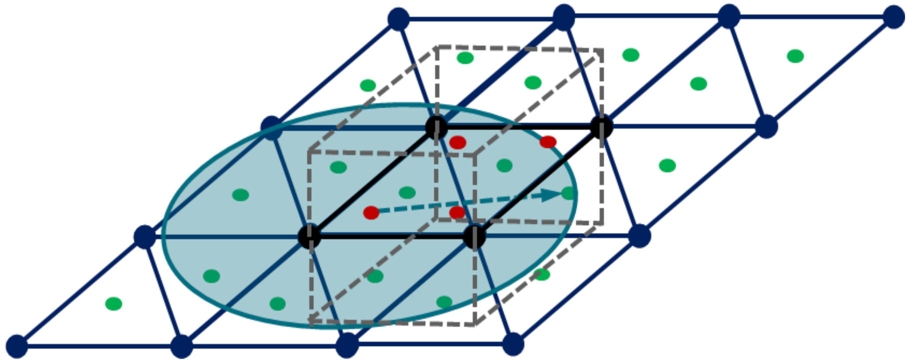
Infoday Automotive and Aerospace Applications, Berlin, GER, 2022

Closed Process Chain for Fiber-Reinforced Composites in LS-DYNA using Envyo



Tolga Usta, DYNAmore GmbH
Christian Liebold, DYNAmore GmbH

A part of the:
DYNAmore ECO SYSTEM

Agenda

ENVYO Overview

Mapping Options for Composites

Selected Further Capabilities

Future Development Plan

Questions & Answers

Envyo Overview

- ENVYO is a multi-purpose mapping tool dedicated to LS-DYNA.

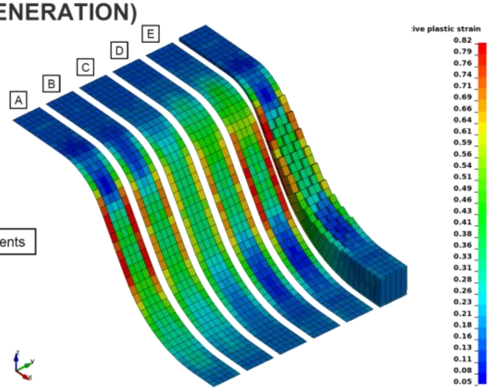
- Standard applications covered by ENVYO:
  - Fiber Reinforced Plastics
  - Metal Forming
  - Bake Hardening
  - Image Processing
  - Particle methods and Temperature mapping

- We integrate new processes based on customer request.

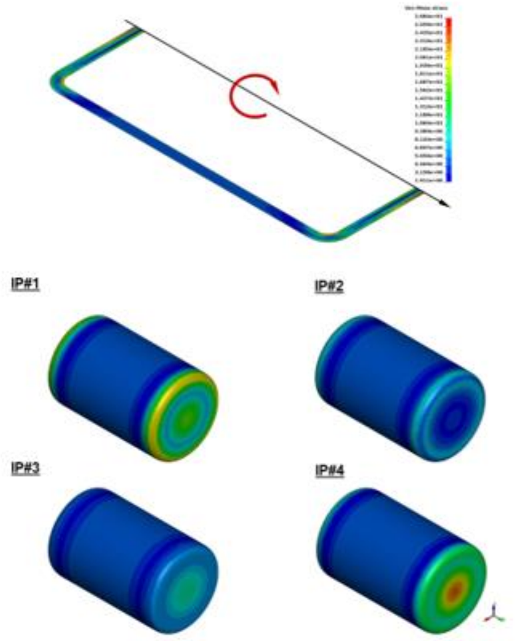
SHELL-SOLID(GENERATION)

Layer	Thickness Position
A	-0.9062
B	-0.5385
C	0.00
D	0.5385
E	0.9062

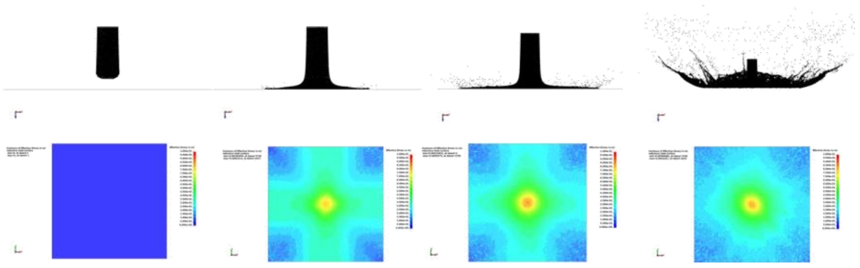
Reduced integrated solid elements



Solid Mesh Generation



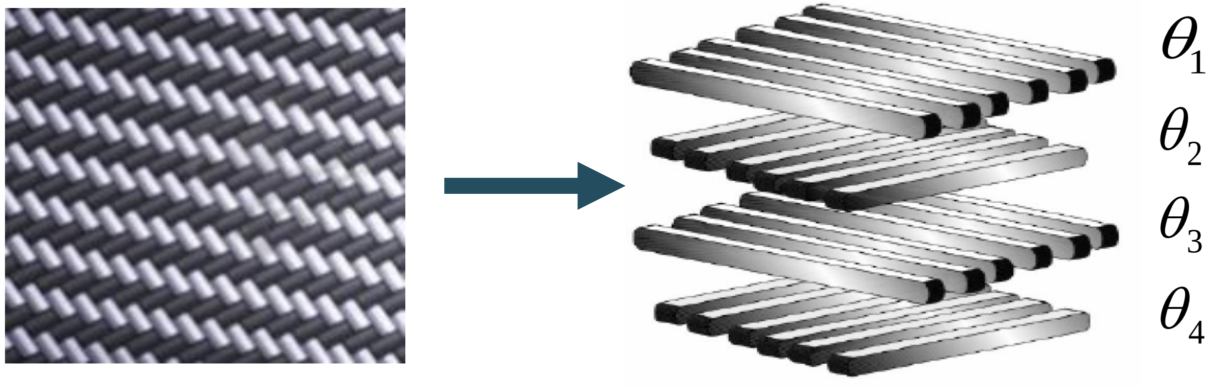
Axisymmetric Mapping

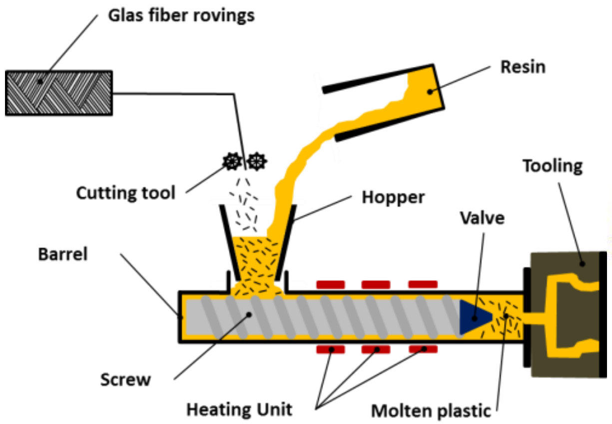


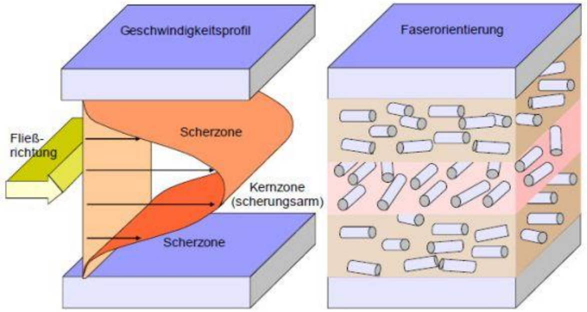
Particle Methods

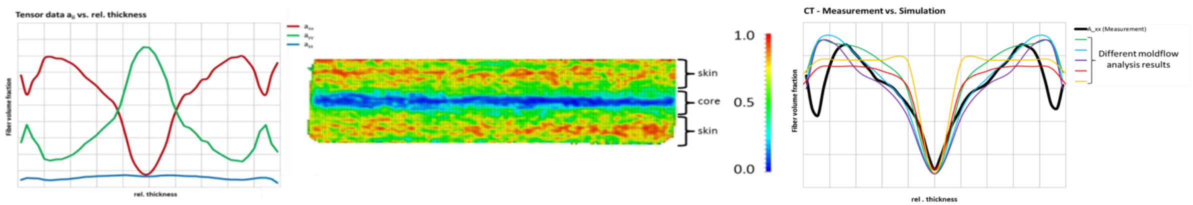
Composites in General

- Composite materials are usually inhomogeneous and non-isotropic.
  - Highly direction dependent characteristics in both in-plane and through the thickness
- Relative complex properties to map
  - Discontinuous layers
  - Undulation of fibers
  - Varying fiber directions/orientations
- Different modeling approaches
  - Fibers as beams/shells
  - Element types and formulations
  - Homogenized layer stacking in one shell element
  - Shell/Solid element discretization of SFRP





