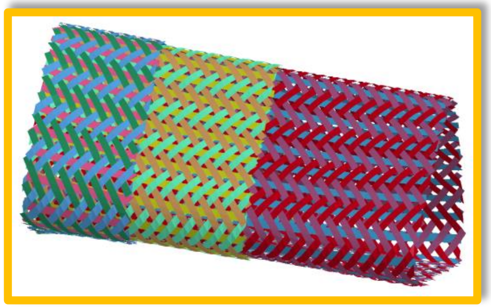
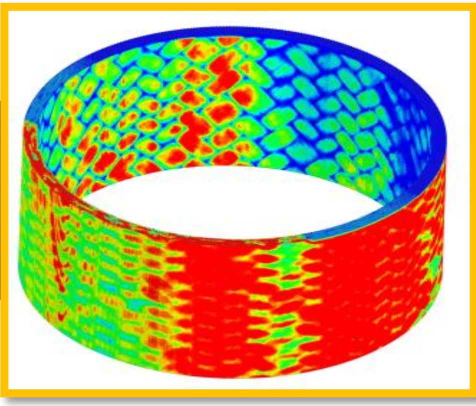
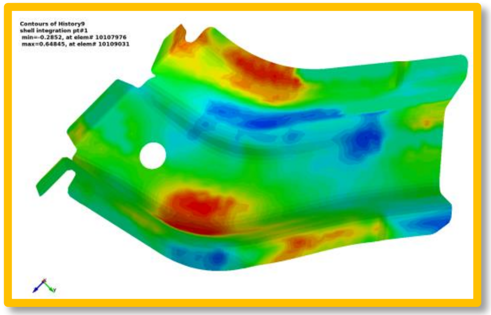




MAPPING AND DATA MANAGEMENT ALONG THE SIMULATION PROCESS CHAIN WITH THE MAPPING TOOL ENVYO®



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13.03.2017

Information Day ENVYO &
COMPOSITE SIMULATION

Stuttgart, Germany

DYNA MORE

AGENDA

- „Historical“ Overview
- Workflow
- Mapping Capabilities
- Example
- Future Plans
- Questions & Answers

„Historical“ Overview

- In 2011, with the start of the government funded research project T-Pult, first implementations were made to enhance the existing tool DYNAmat with mapping capabilities for BEAM -> SHELL mapping as well as to consider CT-scan data.

- Further enhancements led to the consideration of fiber orientations gained from draping simulations with *MAT_249 (*MAT_REINFORCED_THERMOPPLASTIC) on shell meshes with the ORIENTATION -> SHELL mapping capability.

- Several material models for draping simulations (*MAT_034, *MAT_234 & *MAT_235) were considered for orientation mapping within the government funded research project SWIM-RTM.

- In 2013, the mapping capabilities were removed from the Fortran based DYNAmat – tool and transferred to an independent C++ program.

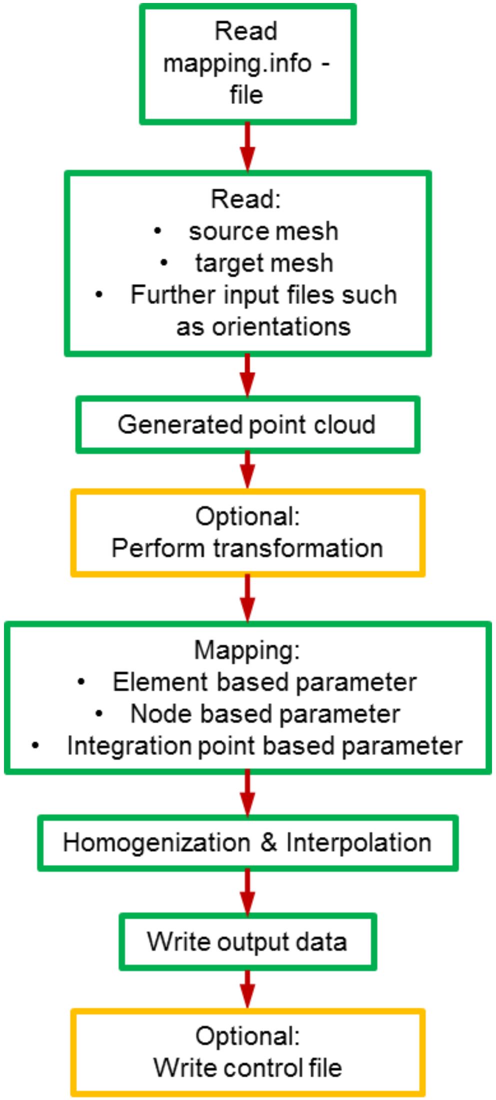
„Historical“ Overview

- Several names existed – „Fibermap“ and „DYNAmap“ were the most common ones.
- With the start of the government funded research project ARNEA2036 in 2014, further software tools such as PAM-Crash, PAM-RTM, FiberSim can be considered within the mapping.
- A link to the HDF5 binary data storage format has been implemented.
- In 2015, a lot of work went into the consideration of fiber orientations as well as resinous areas which can be identified with multi-layer draping simulations.
- Enhancements were made towards the homogenization of stiffness parameters for *MAT_157 for short fiber reinforced composites.

„Historical“ Overview

- In 2016, the consideration of eff. plastic strain resulting from a forming simulation for damage estimation in the GISSMO - *MAT_ADD_EROSION failure and damage model has been implemented.
- Results from forming simulations using shell meshes can be used to generate solid meshes for springback analysis and thickness post-processing.
- A tool to generate vector files for the post-processing of various spring back analysis as been implemented.
- The mapping tool is officially named ENVYO® is introduced to the public at the 14th German LS-DYNA User‘s Meeting in Bamberg, Germany.

Workflow

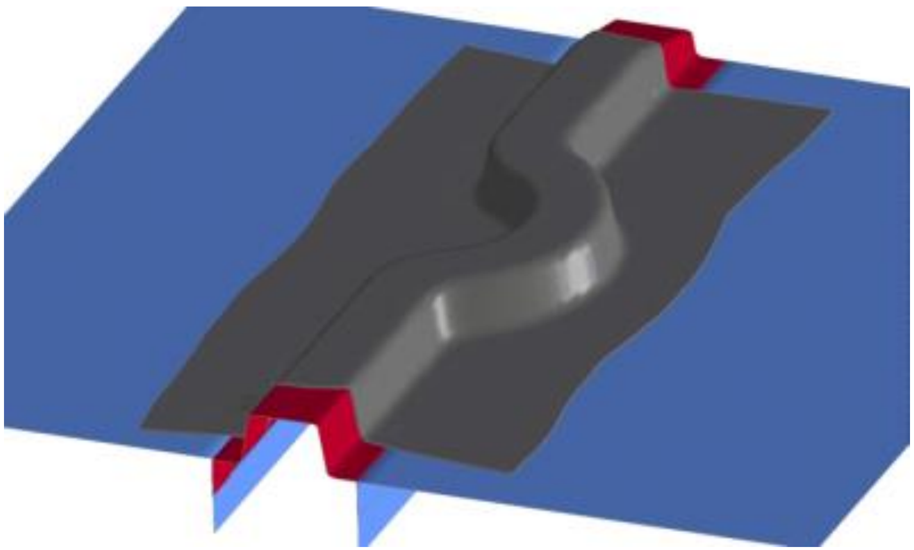

Read mapping.info - file
Read:
• source mesh
• target mesh
• Further input files such as orientations
Generated point cloud
Optional: Perform transformation
Mapping:
• Element based parameter
• Node based parameter
• Integration point based parameter
Homogenization & Interpolation
Write output data
Optional: Write control file

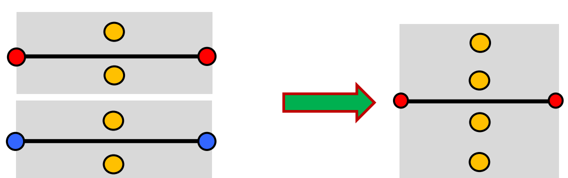
Mapping Capabilities

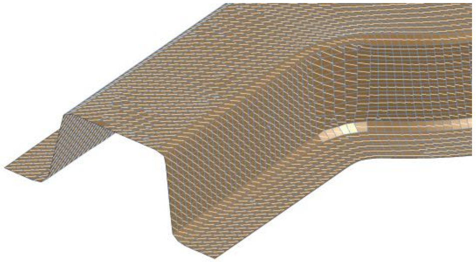
- ORIENTATION -> SHELL
- ORIENTATION -> ALE_MESH
- SHELL -> STACKED_SHELL
- SOLID -> SOLID
- STACKED_SHELL -> SOLID
- BEAM -> ALE_MESH
- SHELL -> SOLID
- SHELL -> THICK_SHELL
- STACKED_SHELL -> STACKED_THICK_SHELL
- SHELL -> SHELL
- SHELL -> SOLID (GENERATION)
- MOLDFLOW -> SHELL
- MOLDFLOW -> SOLID
- MOLDFLOW -> SHELL (with plasticity curve interpolation)
- Moldflow visualization
- CT-Scan -> SHELL
- CT-Scan Visualization
- CT-Scan -> Through Thickness Curves
- MOLDFLOW -> Through Thickness Curves
- MOLDFLOW3D -> Through Thickness Curves
- HDF5-Input
- Springback Analysis

Mapping Capabilities

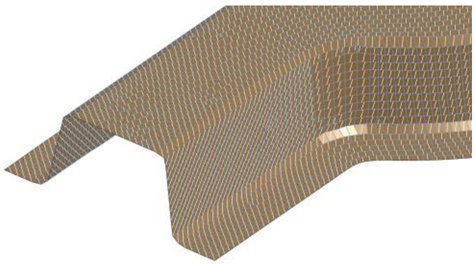
- **ORIENTATION -> SHELL**



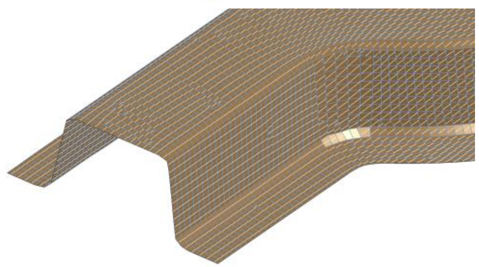




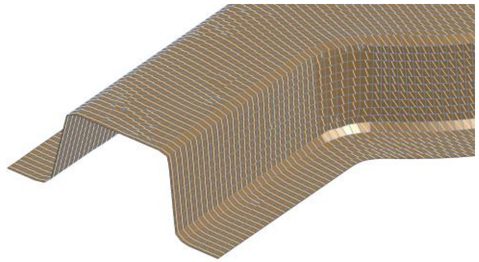
Layer #1:



Layer #2:



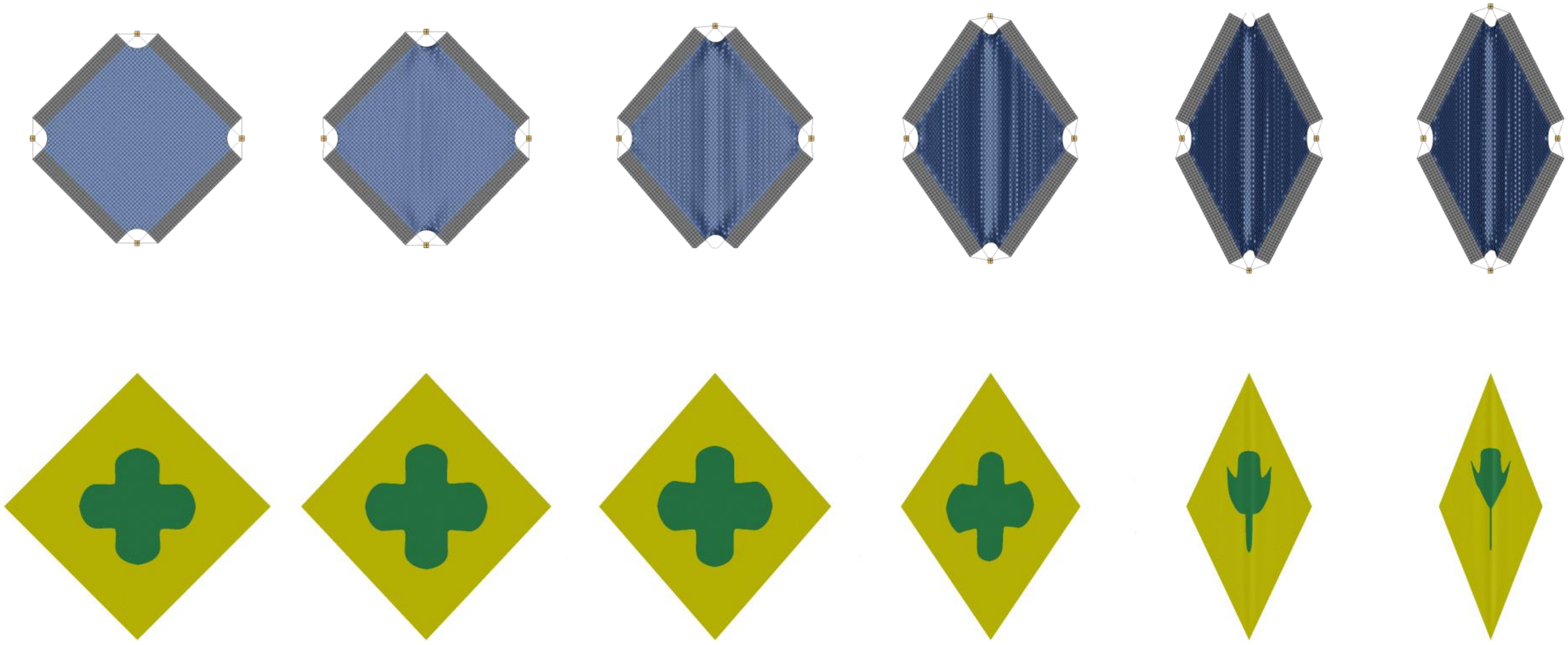
Layer #3:



Layer #4:

Mapping Capabilities

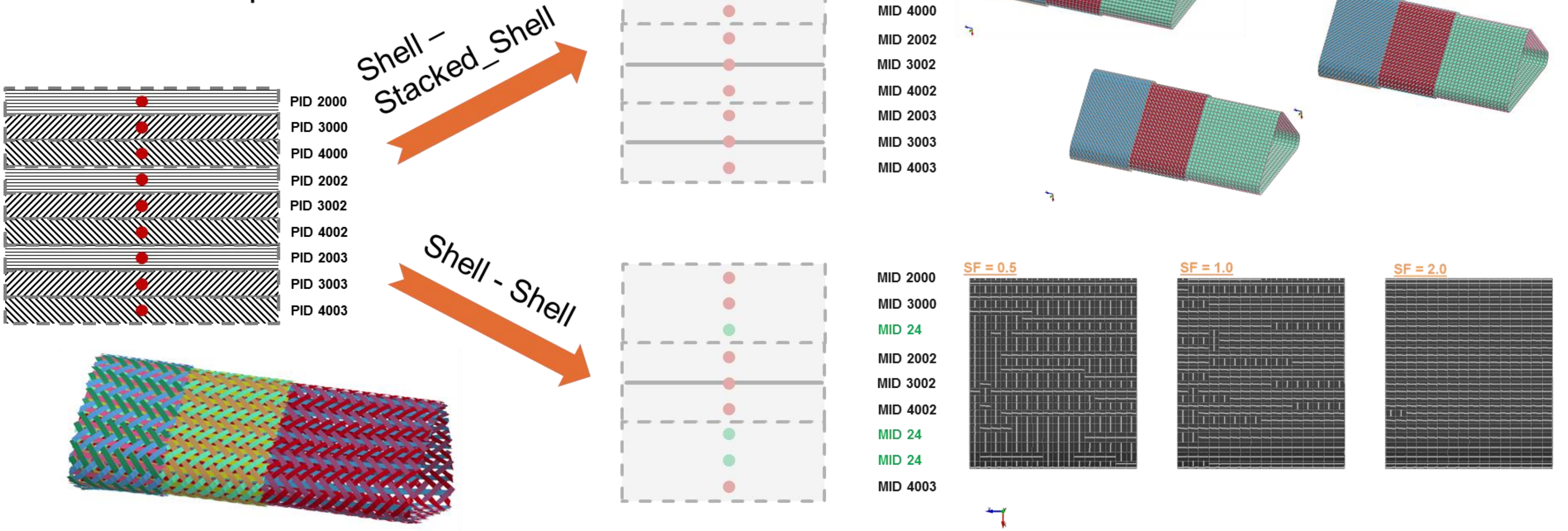
- **ORIENTATION -> ALE_MESH**



Mapping Capabilities

- SHELL -> STACKED_SHELL

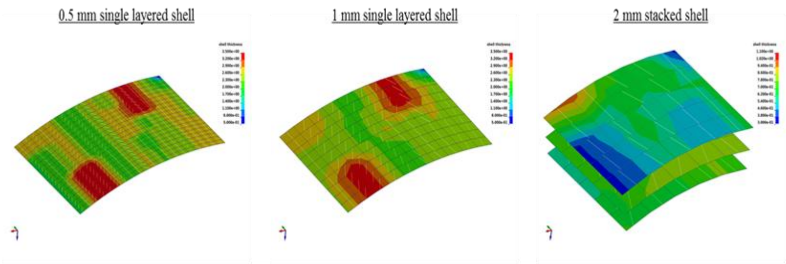
  - Braided composites



Mapping Capabilities

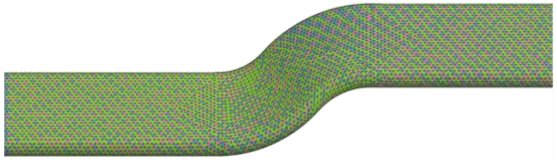
- **SHELL -> STACKED_SHELL**

- **Thickness mapping**

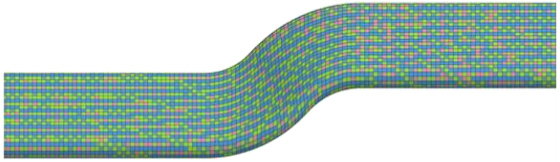


- **Various solvers**

PAM-RTM for infiltration simulation (TRIA – mesh)

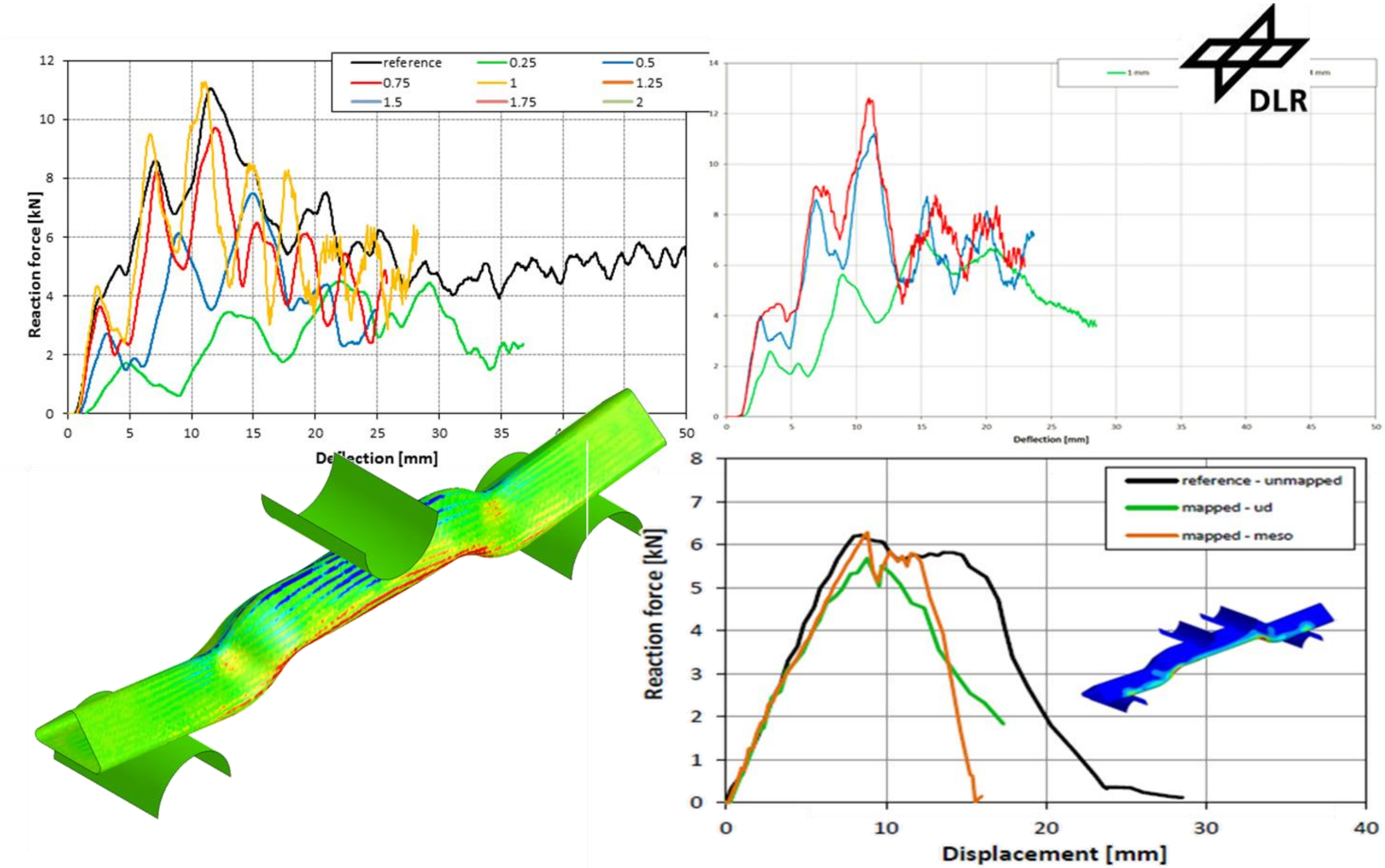


LS-DYNA for crash analysis (QUAD – mesh)



Mapping Capabilities

- **SHELL -> STACKED_SHELL**



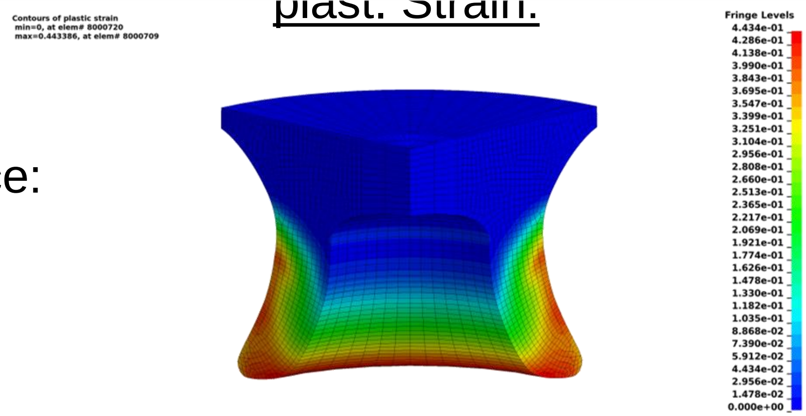
Mapping Capabilities

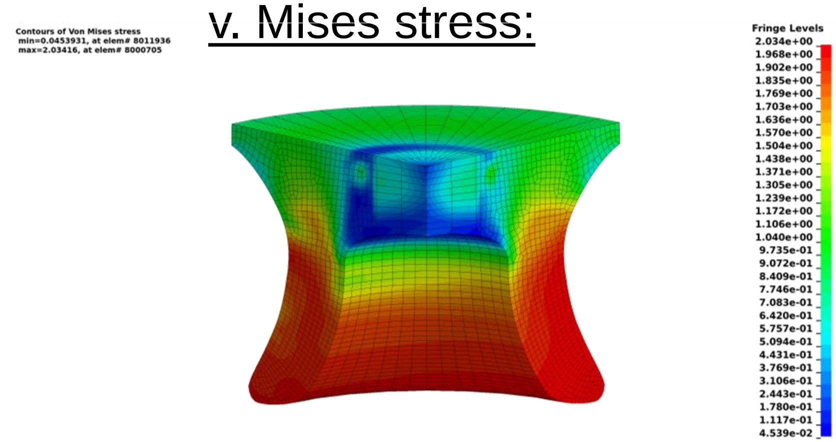
- **SOLID -> SOLID**

plast. Strain:

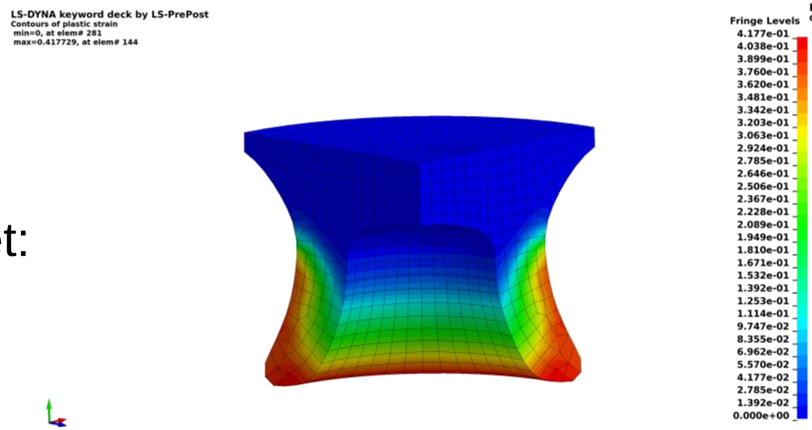
v. Mises stress:

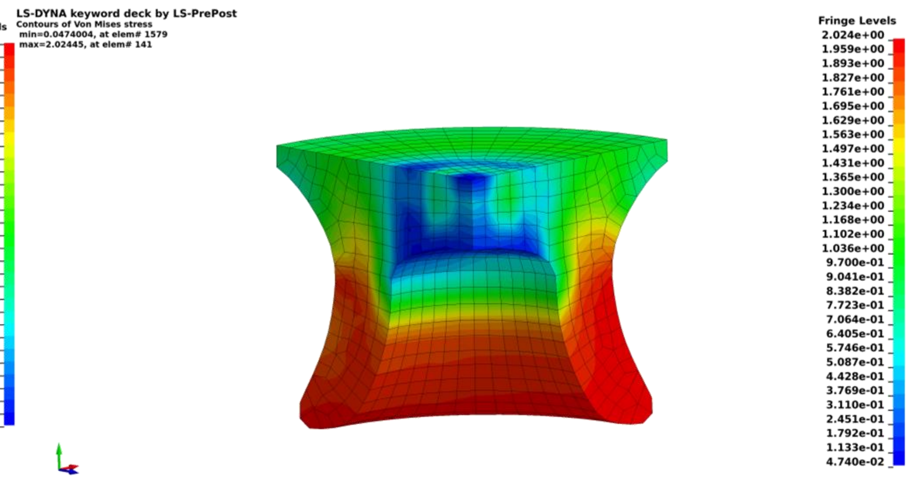
Source:





Target:



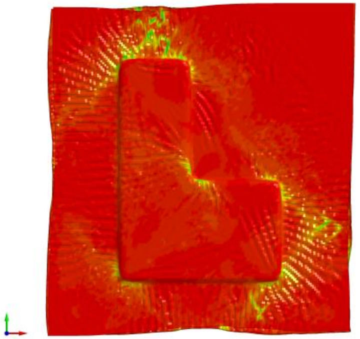


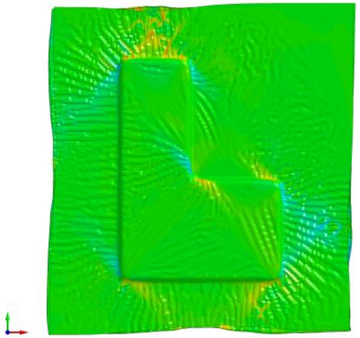
Mapping Capabilities

- STACKED_SHELL -> SOLID

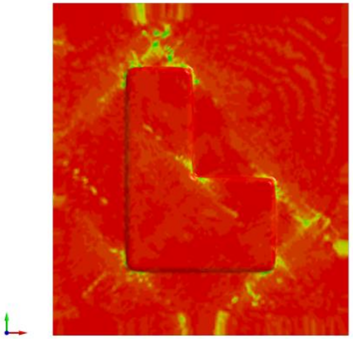
Mean strain: | HISV #1: | Fiber orientation output:

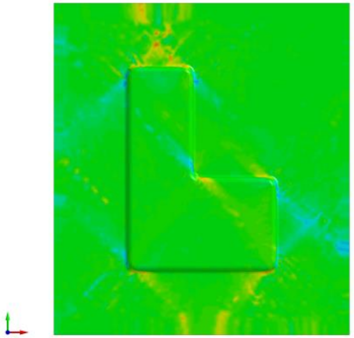
original:

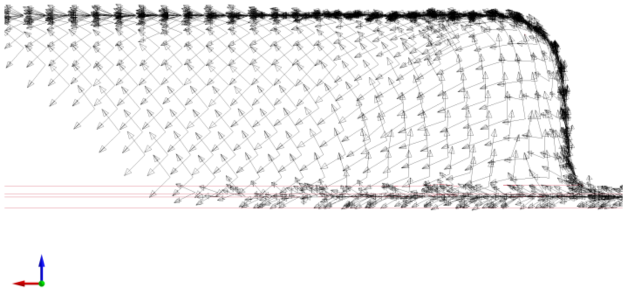




target:



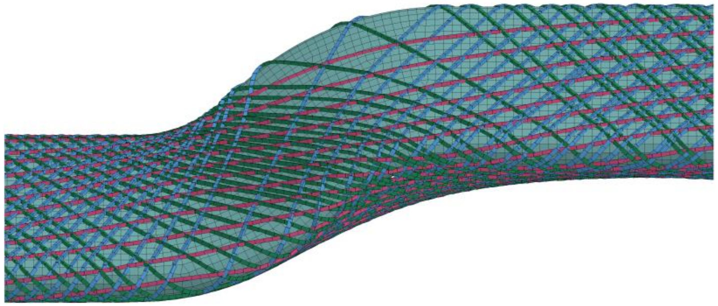




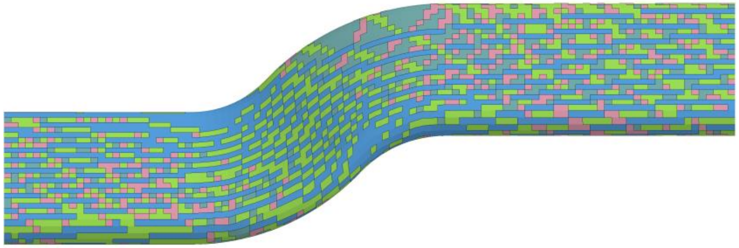
Mapping Capabilities

- **BEAM -> SHELL**

Source – Mesh:



Scale factor = 5.0:



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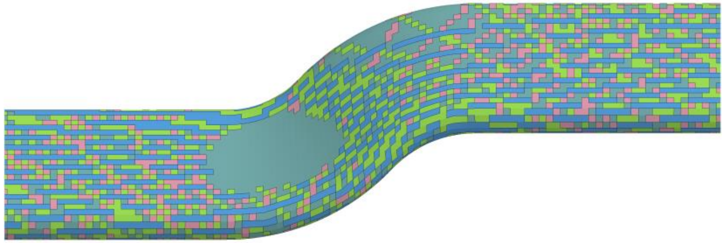
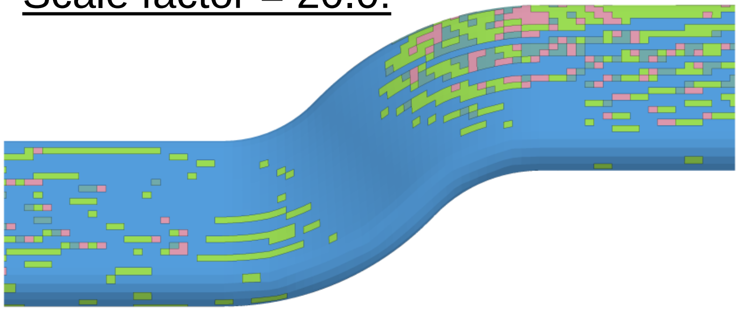


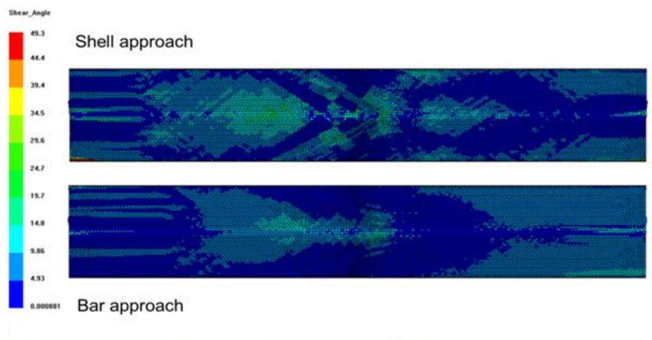
Scale factor = 20.0:

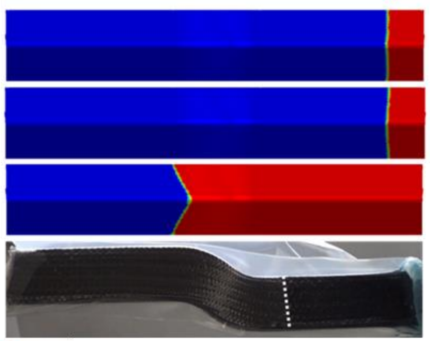


Mapping Capabilities

- **BEAM -> SHELL**

Infiltration Simulation





Bar approach
(t=170s; k = 1.63e-11 m²)

Shell approach
(t=170s; k = 1.63e-11 m²)

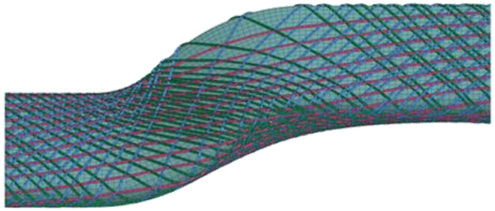
CT-scan approach
(t=170s; k = 8.8e-10 m²)

Vari approach
(t=170s; k = 5.8e-10 m²)

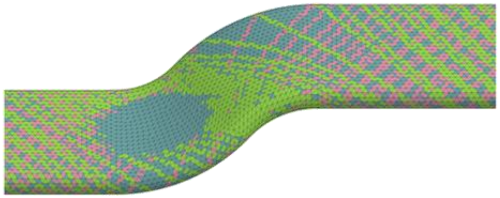
IFB
Universität Stuttgart

IFB

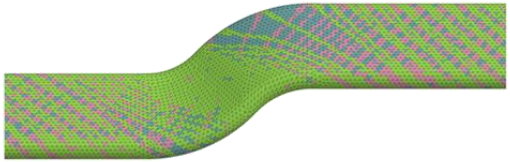
Source – Mesh:



Scale factor = 1.0:

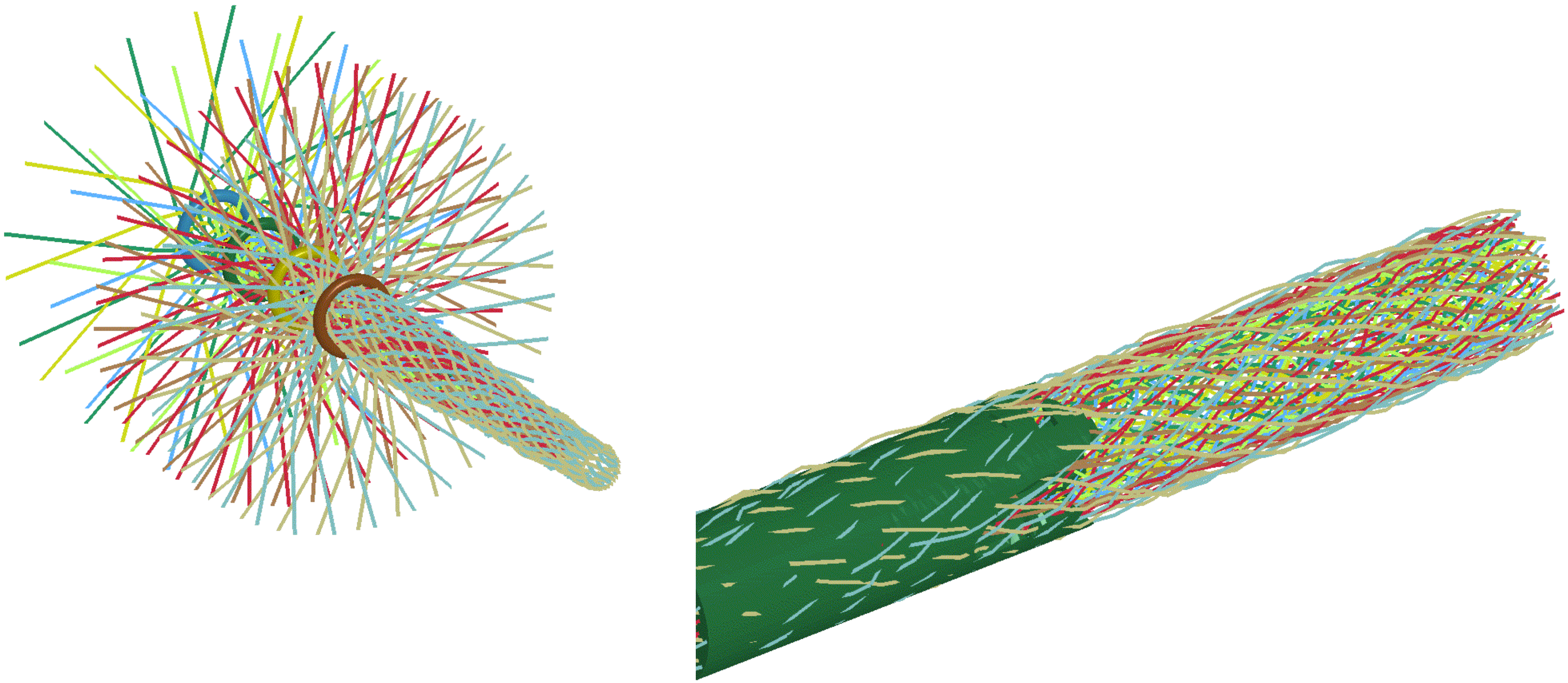


Scale factor = 5.0:



Mapping Capabilities

- **BEAM -> ALE_MESH**



Mapping Capabilities

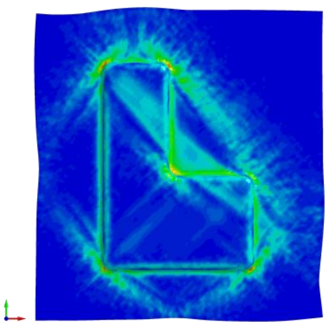
- **SHELL -> SOLID**

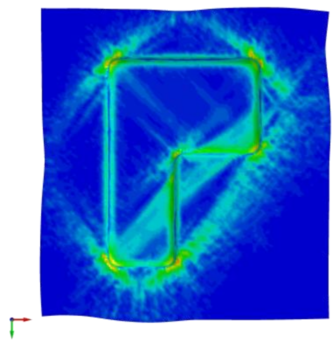
v. Mises IP1:
(top view)

v. Mises IP4:
(bottom view)

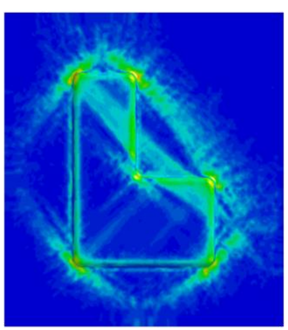
Fiber orientation output:

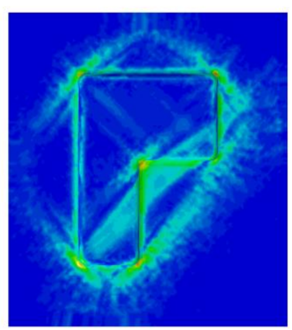
original:

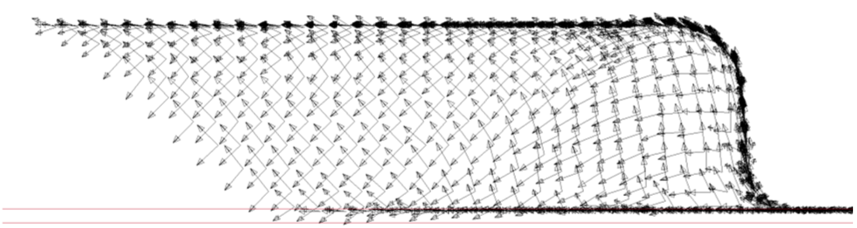




target:

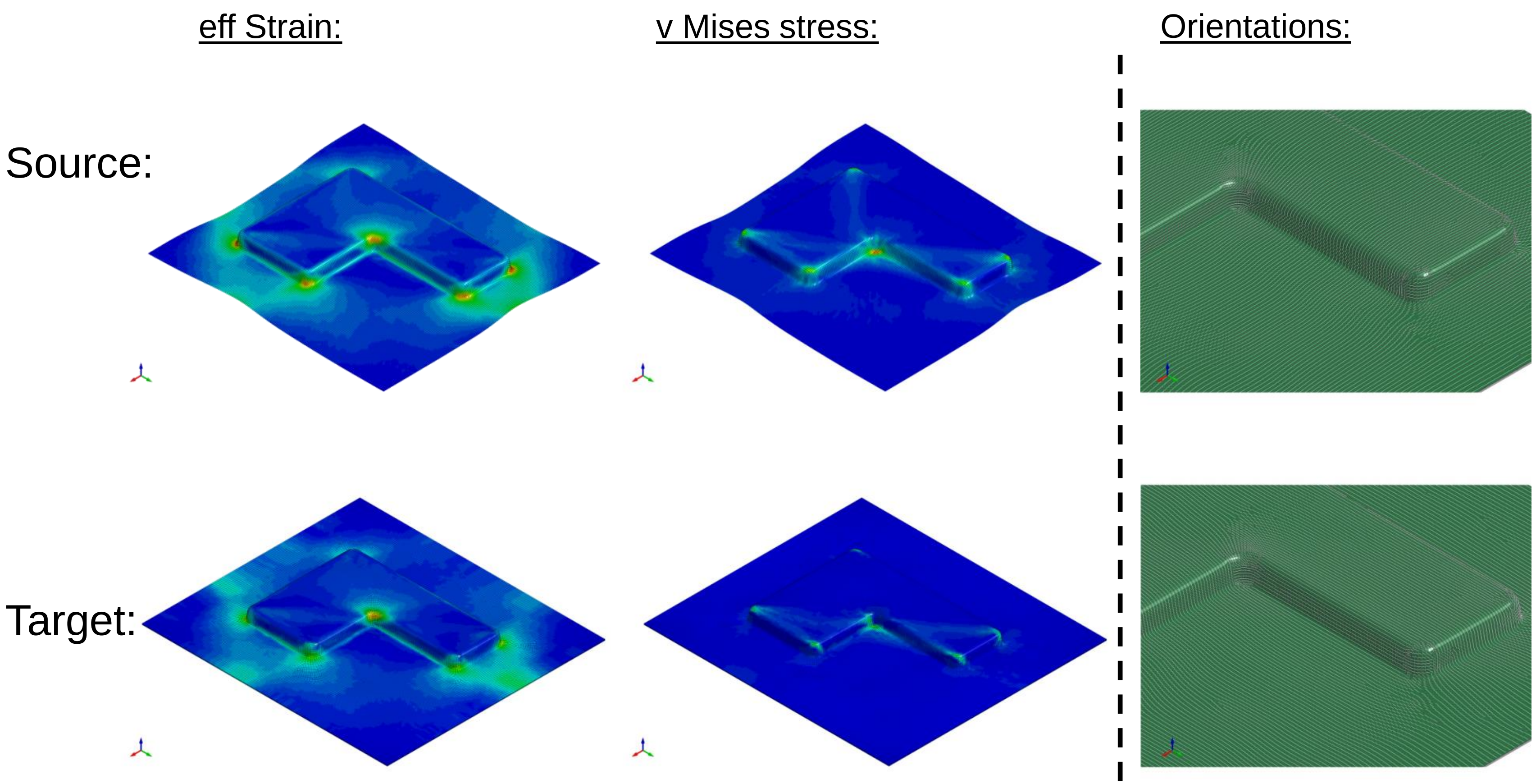






Mapping Capabilities

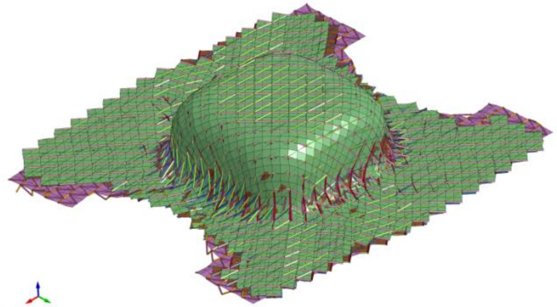
- **SHELL -> THICK_SHELL**



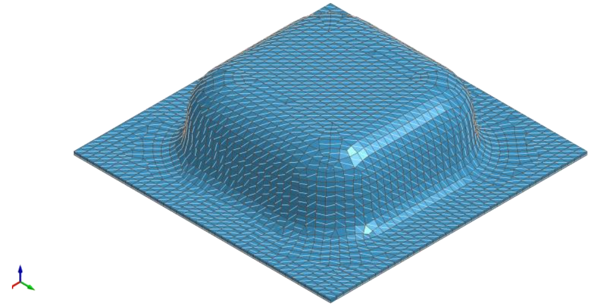
Mapping Capabilities

- **STACKED_SHELL -> STACKED_THICK_SHELL**

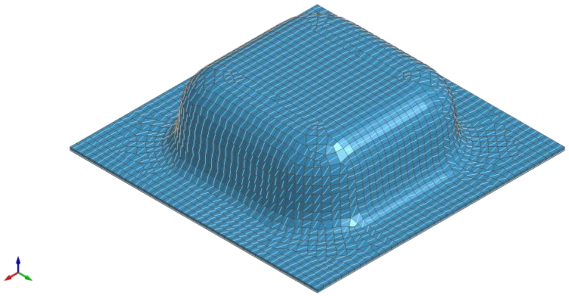
Source – Mesh -Stacked Shells (5 Layers):



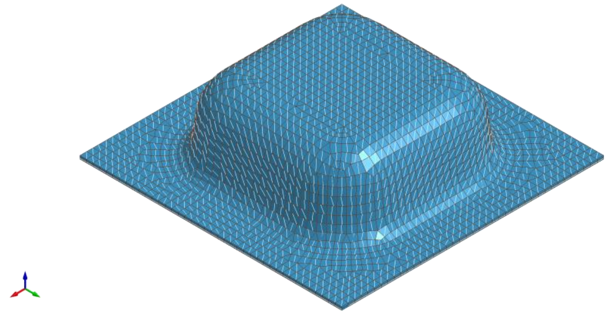
Orientations IP#3:



Orientations IP#1:

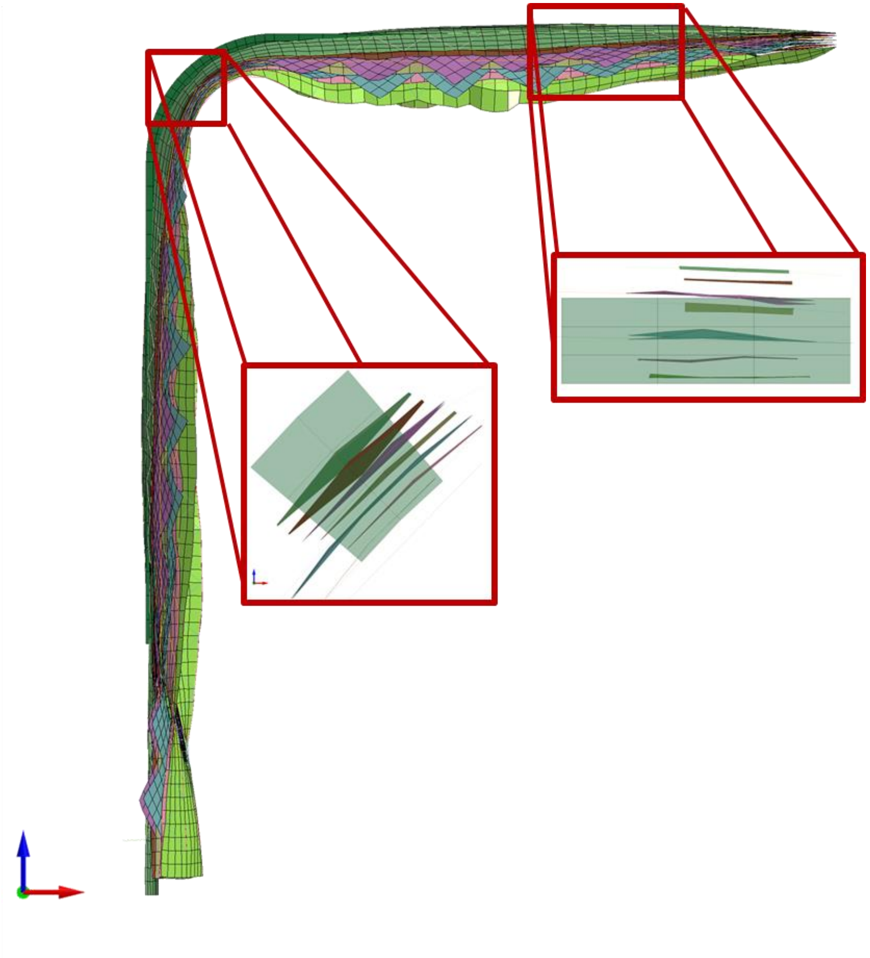


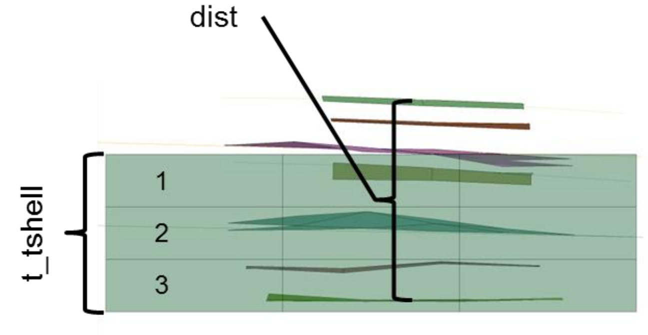
Orientations IP#5:

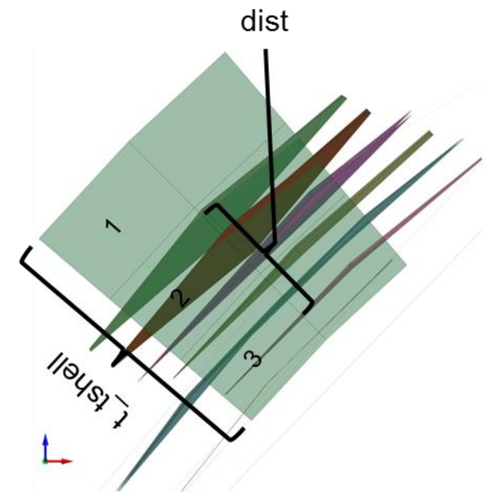


Mapping Capabilities

- **STACKED_SHELL -> STACKED_THICK_SHELL**



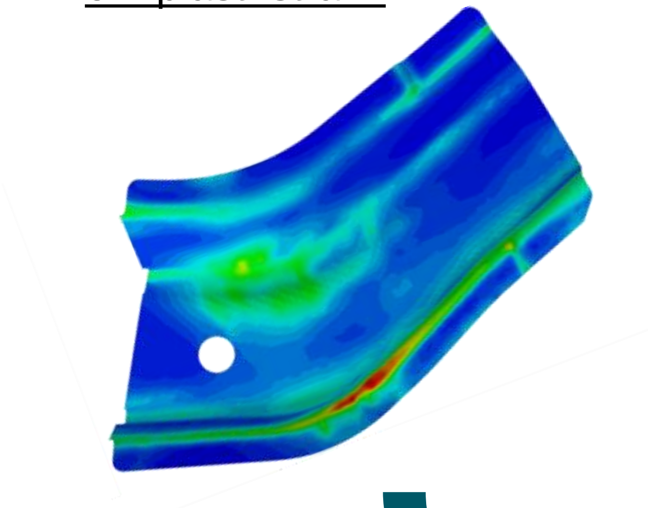




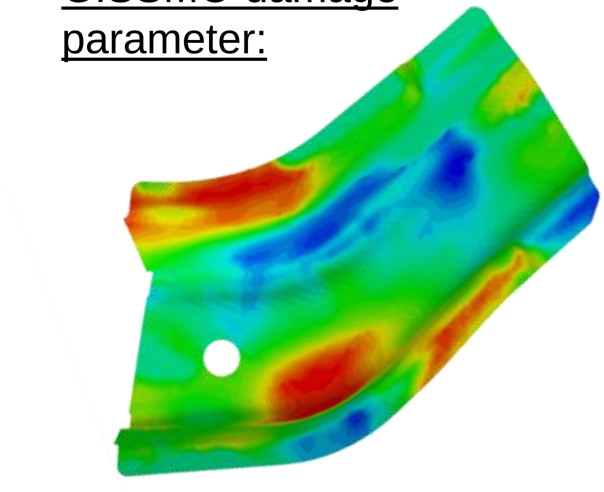
Mapping Capabilities

- **SHELL -> SHELL**

<u>eff. plast. strain:</u>



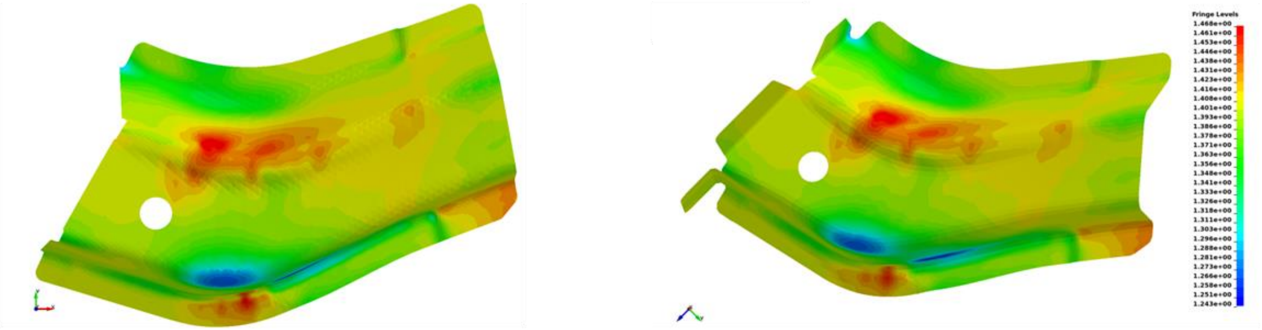
<u>GISSMO damage parameter:</u>



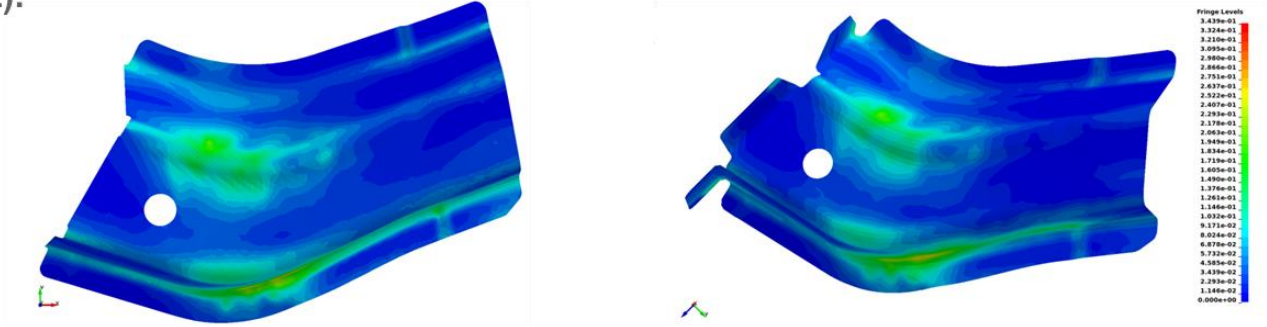
Damage estimation

Mapping Capabilities

- **SHELL -> SHELL**
  - **Shell thickness from Autoform result (left) and after the mapping process (right).**

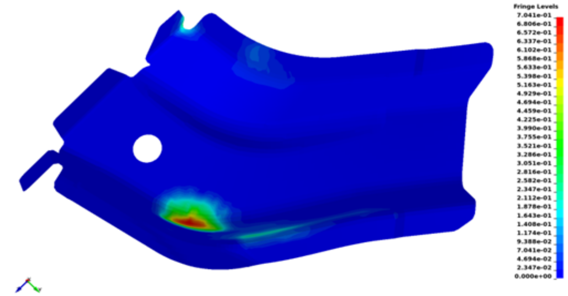


  - **Effective plastic strain from Autoform result (left) and after the mapping process (right).**

