ANSYS Conference & 33rd CADFEM Users' Meeting

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

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Agenda

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

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

Assumptions in Simulations

- Boundary conditions
- Material
- Geometry
- Loads
- …

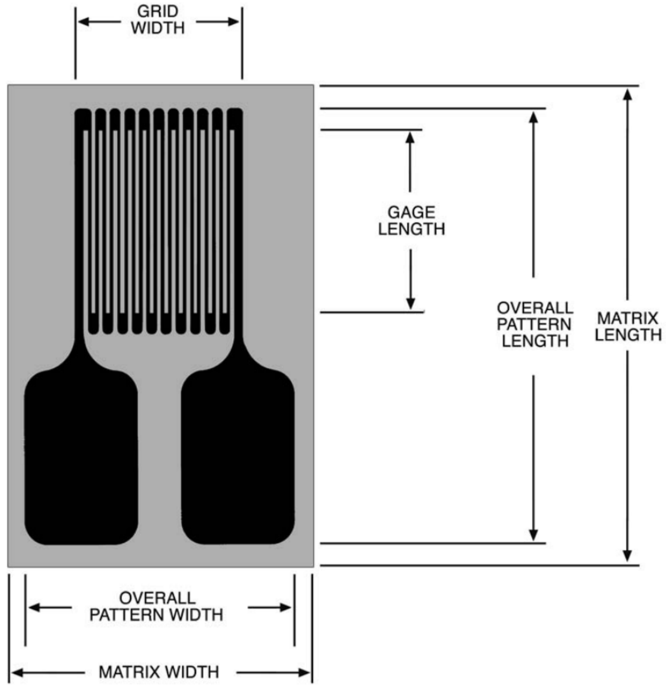
è Correlation, Validation and Verification is essential in simulation based engineering!

Part 1

VIRTUAL STRAIN GAUGES

Virtual Strain Gauges

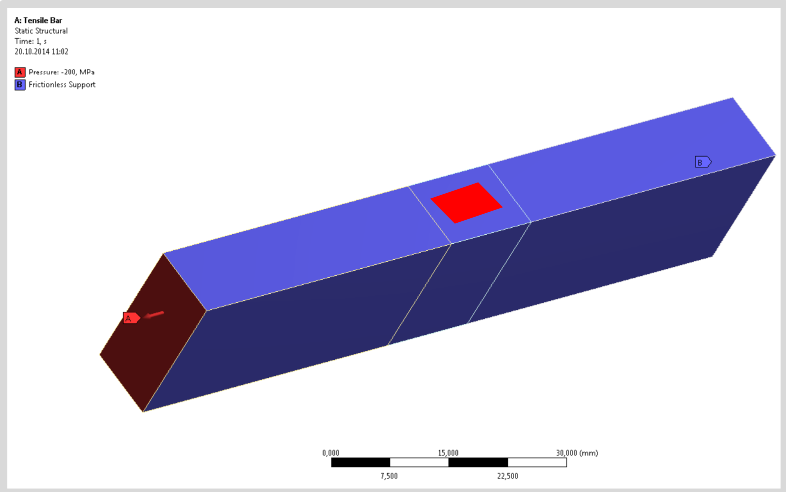
- **Mimicking the behavior of physical strain gauges**
  - Placement and orientation
  - Measuring direction
  - Strain averaging
- **Reliable implementation in ANSYS**
- **Mesh-independence**
- **Investigating different techniques**
- **Sensitivity study**

