COMSOL
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Load Cell Design Using COMSOL Multiphysics

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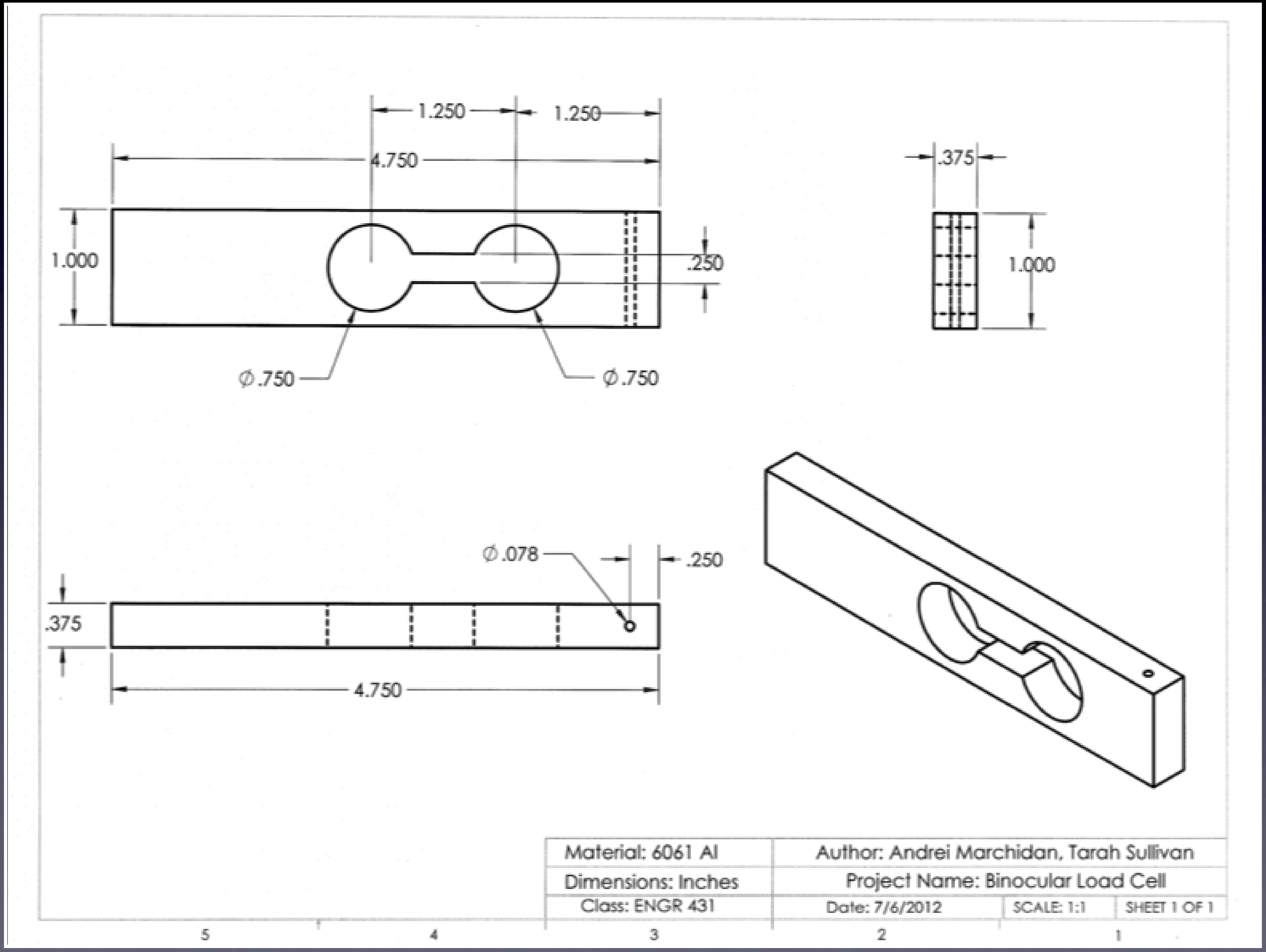
Overview

- COMSOL Multiphysics was used to design a binocular load cell.
- A three-dimensional linear solid model of the load cell spring element was studied to quantify the high-strain regions under loading conditions.
- The load cell was fabricated from 6061 aluminum, and strain gages were installed at the four high-strain regions of the spring element.
- Gages were wired as a full Wheatstone bridge and total strain was measured for applied loads from 0-2.5 kg.
- Model total strain was measured using point probes at each of the four strain locations, and with a load parametric analysis.
- Absolute mean model-predicted strain was 1.41% of measured strain. The load cell was highly linear r^2=0.9999.

