The Use of Digital Image Correlation (DIC) and Strain Gauges to Validate Simulation

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technical center for materials

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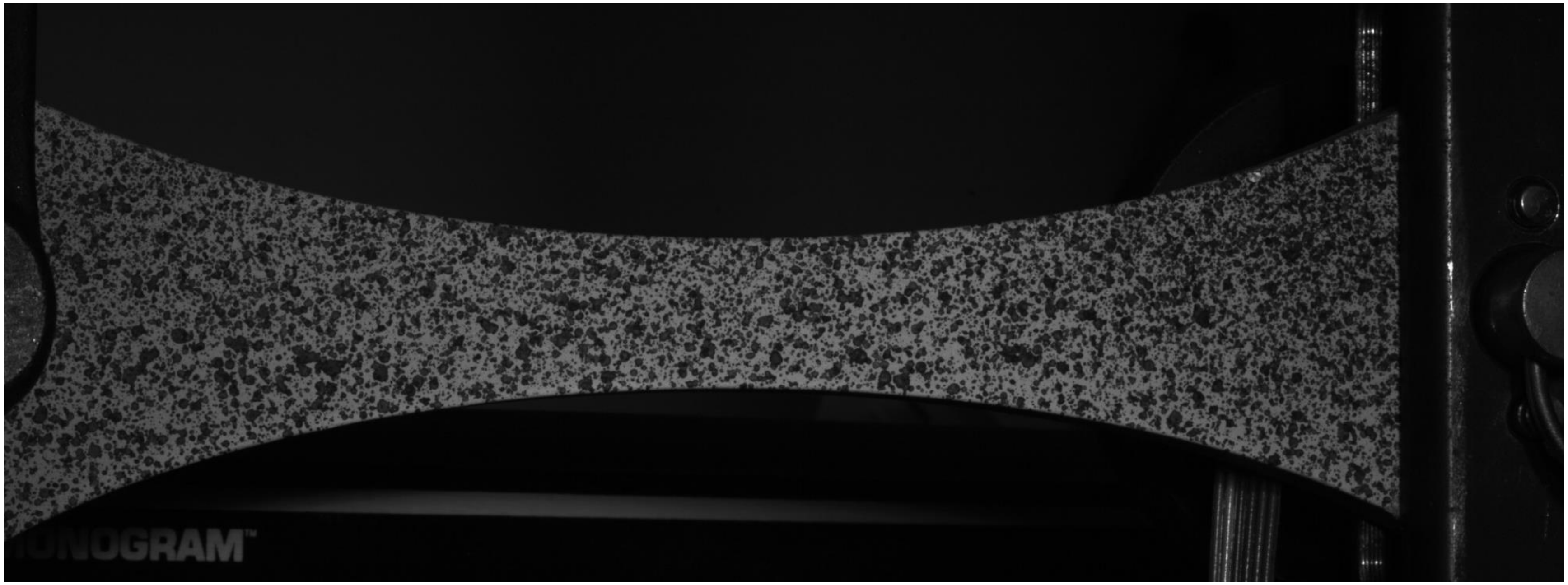
Materials

Testing ¤ Data Infrastructure ¤ Productivity Software

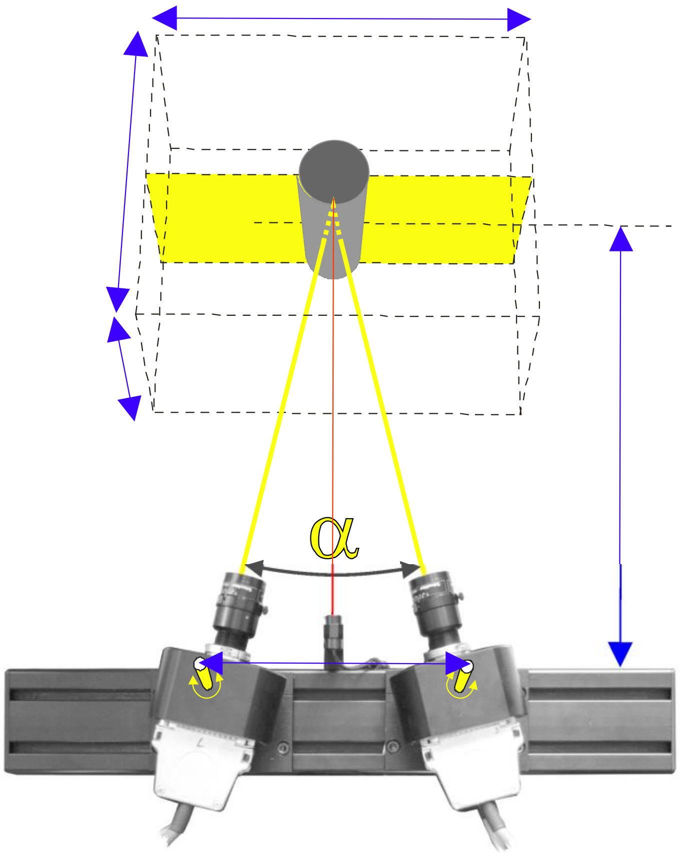
Project Impetus

- Collaboration with Cornell University Mechanical & Aerospace Engineering program
- 4 distinct aluminum beam geometries loaded to 100 lbf
- Theoretical strains are calculated at certain locations along beam
- Strain gauges are attached at these locations to verify calculations
- Simulation of experiment performed in FEA software
- Discrepancies between simulation, theory and measurement often plague these experiments, especially with more complex beam design
- DIC was used to validate simulation and investigate sources of error