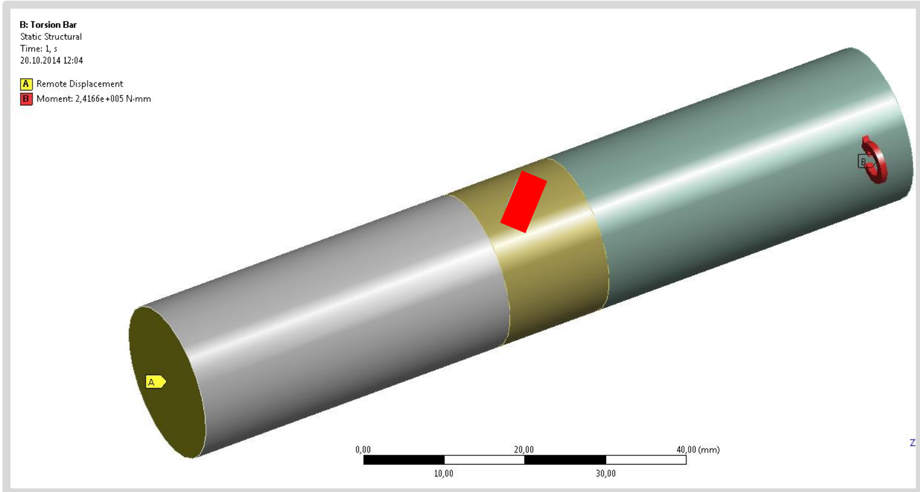


(*VMM-DB0103-1011)*

Test Shapes

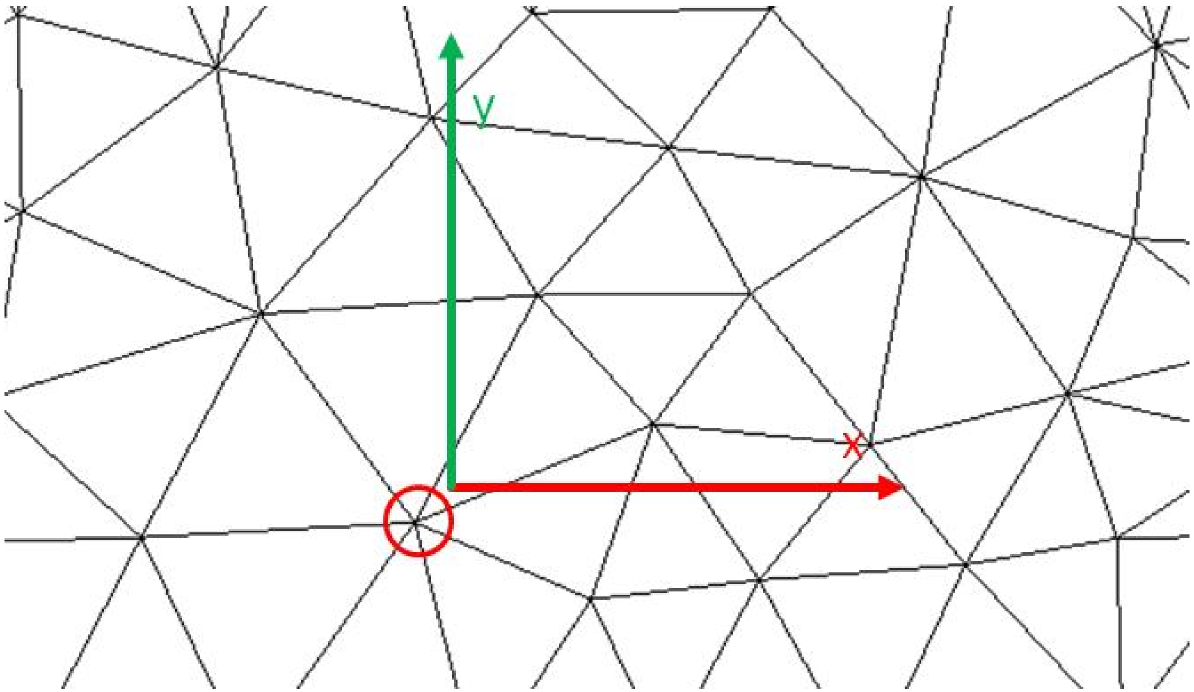
- **Different Virtual Strain Gauges were analyzed on simple structures**
  - Rectangular bar for tension and bending
  - Round bar for torsion





