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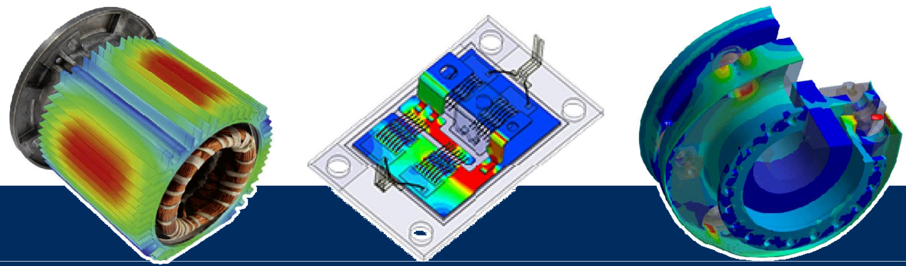

Evaluation of the scatter of continuous fiber-reinforced plastics with Statistics on Structures (SoS)

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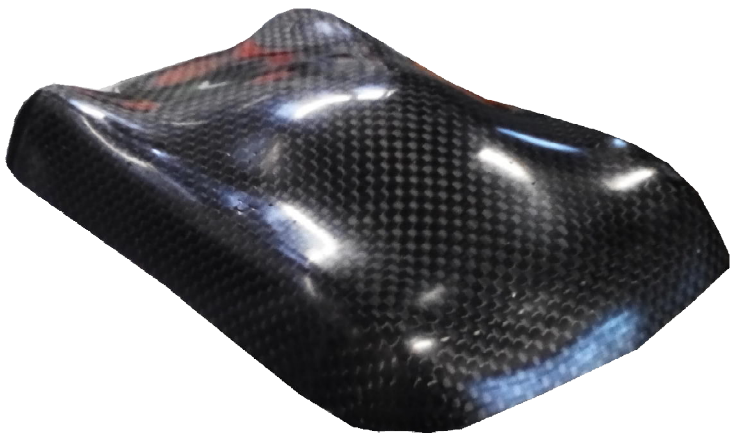
Sandro Wartzack, Universität Erlangen-Nürnberg

Agenda

- Introduction
- Calibration of the draping simulation
  - Experimental results
  - Simulation
  - Calibration
- Calibration of the mechanical values
  - Experimental results
  - Simulation
  - Calibration
- Robustness Evaluation



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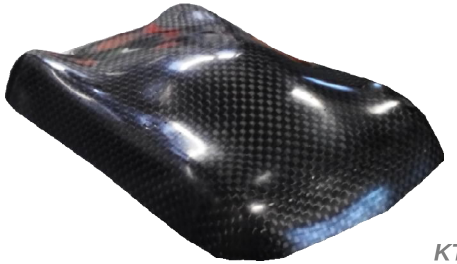
Introduction

- The first task is to calibrate the simulation of a contiuous fiber-reinforced demonstrator with experimental data
- Subsequently robustness evaluations can be carried out



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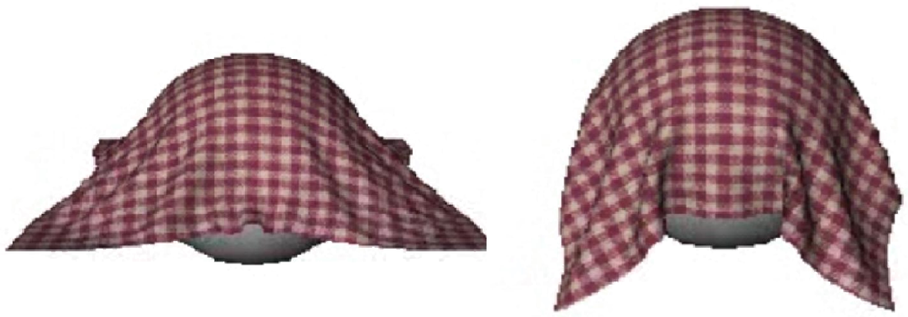
- Focus: Scatter due to draping



University College London (http://www.cs.ucl.ac.uk/research/vr/Projects/3DCentre/staticres.htm)

Calibration of the draping simulation

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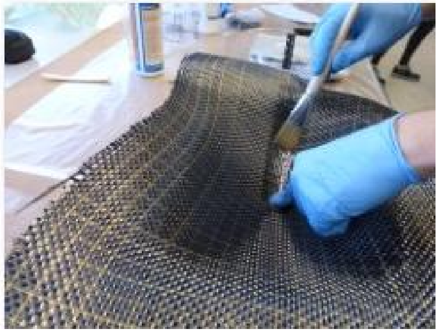
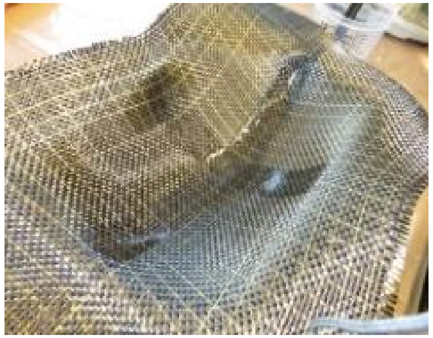
Calibration of the draping simulation - experiments