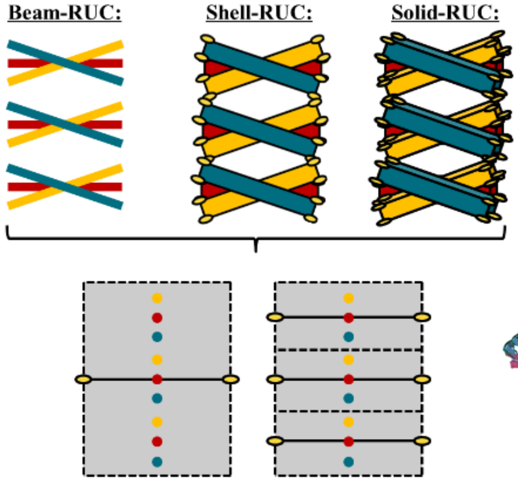


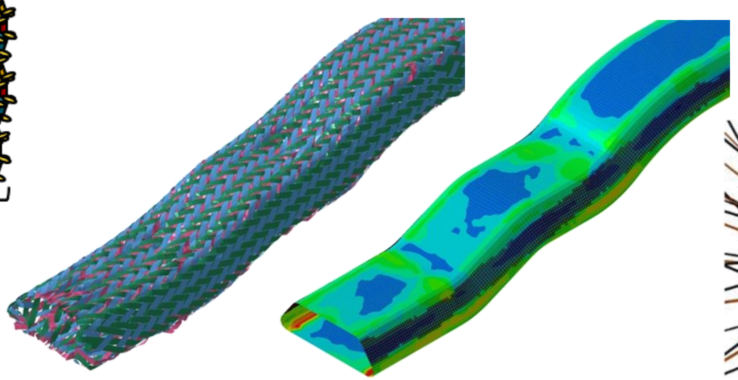


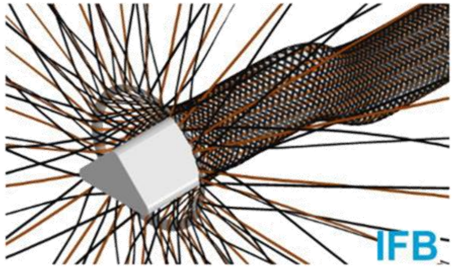
Mapping Options for Composites

- BEAM – SHELL
- BEAM – SOLID
- SHELL – SHELL
- PLYBOOK – SHELL

CFRP

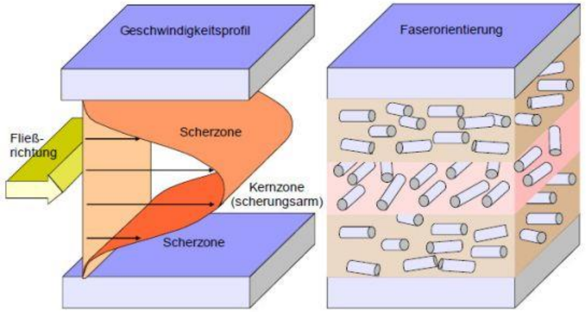


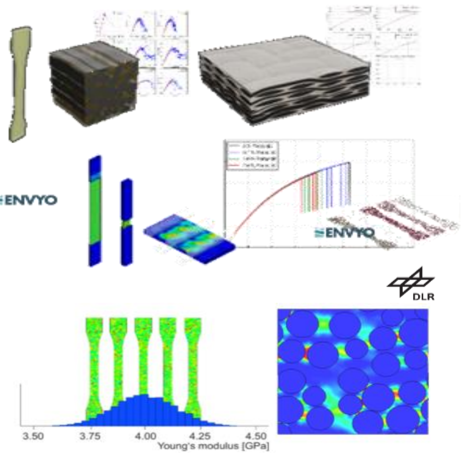


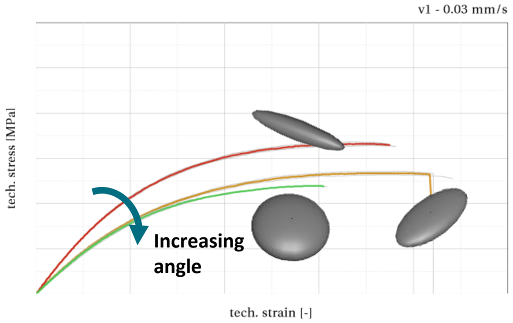


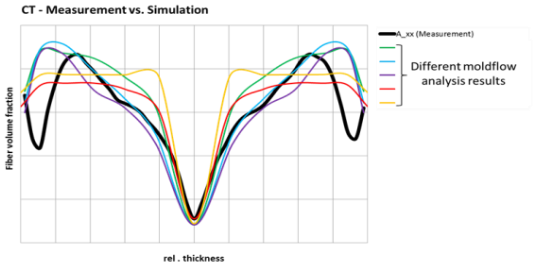
- MOLDEX3D – SHELL
- MOLDEX3D – SOLID
- MOLDFLOW – SHELL
- MOLDFLOW – SOLID
- 3DTIMON – SHELL

SFRP





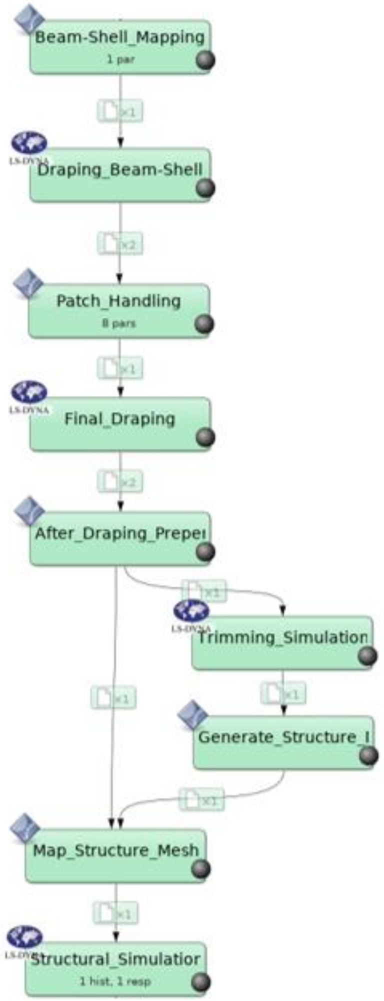




- STOCHASTIC INITIALIZATION

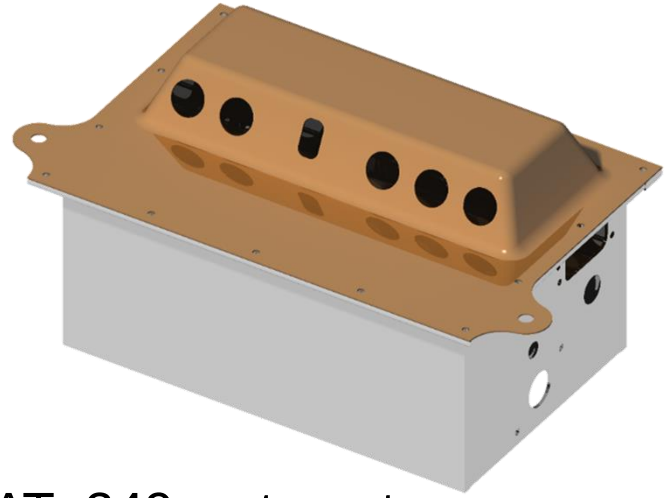
Mapping CFRP Properties

DYNA MORE



- Use Case : Virtual DFA process chain prototype

- We will focus on :
  - BEAM – SHELL
  - SHELL – SHELL
  - PLYBOOK – SHELL mapping options with *MAT_249 as target material model