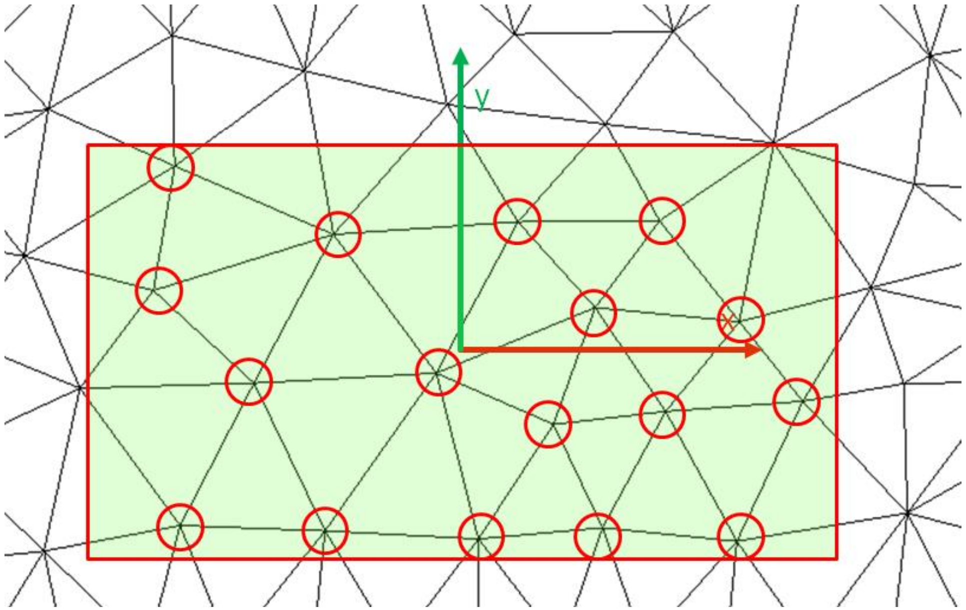
Closest node

- Grid independent
- Select node closest to defined position



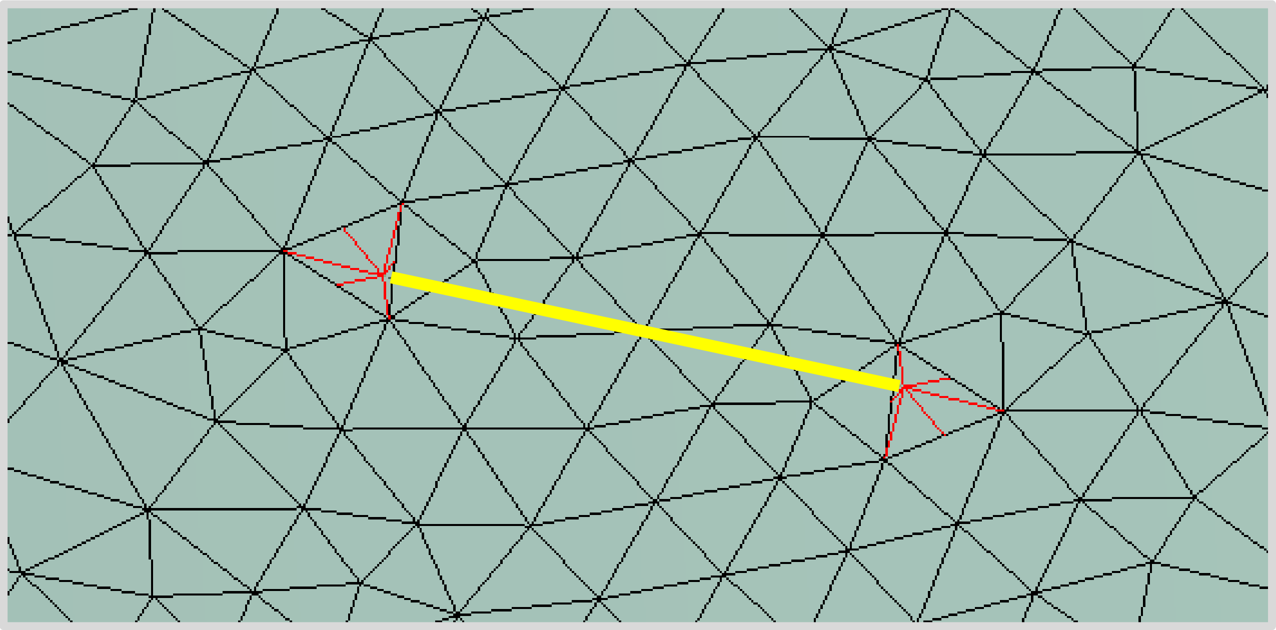
Average of nodes in range

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



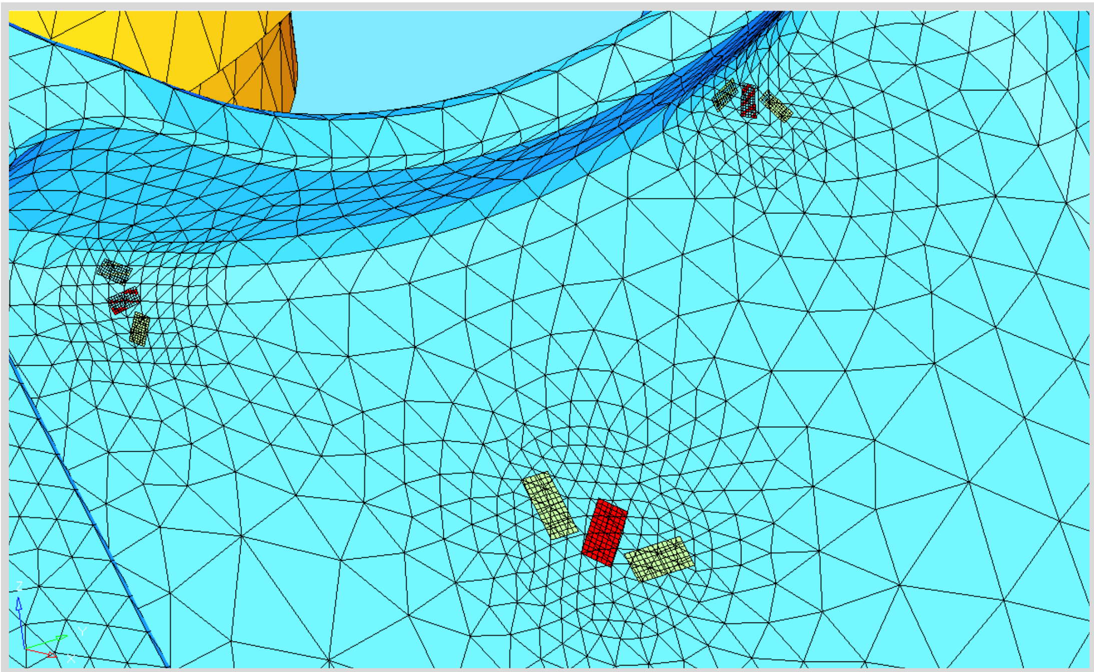