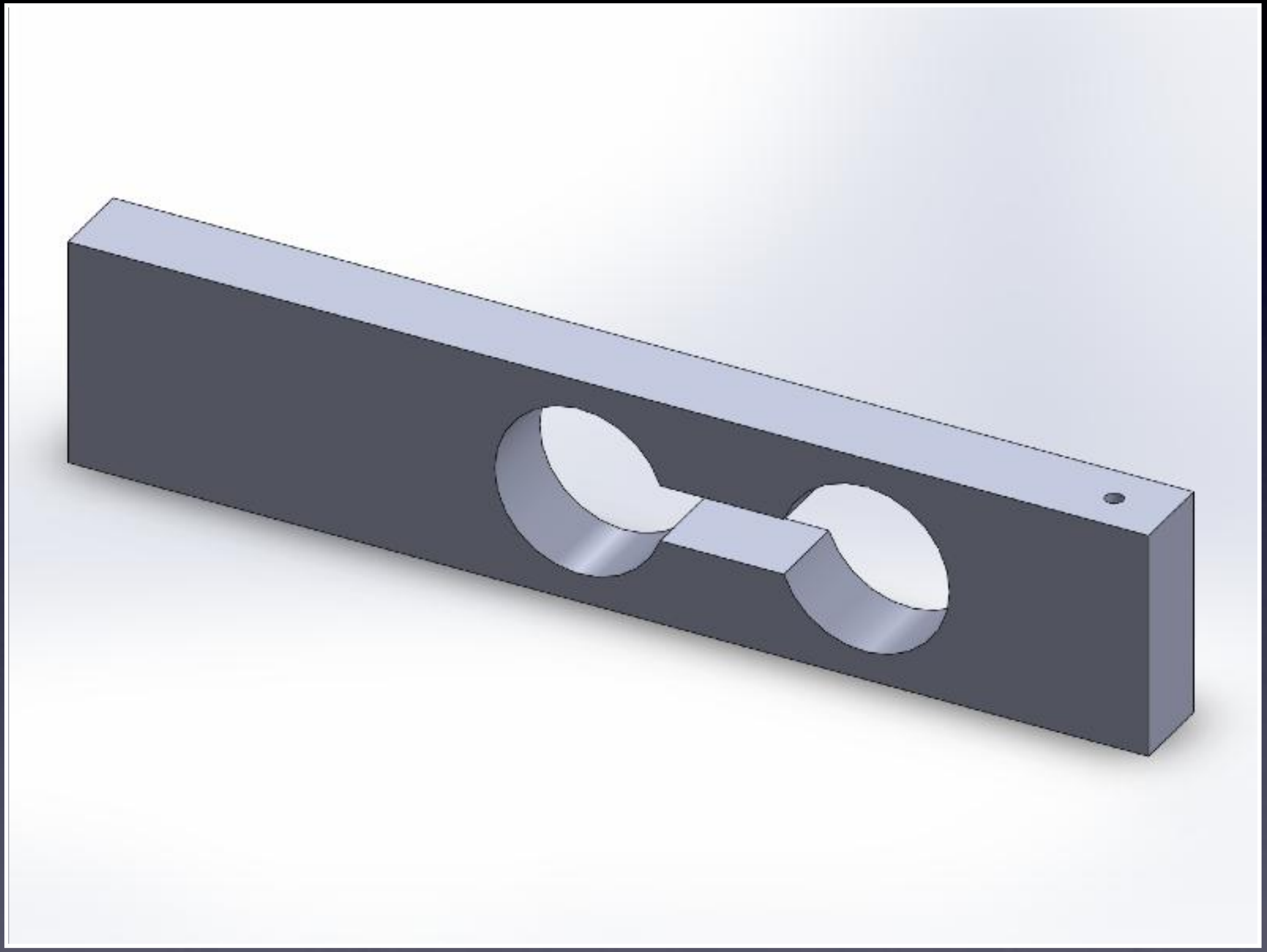
Methods

- Load Cell Spring Element Design
- Full Bridge Strain Gage Design
- Model Predicted Total Strain Measurements
- Load Cell Measurements
- Comparison of COMSOL Model and Experimental Measurements