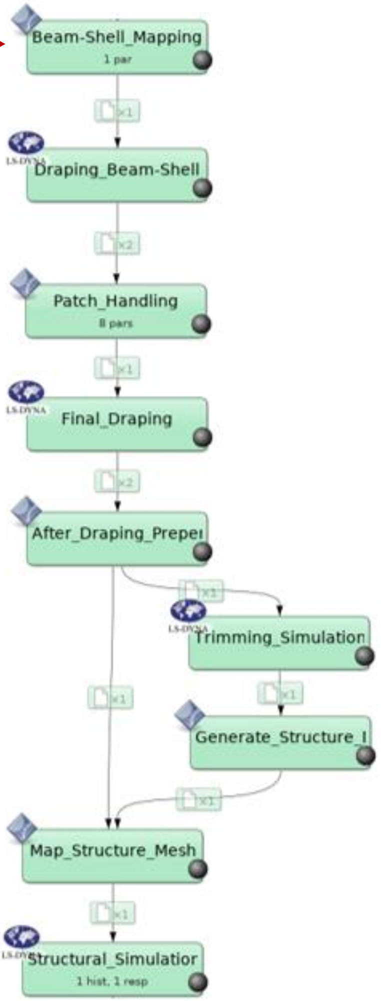


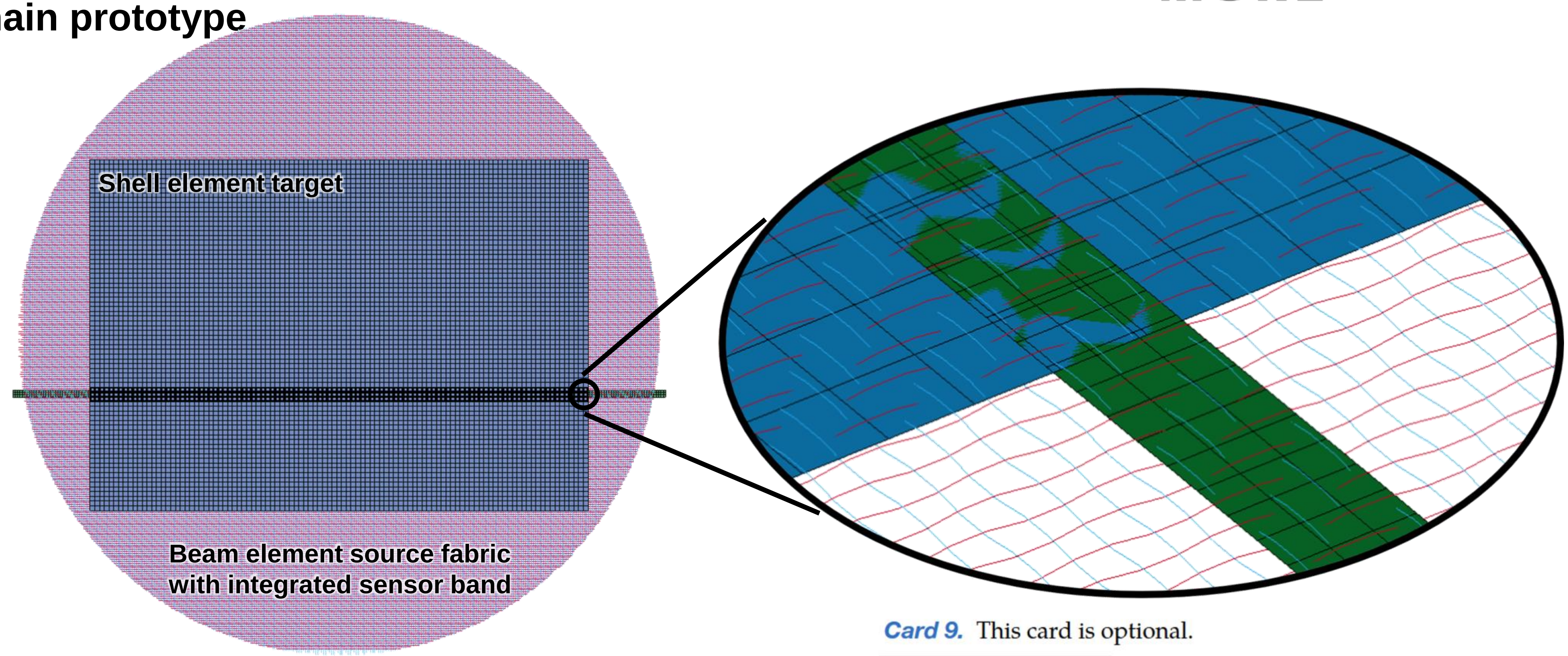
ARENA2036

Altair, BOSCH Technik fürs Leben, Constellium, DAIMLER, DITF, DLR, DXC.technology, Fraunhofer IPA, Universität Stuttgart, DYNA MORE, SIEMENS

Mapping CFRP Properties

Virtual DFA process chain prototype





- **ENVYO=BEAM-SHELL, NTHICK=5**
- ***ELEMENT_SHELL_COMPOSITE**
- ***MAT_249**
- Clustering sensor band elements

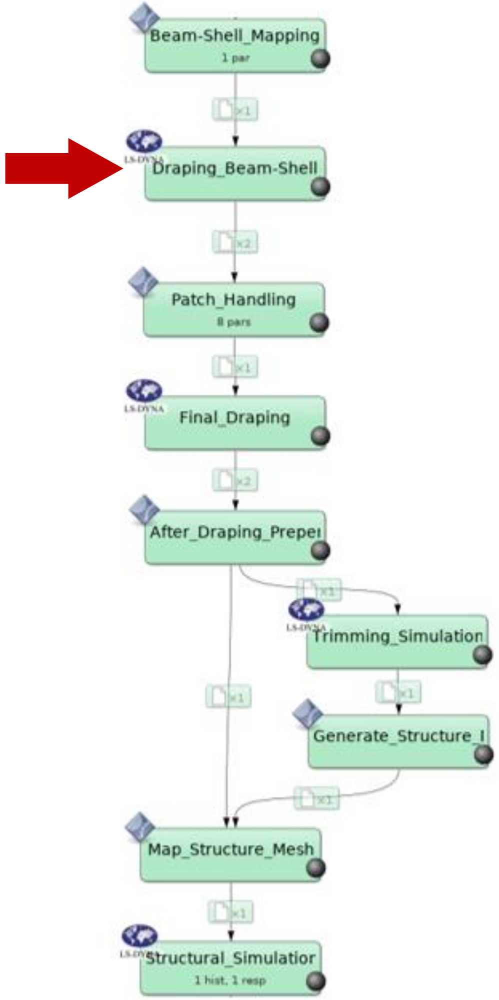
Card 9. This card is optional.

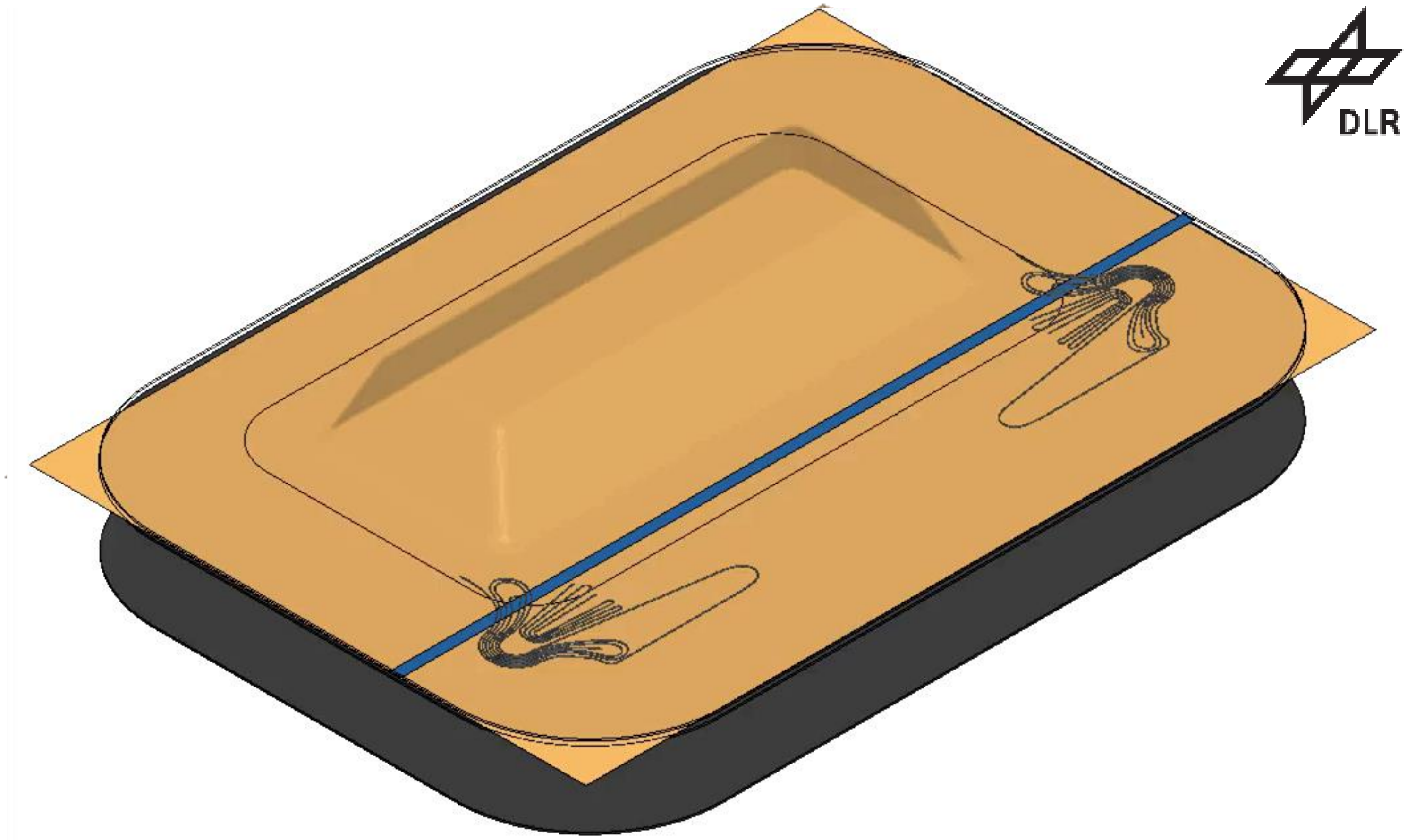
POSTV	IHIS

Flag	Description	Variables	# History Var
a_1	Fiber direction (in global coordinates)	$\mathbf{m}_1^g, \mathbf{m}_2^g, \mathbf{m}_3^g$	9
a_2	Fiber direction (in material coordinates)	$\mathbf{m}_1^m, \mathbf{m}_2^m, \mathbf{m}_3^m$	6