- Insight in the production:

draw grid



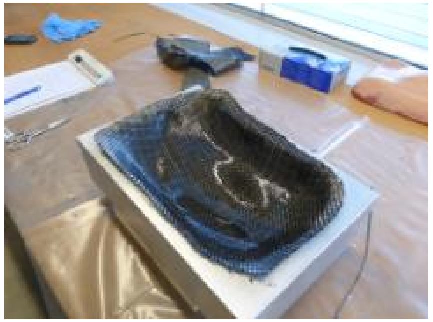
startpoint/-direction



finished cross

perpendicular draping

finished draping

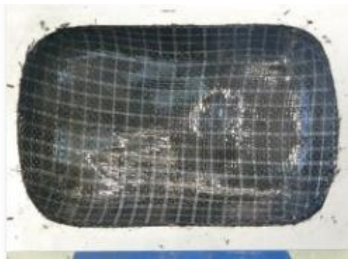


cutting of the edges

Calibration of the draping simulation - experiments

- Capture of the fiber orientation



Calibration of the draping simulation - experiments

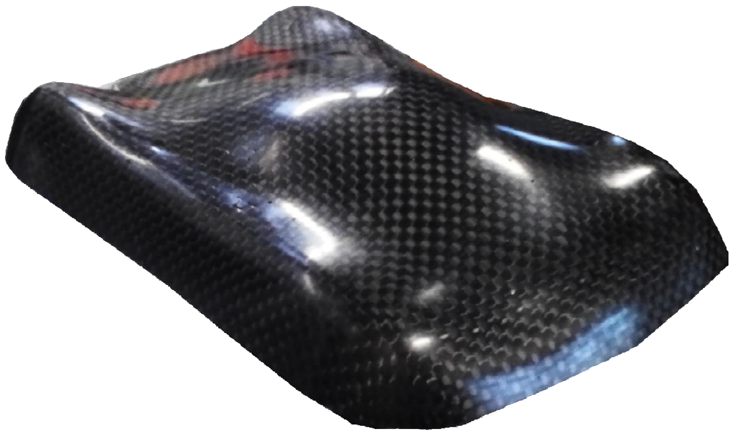
- Next manufacturing steps:

Packaging in bag

Fleece

Vacuum

Curing in oven



Calibration of the draping simulation - experiments

- Import of the fiber-directions from the experiments by using Look-Up Tables in **A**NSYS **C**omposite **P**repost

Look-Up Table Properties

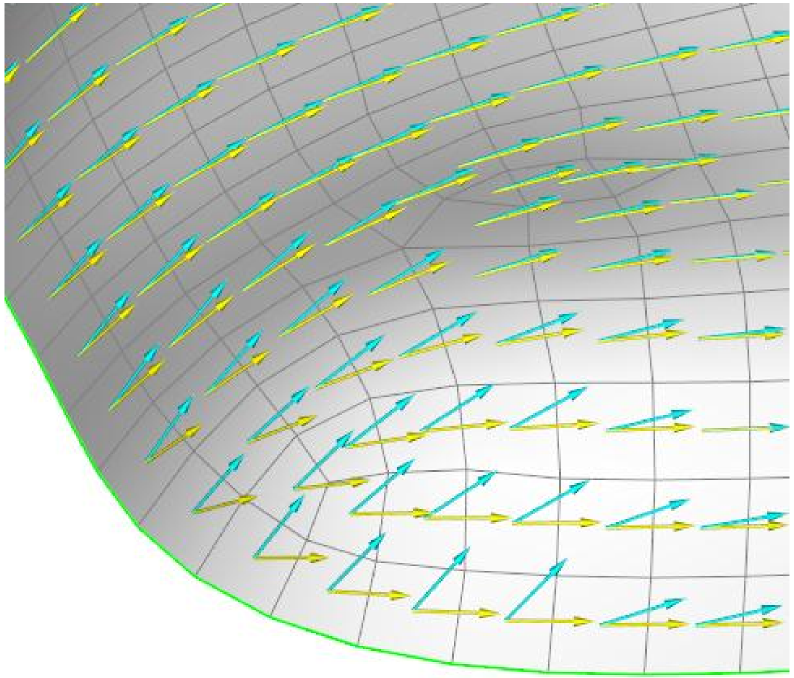
Name: LookUpTable3D.1

ID: LookUpTable3D.1

Values | Interpolation

i	Location.x	Location.y	Location.z	Column.1
0	0.000000	0.000000	0.000000	0.000000
1	−0.156400	0.069700	−0.029400	−24.000000
2	−0.140400	0.087200	−0.025100	−47.000000
3	−0.112600	0.096800	−0.025100	−10.000000
4	−0.087200	0.099500	−0.029400	3.000000
5	−0.051700	0.096100	−0.025000	5.000000
6	−0.021400	0.094700	−0.025000	−1.000000
7	0.008800	0.094300	−0.024900	−3.000000
8	0.044000	0.097500	−0.029400	−9.000000
9	0.074300	0.098400	−0.029400	−15.000000
10	0.099100	0.096400	−0.025600	5.000000
11	0.124200	0.092600	−0.029400	5.000000
12	0.139300	0.079600	−0.029400	30.000000
13	0.146500	0.050400	−0.029400	−10.000000
14	0.149800	0.020200	−0.029400	−7.000000
15	0.150500	−0.010000	−0.029400	−17.000000
16	0.147400	−0.040100	−0.029400	−19.000000
17	0.143400	−0.070200	−0.029400	−45.000000
18	0.124300	−0.092500	−0.029400	−73.000000
19	0.104700	−0.097400	−0.029400	−27.000000