Truss Element Strain Gauge

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



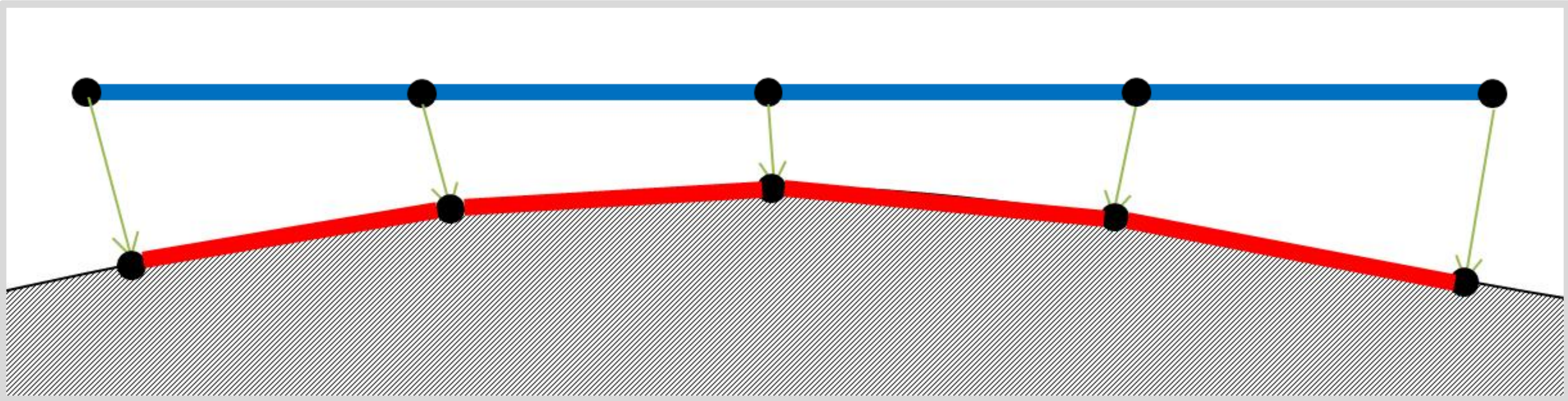
Shell Element Strain Gauge

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



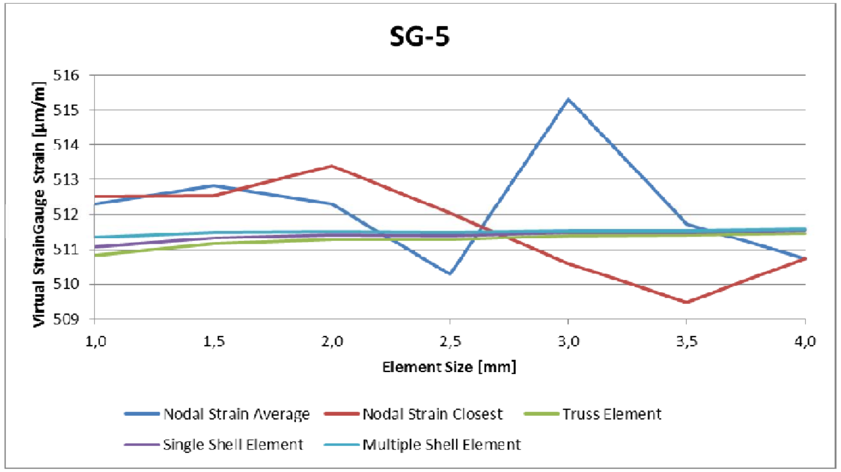
CNCHECK, ADJUST Shape Projection Mechanism