Mapping CFRP Properties

Virtual DFA process chain prototype

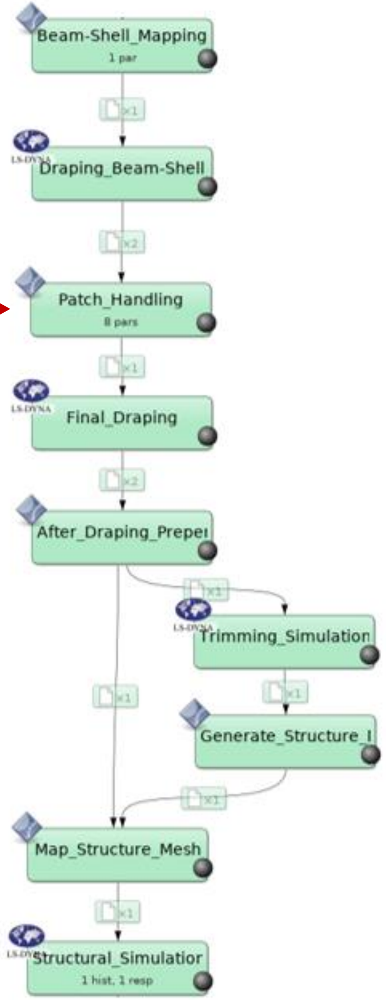


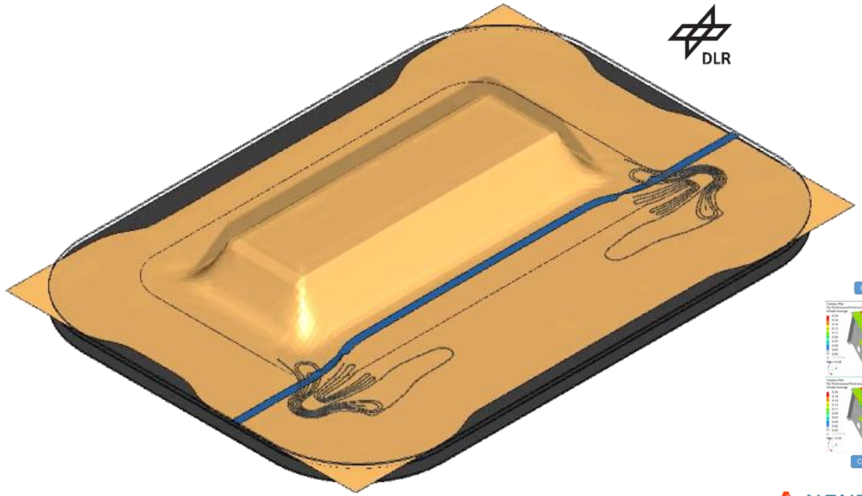


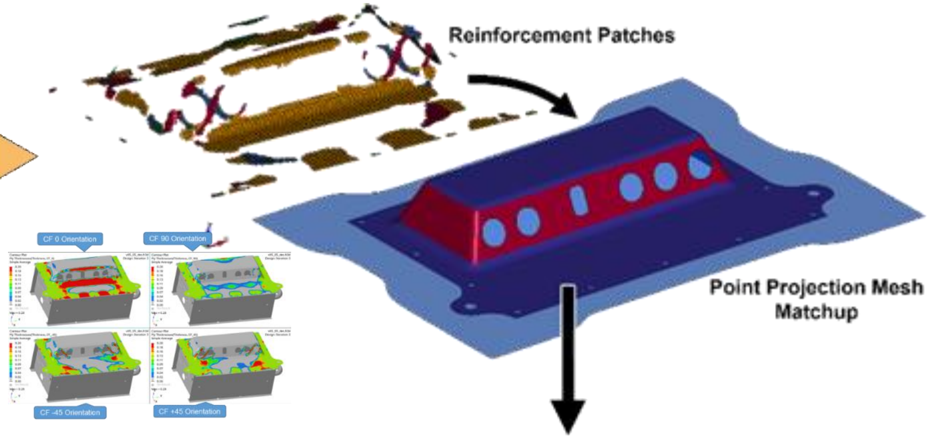
* TFP patches according to an optimization run

