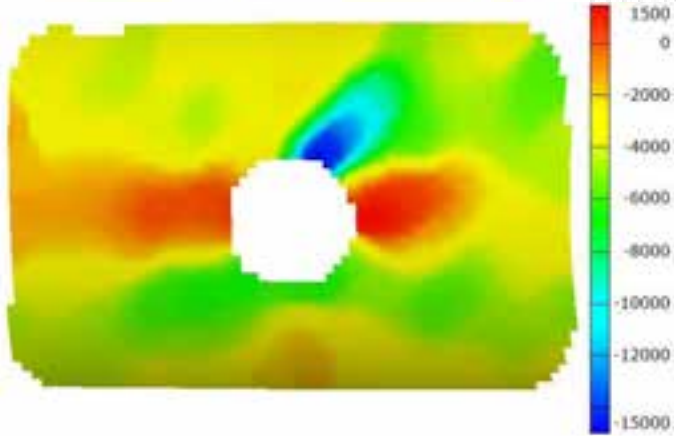
Axial Strain at 300 lbs

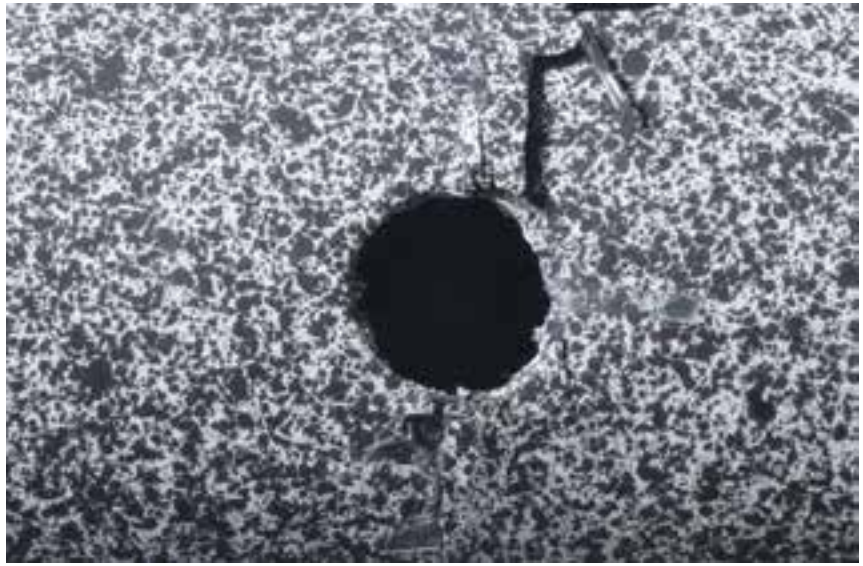
FEA



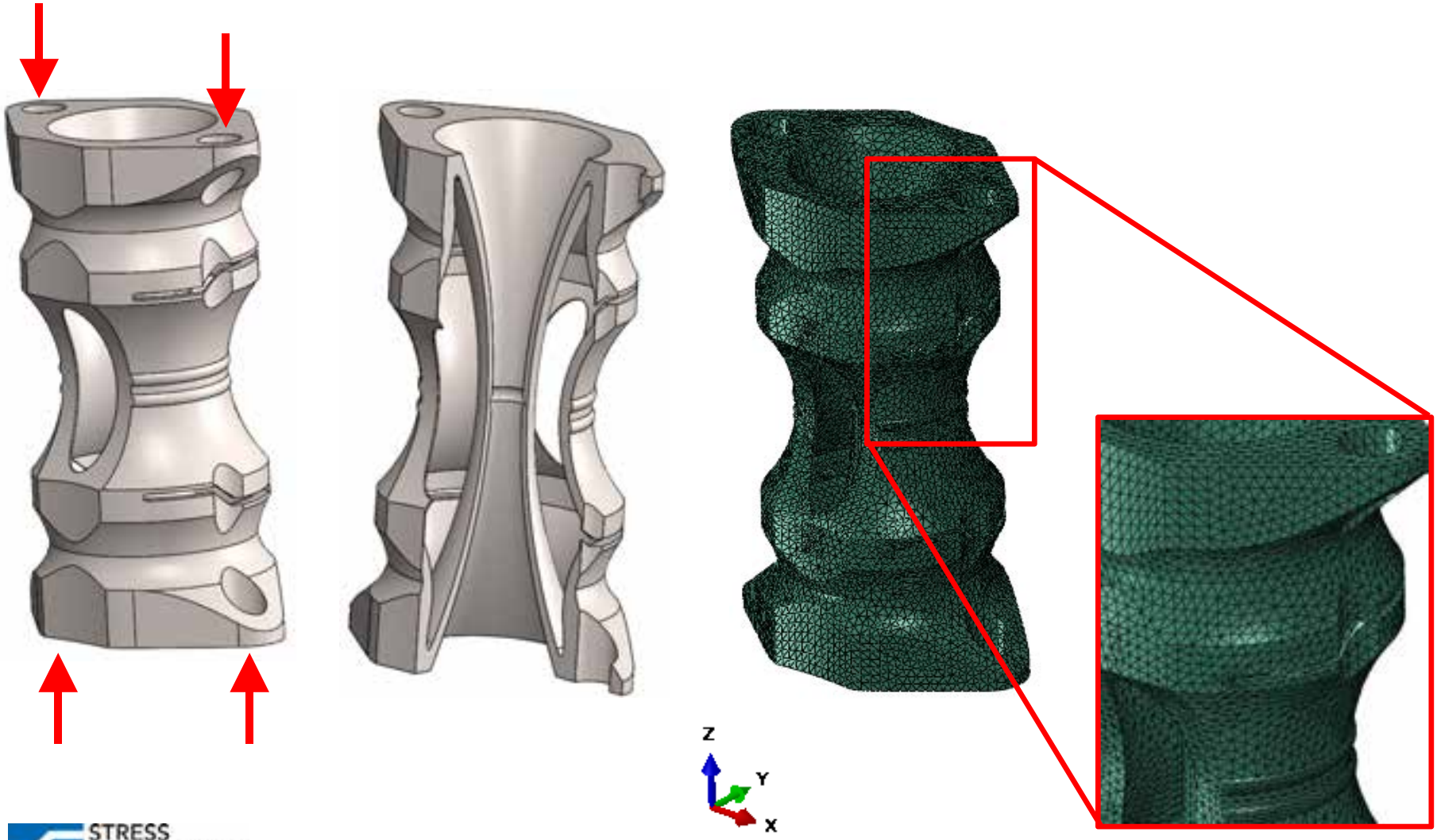


DIC

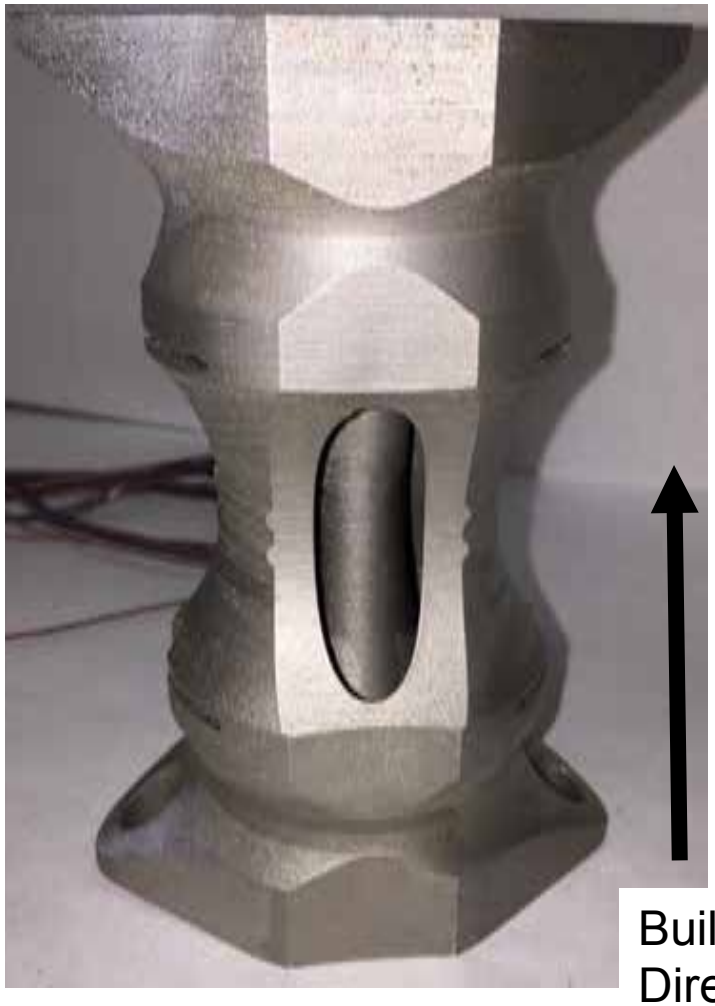




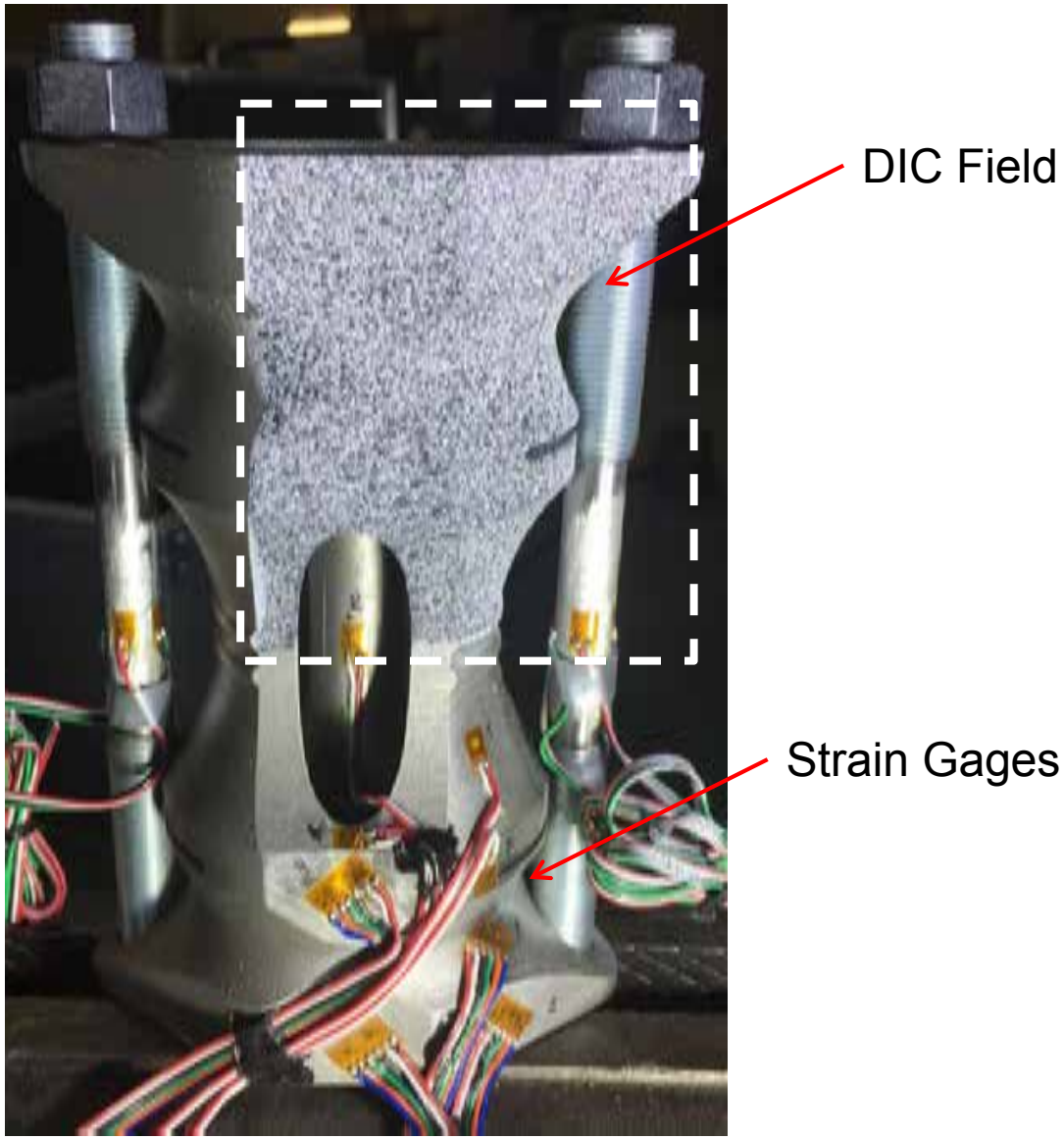
Case Study 3: Complex Nozzle



Additive Manufactured Alloy 718 Part

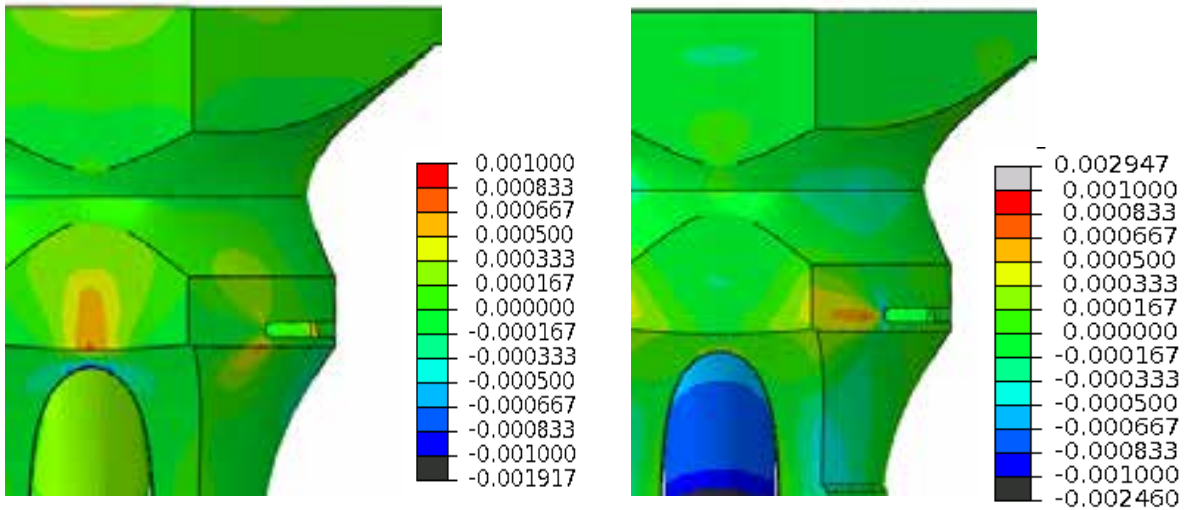


Source: Renishaw


DIC Field
Strain Gages

Alloy 718 AM Part Test Results

FEA