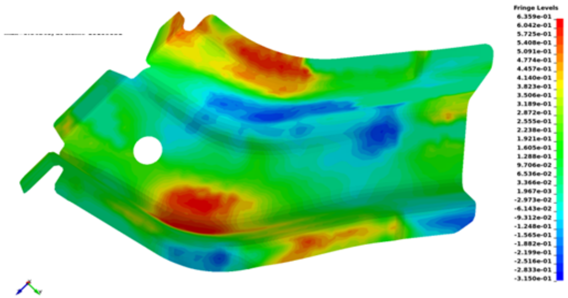


Mapping Capabilities

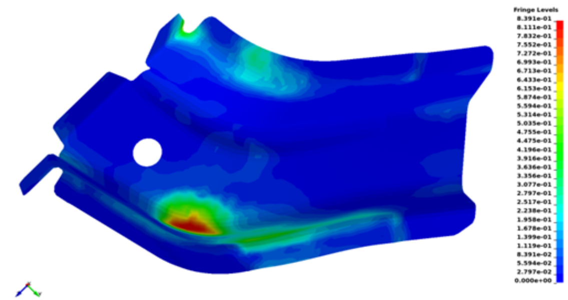
- **SHELL -> SHELL**
  - **History-Variable 6 (Damage)**



  - **History-Variable 9 (Triaxiality)**



  - **History-Variable 19 (damage ,`til failure strain)**

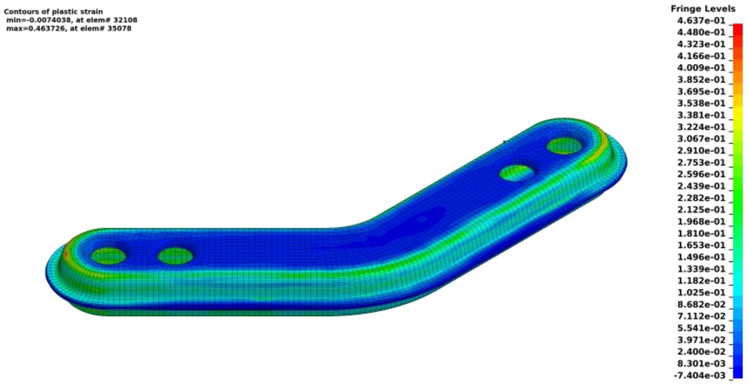


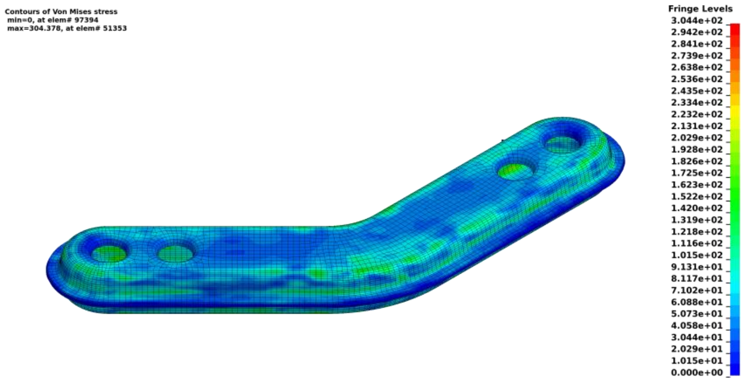
Mapping Capabilities

- **SOLID -> SHELL**

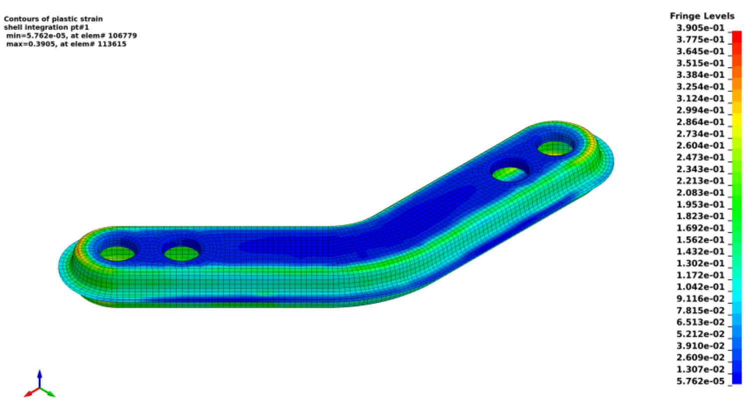
plast. Strain: v. Mises stress:

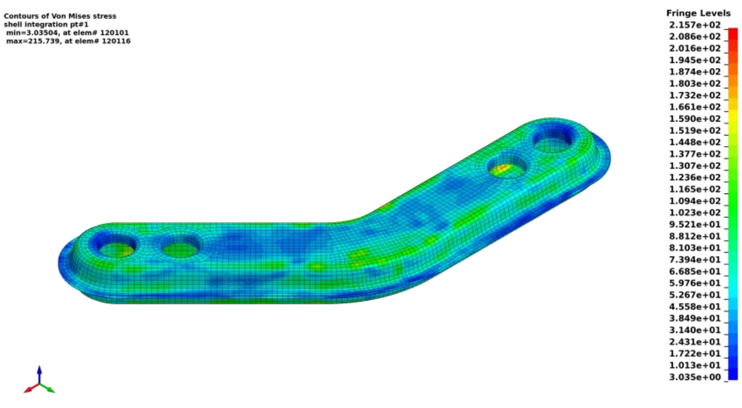
Source:





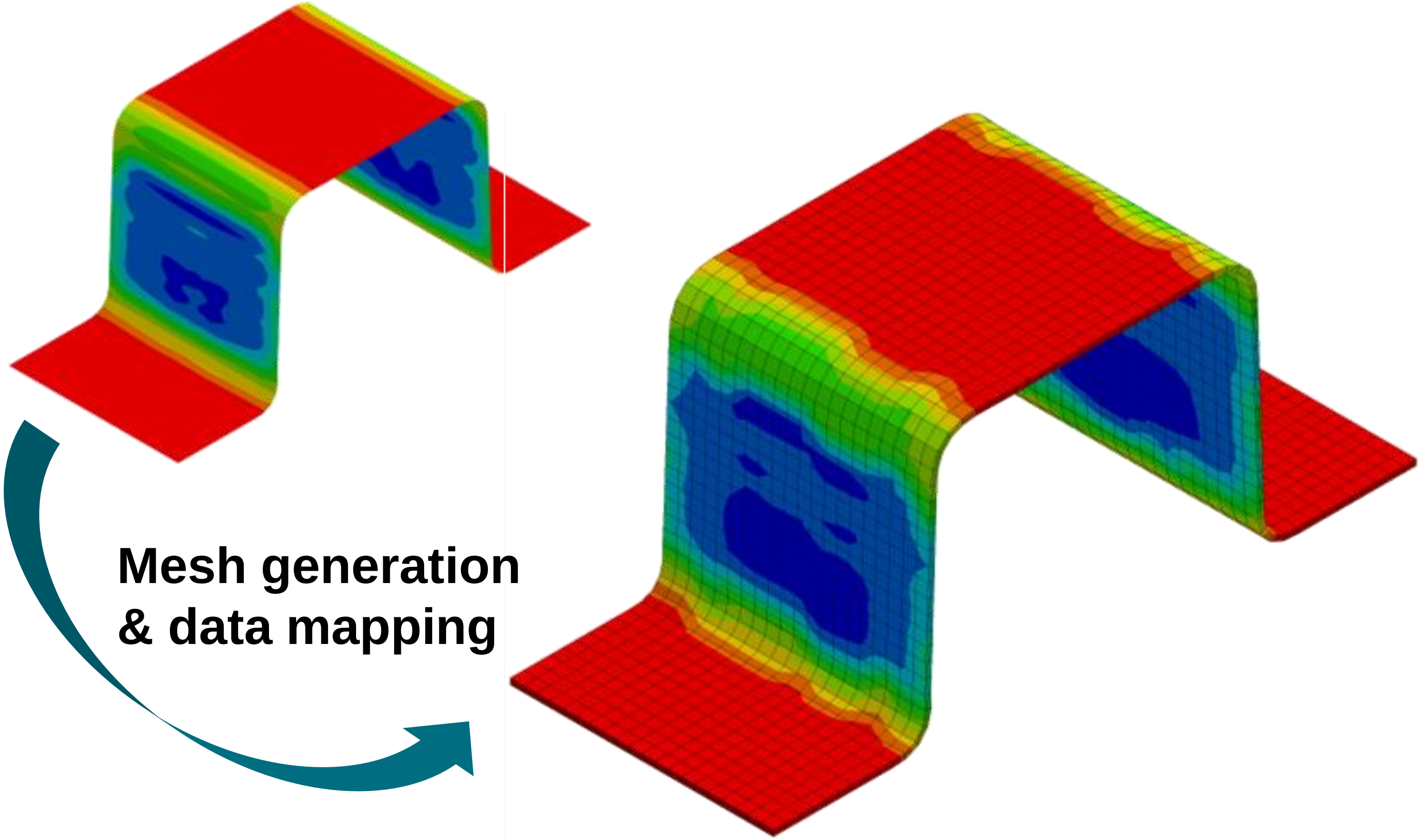
Target:





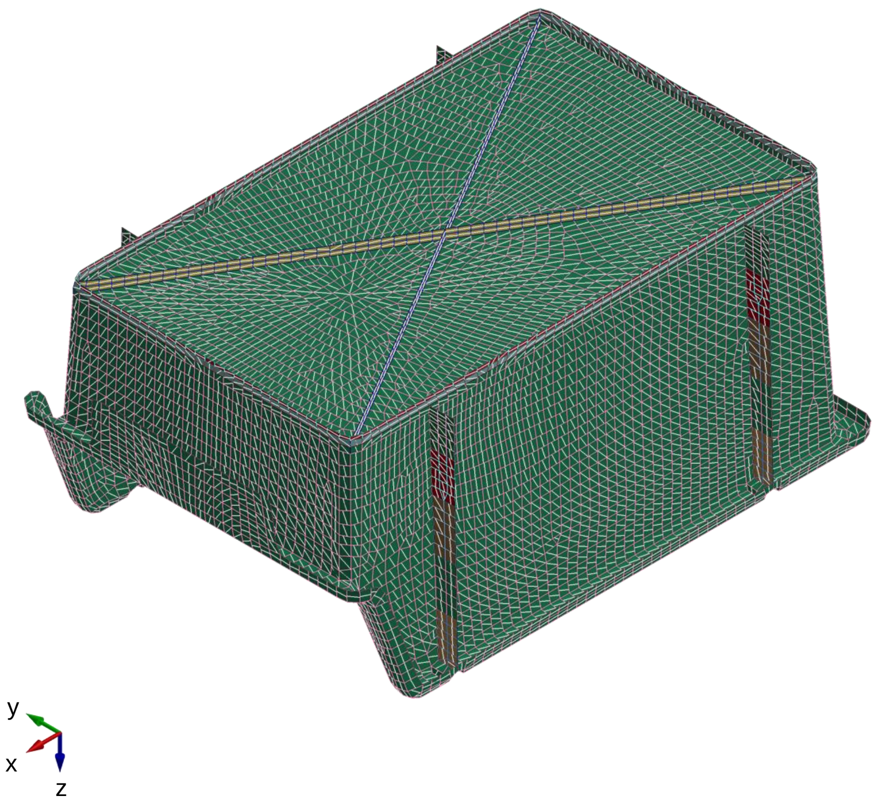
Mapping Capabilities

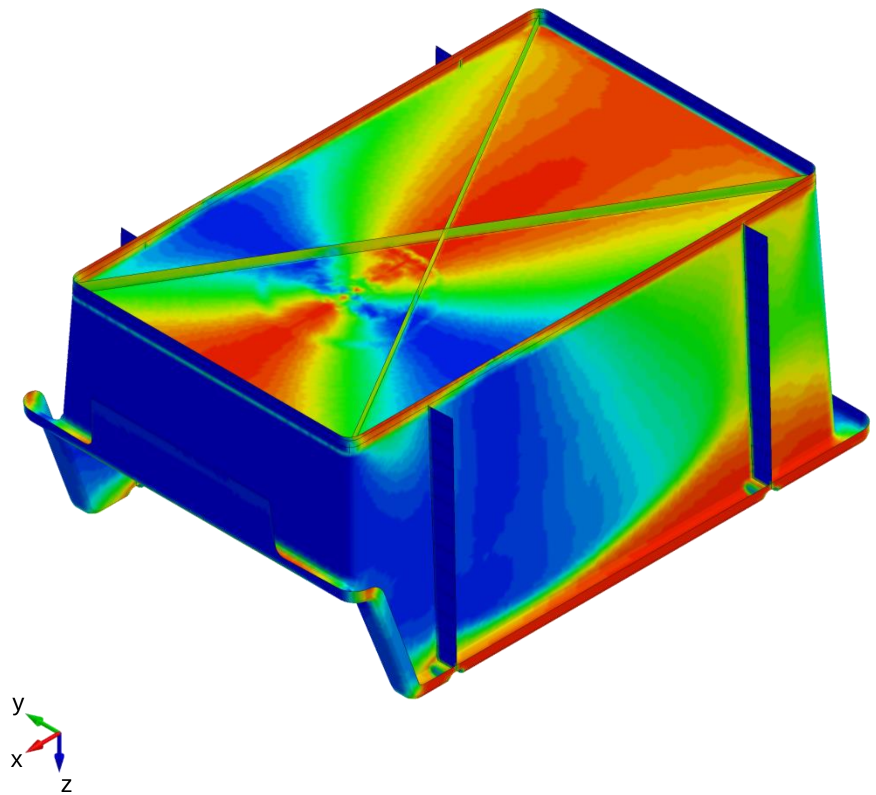
- SHELL -> SOLID (GENERATION)



Mapping Capabilities

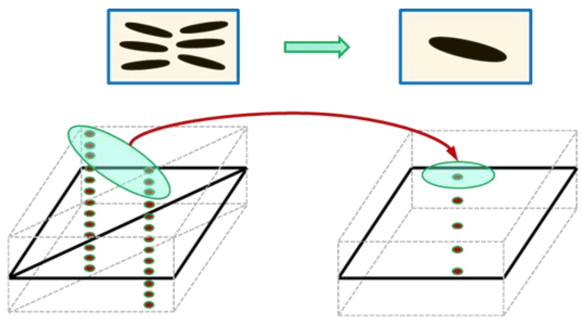
- **MOLDFLOW -> SHELL**

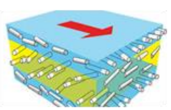


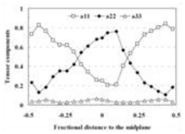


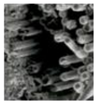
Mapping Capabilities

- **MOLDFLOW -> SHELL (with plasticity curve interpolation)**
  - Mapping (Moldflow/Moldex -> Shell) and homogenization for SFRP – components