SolidWorks Geometry - CAD Import Module



Binocular Load Cell Spring Element



COMSOL Model Equations

Equilibrium Balance

$$\nabla \cdot \boldsymbol{\sigma} + \boldsymbol{F}_v = \rho\, \ddot{\mathbf{u}}$$

Constitutive Relation

$$\boldsymbol{\sigma} - \boldsymbol{\sigma}_0 = \boldsymbol{C} : (\boldsymbol{\epsilon} - \boldsymbol{\epsilon}_0 - \boldsymbol{\epsilon}_{\mathbf{inel}})$$

Kinematic Relation

$$\epsilon = \frac{1}{2}\left[\nabla u + (\nabla u)^T\right]$$

Stationary Analysis

Equilibrium Balance

$$\nabla \cdot \boldsymbol{\sigma} + \boldsymbol{F_v} = \rho\, \ddot{\mathbf{u}}$$

right-hand side goes to zero

Constitutive Relation

$$\sigma - \sigma_0 = C : (\epsilon - \epsilon_0 - \epsilon_{\mathrm{inel}})$$

initial stress, initial strain and inelastic strain are all zero

Isotropic Elastic Material

Generalized Hooke's Law reduces to elasticity matrix

$$\begin{bmatrix} 2\mu+\lambda & \lambda & \lambda & 0 & 0 & 0 \\ \lambda & 2\mu+\lambda & \lambda & 0 & 0 & 0 \\ \lambda & \lambda & 2\mu+\lambda & 0 & 0 & 0 \\ 0 & 0 & 0 & \mu & 0 & 0 \\ 0 & 0 & 0 & 0 & \mu & 0 \\ 0 & 0 & 0 & 0 & 0 & \mu \end{bmatrix}$$

$$\lambda = \frac{E\,\nu}{(1+\nu)(1-2\nu)} \quad \text{and} \quad \mu = \frac{E}{2(1+\nu)}$$

Kinematic Relation

$$\boldsymbol{\epsilon} = \frac{1}{2}\left[\boldsymbol{\nabla u} + (\boldsymbol{\nabla u})^T\right]$$

Reduces to Cauchy infinitesimal strain tensor

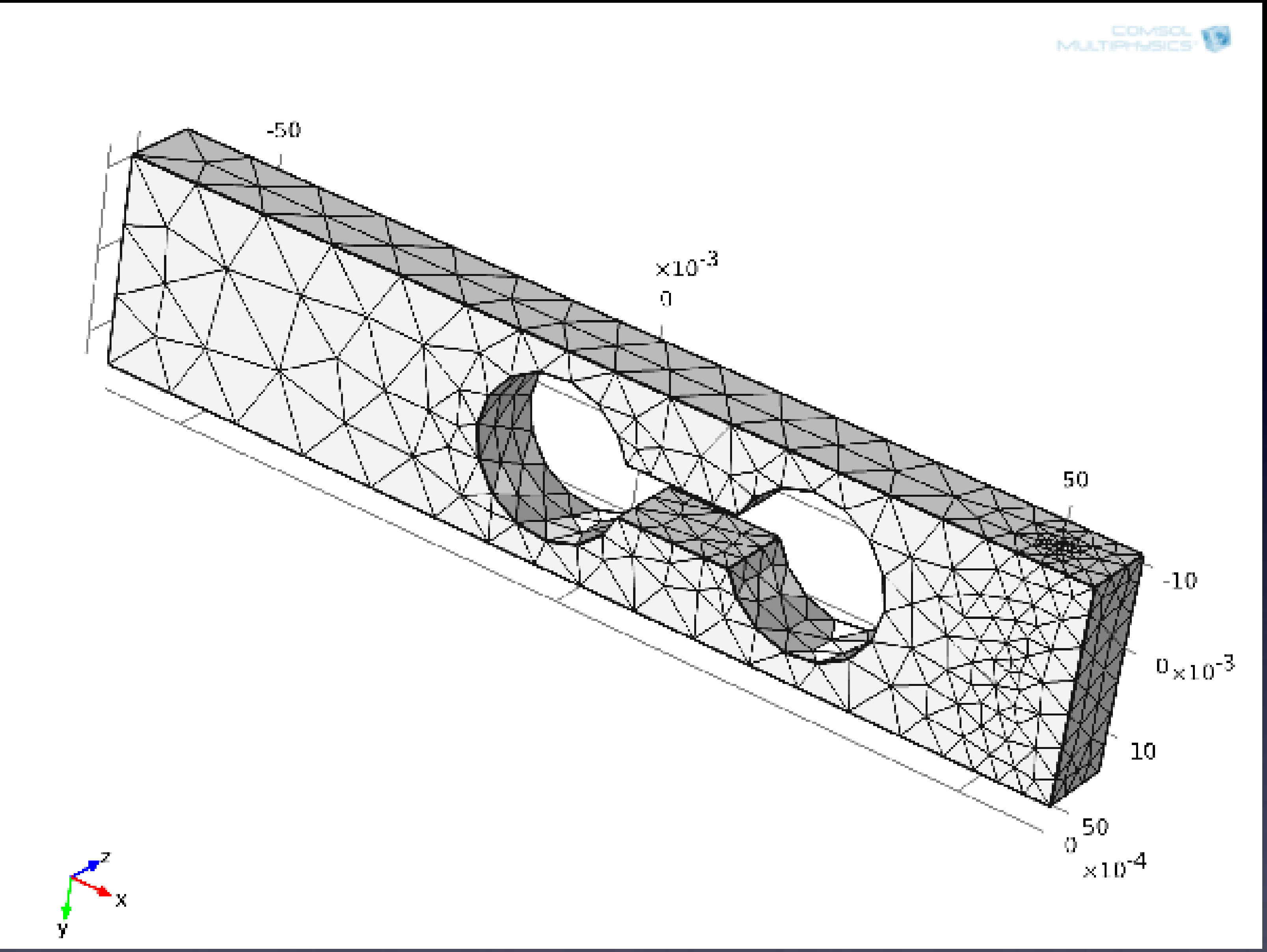
$$\epsilon_{ij} = \frac{1}{2}\left[\frac{\partial u_j}{\partial x_i} + \frac{\partial u_i}{\partial x_j}\right]$$