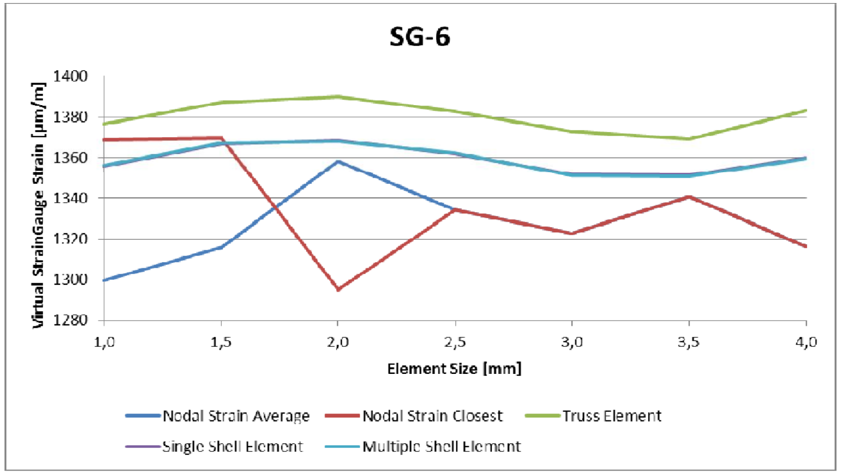
- Strain gauges are modelled flat
- Nodes of strain gauge elements are projected on part surface



Parameter Study – Element Size

- **Virtual Strain Gauges with best suitable parameters**
- **Element size of part was varied in steps**
  - Element based Virtual Strain Gauges show consistent results
  - Nodal based methods scatter