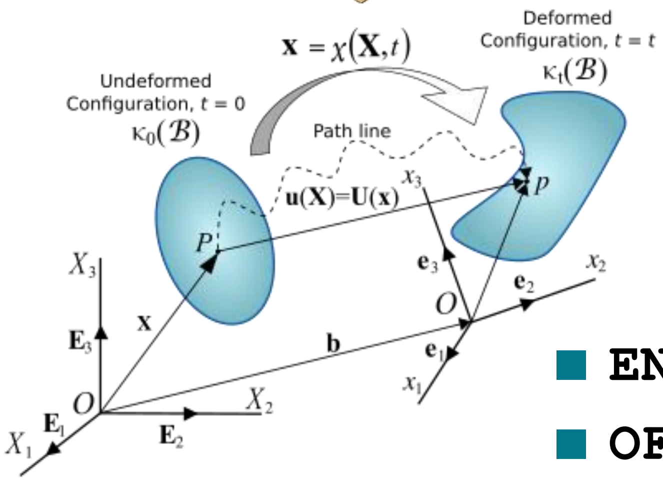
Mapping CFRP Properties

Virtual DFA process chain prototype

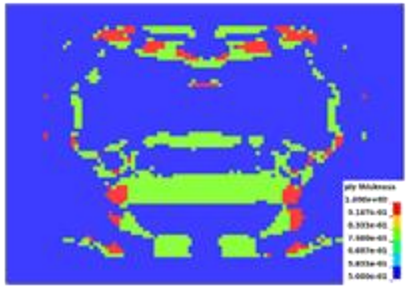


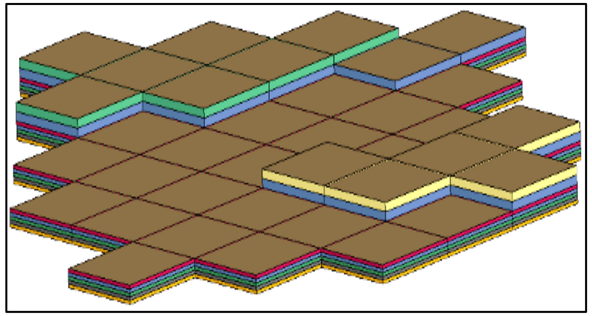






ALTAIR

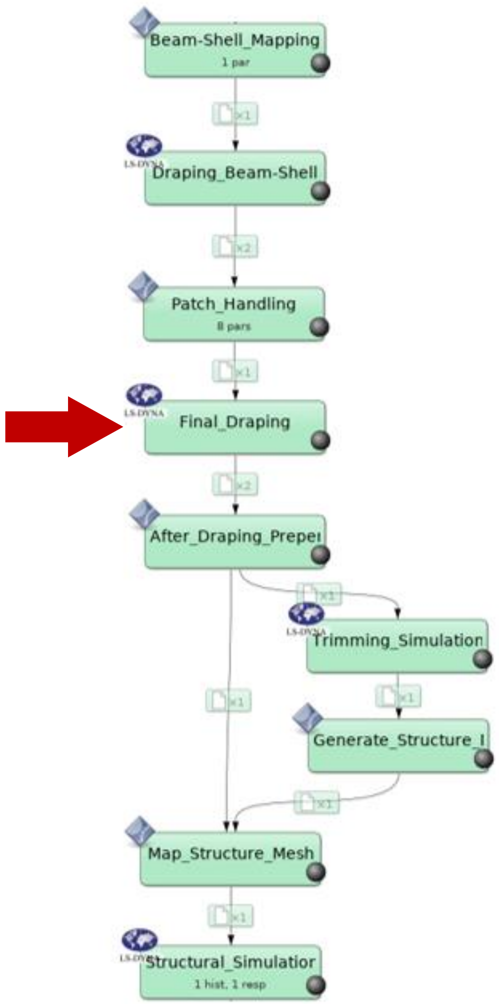


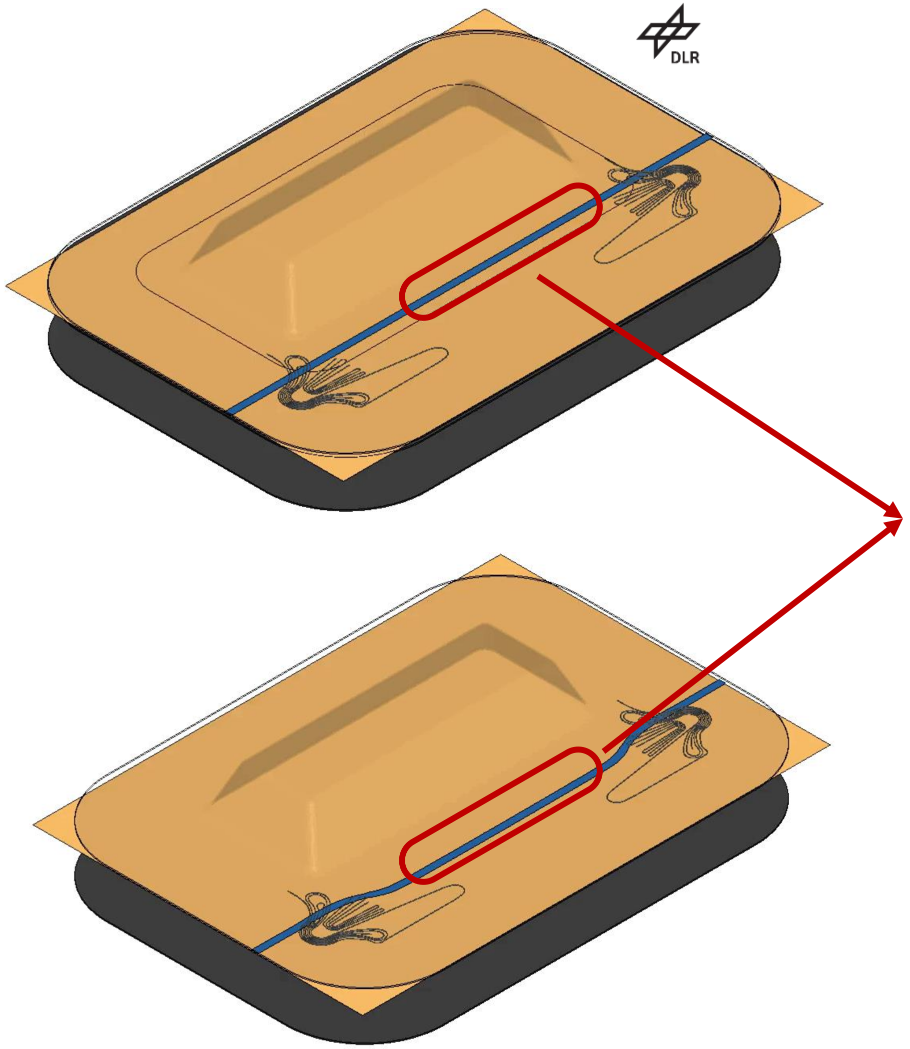


- ENVYO=PLYBOOK-SHELL
- OFFSET_OPTION=FLAT_LOWER
- *ELEMENT_SHELL_THICKNESS_OFFSET_COMPOSITE

Mapping CFRP Properties

Virtual DFA process chain prototype

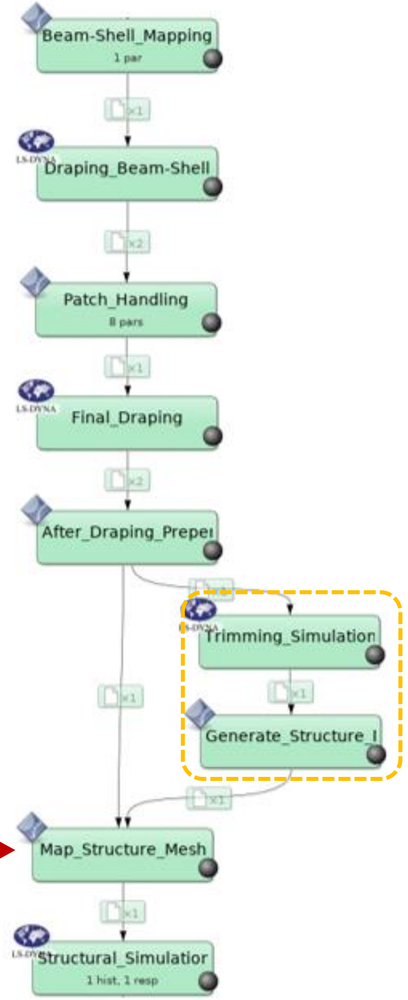


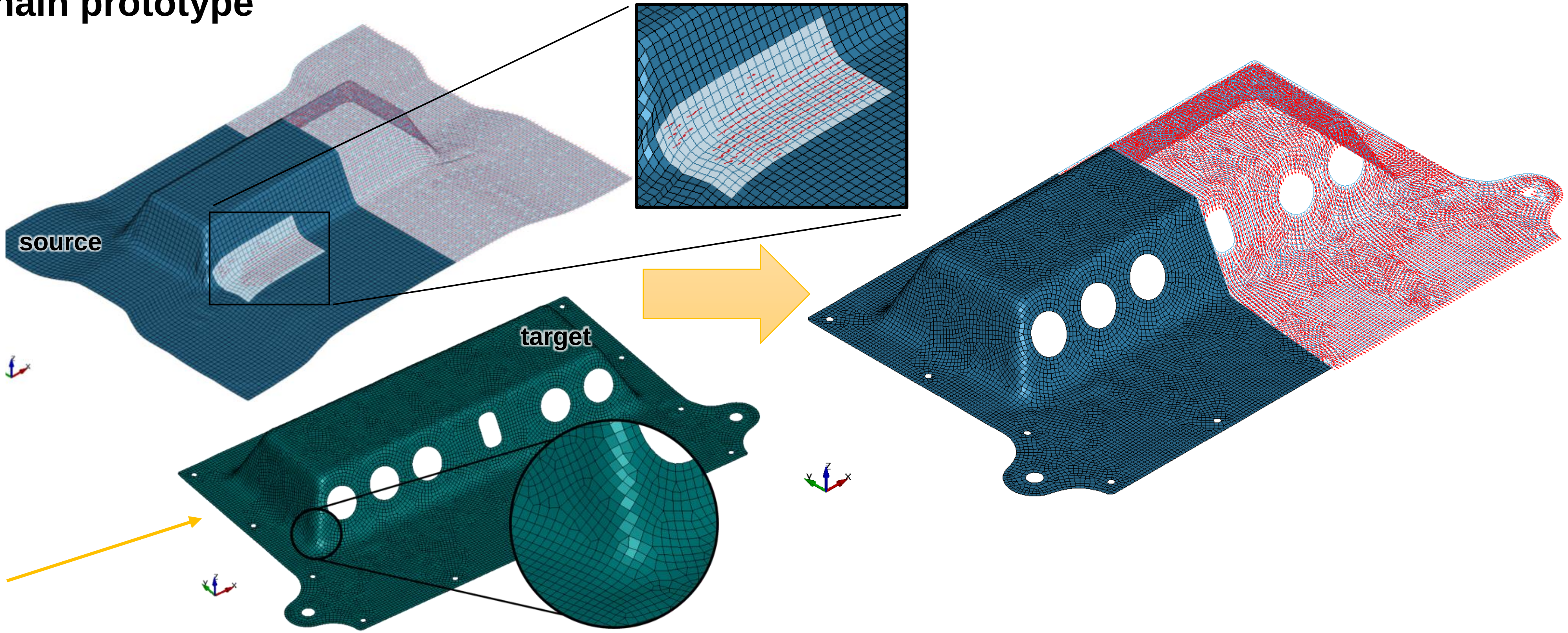


- ✓ Considering undeformed/deformed configuration differences leads to correct sensor band positioning

Mapping CFRP Properties

Virtual DFA process chain prototype



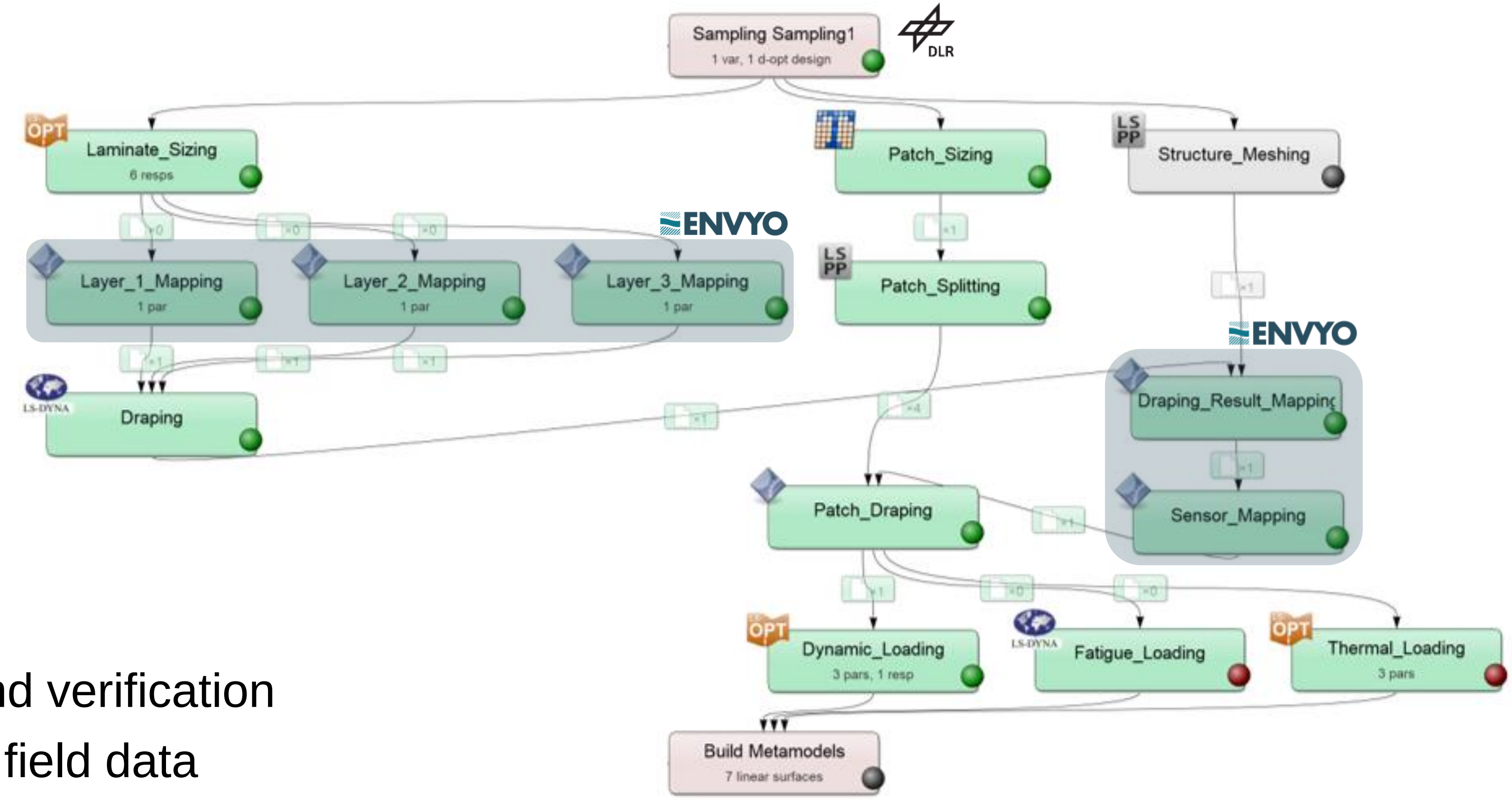


- **ENVYO=SHELL-SHELL**
- ***MAT_249**
- ***ELEMENT_SHELL_THICKNESS_OFFSET_COMPOSITE**
  - ➢The structure is ready for the consecutive structural simulation.