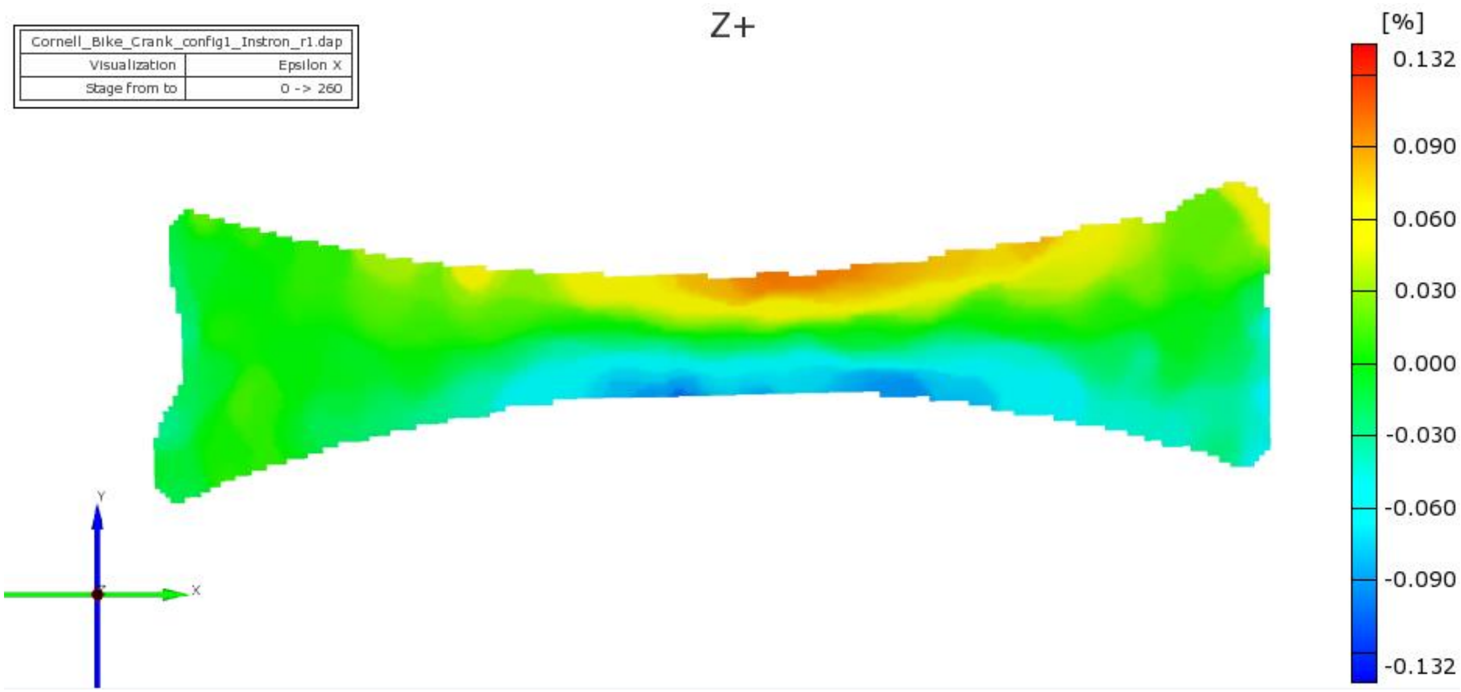
Digital Image Correlation



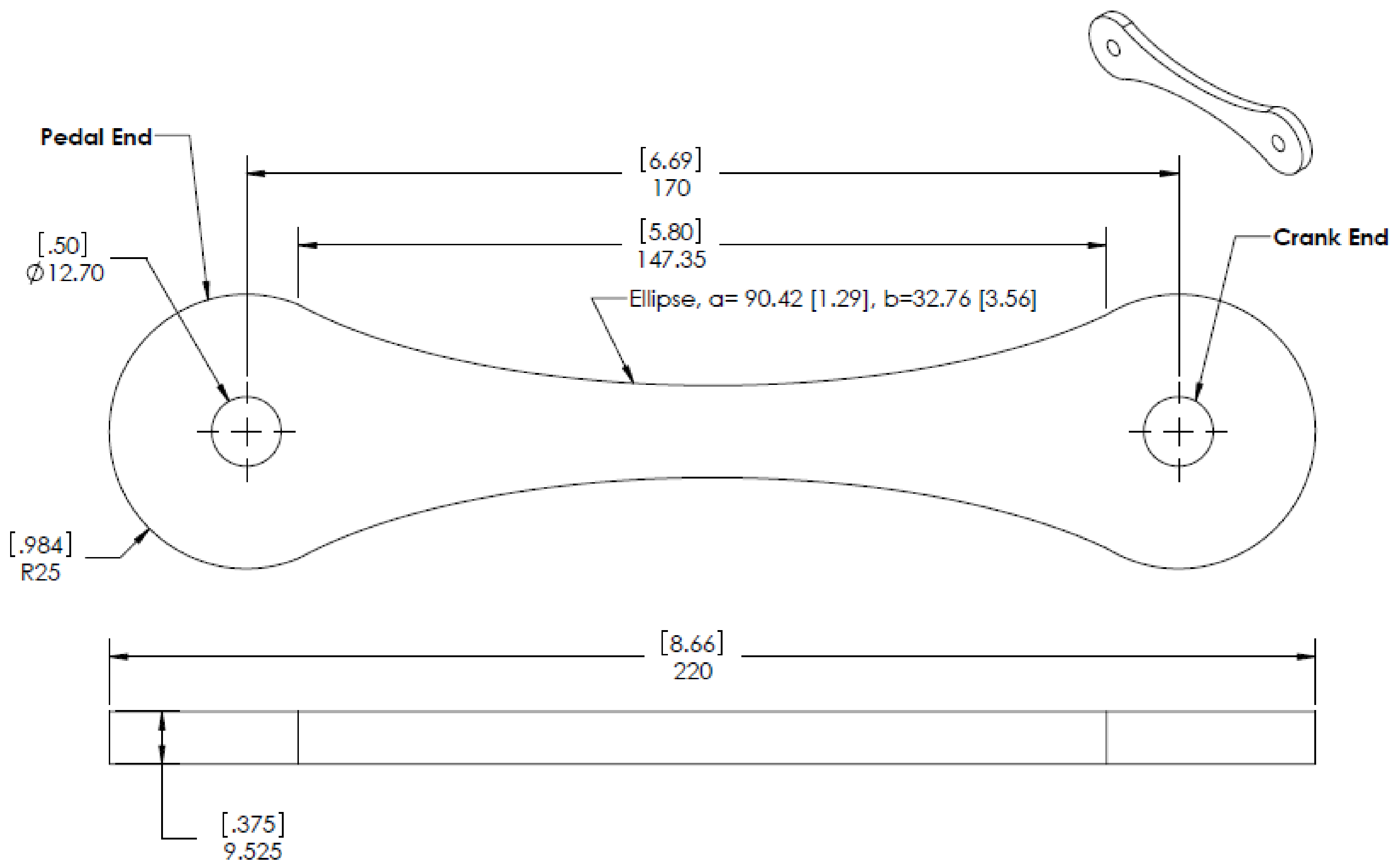
- Specimens are coated with a speckle pattern