Material Properties for Spring Element

Material properties for 6061 aluminum used in the COMSOL model [Metals Handbook 2ed, ASM 1998]

Parameter	Symbol	Value
Elastic Modulus	E	69 GPa
Poisson's Ratio	ν	0.33
Density	ρ	2700 $\mathrm{kg/m^3}$

Spring Element Mesh

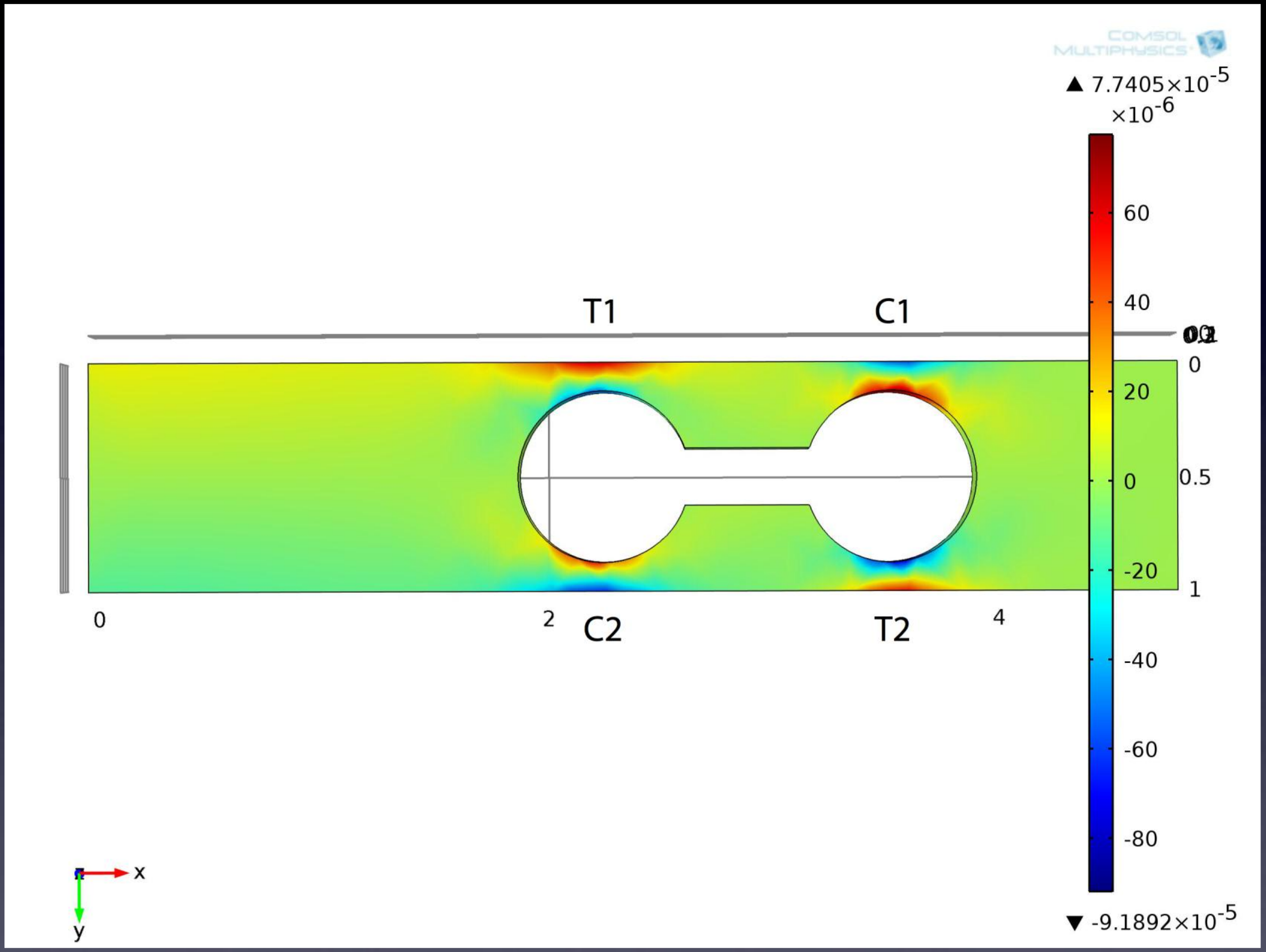


Physics Controlled Fine Mesh

4,885 tetrahedral elements

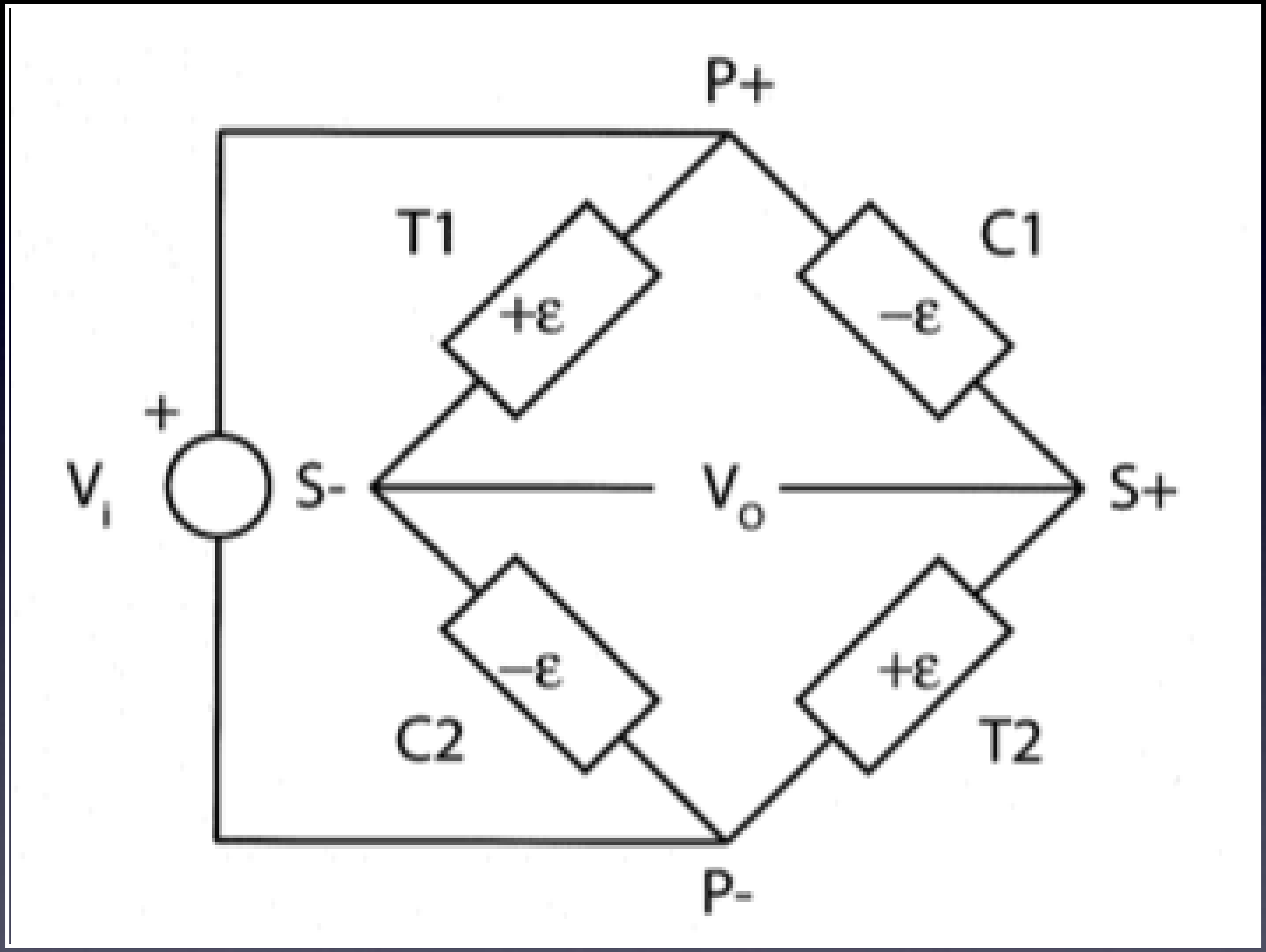