OK | Apply | Cancel

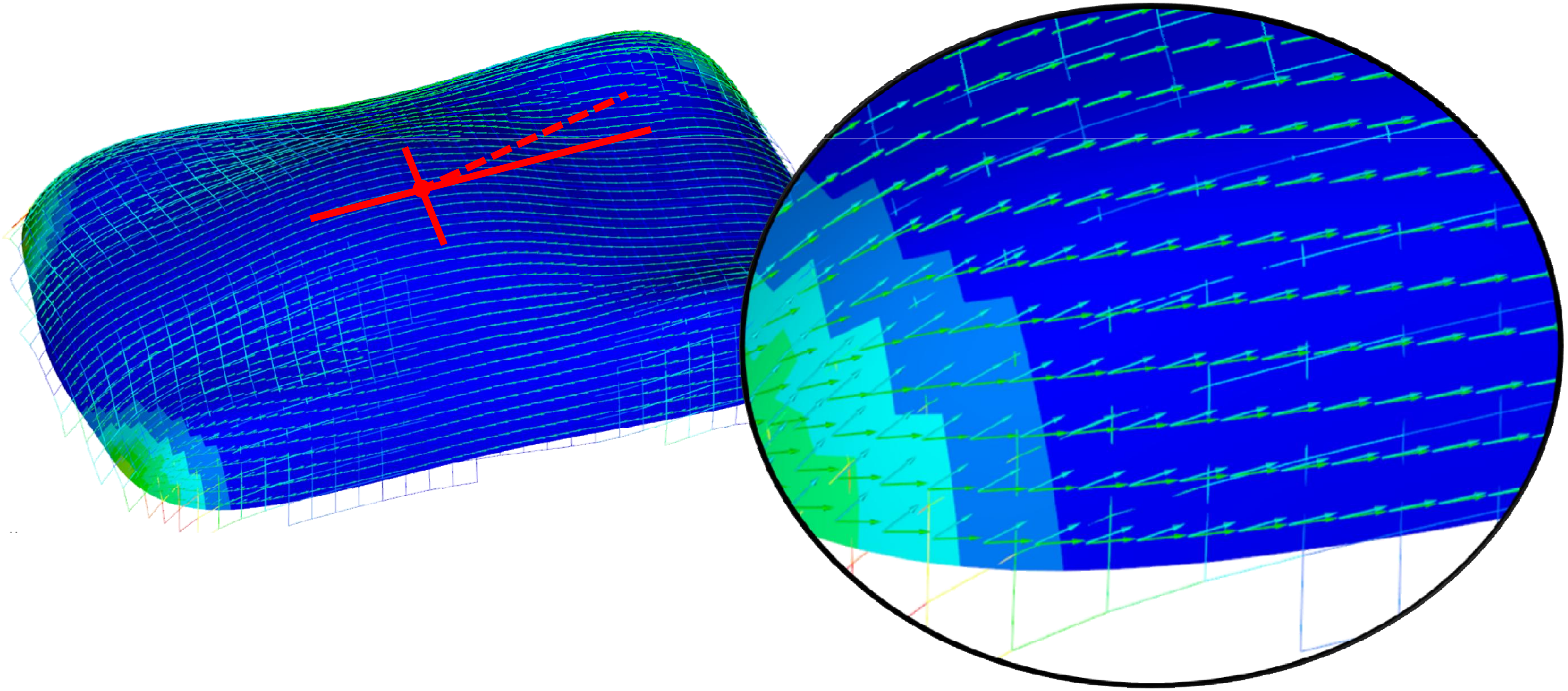


Fiber orientation without draping

Fiber orientation with draping (experiment)

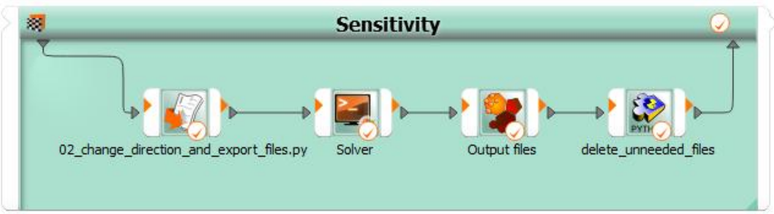
Calibration of the draping simulation - simluation

- Draping simulation: Change of the fiber orientation due to the ACP draping algorithm
- Defined by startpoint/-direction and numerical parameters

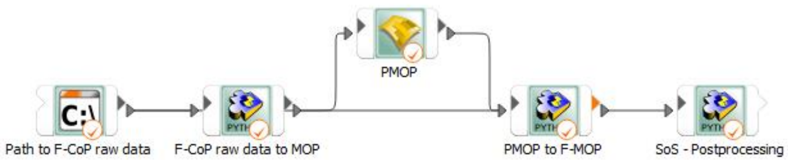


Calibration of the draping simulation - calibration

- Calibration of the resulting fields of the fiber-directions with SoS
- Input parameters:
  - Orientation of the layer
  - Startpoint of the draping (x,y)
  - Draping direction
  - Numerical parameters of the draping algorithm
- Output:
  - Angle deviations as a field



Creation of samples with optiSLang

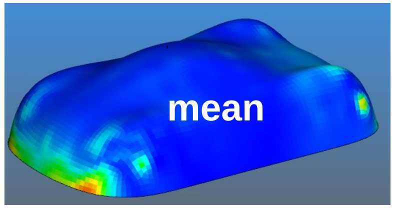


Building the F-MOP with SoS and optiSLang

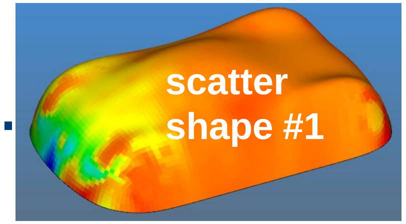
Calibration of the draping simulation - calibration

- Calibration of the fiber orientation with SoS:
  - Decomposition of the angle difference field
  - With the first 16 shapes 99% of the variation of the angle difference field can be explained

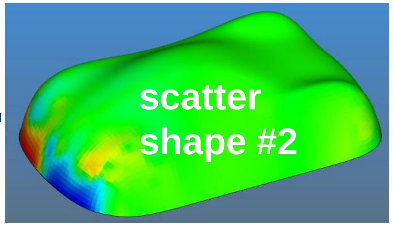
	06_winkeldifferenz_simulatio
shape[1]	44.0294 %
shape[2]	75.6937 %
shape[3]	84.9732 %
shape[4]	89.4074 %
shape[5]	92.6688 %
shape[6]	94.2422 %
shape[7]	95.4069 %
shape[8]	96.3388 %
shape[9]	96.97 %
shape[10]	97.4991 %



