

# ANSYS Conference & 33rd CADFEM Users' Meeting

## Virtual Strain Gauges and Virtual Calibration for the Correlation of Landing Gear Simulation Models

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# LIEBHERR

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# Agenda

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1. **Virtual Strain Gauges**
2. **Virtual Calibration**
3. **Non-linear FE Section Load Extraction**
4. **Summary**

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*„Simulation models are only as good as the assumptions that were made when they were created.“*

# Assumptions in Simulations

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n Boundary conditions

n Material

n Geometry

n Loads

n ...

**è Correlation, Validation and Verification is essential in simulation based engineering!**

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Part 1

# VIRTUAL STRAIN GAUGES

# Virtual Strain Gauges

## n Mimicking the behavior of physical strain gauges

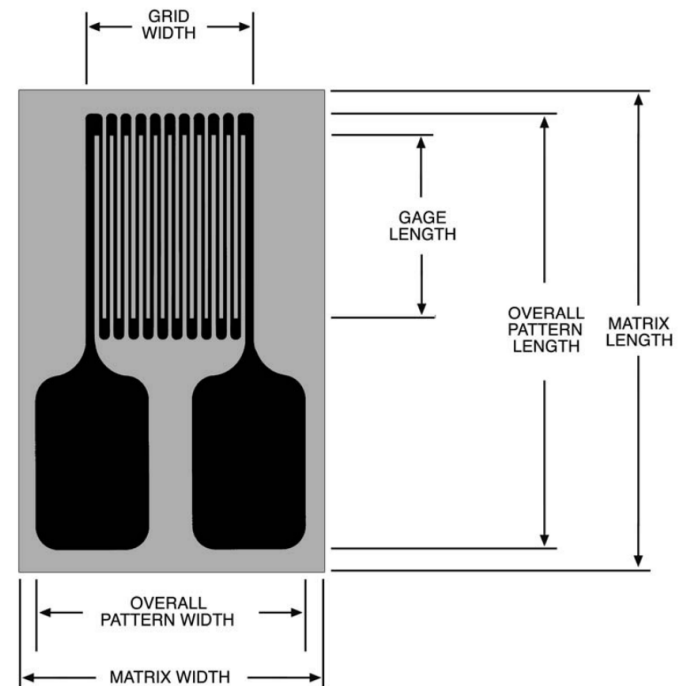
- n Placement and orientation
- n Measuring direction
- n Strain averaging

## n Reliable implementation in ANSYS

## n Mesh-independence

## n Investigating different techniques

## n Sensitivity study

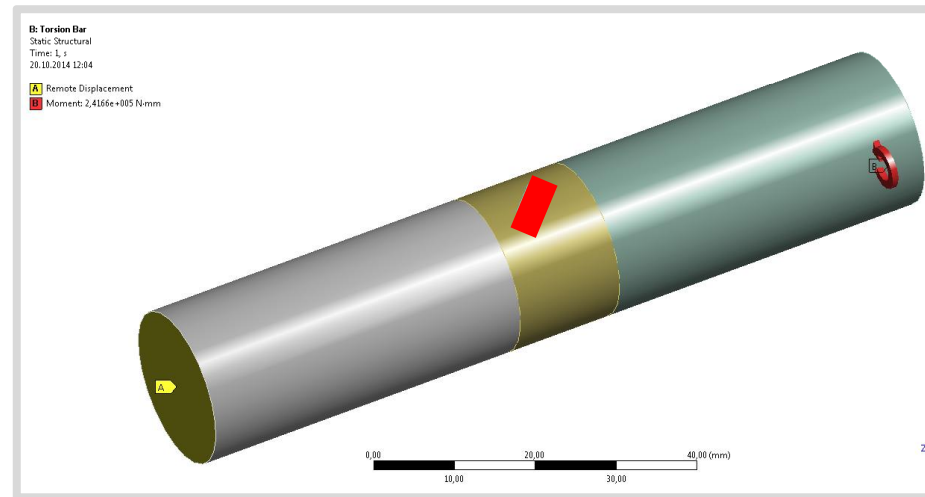
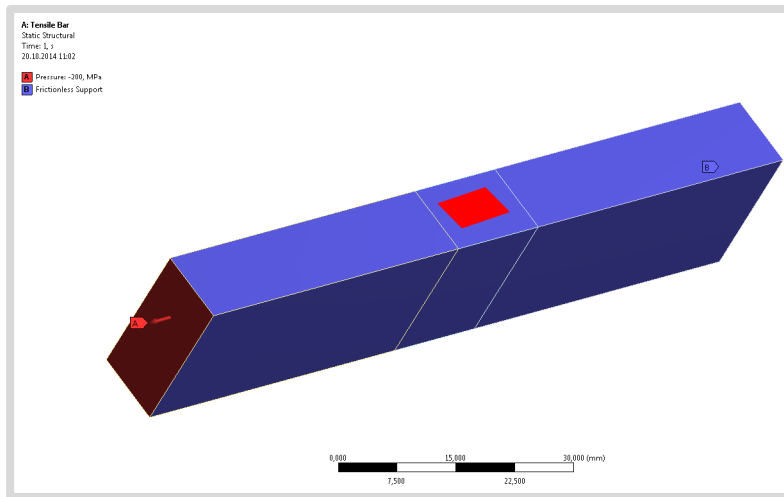