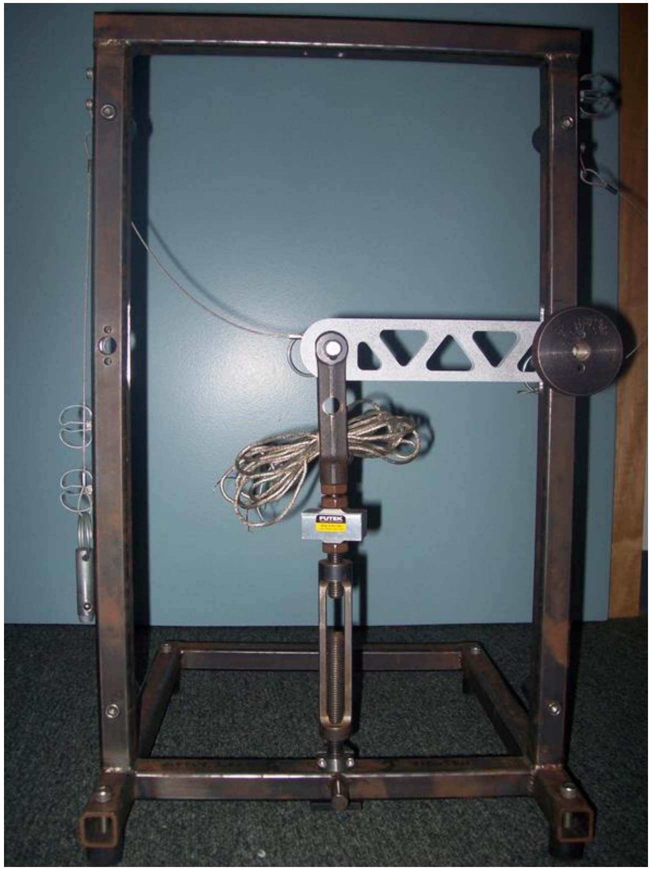
As the specimen is loaded, stereo pairs of pictures are taken and the software is able to track the movements of the facets. Facets = elements.



- From the displacements of the facets, the software calculates the strain field across the part


Pedal End
[6.69]
170
[5.80]
147.35
Crank End
[.50]
∅12.70
Ellipse, a= 90.42 [1.29], b=32.76 [3.56]
[.984]
R25
[8.66]
220
[.375]
9.525

Cornell's Load Frame



FEA Parameters

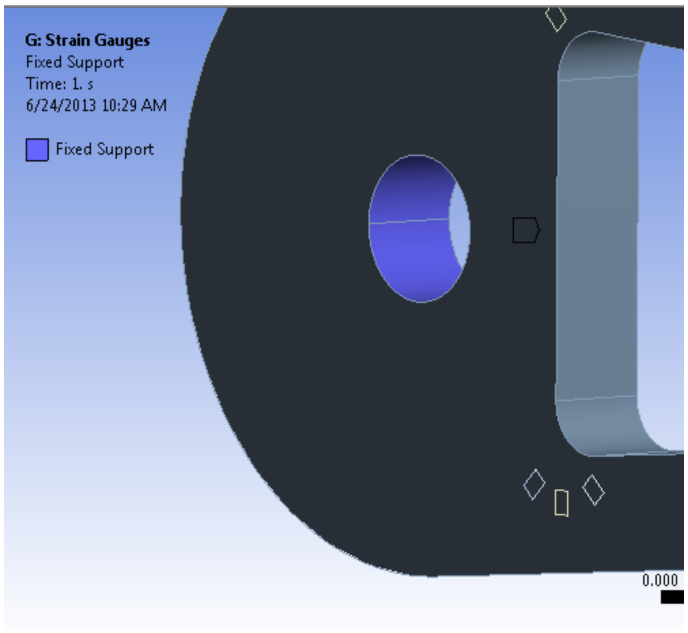
- Material: Al 6061 T6

  E = 68900 MPa   ν = .34

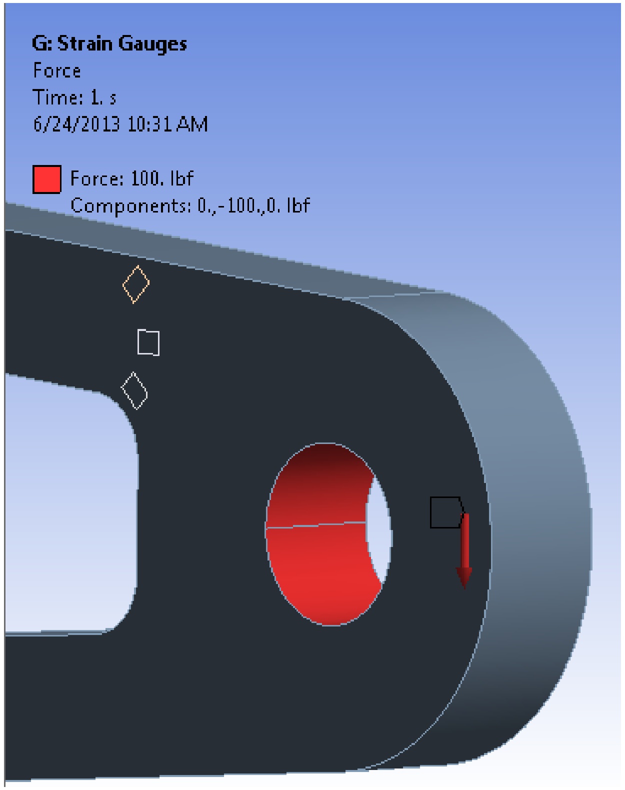
- Boundary Conditions:
  - Fixed Support around inside of support hole; no rotations, no displacements
  - 100 pound force in y-direction along inside of pin hole.