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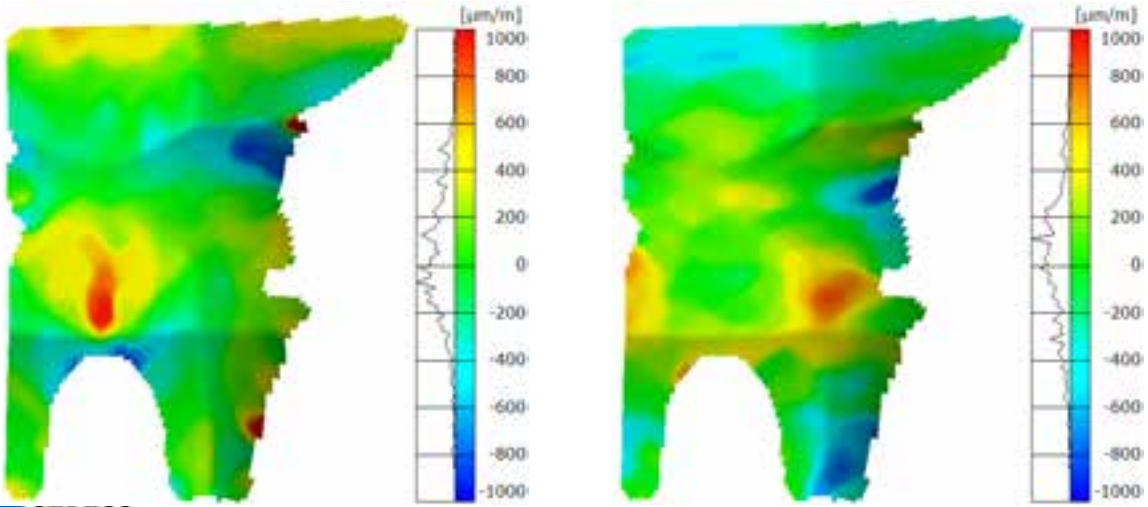

Strain Gages

Location	MicroStrain [ue]
1	150
2	-376
3	224
4	NA
5	714
6*	-866
7	-465
8	-1,273

Summary

- Need for Proper FEA Validation
- Difficulties in correlating test data
  - Strain Gage Limitations
  - Materials do not always deform evenly
  - The real world does not have perfect geometries or loadings
    - Buckling, Bending, Torsion can be difficult to predict and apply
  - High Stress Gradients are difficult to measure
    - Welds, Ribs, Holes, Transitions
  - Anisotropic Material Properties need to be accounted for
    - Composites & Additive Manufactured Parts

Summary

- Finite Element Analysis, Testing, and DIC all have limitations individually,
- A combination of proper test methods, full-field DIC & strain gage data, used with FEA will provide the best opportunity for understanding how complex materials and geometries perform under load
- This combination leads to a better design process.

Acknowledgements

Design Analysis Testing

Thank You!

STRESS ENGINEERING SERVICES INC.

Design Analysis Testing

- Founded in 1972
- Employee Owned
- Independent
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- Engineering Disciplines:
  - Mechanical
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  - Chemical
  - Subsea
  - Testing
  - Pipeline