23,658 degrees of freedom

Predicted High Strain Regions



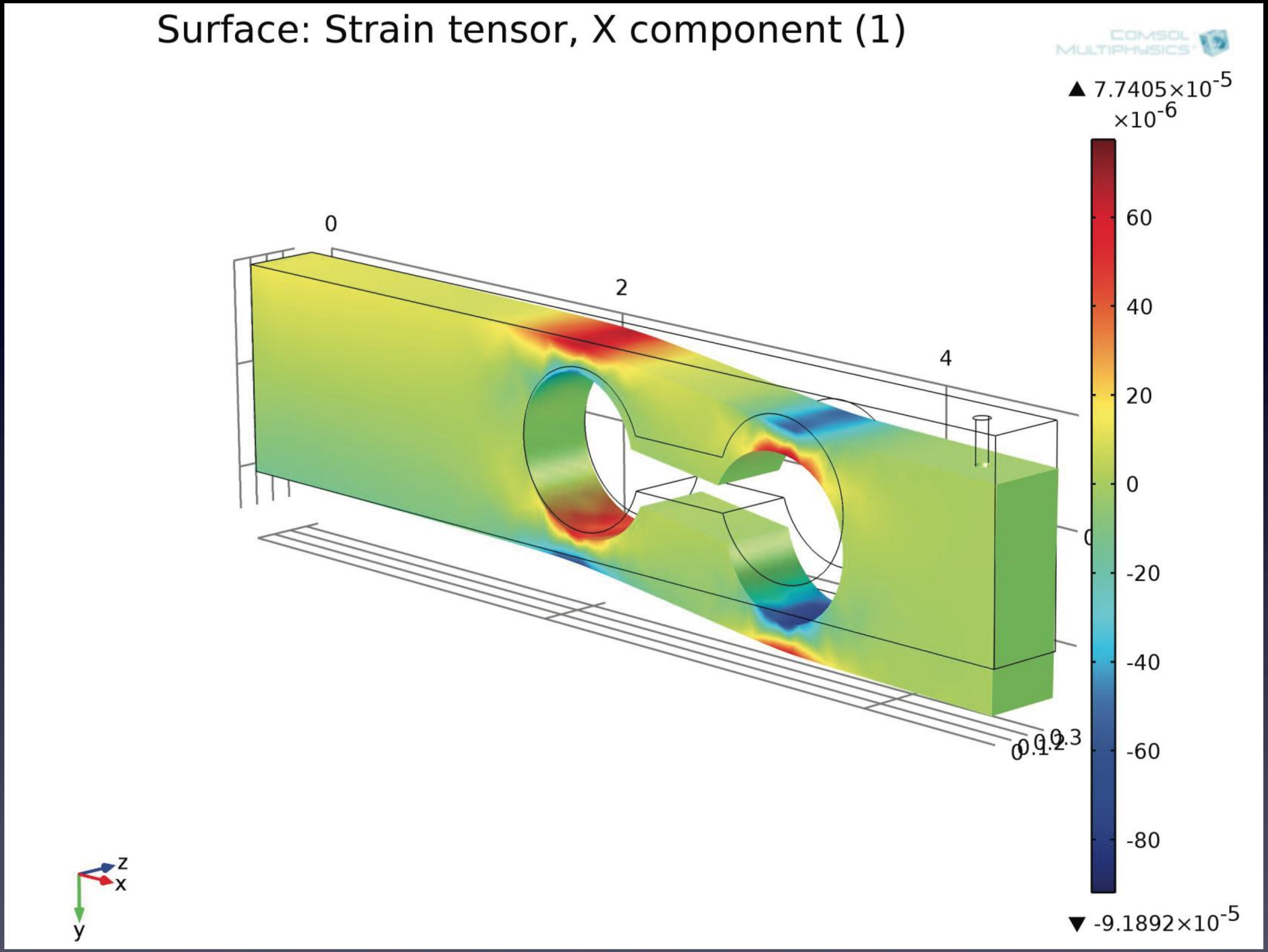
Location of high strain regions: tension T1 and T2, and compression C1 and C2