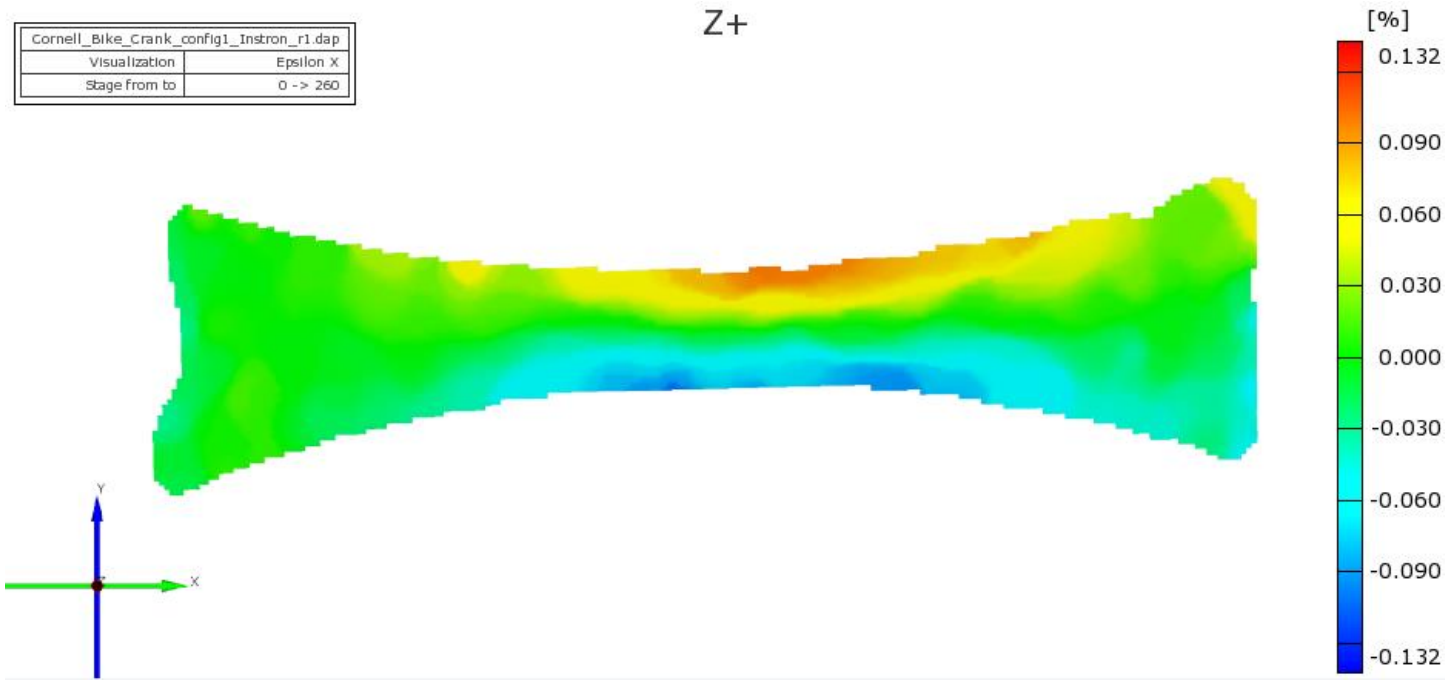
Boundary Conditions

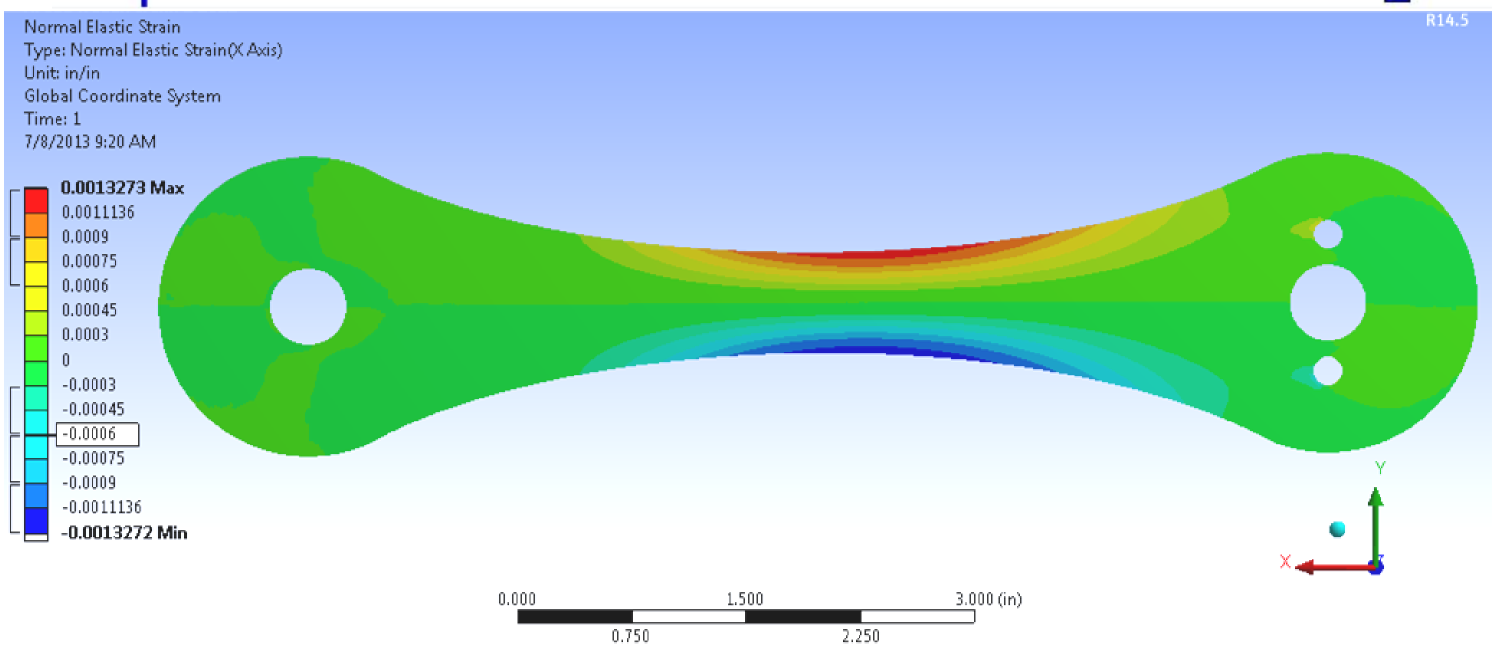
- Fixed Support



- Force



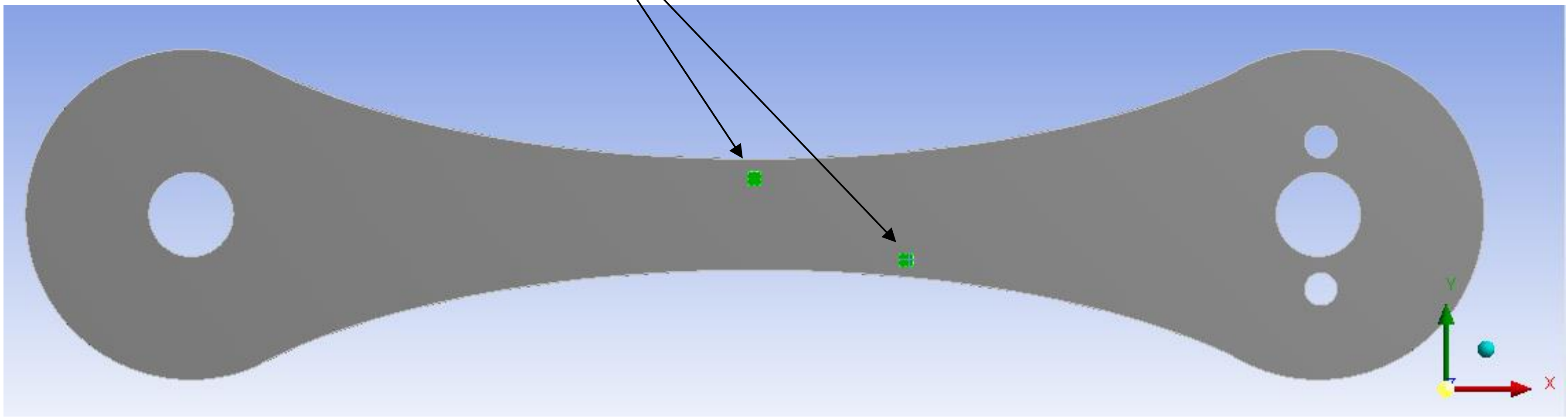

Cornell_Bike_Crank_config1_Instron_r1.dap
Visualization Epsilon X
Stage from to 0 -> 260
Z+
[%]
0.132
0.090
0.060
0.030
0.000
-0.030
-0.060
-0.090
-0.132
Y
X


Normal Elastic Strain
Type: Normal Elastic Strain(X Axis)
Unit: in/in
Global Coordinate System
Time: 1
7/8/2013 9:20 AM
R14.5
0.0013273 Max
0.0011136
0.0009
0.00075
0.0006
0.00045
0.0003
0
-0.0003
-0.00045
-0.0006
-0.00075
-0.0009
-0.0011136
-0.0013272 Min
Y
X
0.000
1.500
3.000 (in)
0.750
2.250

Virtual Strain Gauges