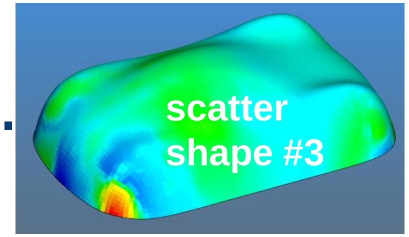
$+ z_1 \cdot$



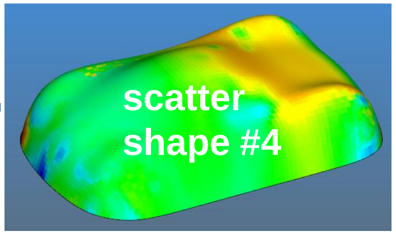
$+ \; + z_2 \cdot$



$+ z_3 \cdot$



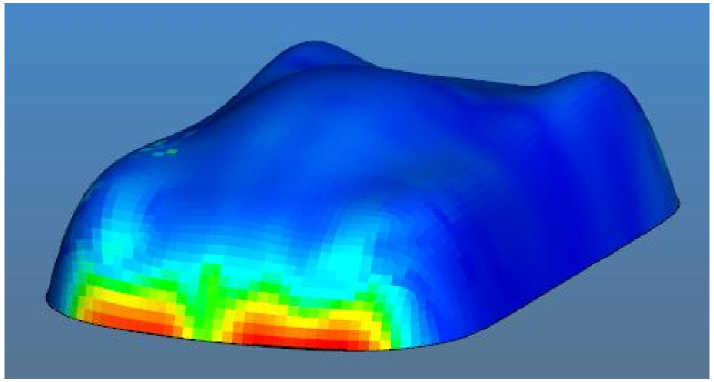
$+ \; + z_4 \cdot$

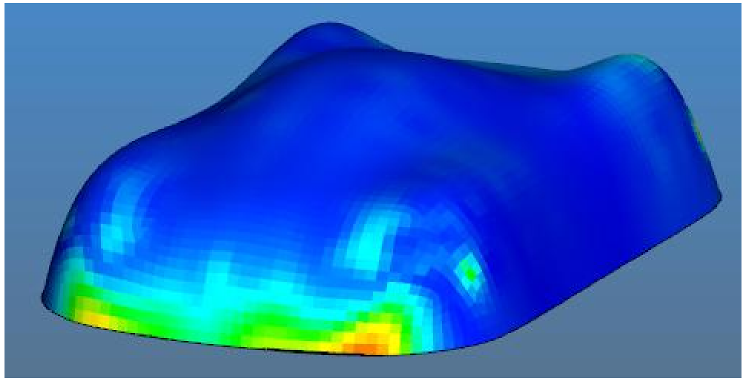


$+ \quad \ldots$

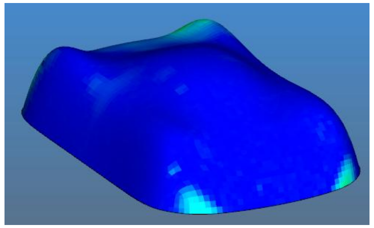
Calibration of the draping simulation - calibration

- Mean values and standard deviations of the angle differences:





- The numerical draping process is very sensitive at the end of the curved structure
- Further finding: with the defined bounds of the input parameters the results of the experiments are within the variation intervall of the simulation (found out with the min.-fields)



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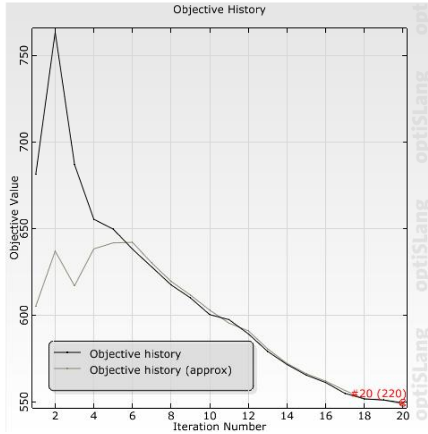
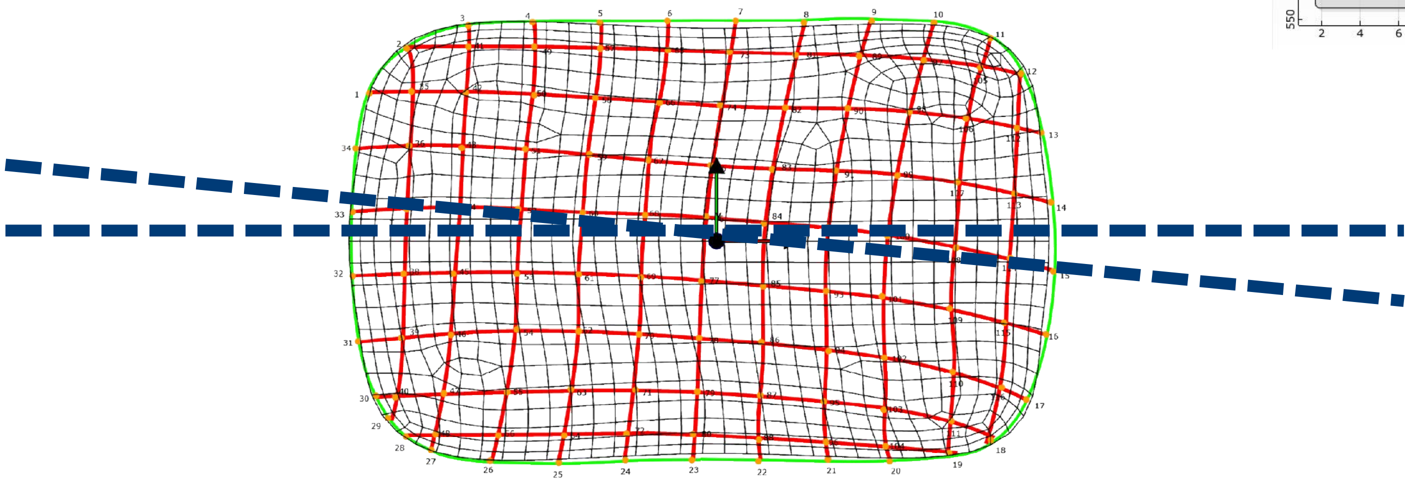
Calibration of the draping simulation - calibration