Mapping CFRP Properties

Current virtual DFA process chain

- We can investigate :
  - ✓production tolerances
  - ✓quickly adapt new load cases
  - ✓save CAE cost
  - ✓save material



- We can benefit from:
  - ➢Agile product development and verification
  - ➢Version updates according to field data
  - ➢Investigating predictive maintenance capabilities

Mapping SFRP Properties

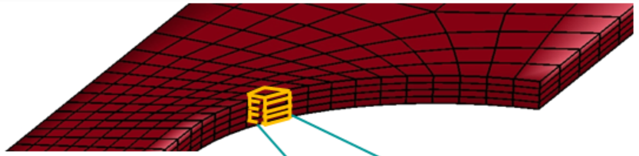
- MOLDEX3D – SHELL
- MOLDEX3D – SOLID
- MOLDFLOW – SHELL
- MOLDFLOW – SOLID
- 3DTIMON – SHELL

With *INITIAL_STRESS_SHELL
With *INITIAL_STRESS_SOLID

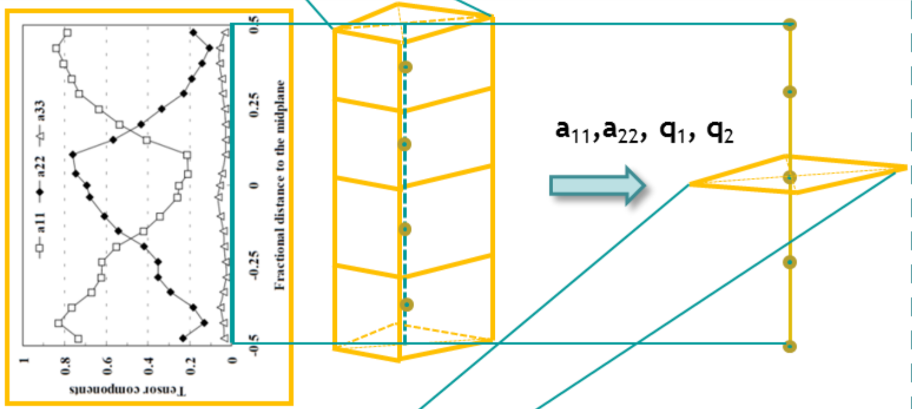
Only one part definition for whole component.

flag	description	variables	number
a_0	material directions	q_1, q_2	2
a_1	anisotropic elastic stiffness	C_{ij}	21
a_2	anisotropic plasticity	r_{00}, r_{45}, r_{90}	3
a_3	hardening curve	LCSS	1

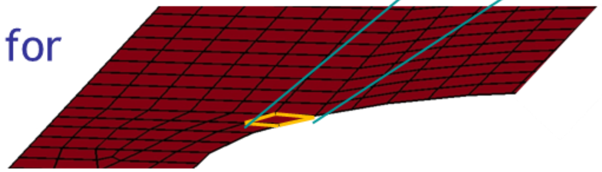
- **Process simulation:**
  fiber orientation / fiber content



- **Mapping of fiber orientation tensor**
  (main values und main directions)
  - fiber content



- Data mapping and homogenization for *MAT_002, *MAT_157, *MAT_215



- Structural analysis using homogenized anisotropic material model (*MAT_157)
- Structural analysis with homogenization in the material model (*MAT_215)

Mapping SFRP Properties

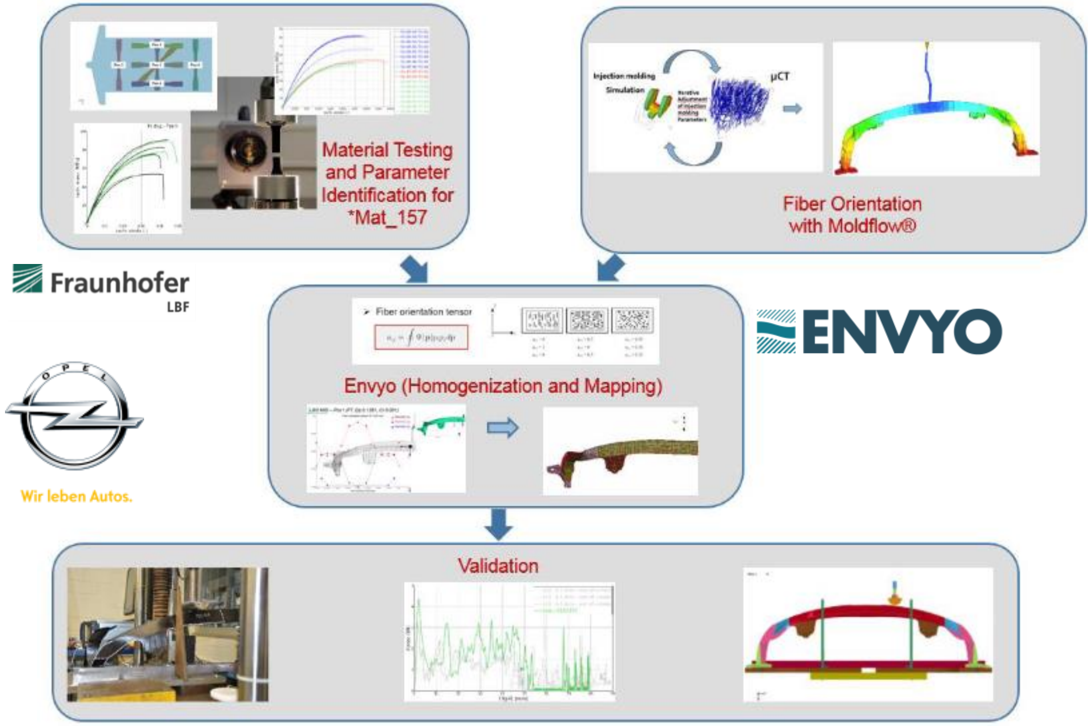
*MAT_ANISOTROPIC_ELASTIC_PLASTIC (*MAT_157)

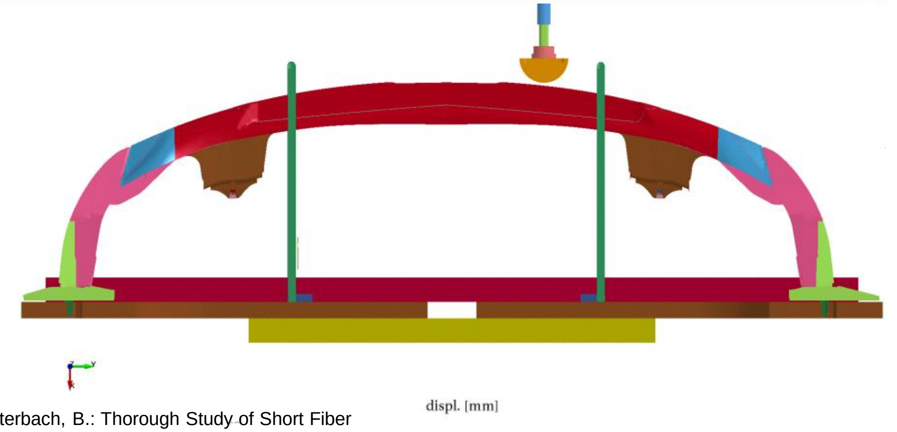
- Each IP material properties like :
    - Fiber orientations
    - Stiffness components

can be initialised using ***INITIAL_STRESS(_OPTION)** cards via IHIS flag.

- Multiple homogenization and closure approximation options are available for stiffness computation.
- IP material IDs with respect to user defined material cards for different orientation tensors.

```
*MAT_ANISOTROPIC_ELASTIC_PLASTIC_TITLE
EnvyoOrient:0.6;0.3;0.1
$#------1|--------2|--------3|--------4|--------5|--------6|--------7|--------8|
$#     mid        ro      sigy      lcss       qr1       cr1       qr2       cr2
$#     c11       c12       c13       c14       c15       c16       c22       c23
$#     c24       c25       c26       c33       c34       c35       c36       c44
$#     c45       c46       c55       c56       c66       r00       r45       r90
$#     s11       s22       s33       s12      aopt        vp         -      macf
$#      xp        yp        zp        a1        a2        a3         -     extra
$#      v1        v2        v3        d1        d2        d3      beta      ihis
$#      xt        xc        yt        yc       sxy      ff12              ncfail
$#      zt        zc       syz       szx      ff23      ff31
*ELEMENT_SHELL_COMPOSITE
$#------1|--------2|--------3|--------4|--------5|--------6|--------7|--------8|
$#   eid     pid       n1       n2       n3       n4       n5       n6       n7       n8
$#------1|--------2|--------3|--------4|--------5|--------6|--------7|--------8|
$#    mid1    thick1        b1                mid2    thick2        b2
         .         .         .                   .         .         .
```





Liebold, C., Haufe, A., Lauterbach, B.: Thorough Study of Short Fiber Reinforced Composites: from Micro-CT to Structural Analysis, Fachkongress Composite Simulation, Fellbach, GER, 2017

Mapping SFRP Properties

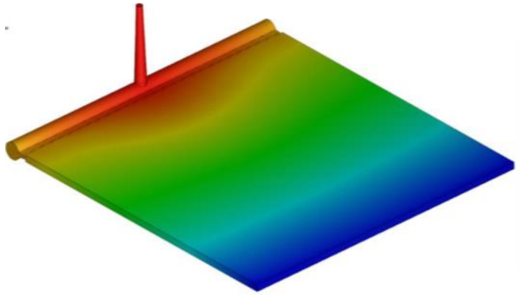
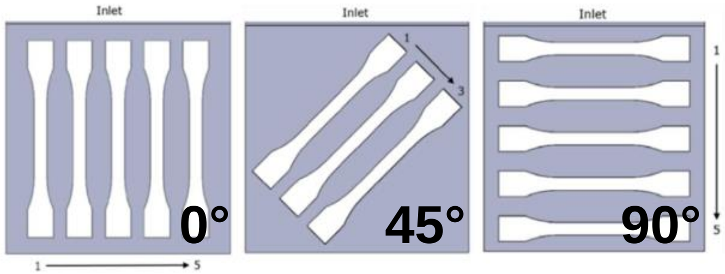