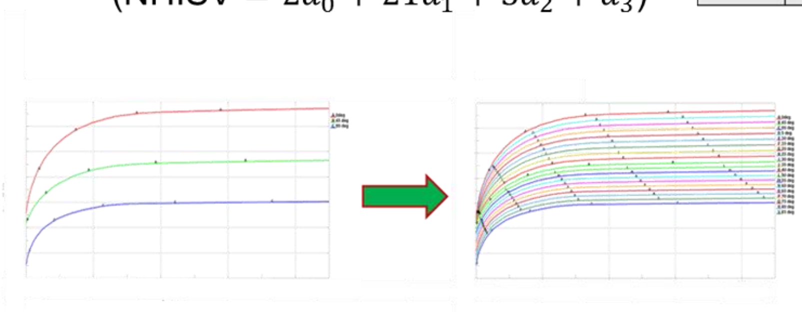


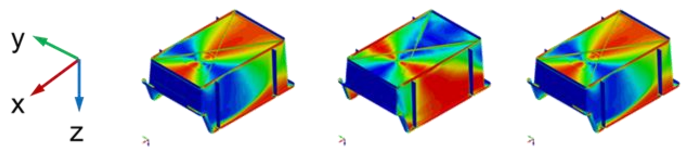


  - Usage of elastic-viscoplastic material model *MAT_157 + *Initial_Stress_Shell (NHISV $= 2a_0 + 21a_1 + 3a_2 + a_3$)

CARD 1	eid	nplane	nthick	nhisv	ntensor	large	nthint	nthhsv
CARD 2	t	sigxx	sigyy	sigzz	sigxy	sigyz	sigzx	eps
CARD 3	hisv1=q_1	hisv2=q_2	#3=C_{11}	#4=C_{12}	#5=C_{13}	#6=C_{14}	#7=C_{15}	#8=C_{16}
CARD 4	#9=C_{22}	#10=C_{23}	#11=C_{24}	#12=C_{25}	#13=C_{26}	#14=C_{33}	#15=C_{34}	#16=C_{35}
CARD 5	#17=C_{36}	#18=C_{44}	#19=C_{45}	#20=C_{46}	#21=C_{55}	#22=C_{56}	#23=C_{66}	

Flag	Description	Variables	#
a_0	Material directions	q_1, q_2	2
a_1	Anisotropic stiffness	Cij	21
a_2	Anisotropic constants	r_{00}, r_{45}, r_{90}	3
a_3	Stress-strain Curve	LCSS	1



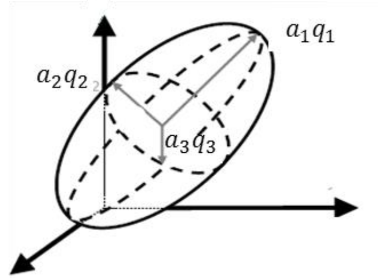


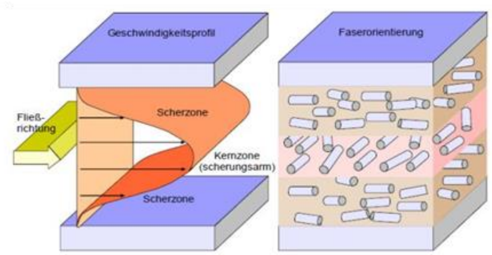
Mapping Capabilities

- **MOLDFLOW -> SHELL (with plasticity curve interpolation)**

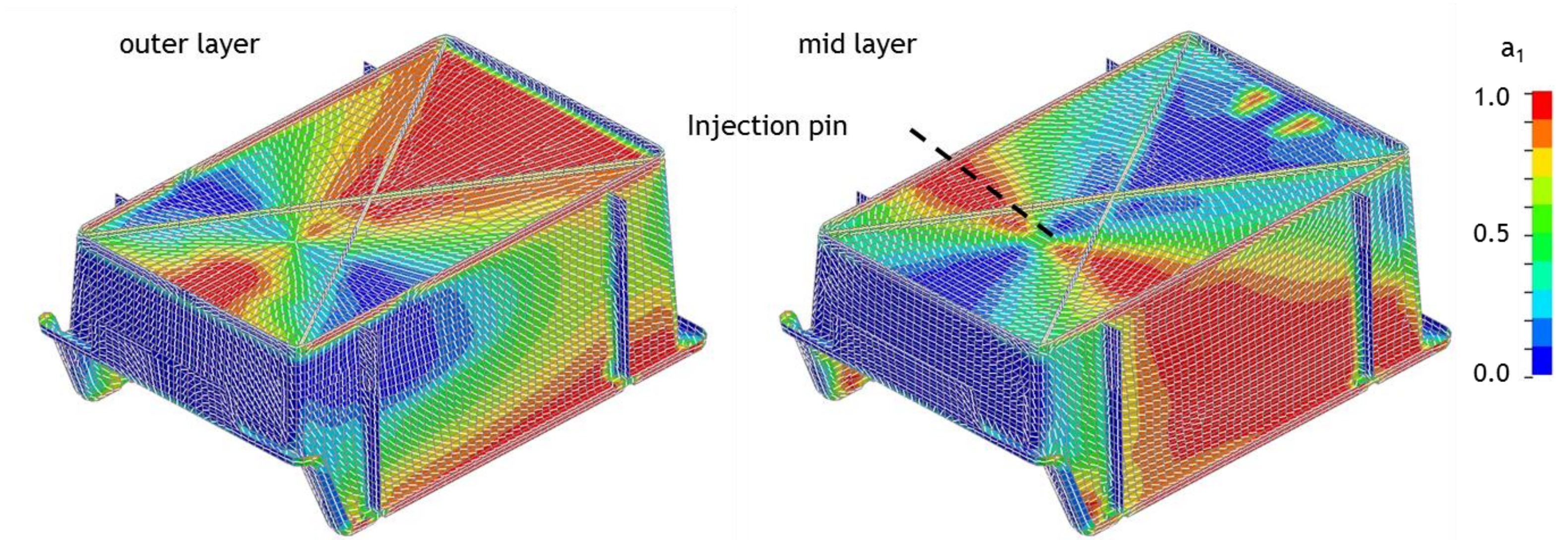
Orientation tensor 2nd order $\boldsymbol{a}$: Mapped from process simulation as

- eigenvectors $\boldsymbol{q}_i$ (main fiber directions)
- eigenvalues a_i (orientation probability)



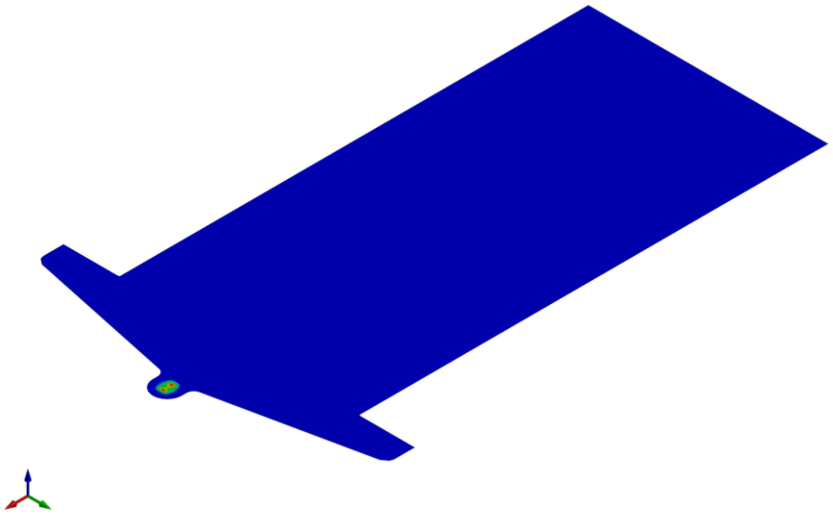


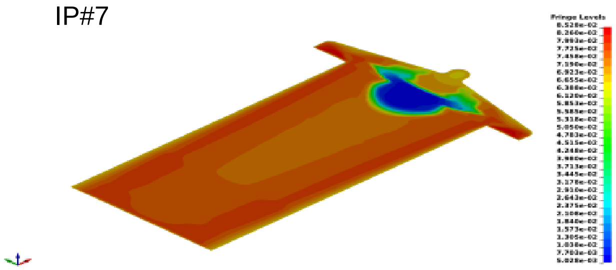
Example: **“Nutini-box” eigenvalue a_1 and eigenvector q_1**