- Result after the calibration (e.g. layer 4) :

  - Without draping algorithm: ø 8.1° deviation
  - With draping algorithm : ø 7.3° deviation
  - With calibrated draping algorithm (calibrated using the random field): ø 5.2° deviation
  - With calibrated draping algorithm (recalculated): ø 5.1% deviation





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Calibration of the mechanical values

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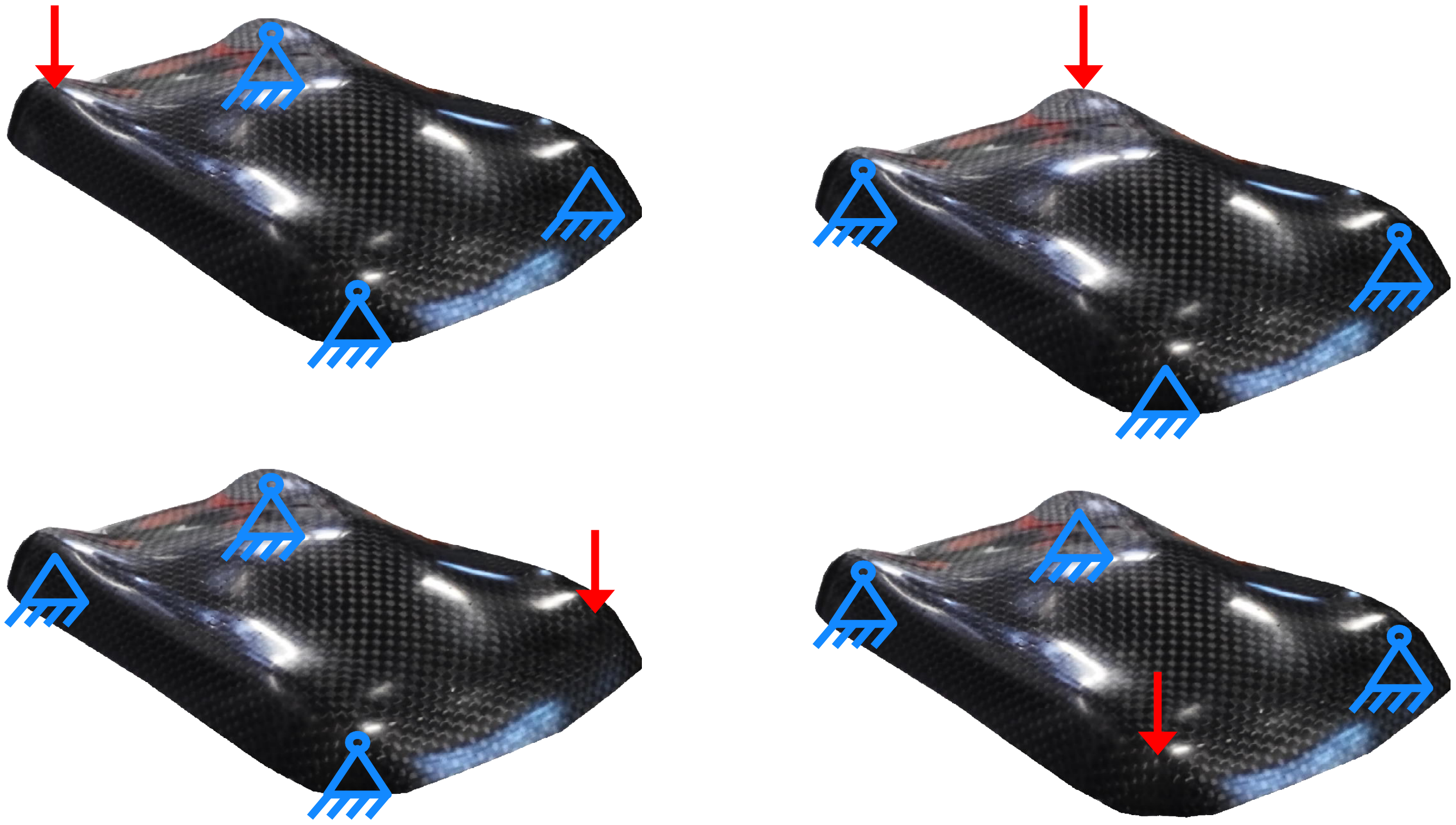
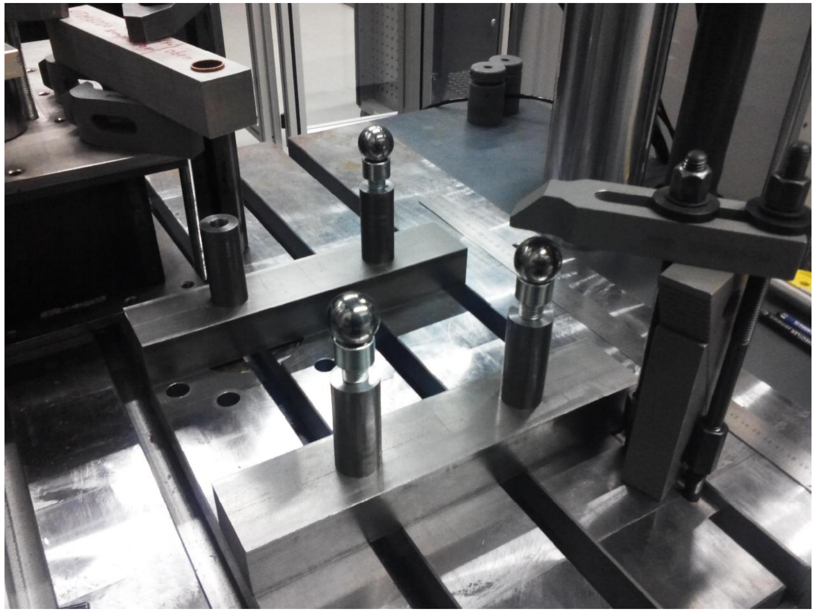
Calibration of the mechanical values - experiments