Full-bridge Strain Gage Configuration



$$\epsilon_{\text{total}} = \epsilon_{\text{T1}} - \epsilon_{\text{C1}} + \epsilon_{\text{T2}} - \epsilon_{\text{C2}}$$

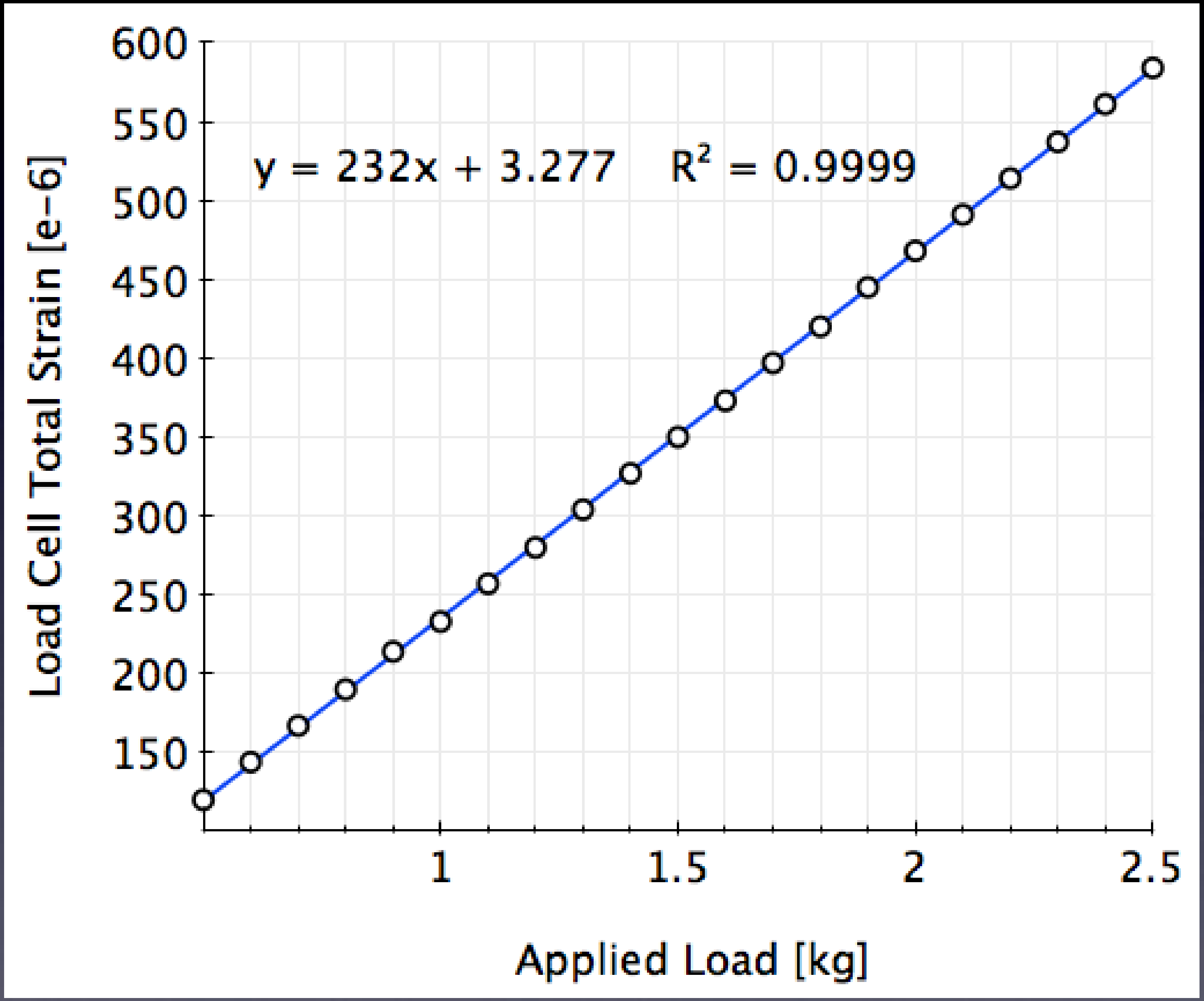
Load Cell Model
Strain



Model Predicted vs. Measured Strain

Mass [g]	T1 [ϵ]	C1 [ϵ]	T2 [ϵ]	C2 [ϵ]	COMSOL [$\mu\epsilon$]	Measured [$\mu\epsilon$]	Difference [%]
500	3.24E-05	-2.71E-05	2.69E-05	-3.26E-05	119	120	0.840
600	3.89E-05	-3.25E-05	3.23E-05	-3.92E-05	143	144	0.770
700	4.54E-05	-3.80E-05	3.76E-05	-4.57E-05	167	167	0.180
800	5.19E-05	-4.34E-05	4.30E-05	-5.22E-05	191	190	-0.262
900	5.84E-05	-4.88E-05	4.84E-05	-5.88E-05	214	214	-0.187
1,000	6.49E-05	-5.42E-05	5.38E-05	-6.53E-05	238	233	-2.183
1,100	7.14E-05	-5.96E-05	5.92E-05	-7.18E-05	262	257	-1.908
1,200	7.78E-05	-6.51E-05	6.45E-05	-7.83E-05	286	280	-1.995
1,300	8.43E-05	-7.05E-05	6.99E-05	-8.49E-05	310	304	-1.809
1,400	9.08E-05	-7.59E-05	7.53E-05	-9.14E-05	333	327	-1.920
1,500	9.73E-05	-8.13E-05	8.07E-05	-9.79E-05	357	350	-2.016
1,600	1.04E-04	-8.68E-05	8.60E-05	-1.04E-04	381	373	-2.048
1,700	1.10E-04	-9.22E-05	9.14E-05	-1.11E-04	405	397	-1.878
1,800	1.17E-04	-9.76E-05	9.68E-05	-1.18E-04	429	420	-2.189
1,900	1.23E-04	-1.03E-04	1.02E-04	-1.24E-04	452	445	-1.549
2,000	1.30E-04	-1.08E-04	1.08E-04	-1.31E-04	477	468	-1.887
2,100	1.36E-04	-1.14E-04	1.13E-04	-1.37E-04	500	491	-1.800