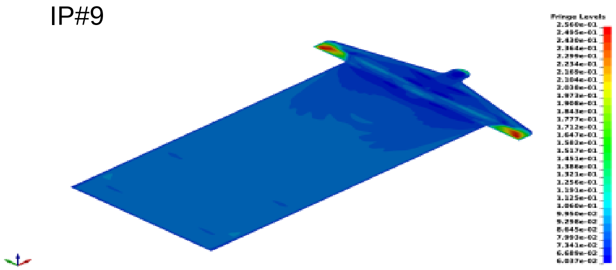


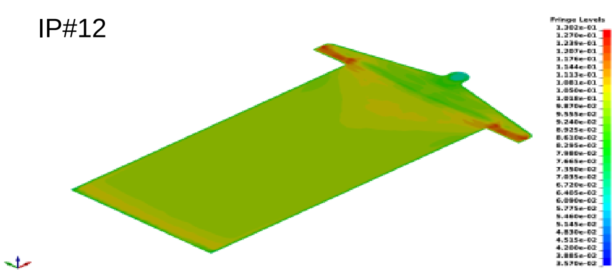
Mapping Capabilities

- **Moldflow visualization**



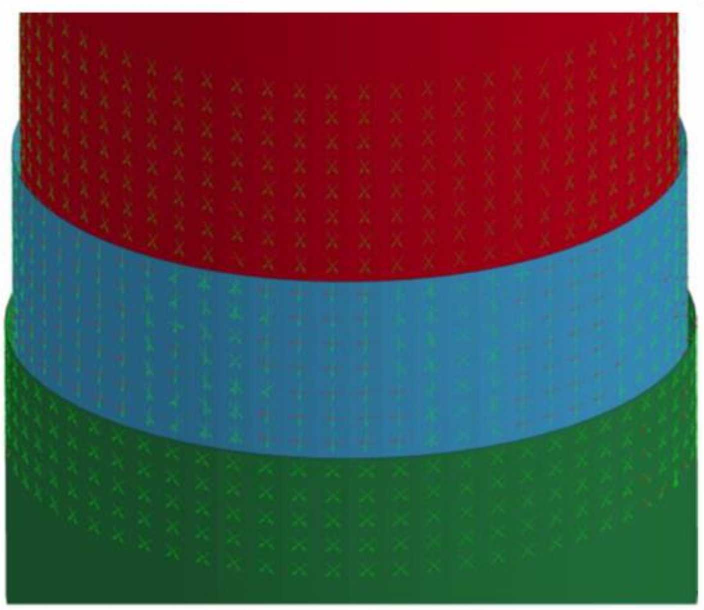


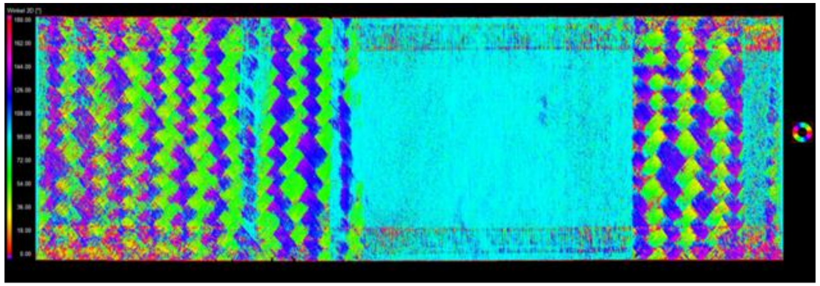


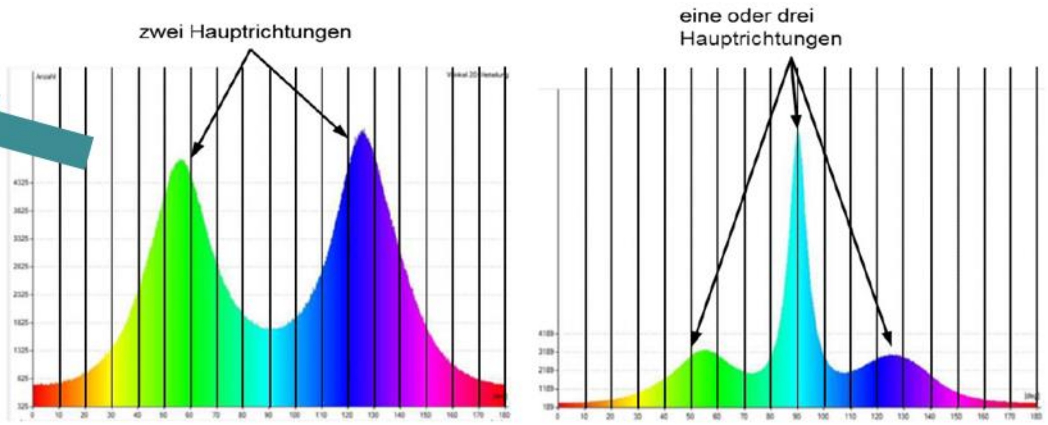


Mapping Capabilities

- **CT-Scan -> SHELL**

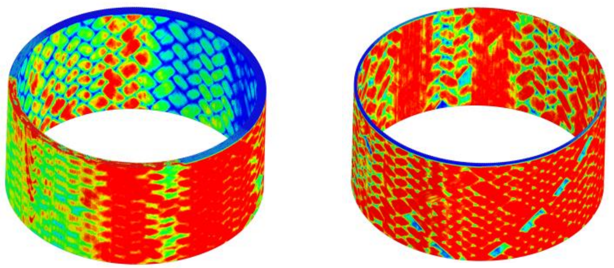




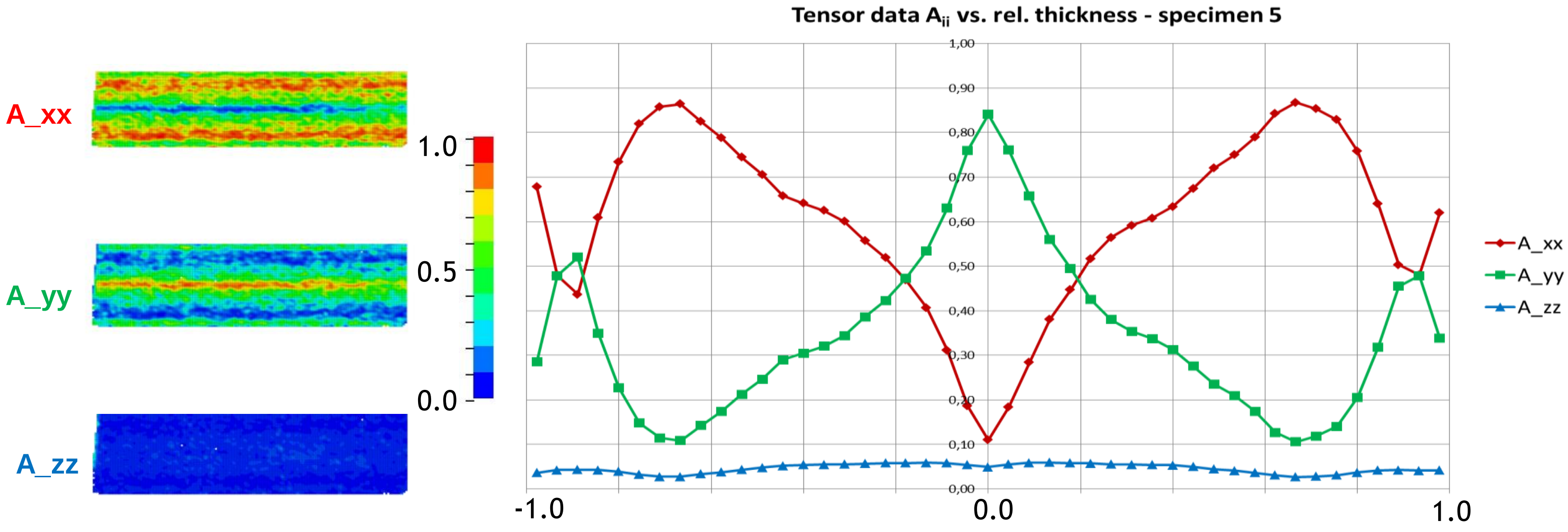


Mapping Capabilities

- CT-Scan Visualization

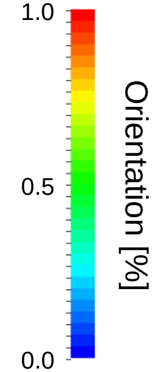


- CT-Scan -> Through Thickness Curves
  - Fiber orientation of 0°- specimen over thickness:

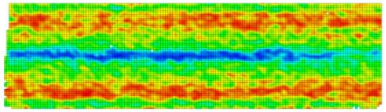


Mapping Capabilities

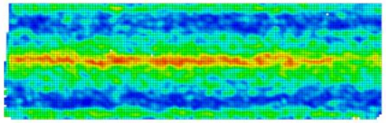
- **MOLDFLOW -> Through Thickness Curves**



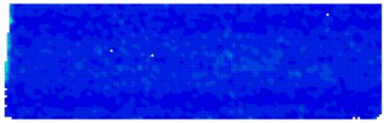
a_xx



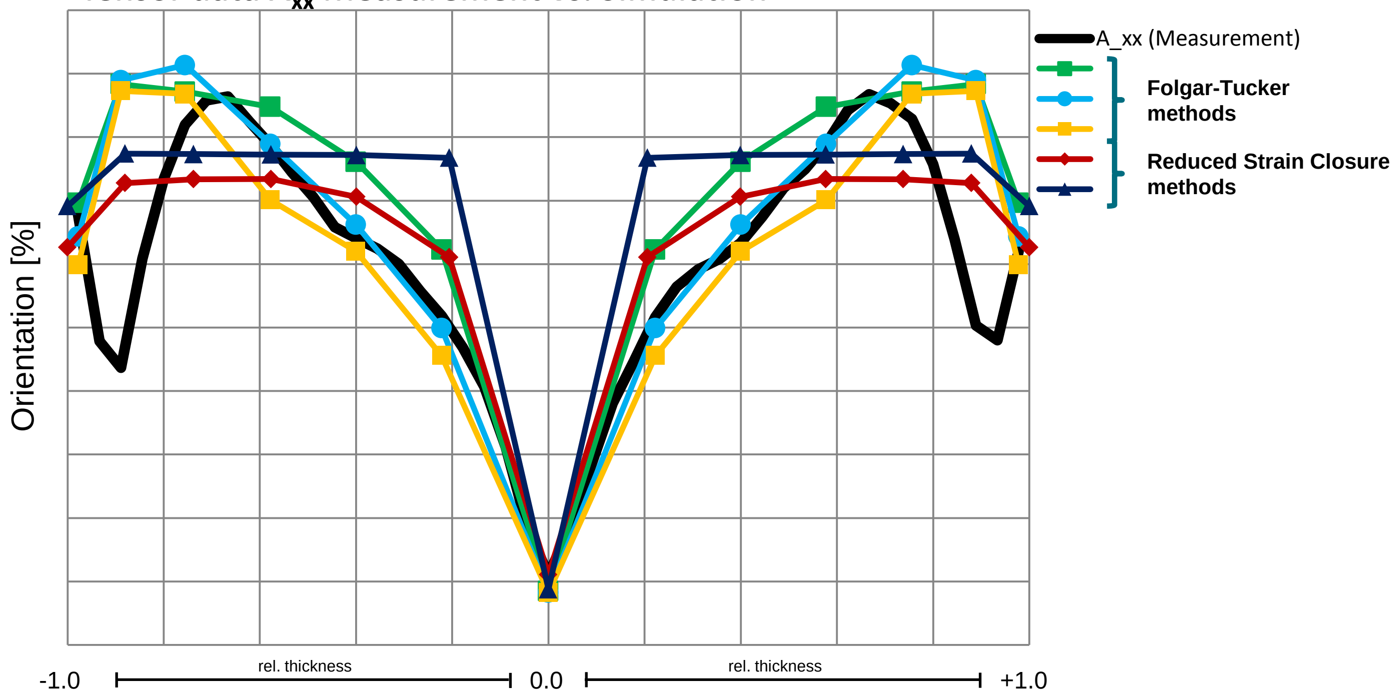
a_yy



a_zz

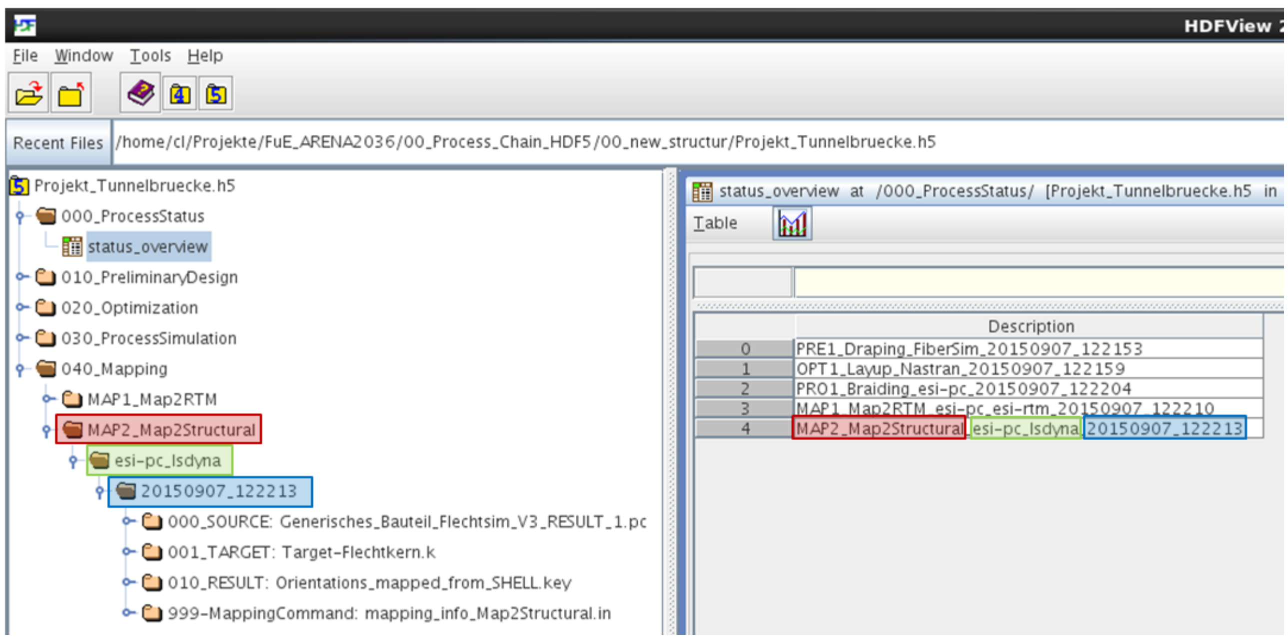


Tensor data A_{xx} Measurement vs. Simulation



Mapping Capabilities

- ## HDF5-Input
  - A platform independent, HDF5 data storage container is defined within the ARENA2036 project, allowing to access and track simulation results from other partners within a defined project.
  - This is available for different FE solvers an will be extended as needed



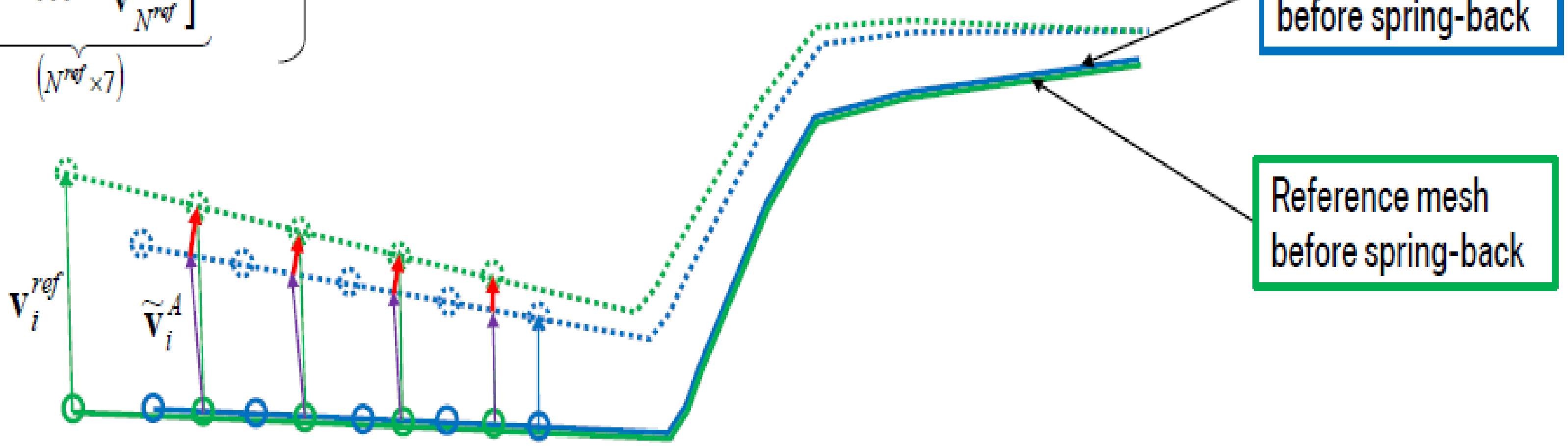
Mapping Capabilities

- **Springback Analysis**

$$\mathbf{V}^* = \underbrace{\left[\mathbf{v}_1^* \quad \cdots \quad \mathbf{v}_{N^{ref}}^*\right]^T}_{(N^* \times 7)}$$

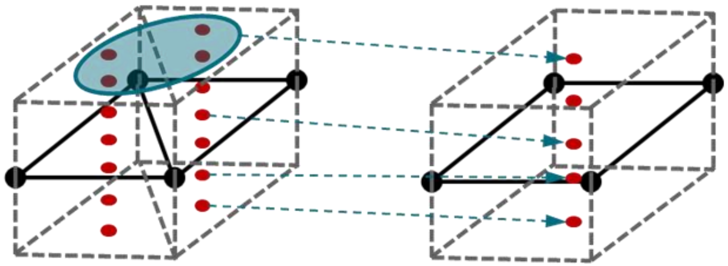
$$\mathbf{v}_i^* = \left[NID \quad x_{start} \quad y_{start} \quad z_{start} \quad x_{end} \quad y_{end} \quad z_{end}\right]$$

$$\left.\begin{aligned} \mathbf{V}^{ref} &= \underbrace{\left[\mathbf{v}_1^{ref} \quad \cdots \quad \mathbf{v}_{N^{ref}}^{ref}\right]^T}_{(N^{ref} \times 7)} \\ \tilde{\mathbf{V}}^A &= \underbrace{\left[\tilde{\mathbf{v}}_1^A \quad \cdots \quad \tilde{\mathbf{v}}_{N^{ref}}^A\right]^T}_{(N^{ref} \times 7)} \end{aligned}\right\} \Rightarrow \boxed{\underbrace{\mathbf{D}}_{(N^{ref} \times 7)} = \underbrace{\mathbf{V}^{ref}}_{(N^{ref} \times 7)} - \underbrace{\tilde{\mathbf{V}}^A}_{(N^{ref} \times 7)}}$$

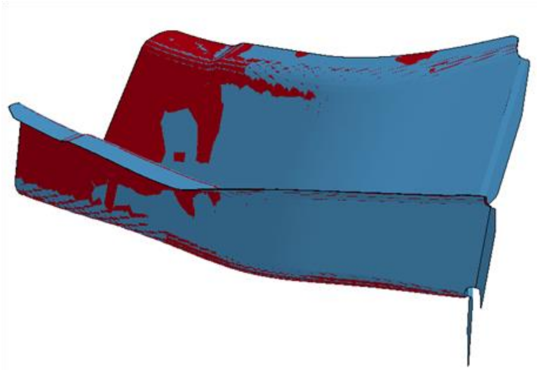


Mapping Capabilities

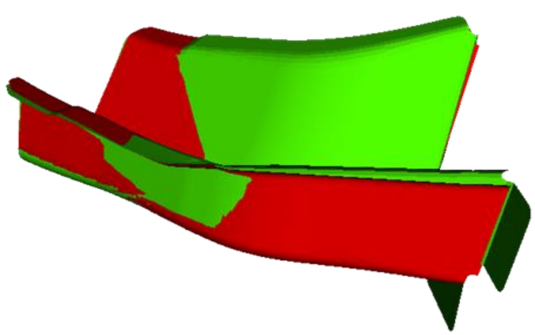
- **Geometry matching**
  - **A „Closest Point“ search is implemented, but averaging techniques shall be realized soon.**