(VMM-DB0103-1011)

# Test Shapes

## n Different Virtual Strain Gauges were analyzed on simple structures

- n Rectangular bar for tension and bending
- n Round bar for torsion



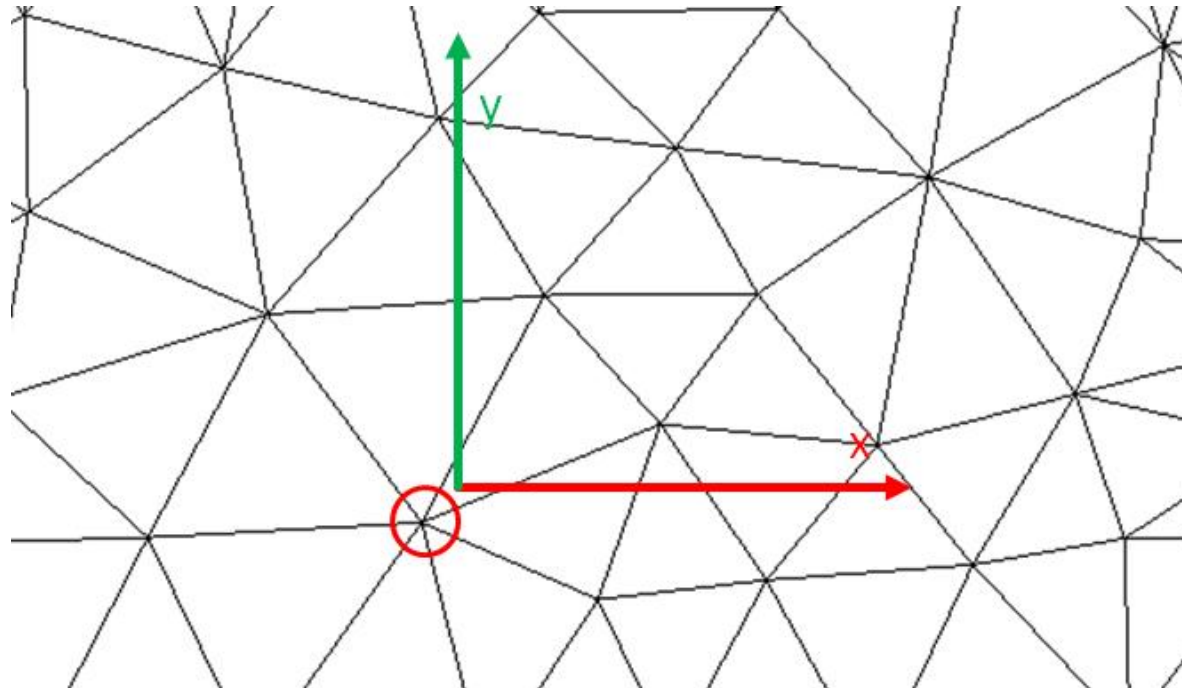
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# Closest node