- Modeled as shell elements with zero stiffness
- Created in CAD as a plane with zero thickness
- Meshed as one element overlaid on surface mesh
- Strain is calculated based on the average strain from the surface mesh below the gauge

- Strain gauges placed in areas of high tensile and compressive strain



Theory

- Cantilever beam with constant cross section
- Isotropic material
- Plane stress
- $\sigma_x >> \sigma_y$
- ε_x calculated according to Hooke's Law:

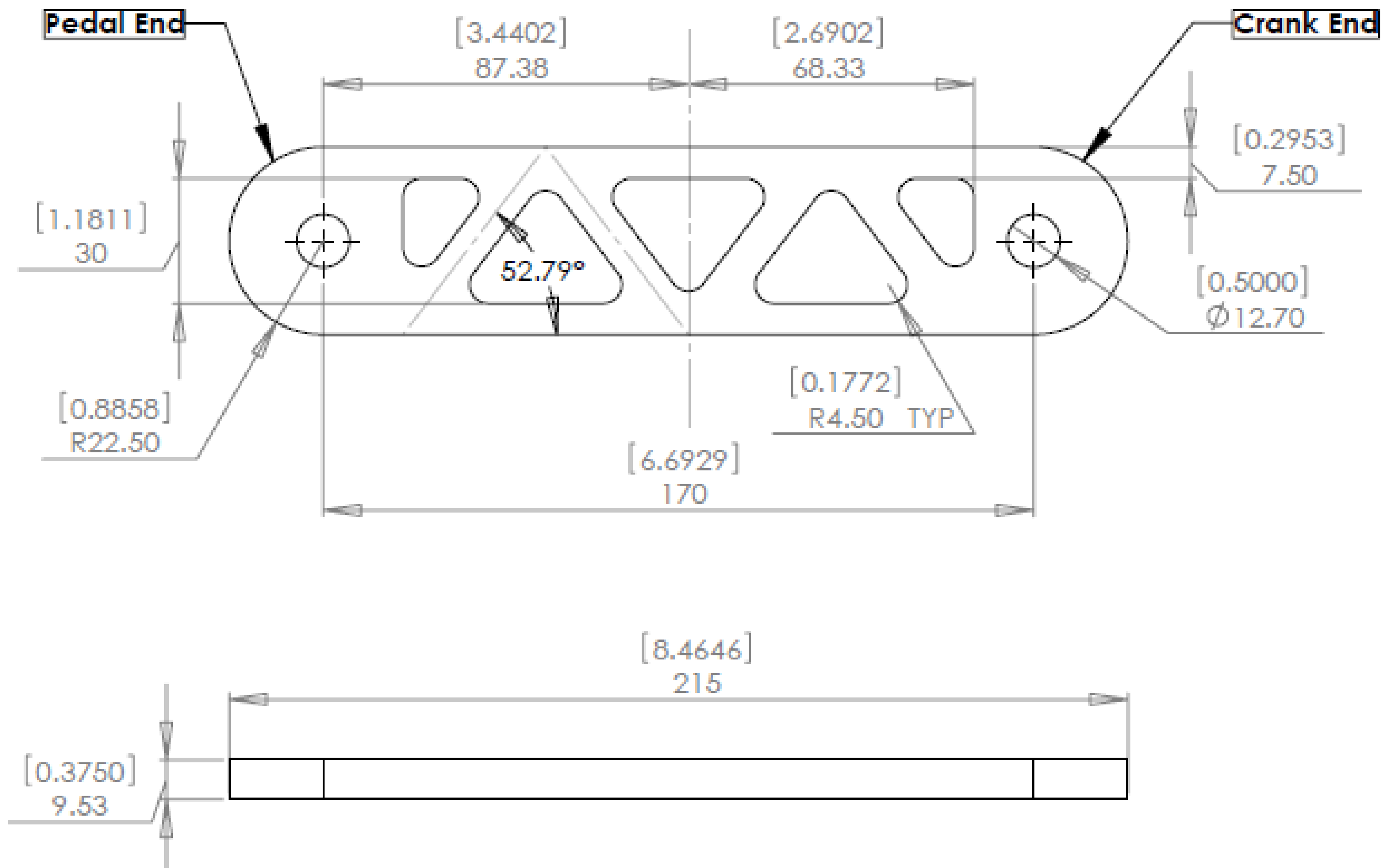
$$\begin{bmatrix} \varepsilon_x \\ \varepsilon_y \end{bmatrix} = \frac{1}{E} \begin{bmatrix} 1 & -\nu \\ -\nu & 1 \end{bmatrix} \begin{bmatrix} \sigma_x \\ \sigma_y \end{bmatrix}$$