  - **Two geometry matching algorithms are implemented for automatic transformations**



4-Point Congruent Sets



Iterative Closest Point

Example

```
$#---------------------------
$# Main mapping definition
$#---------------------------
FIBERMAP=MOLDFLOW-SHELL(PLASTICITY_CURVE-GEN)
$#---------------------------
$# Activate transformation
$#---------------------------
TRANSFORMATION=NO
SourceUnitSystem=kg-m-s
TargetUnitSystem=kg-mm-ms
$#---------------------------
$# In- and output meshes
$#---------------------------
SourceFile=MOLDFLOW_SOURCE.key
TargetFile=TARGET_LS-DYNA.key
MappingResult=FILE_FOR_STRUCTURAL_ANALYSIS.key
OrientationFile=MOLDFLOW-ORIENTATIONS.xml
SectionFile=SECTION_CARDS.key
```

Example

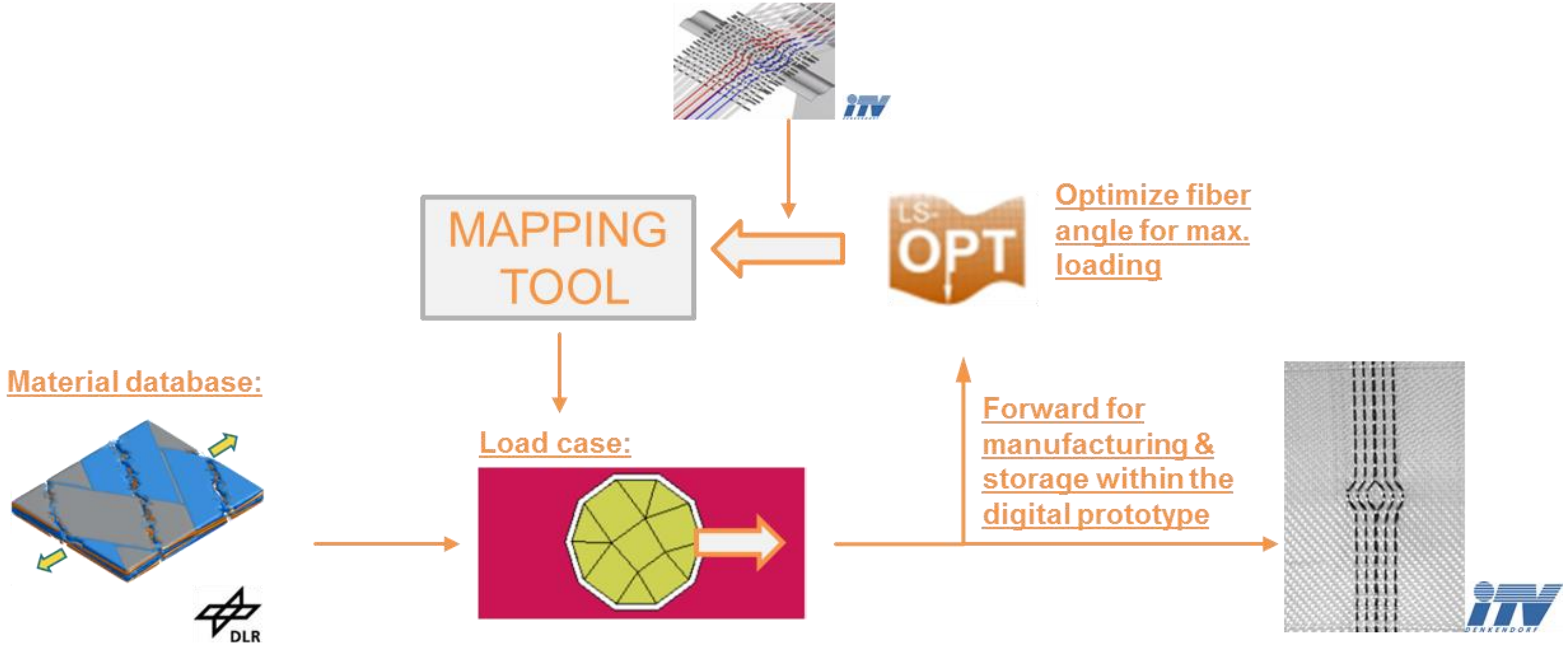
$#---------------------------
Target – Properties
$#---------------------------
NumberOfTARLayers=5
NumberOfTARInPlaneIPs=4
MapStress=YES
TargetThickness=2.5
MapMainDir=NO
$#---------------------------
$# Mapping-Options
$#---------------------------
ALGORITHM=ClosestPoint
SORT=BUCKET
TargetMaterialModel=157
HomogenizationMethod=Mori-Tanaka
ClosureApproximation=hybrid
E11F=
E22F=
RHOF=
PRBAF=
PRCBF=
G12F=
EM=
RHOM=
PRM=
AspectRatio=
FiberVolumeFraction=
InclusionShape=Spheroidal

Example

```
$#---------------------------
$# Define Curve Input
$#---------------------------
NumberOfCurveFiles=3
CurveFileName#1=0deg_curves.inc
…
$#---------------------------
$# Strain Rate Info
$#---------------------------
NumberOfDirections=3
Direction#1=0
…
NumberOfStrainRates=4
StrainRate#1=
…
StrainRate#1Direction#1=995
...
StrainRate#1Direction#2=45995
...
StrainRate#1Direction#3=90995
…
StrainRate#4Direction#3=90998
$#---------------------------
$# END-OF-FILE
$#---------------------------
```

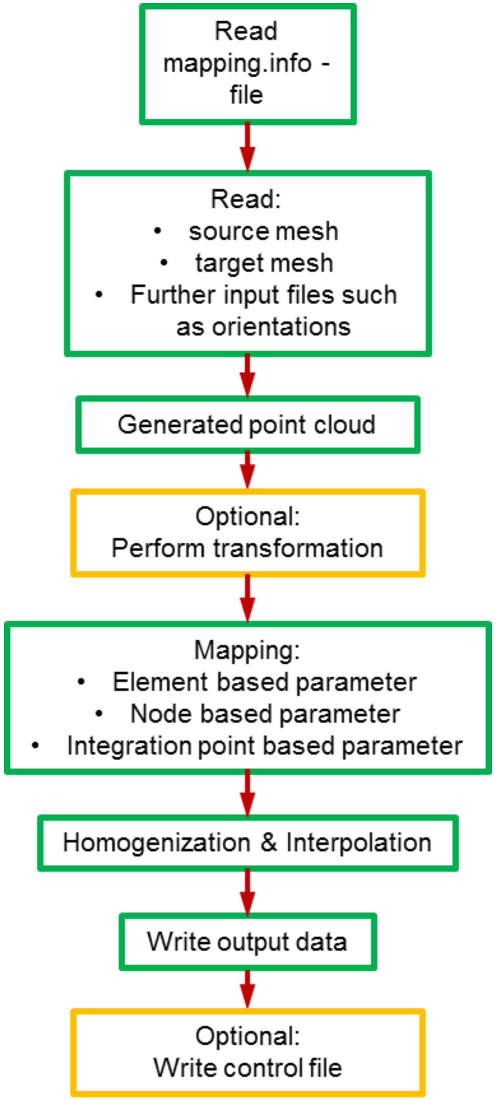
Future Plans

- **Link to optimization:**



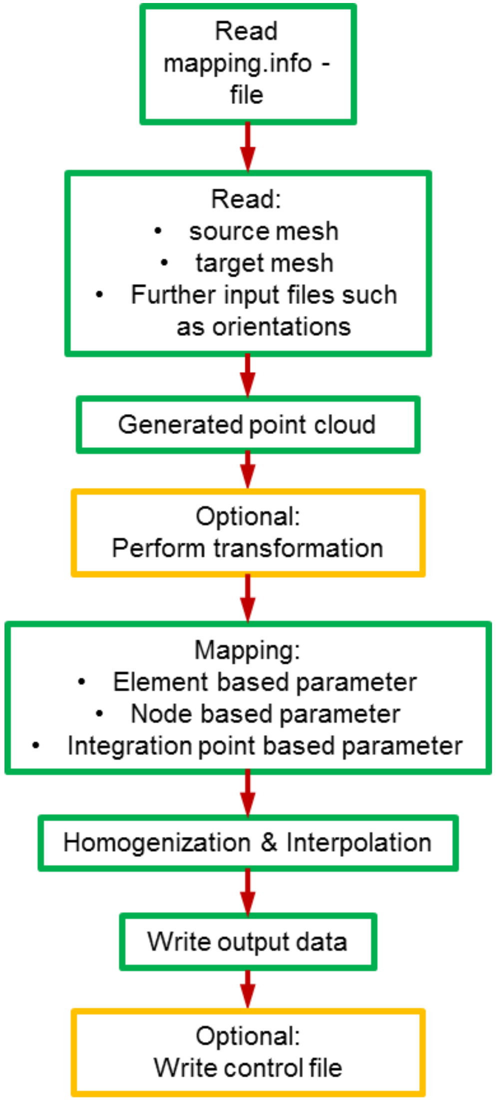
Future Plans

- GUI implementation
- A return mapping has to be performed in order to quantify and „post-process“ the loss of information during the mapping process (by now, only visual quality check).
- Possible evaluation criteria:
  - Overlap of mapped areas
  - Average offset btw. meshes
  - Comparison btw. element normals
  - „jumps“ within the mapped parameter
  - Difference btw. transferred energies
  - Offsets btw. corresponding elements
- Output can be local (element or node-wise) or global
- …



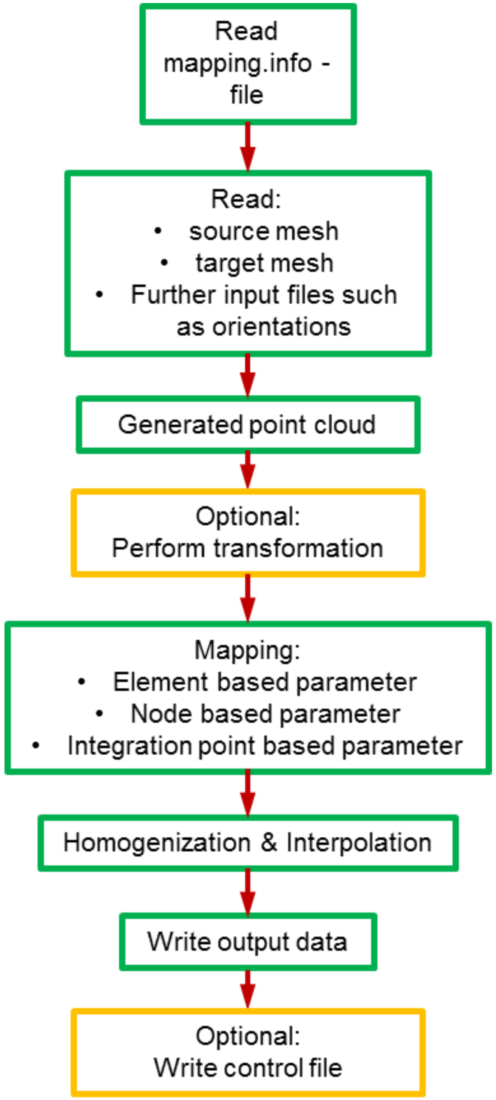
Future Plans

- **Tensor interpolation methods:**
  - Several approaches exist:
    - Euclidean interpolation
    - Riemannian interpolation
    - Log-Euclidean method
    - Geodesic-loxodrome approach
    - Approaches using partial differential equations
  - Target: properly transfer shape and orientation
  - Tensor characteristics are described by eigenvalues, eigenvectors
  - The usage of tensor invariants is proposed for tensor interpolation



Future Plans

- **Scalar value interpolation methods:**
  - **Several approaches exist:**
    - Inverse distance weighted methods (Shepard's method)
    - Rectangle based blending methods
    - Triangle based blending methods
    - Finite element based methods
    - Foley's methods
    - Global basis function type methods
    - Modified maud methods



Future Plans

- Envyo® will be available on Windows and Linux platforms
- first test versions will be available by the end of this year
- after a successful testing period it is thought to distribute Envyo® commercially. Details will follow in due time.

Remark:

- The quality and the capability of the program are highly dependent on its usage. Feedback is very appreciated.

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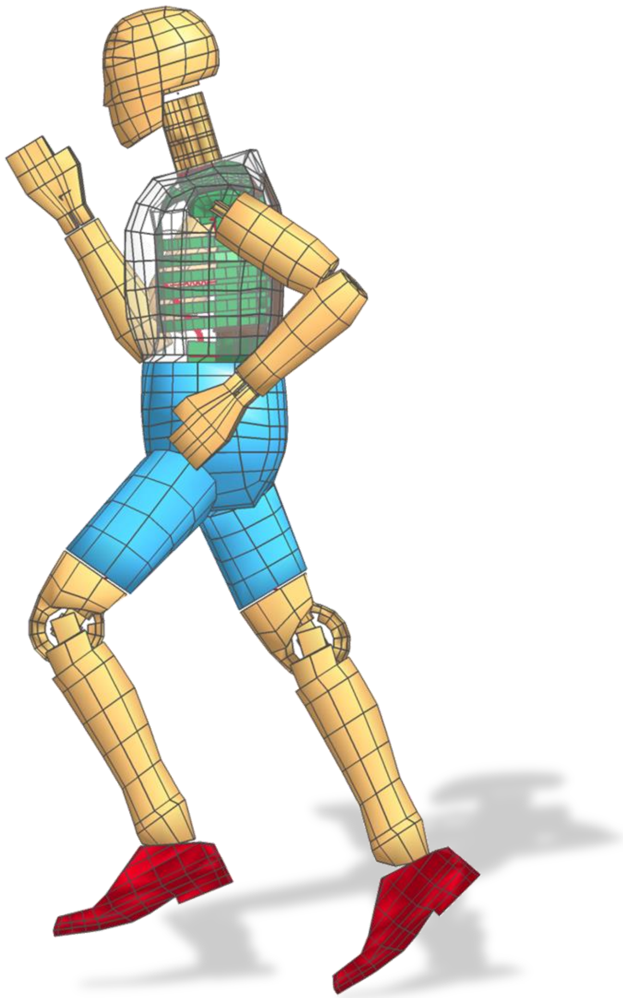
Questions & Answers



FIN

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