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n Grid independent

n Select node closest to defined position

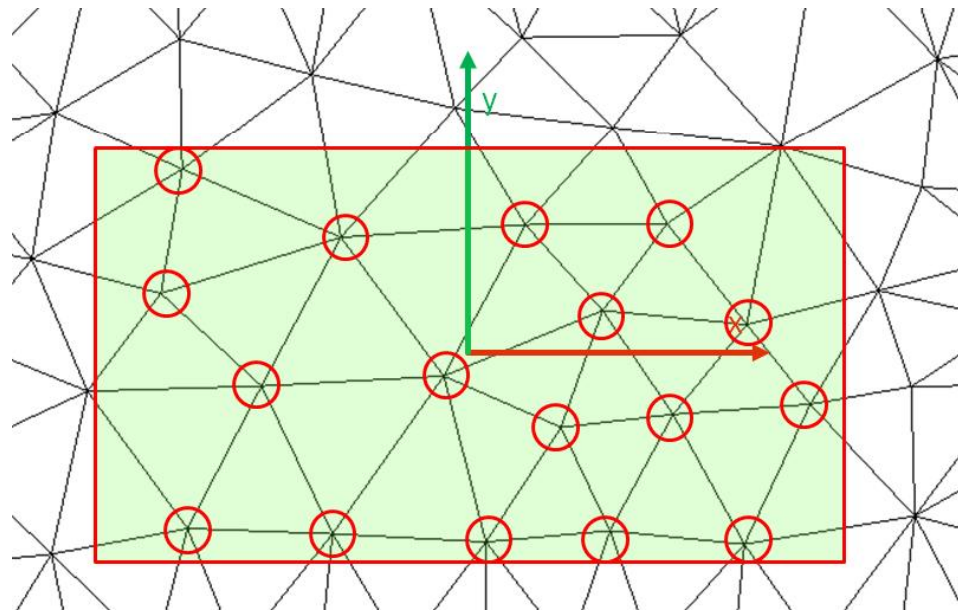




# Average of nodes in range

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- n Similar to previous method but uses multiple nodes
- n Mean strain of nodes which are covered by strain gauge grid is calculated

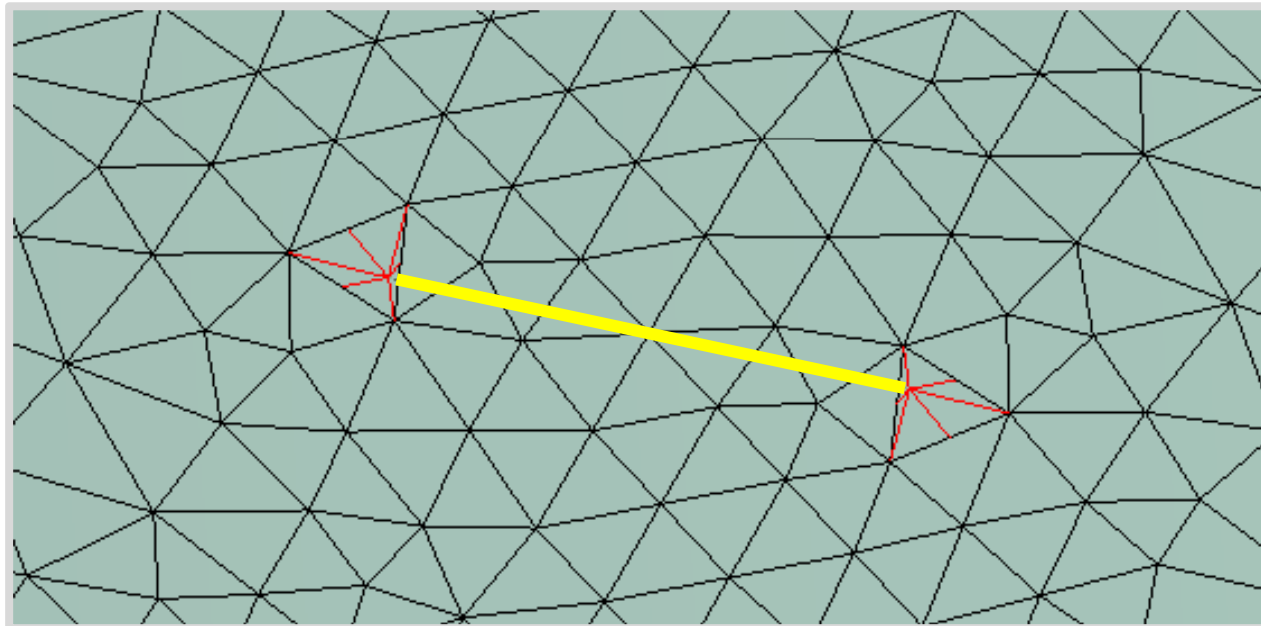


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# Truss Element Strain Gauge

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- n Truss element with the length of the measuring grid is connected to the existing mesh
- n Uses MPC contacts