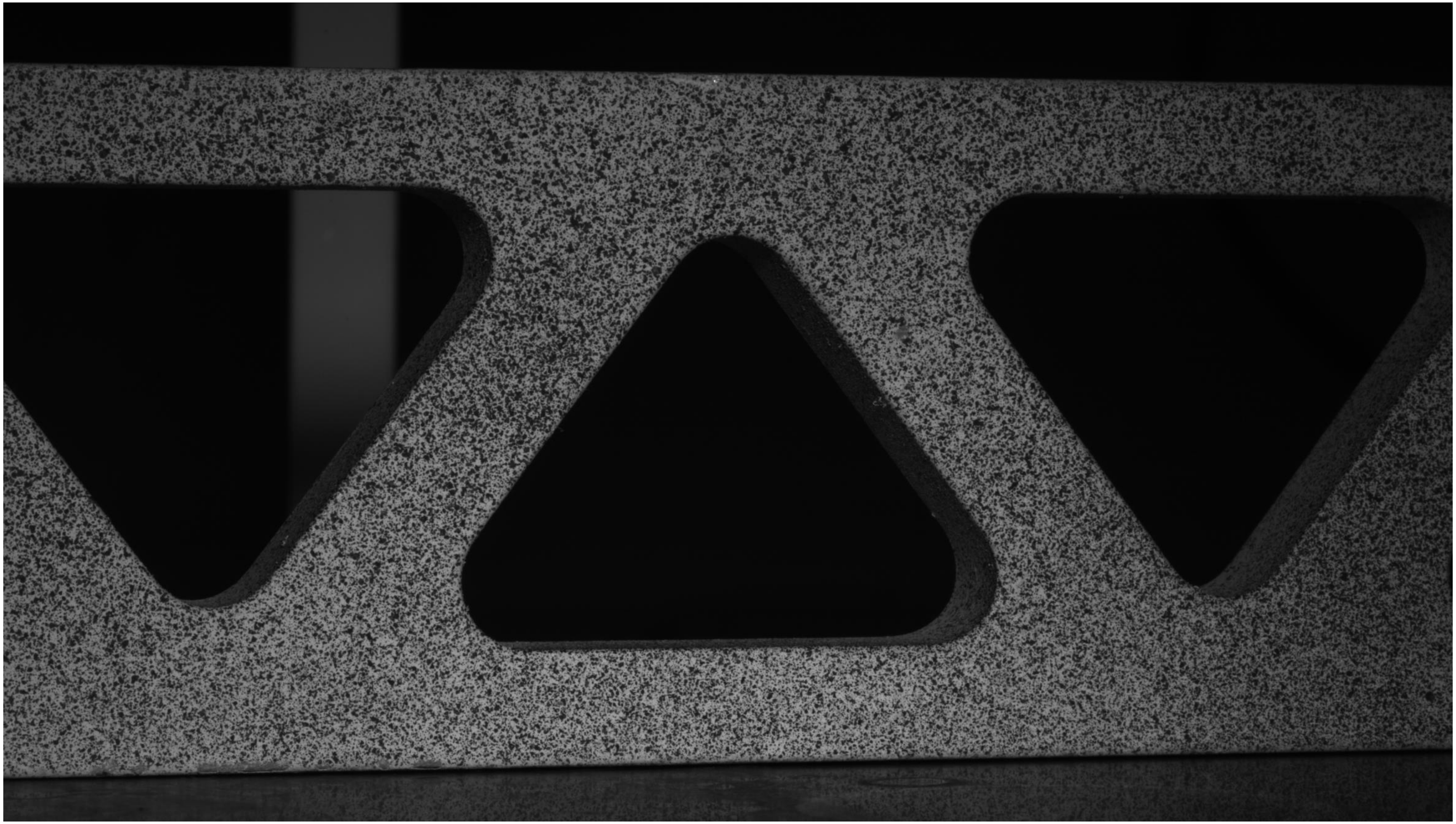
Simulation, DIC, and Theoretical ε_x Values

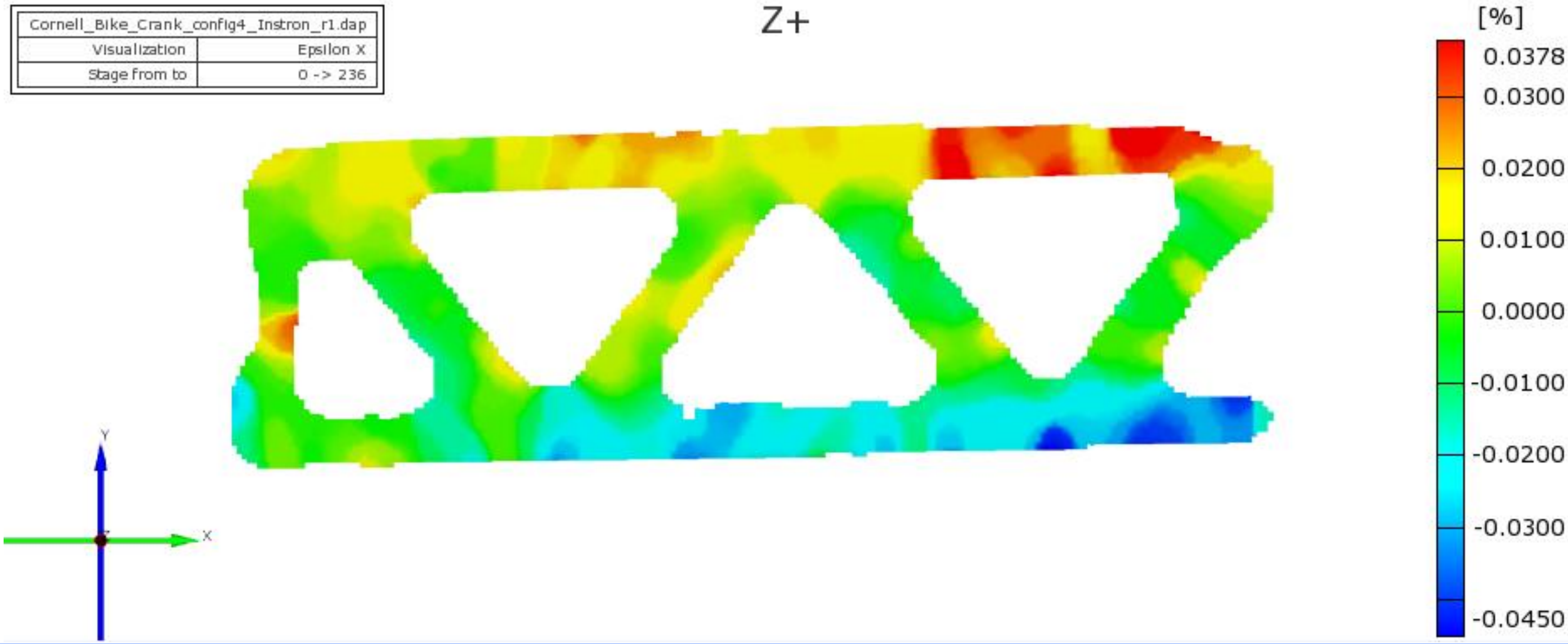
	Simulation	DIC	Theory
Upper gauge (με)	782	932	789
Lower gauge (με)	-883	-918	-893