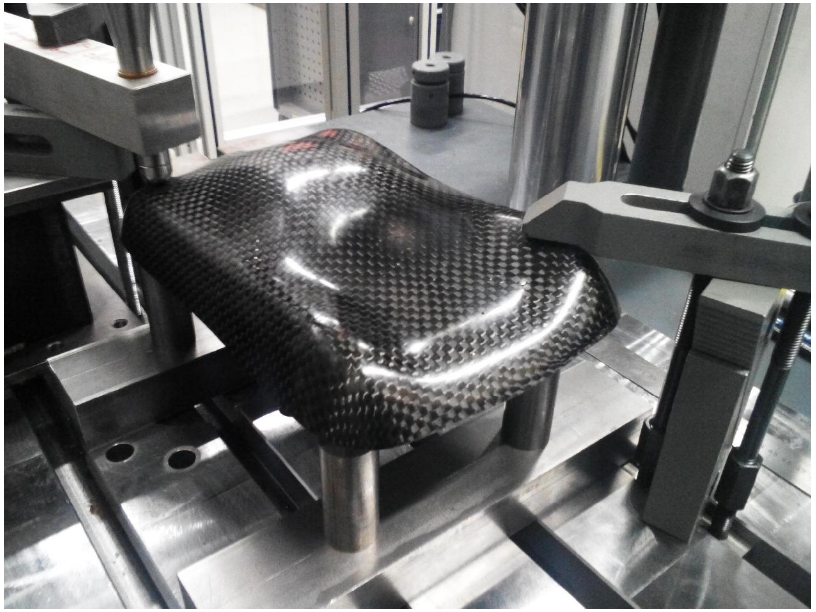
- Load case 1-4



Calibration of the mechanical values - experiments

- Experimental setup to measure the stiffness





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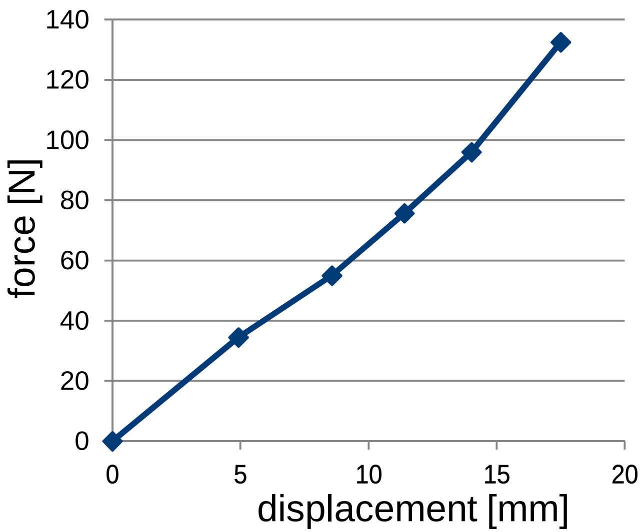
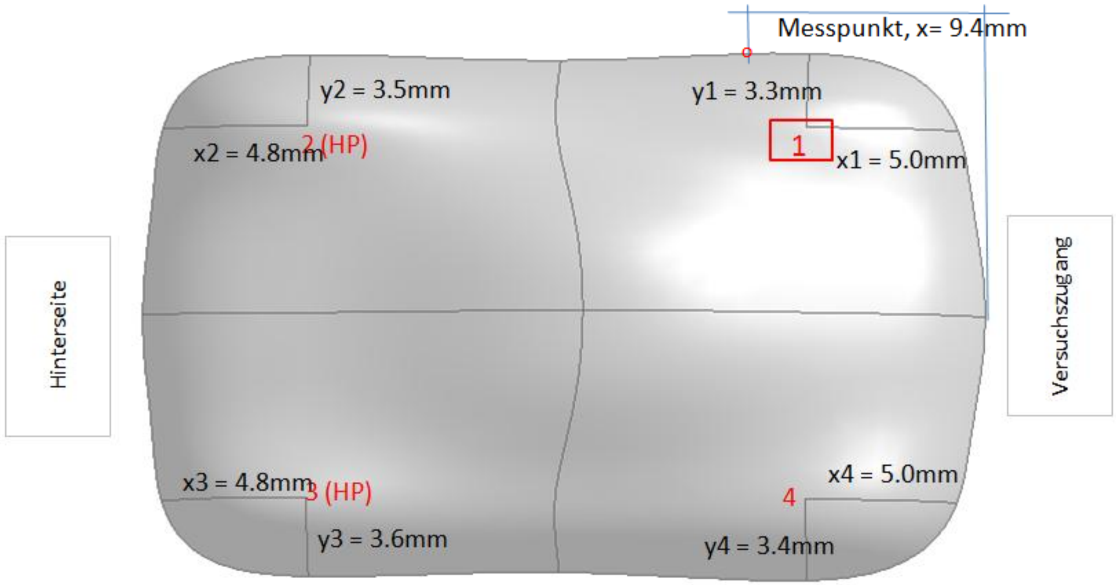
- Same experimental conditions for the 4 bending tests

Calibration of the mechanical values - experiments

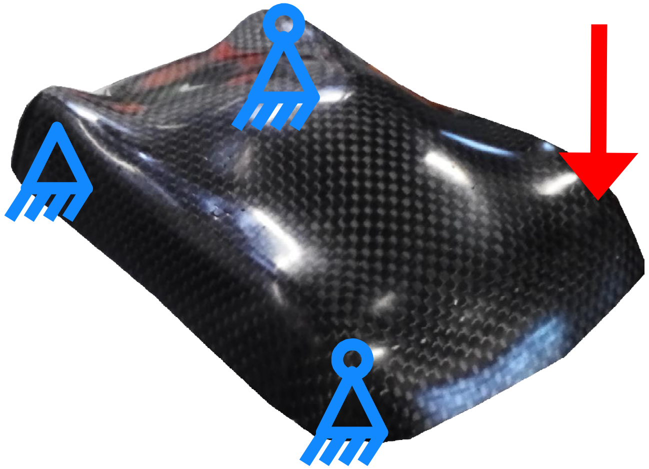
- Measurement of the curves of the 4 load cases
- Parametric model setup to adapt the simulation to the boundary conditions and measurement points in the experiments