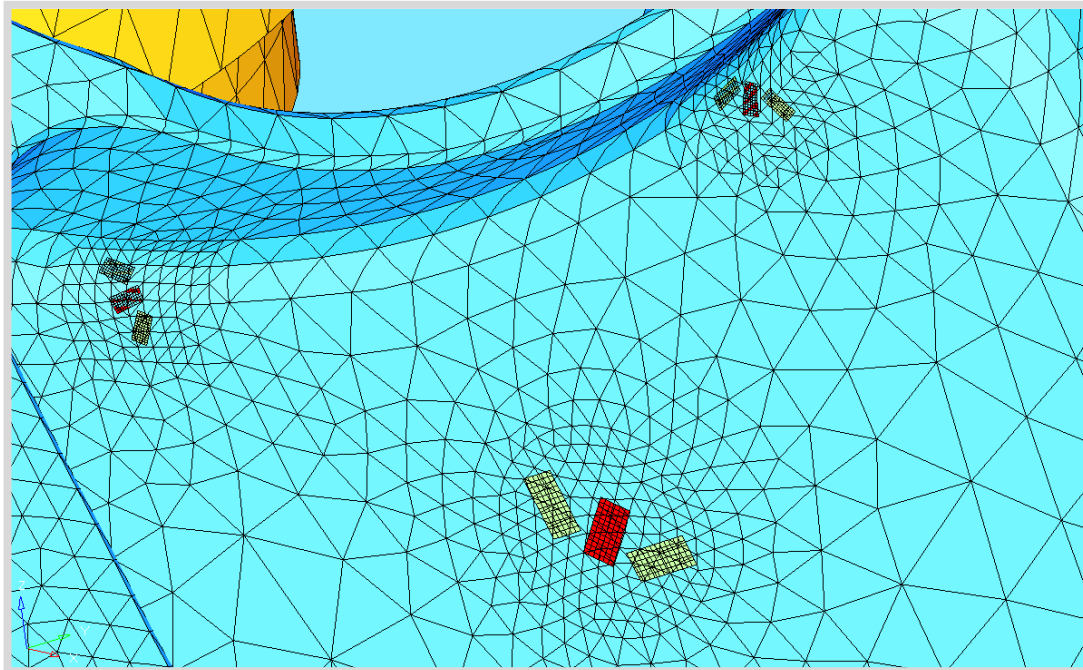


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# Shell Element Strain Gauge

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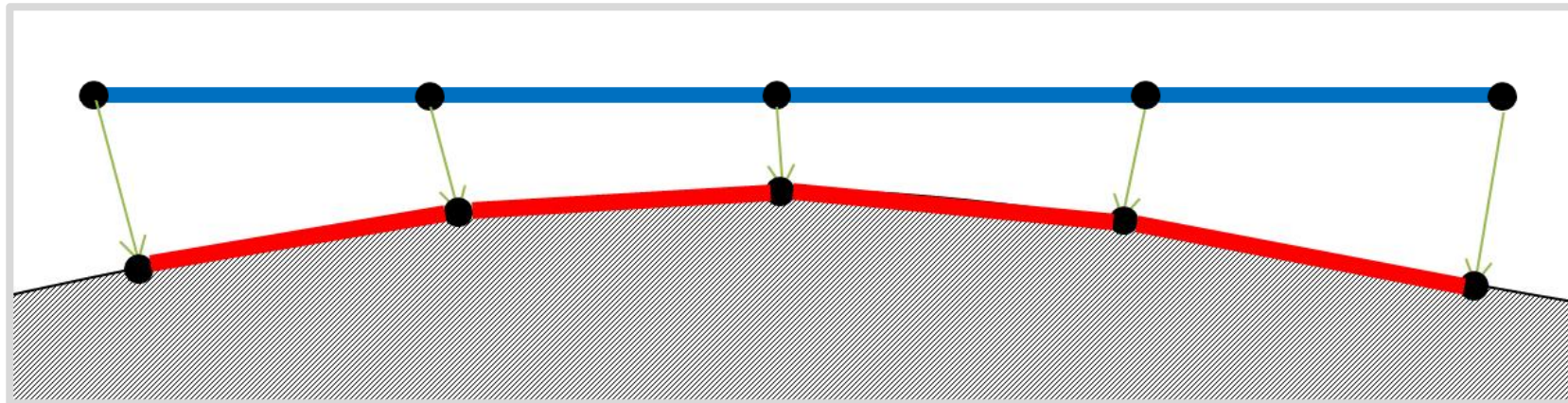
- n Strain Gauges are modelled by single or multiple shell elements
- n Elements are bonded to the FE mesh by contacts
- n *CNCHECK, ADJUST* for shape projection



## *CNCHECK, ADJUST* Shape Projection Mechanism

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- n Strain gauges are modelled flat
- n Nodes of strain gauge elements are projected on part surface



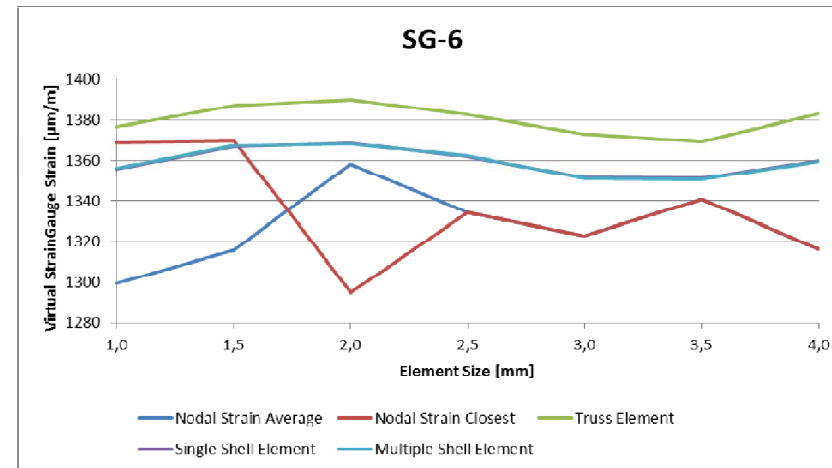
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# Parameter Study – Element Size

n Virtual Strain Gauges with best suitable parameters

n Element size of part was varied in steps

- n Element based Virtual Strain Gauges show consistent results
- n Nodal based methods scatter