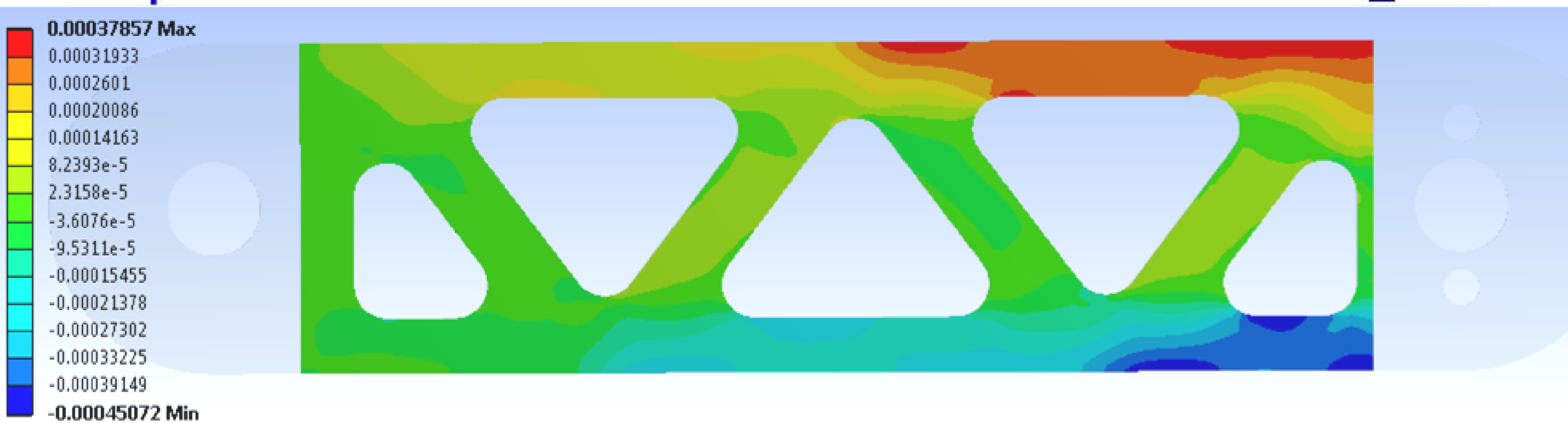
Percent Differences

	Simulation vs. Theory	DIC vs. Theory	DIC vs. Simulation
Upper gauge	.887 %	18.1 %	16.1 %
Lower gauge	1.12 %	2.8 %	3.81 %

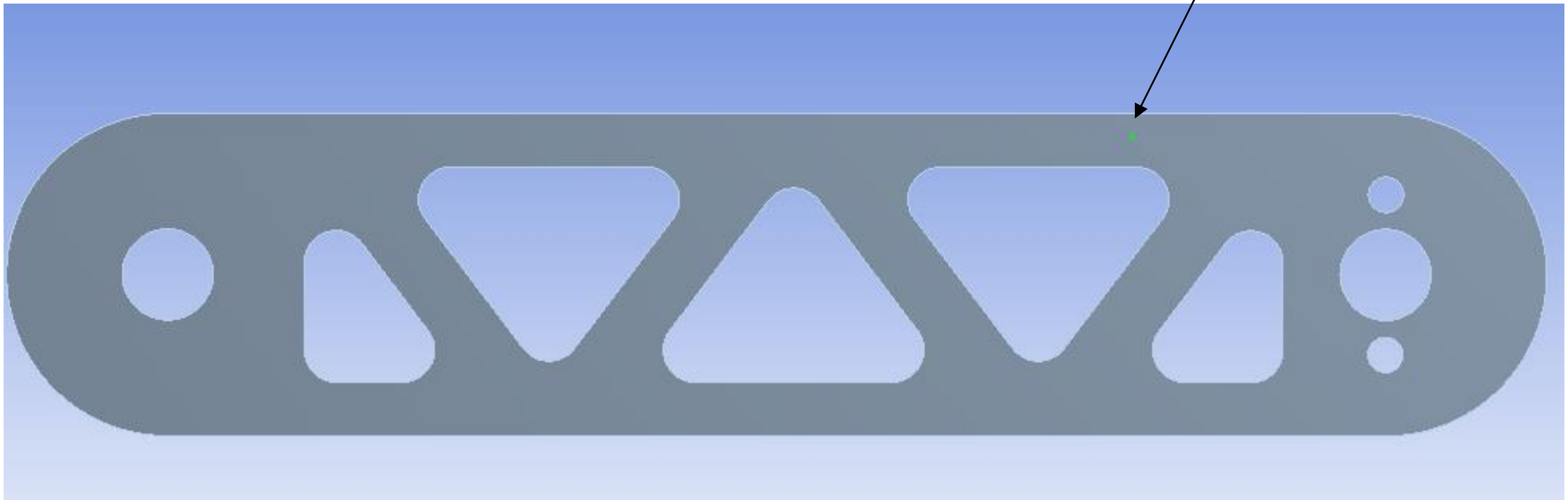

Pedal End
Crank End
[3.4402]
87.38
[2.6902]
68.33
[0.2953]
7.50
[1.1811]
30
52.79°
[0.5000]
Ø12.70
[0.8858]
R22.50
[0.1772]
R4.50 TYP
[6.6929]
170
[8.4646]
215
[0.3750]
9.53