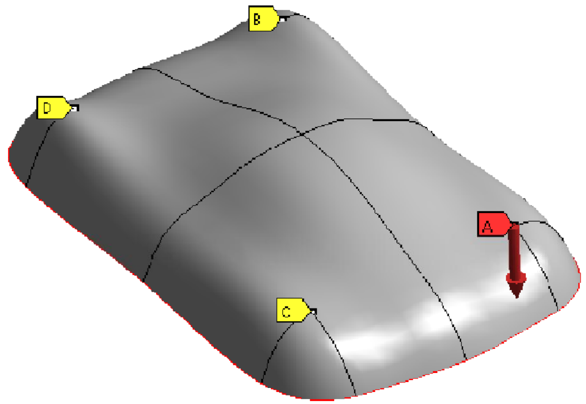


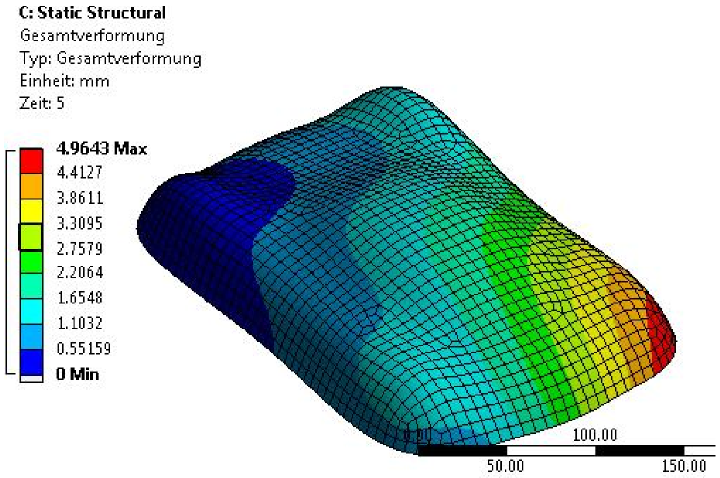


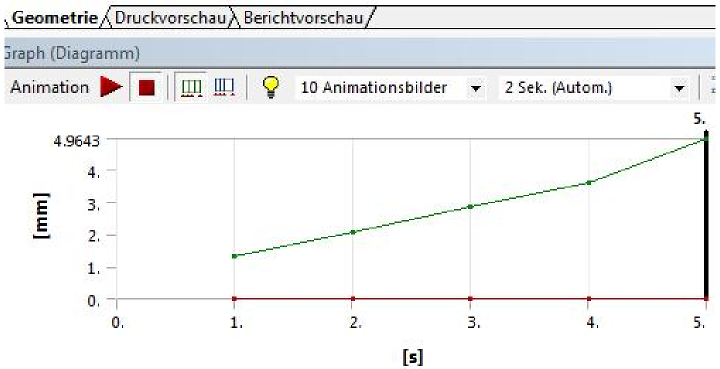
Calibration of the mechanical values - simulations

- Approximation of the supports with deformable external displacements









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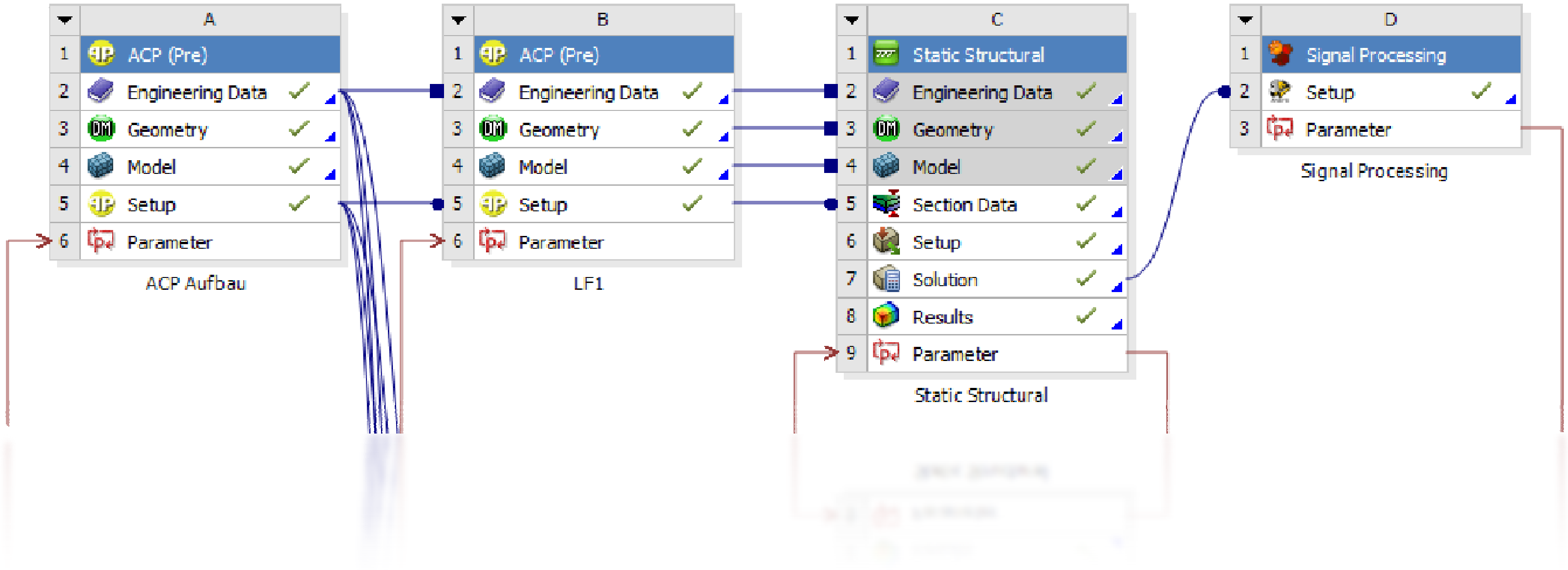
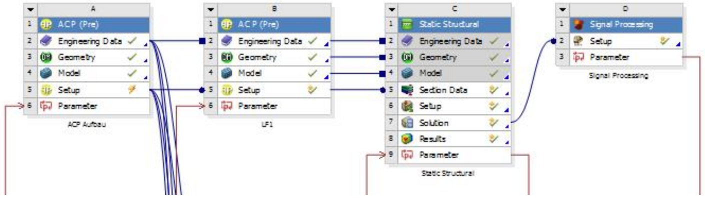
Calibration of the mechanical values - calibration