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# Submodelling Technique

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- n Post-processing step**
- n Shell Element Virtual Strain Gauges**
- n ONLY a solution for the Strain Gauge elements is calculated**
- n *CNCHECK, ADJUST* for geometry projection**
- n Submodelling step à Map structural displacements on strain gauge elements (*CBDO*)**
- n Very low computation time**
- n Suitable for big models**

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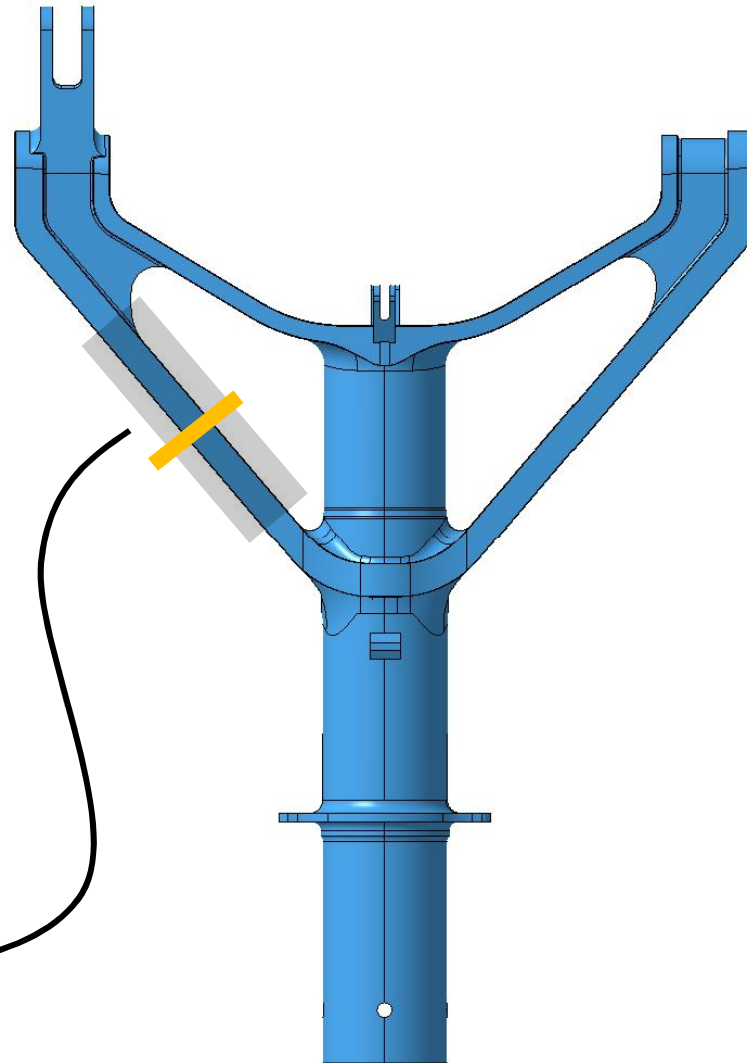
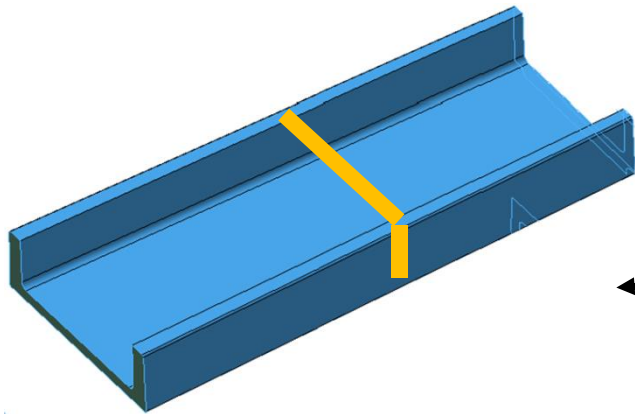
Part 2

# VIRTUAL CALIBRATION

# Virtual Calibration

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- n Similar to physical calibration
- n Superposition principle
- n Calibration for external loads OR internal loads
  