2,200	1.43E-04	-1.19E-04	1.18E-04	-1.44E-04	524	514	-1.908
2,300	1.49E-04	-1.25E-04	1.24E-04	-1.50E-04	548	537	-2.007
2,400	1.56E-04	-1.30E-04	1.29E-04	-1.57E-04	572	561	-1.923
2,500	1.62E-04	-1.36E-04	1.34E-04	-1.63E-04	595	584	-1.849
					Absolute Mean % Difference		1.41

Load Cell Linearity



Discussion and Conclusions

- Load cell design is challenging due to their complex geometry.
- COMSOL solid models are useful for predicting strain in these designs, for locating strain gage mounting positions and especially for optimizing maximum strain for the desired load range.
- Model predictions were validated by measurements performed with the completed load cell, and model and experiment agreed with absolute mean percent difference of 1.41%.

Discussion and Conclusions (Continued)

- Uniformly close agreement between the COMSOL finite-element model and the measured strain demonstrates the load cell's accuracy over the load range.
- Measured strains also show that this transducer is linear over the entire range.
- For maximum transducer load of 2.5~kg the maximum von Mises stress was 15 ksi, which is much less than the yield stress for 6061 aluminum (40 ksi), indicating that the transducer spring element is within the linear elastic range. Maximum displacement was 0.002 in, confirming small deformation of the spring element.

Thank you!

Questions?