Submodelling Technique

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

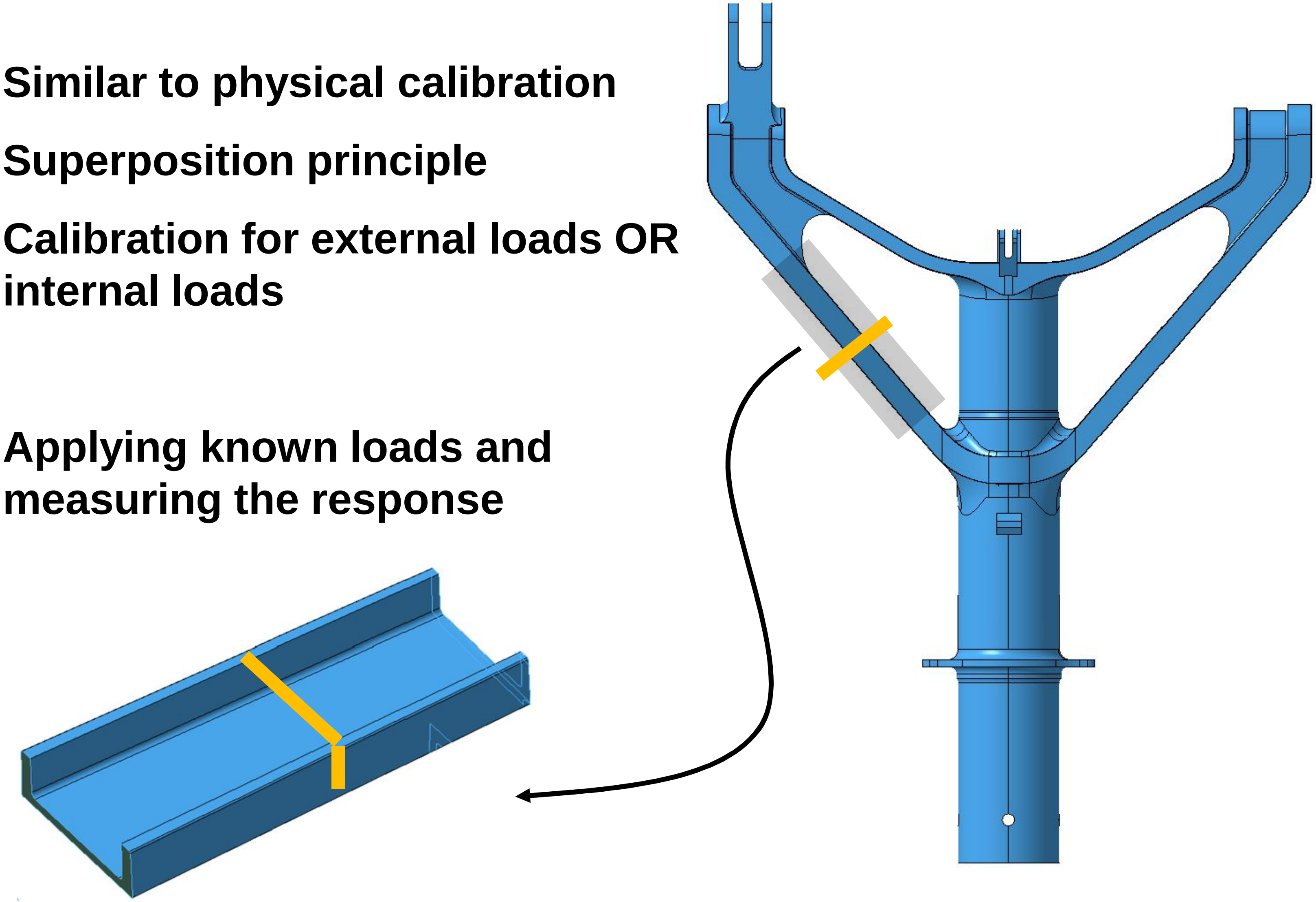
Part 2

VIRTUAL CALIBRATION

Virtual Calibration

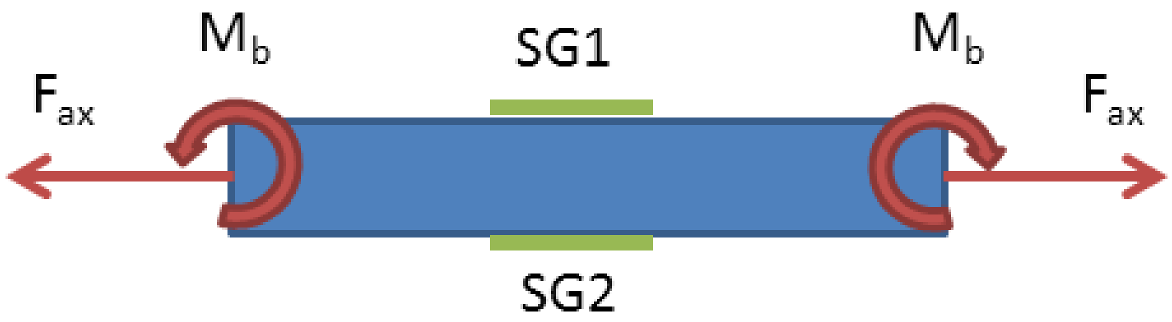
- Similar to physical calibration
- Superposition principle
- Calibration for external loads OR internal loads