Cornell_Bike_Crank_config4_Instron_r1.dap
Visualization
Epsilon X
Stage from to
0 -> 236
Z+
[%]
0.0378
0.0300
0.0200
0.0100
0.0000
-0.0100
-0.0200
-0.0300
-0.0450
Y
X


0.00037857 Max
0.00031933
0.0002601
0.00020086
0.00014163
8.2393e-5
2.3158e-5
-3.6076e-5
-9.5311e-5
-0.00015455
-0.00021378
-0.00027302
-0.00033225
-0.00039149
-0.00045072 Min

- Strain gauge placed on an area of high tensile strain



Theory

- Beam treated as a truss with a 100 pound force applied at one end, and fixed supports on the members at the opposite end

- The magnitude and direction of the force in each member was determined, and from this the stress and strain at the position of the strain gauge were calculated

Simulation, DIC, and Theoretical ε_x Values

	Simulation	DIC	Theory
Gauge X-strain (με)	292	270	262

Percent Differences

Simulation vs.Theory	DIC vs. Theory	DIC vs. Simulation
11.5 %	2.96 %	8.15 %

Conclusions

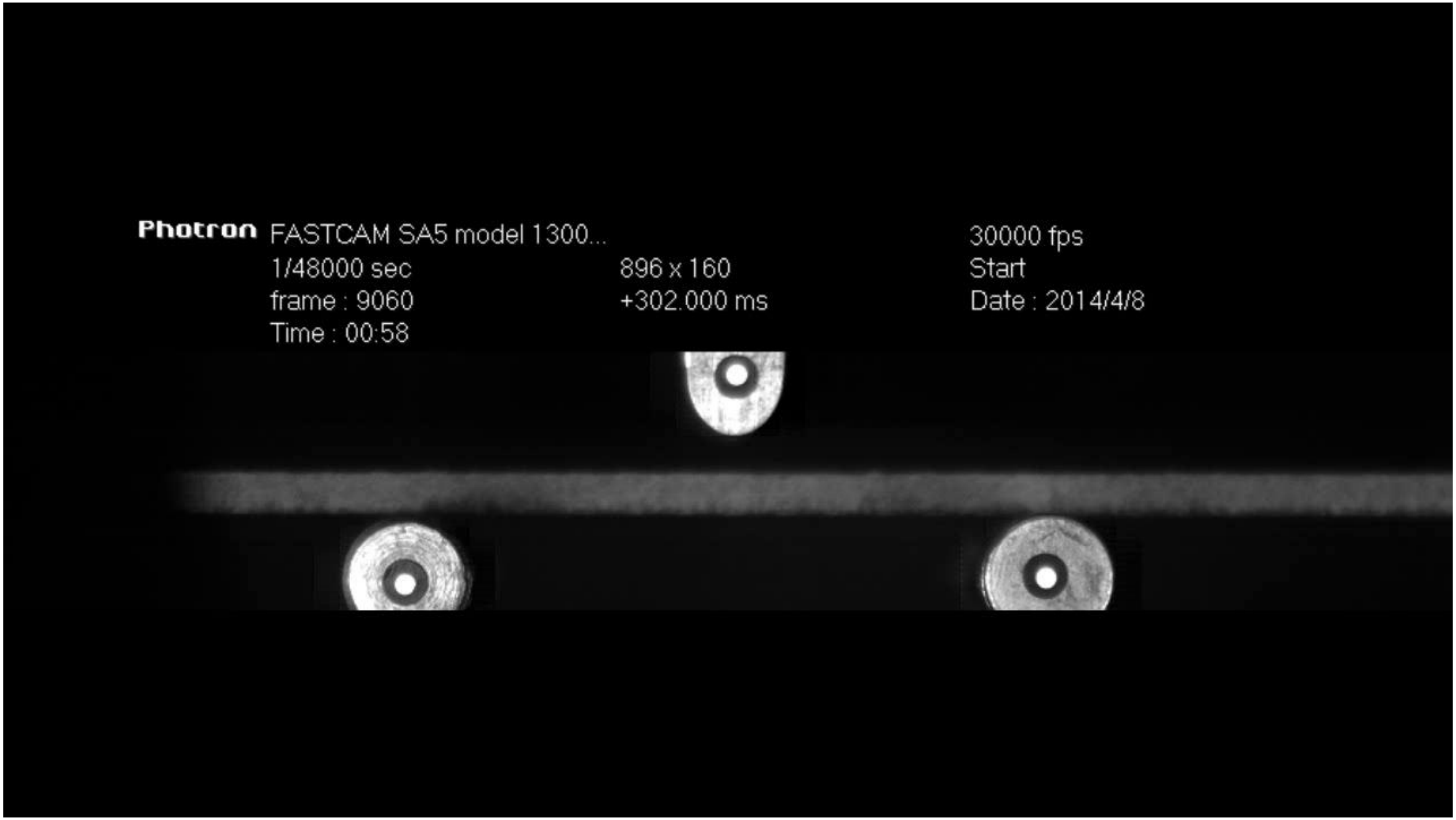
- DIC provides full field validation of simulation data rather than single-point spot checks
- Ability to pinpoint problem areas in beam analysis
- Provides better understanding of localized strain behavior at any location
- Eliminates error associated with strain gauge placement
- Less likely to miss strain “hot spots” that can arise with complex loadings or geometries

Acknowledgments

DatapointLabs would like to acknowledge the contribution of Jennifer Borshoff, who performed the work presented here, and the support of Rajesh Bhaskaran, Senior Lecturer and Swanson Director of Engineering Simulation at Cornell University, School of Mechanical & Aerospace Engineering

Future Work

- High speed video
- 1M frame/s capability
- High speed tensile testing
- > 1000/s strain rates
- Validating crash simulation


Photron FASTCAM SA5 model 1300...
30000 fps
1/48000 sec
896 x 160
Start
frame : 9060
+302.000 ms
Date : 2014/4/8
Time : 00:58

Thank you!