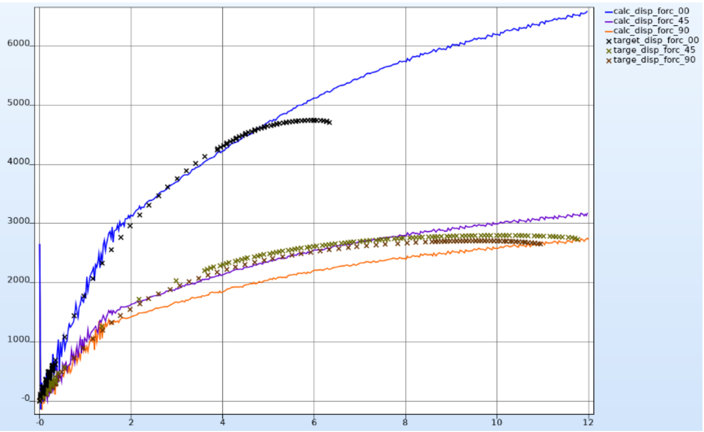
plate molding



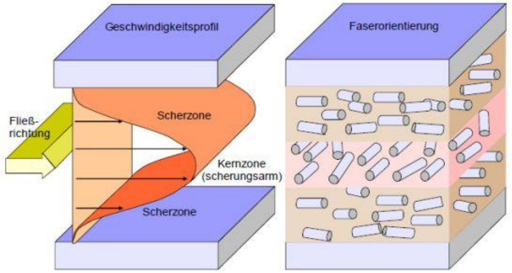
cutting test specimens

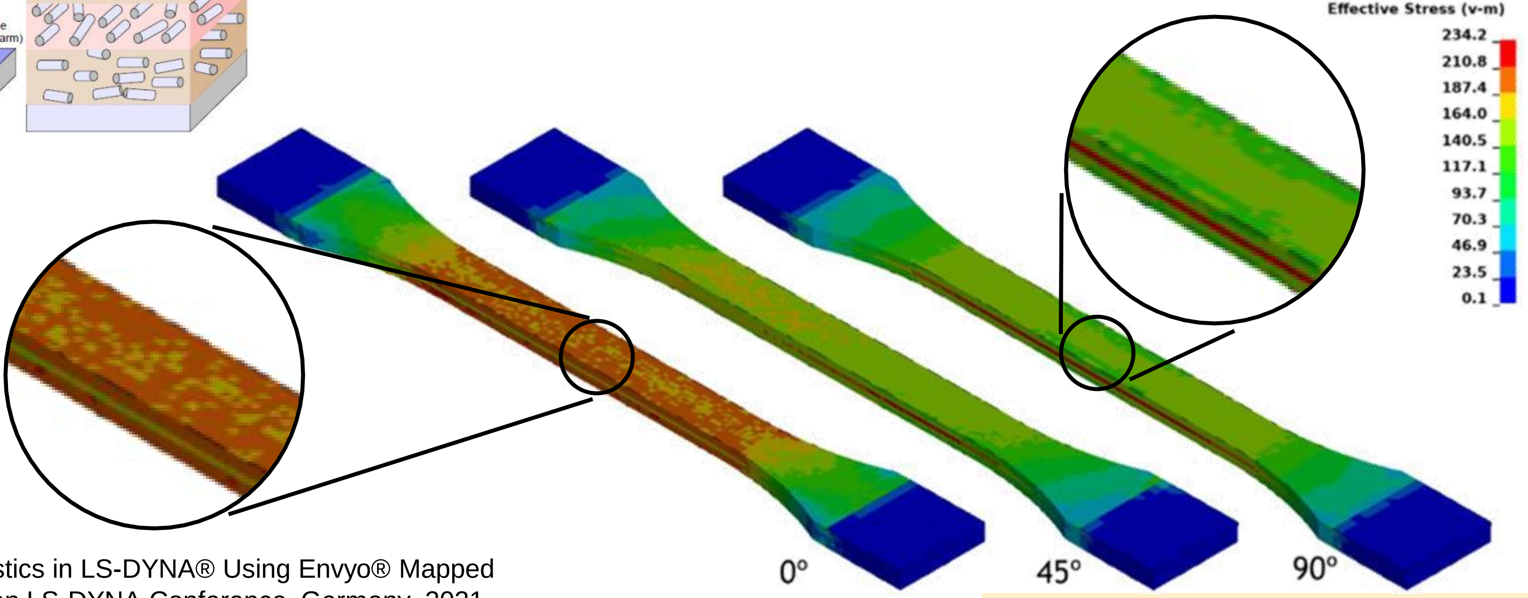
*** MAT_4A_MICROMEC** (*MAT_215)

- Fiber orientations can be initialised using **`*INITIAL_STRESS(_OPTION)`** cards.
- Material has already an ansatz to compute stiffness. (see, LS-DYNA Manual Vol. II)



*MAT_215 characterization



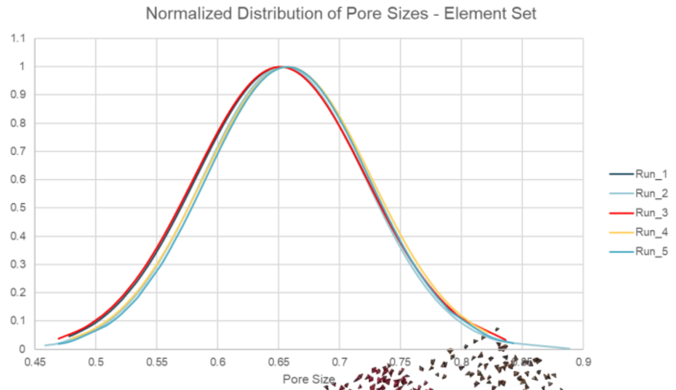


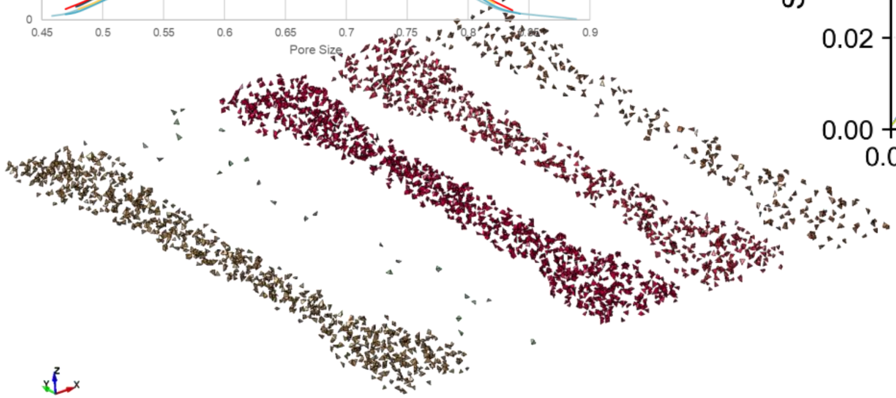
Gustavson, M., Aspenberg, D., Stoltz, B.:Simulation of Short Fiber Reinforced Plastics in LS-DYNA® Using Envyo® Mapped Fiber Orientations Obtained from Process Simulation in Moldex3D®, 13th European LS-DYNA Conference, Germany, 2021

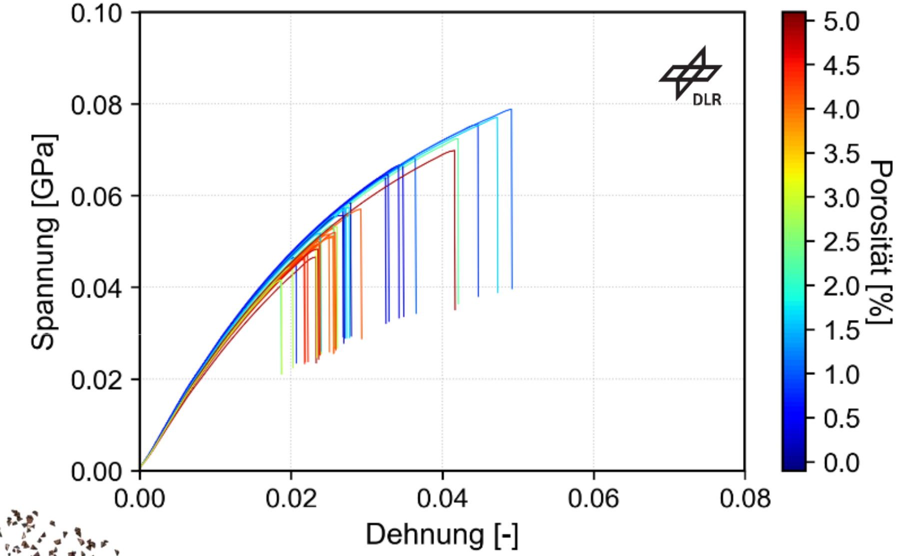
Stochastic Initialization

- **`ENVYO=STOCHASTIC_INIT`** using **`*MAT_157`**
- Mimic pore (or, inclusion) effects in a model by modifying stiffness and/or strength parameters of randomly selected IPs.
- It is completely random; but, reproducible.

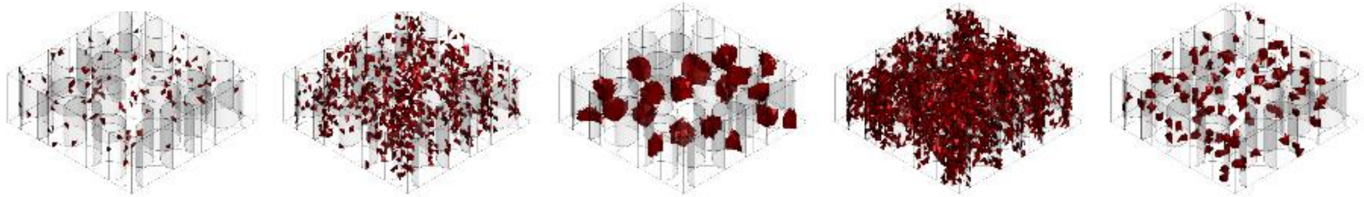
```
$#-------------------------------------
$# Model Scale (Micro ; Meso-Macro)
$#-------------------------------------
Model_Scale=Meso-Macro
$#-------------------------------------
$# Source PIDs
$#-------------------------------------
NumSourcePIDs=1
SourcePID#1=28
$#-------------------------------------
$# Posority Parameters
$# Pore_Size=Min Max
Pore_Size=0.1 0.8
$# MaxPorosity=[%]
MaxPorosity=2
$# PoreEffect=ReductionFactor
PoreEffect=0.001
$#-------------------------------------
```







after a simple modification, this method can handle an „inclusion effect“.