- Applying known loads and measuring the response



Simple example

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



Simple example

Measured data

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

System of linear equations

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

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

Matrix form

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

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

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

Part 3

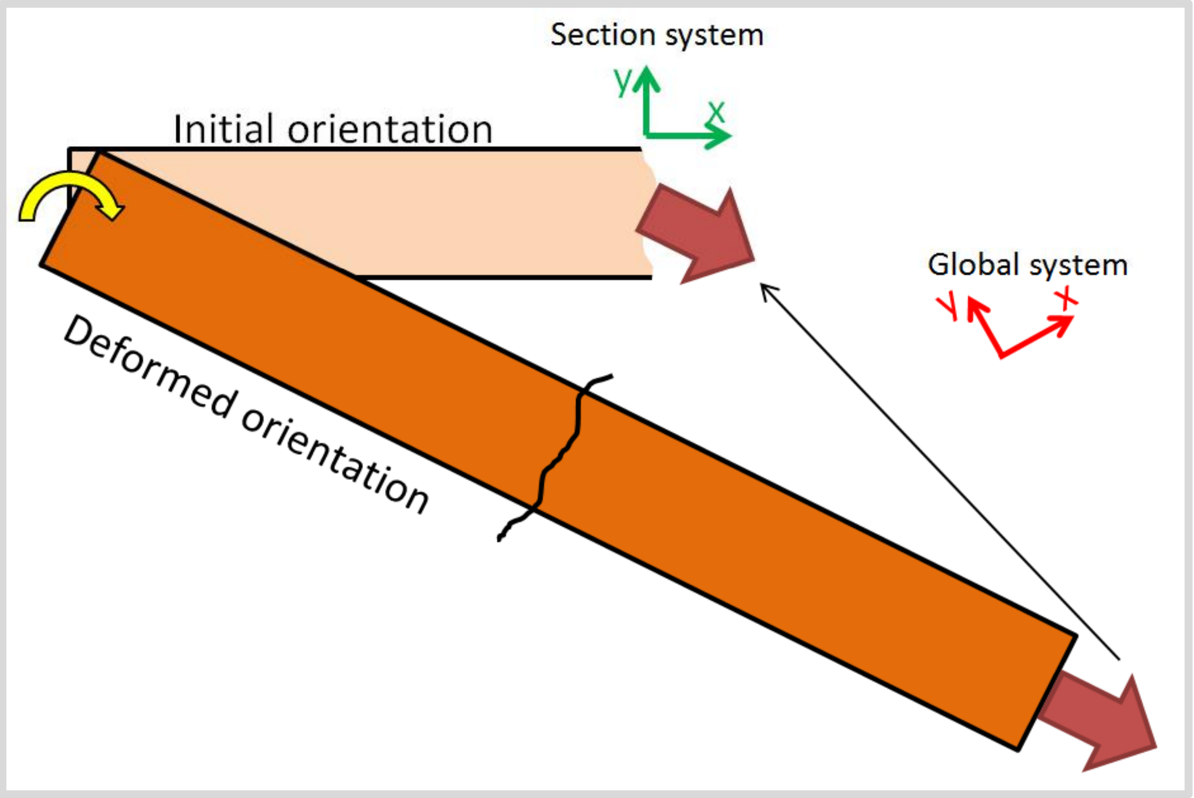
NON-LINEAR FE SECTION LOAD EXTRACTION

Non-linear FE Section Load Extraction - Problem

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

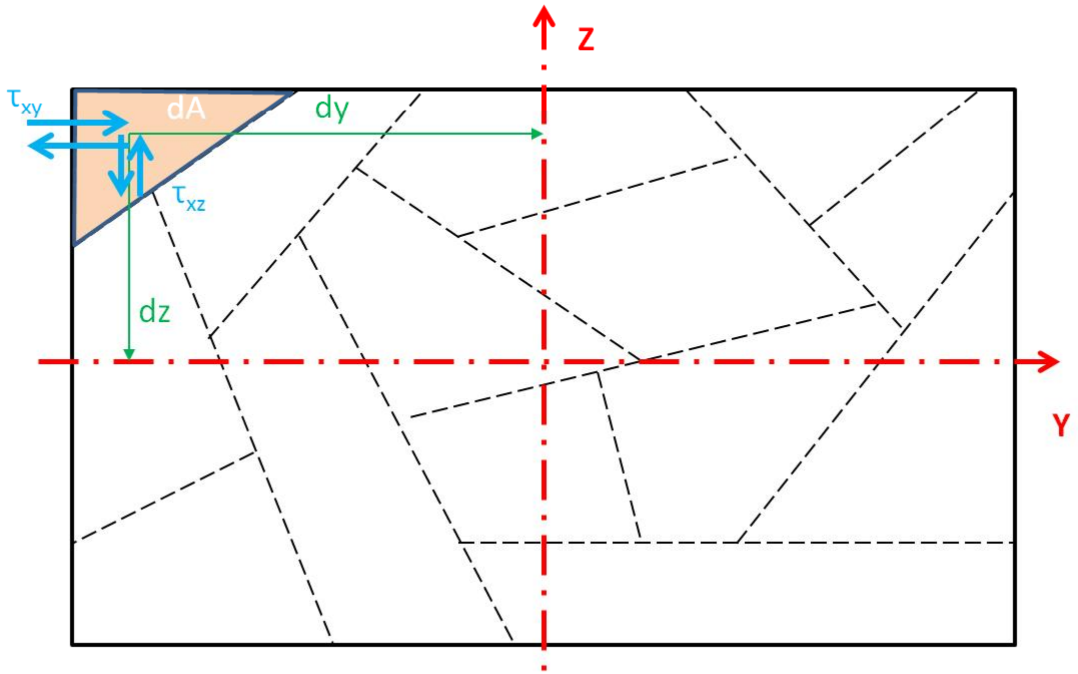
Non-linear FE Section Load Extraction - Problem

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



Non-linear FE Section Load Extraction - Solution

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



Non-linear FE Section Load Extraction - Solution

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

$$F_x = \int \sigma_x dA$$

⇩

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

$$F_y = \sum_{i=1}^{n} \tau_{xy_i} \cdot dA_i \qquad M_y = \sum_{i=1}^{n} \sigma_{x_i} \cdot dA_i \cdot d_{z_i}$$

$$F_z = \sum_{i=1}^{n} \tau_{xz_i} \cdot dA_i \qquad M_z = \sum_{i=1}^{n} \sigma_{x_i} \cdot dA_i \cdot d_{y_i}$$

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

Non-linear FE Section Load Extraction

- Center of gravity is calculated similarly

- Easily implemented in ANSYS
- Usable for small and large displacement analysis
- Important tool in inter-simulation correlation