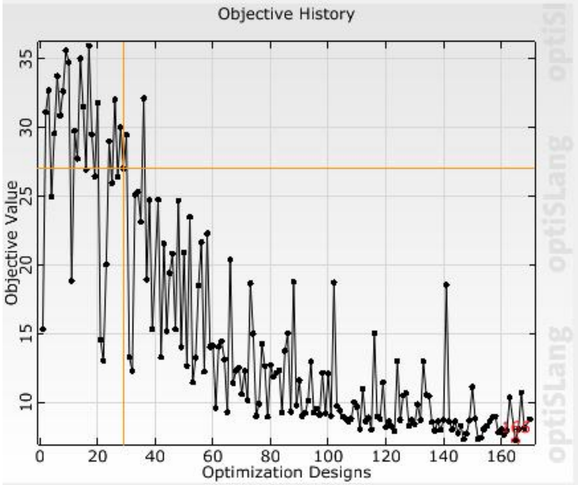


- Transferring the measured fiber orientations
- Load case definition
- Calculation
- Evaluation of the displacement curves
- Comparison with the measured values from the experiment

Calibration of the mechanical values - calibration



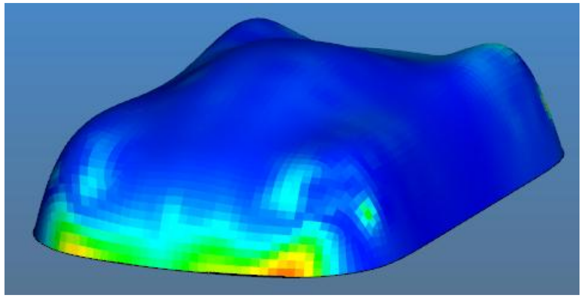
- Consideration of 4 load cases at the same time
- Sensitivity Study
- Calibration with about 160 calculations



Interim conclusion

- Mechanical values are calibrated ✓

- Accuracy of the draping algorithm can be estimated at each location (what can I expect from the results) ✓



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Robustness Evaluation

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Robustness Evaluation – Definition of the input scatters

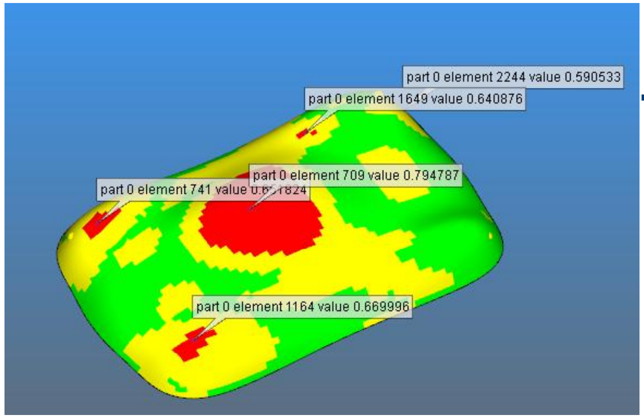
- New Model:

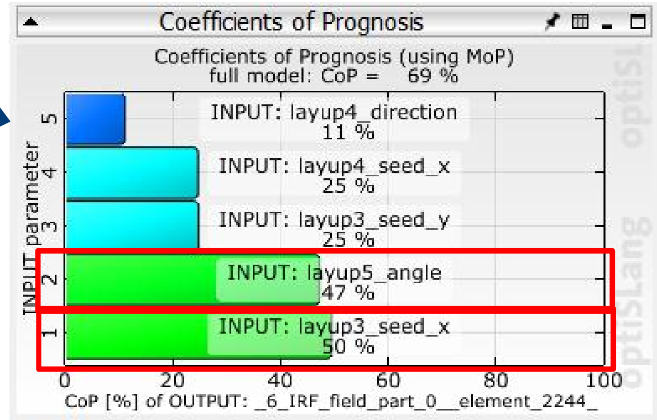
- Definition of 6 layers with different orientations
- Definition the scatters occuring in the manufacturing process (24 parameters, scatter estimated from experience, conservative)
- 1 load scenario
- Evaluation of one failure criteria (max. stress)

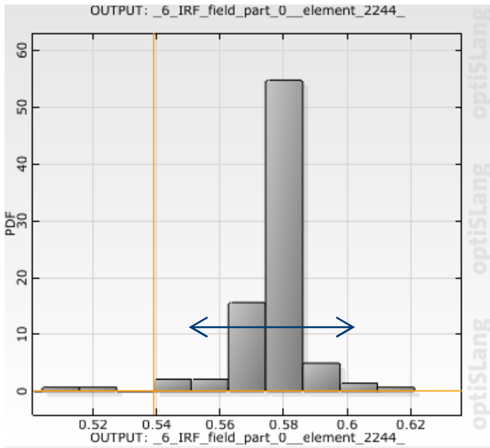
à creation of samples with optiSLang (120 designs)
à Importing the fields in SoS
à Automatic hot spot detection with quantil plots
à Export of the hot spots to optiSLang
à Robustness Evaluation of the hot spots

Robustness Evaluation – Conclusions

- Robustness Evaluation with SoS, detection of the hot spots, evaluation of the sensitivities, conclusions







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