- n Applying known loads and measuring the response



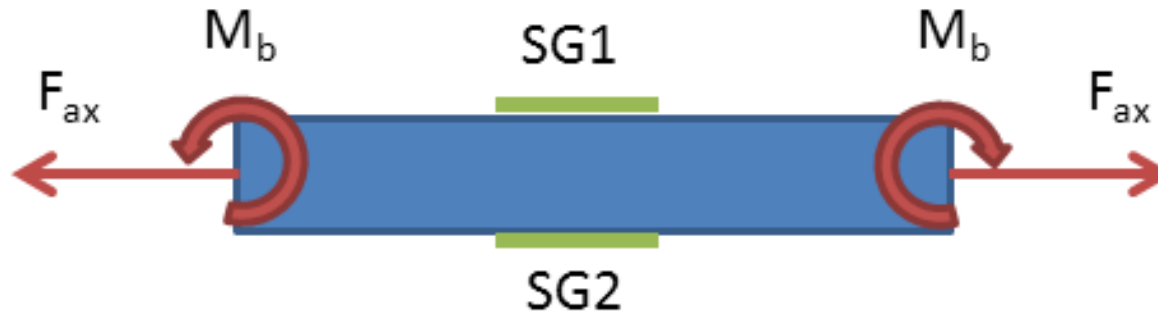
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# Simple example

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- n Simple bar equipped with two strain gauges
- n Two unit load cases applied
  - n Tension
  - n Bending



# Simple example

Measured data

	SG1 [μm/m]	SG2 [μm/m]
<b>Tension</b> = 1000N	200	200
<b>Bending</b> = 1000Nmm	300	-300
<b>Tension + Bending</b> = 1000N + 1000Nmm	500	-100



System of linear equations

$$200 \frac{\mu\text{m}}{1000\text{N}} \cdot F_{ax} + 300 \frac{\mu\text{m}}{1000\text{Nmm}} \cdot M_b = \varepsilon_{SG1}$$

$$200 \frac{\mu\text{m}}{1000\text{N}} \cdot F_{ax} - 300 \frac{\mu\text{m}}{1000\text{Nmm}} \cdot M_b = \varepsilon_{SG2}$$



Matrix form

$$\begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \cdot \begin{Bmatrix} F_{ax} \\ M_b \end{Bmatrix} = \begin{Bmatrix} \varepsilon_{SG1} \\ \varepsilon_{SG2} \end{Bmatrix}$$

$$[S]\{F\} = \{\varepsilon\}$$

$$\{F\} = [S]^{-1}\{\varepsilon\}$$

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**Part 3**

# **NON-LINEAR FE SECTION LOAD EXTRACTION**

# Non-linear FE Section Load Extraction - Problem

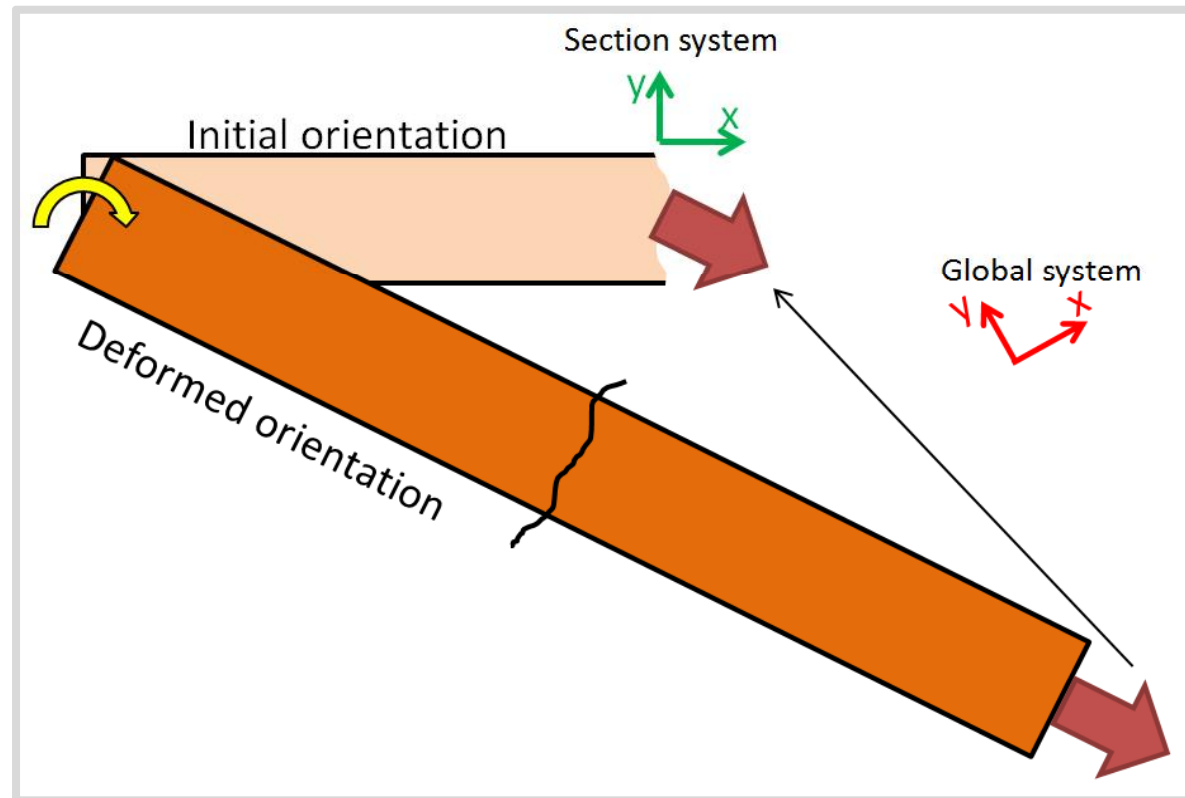
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- n *Problem:* Section load extraction methods in ANSYS use the initial coordinate system**
- n Section CoG needs to be calculated for moments**
- n In large deflection analysis this system changes**
- n Source of error for arbitrary calibration AND simulation model correlation**