- Should only be used in low stress gradient areas

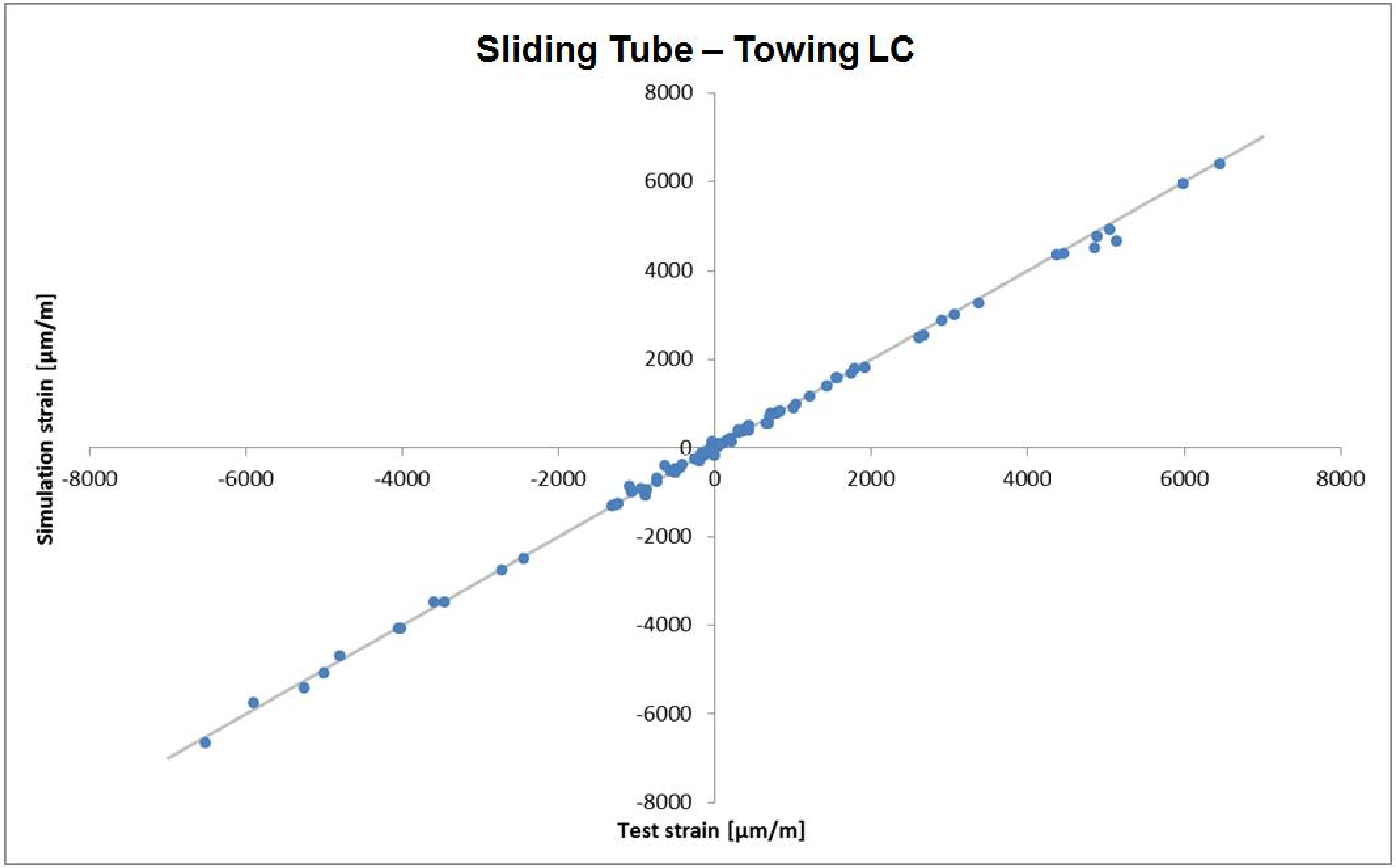
Part 4

SUMMARY

Summary

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

Landing Gear – Virtual Strain Gauge Correlation



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Electronic Resources

- Micro-Measurements: *Precision Strain Gages: VMM-DB0103-1011*, URL: http://www.vishaypg.com/docs/50003/precsg.pdf (visited on 12.09.2014)
- ANSYS Inc.: *ANSYS 14.5 Help*
- Micro-Measurements: *Errors Due to Misalignment of Strain Gages: TN-511,* URL: http://www.vishaypg.com/docs/11061/tn511tn5.pdf (visited on 01.12.2014)
- 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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