# Non-linear FE Section Load Extraction - Problem

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- n Problem: Section load extraction methods in ANSYS use the initial coordinate system**

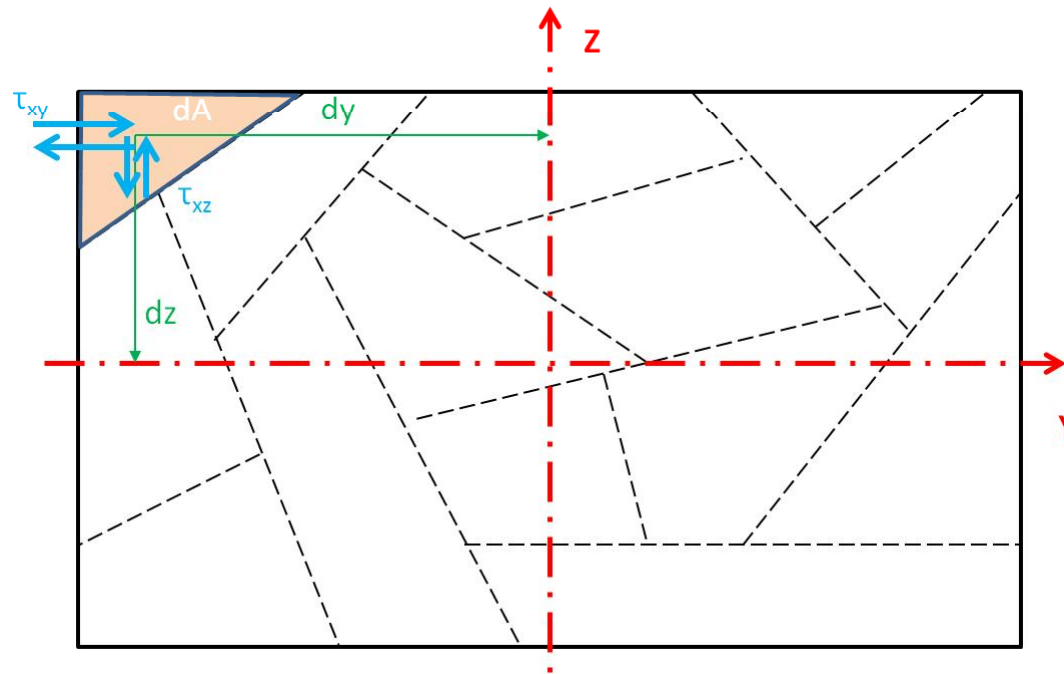


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# Non-linear FE Section Load Extraction - Solution

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- n Use of stresses in the deformed coordinate system
- n ANSYS surface tool maps results on cutting section
- n Integrating stresses over area results in section forces and moments



# Non-linear FE Section Load Extraction - Solution

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**n** Integral can be replaced by a sum since results for all sub-areas are known

$$F_x = \int \sigma_x dA$$

$$F_x = \sum_{i=1}^n \sigma_{x_i} \cdot dA_i$$

$$F_y = \sum_{i=1}^n \tau_{xy_i} \cdot dA_i \quad M_y = \sum_{i=1}^n \sigma_{x_i} \cdot dA_i \cdot d_{z_i}$$
$$F_z = \sum_{i=1}^n \tau_{xz_i} \cdot dA_i \quad M_z = \sum_{i=1}^n \sigma_{x_i} \cdot dA_i \cdot d_{y_i}$$

$$M_x = \sum_{i=1}^n \tau_{xy_i} \cdot dA_i \cdot d_{z_i} + \tau_{xz_i} \cdot dA_i \cdot d_{y_i}$$

# Non-linear FE Section Load Extraction

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- n Center of gravity is calculated similarly**
- n Easily implemented in ANSYS**
- n Usable for small and large displacement analysis**
- n Important tool in inter-simulation correlation**
- n Should only be used in low stress gradient areas**



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Part 4

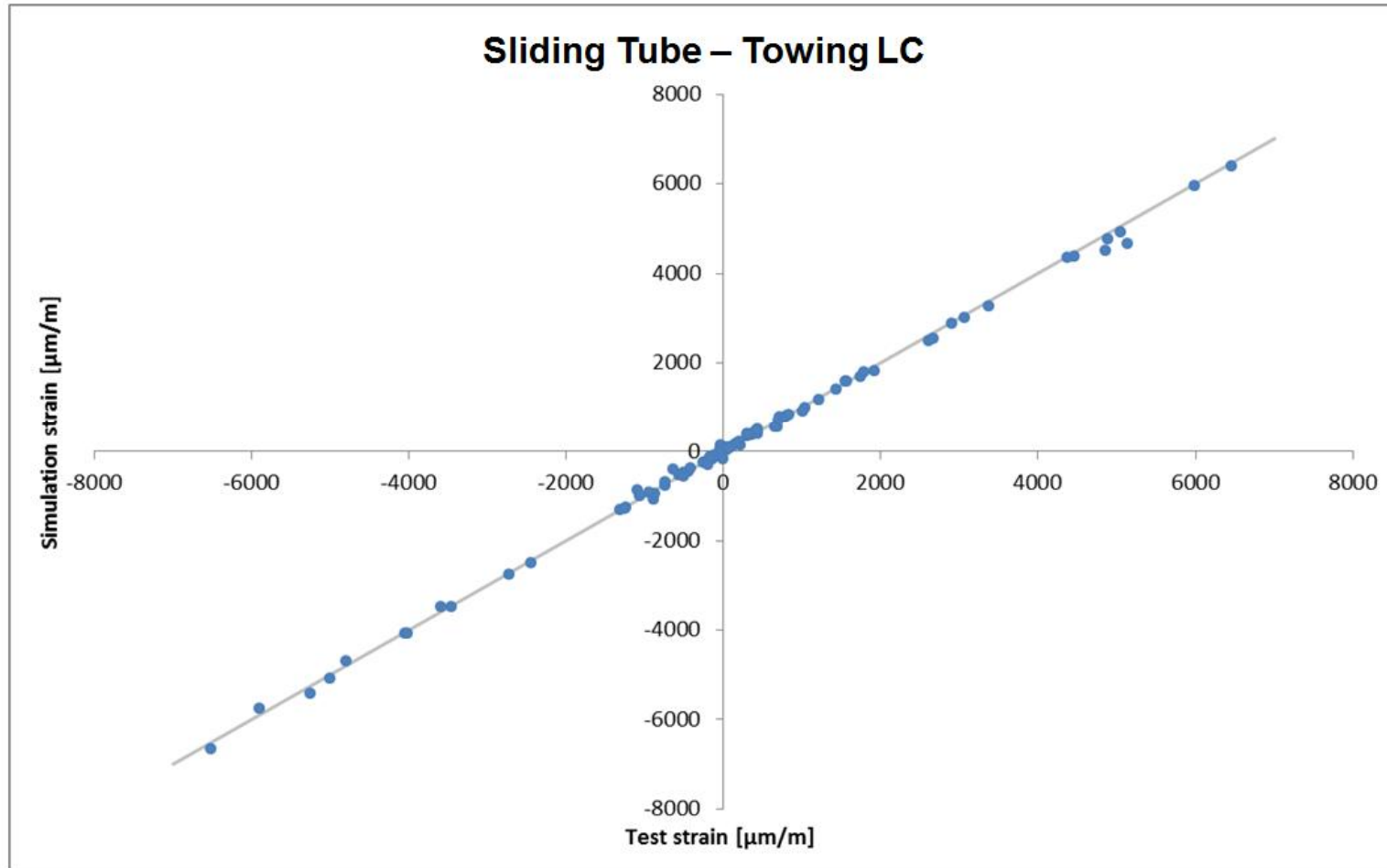
# SUMMARY

# Summary

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- n Analyzing different methods of applying Virtual Strain Gauges in Finite Element Analysis**
- n Applying methods in Virtual Calibration**
- n Developing a method of measuring section loads in large displacement FE simulations**
- n Applying all the methods on real life tests**
  - n Efficient and reliable correlation technique for LIEBHERR to correlate simulation models with tests**
  - n Ensuring high quality simulation models**
- n TODO: Implementing the methods even deeper in ANSYS Workbench using ANSYS ACT**

# Landing Gear – Virtual Strain Gauge Correlation



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## Electronic Resources

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- n ANSYS Inc.: *ANSYS 14.5 Help*
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- n Micro-Measurements: *Strain Gage Selection: Criteria, Procedures, Recommendations: TN-505*, URL: <http://www.vishaypg.com/docs/11055/tn505.pdf> (visited on 14.11.2014)

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