Vinot, M. et. al.: Stochastic modelling of continuous glass-fibre reinforced plastics-considering material uncertainty in microscale simulations, Journal of Composite Materials, 2022

Further Capabilities

Considering Bake-Hardening Effects

- Calculation of the hardening degree based on the JMAK equation:

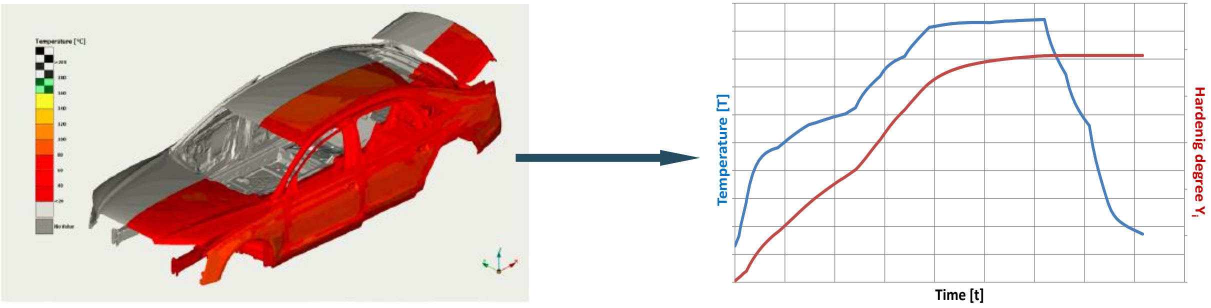
$$Y = 1 - \exp\left(-\left(\frac{t}{\tau}\right)^n\right)$$

with:

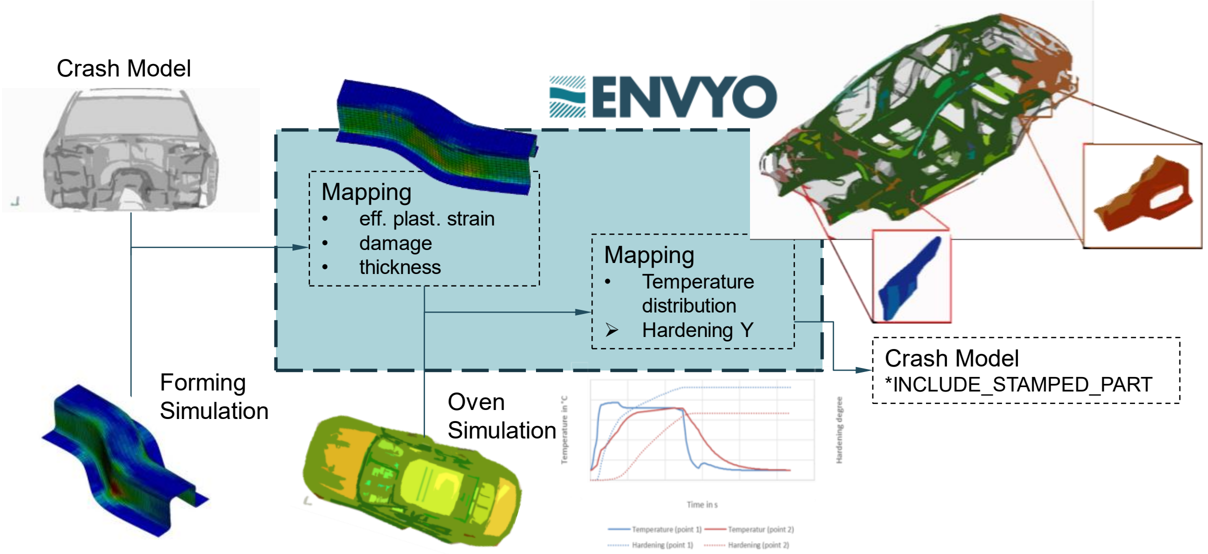
$$\tau(T) = t_0 \exp\left(\frac{Q}{RT}\right)$$

- The parameters n, t_0 and Q can be determined by experiments.

- Temperature profiles can be mapped from THESEUS-OVEN software either for hardening estimation or thermal simulation within LS-DYNA (`*MAT_GENERALIZED_PHASE_CHANGE`).



L. Greve, G. Krabbenborg, T.K. Eller, M. Andres, B. Geijselaers: Characterization and Modeling of the Deformation and Fracture Behavior of a Bake-Hardenable Aluminum Sheet Alloy Depending on the State of the Hardening and Pre-Strain, Crashmat 2018, Freiburg, GER.

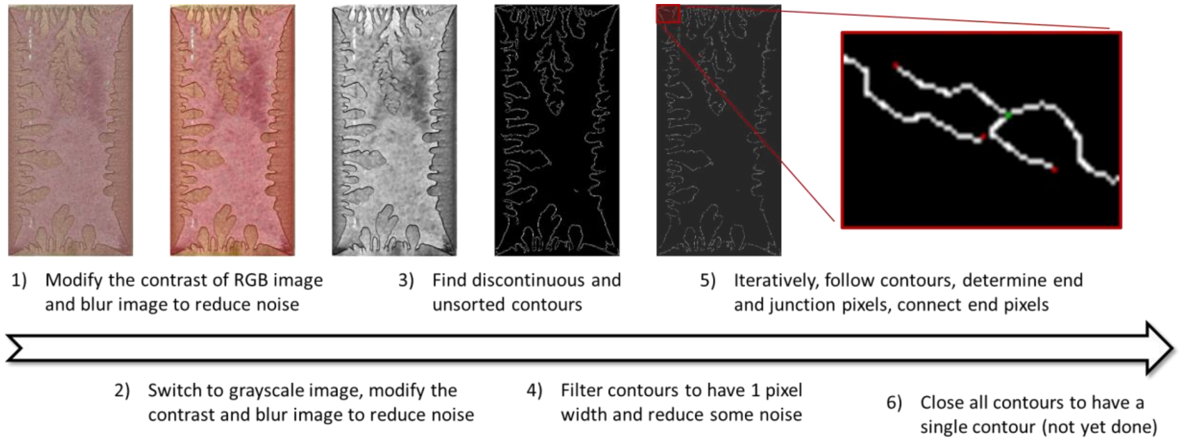


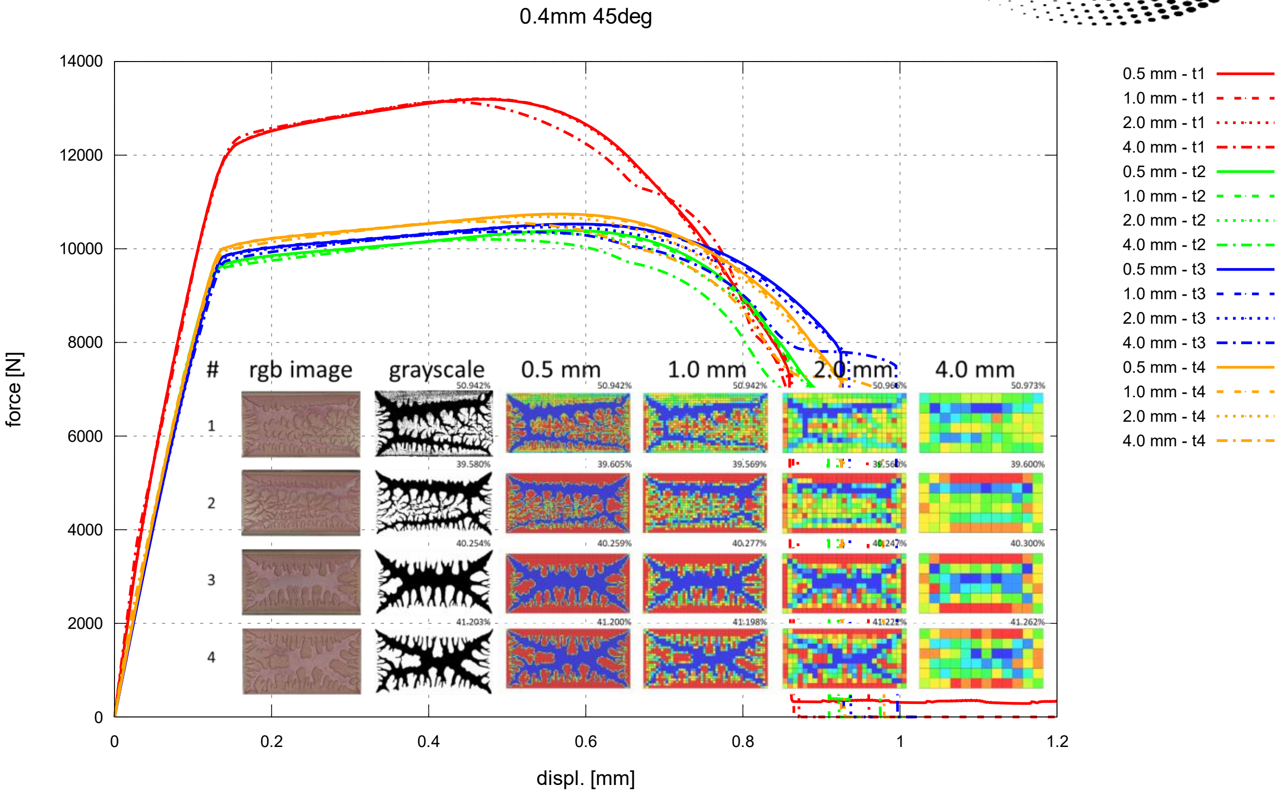
Liebold, C., Wilking, C., Koch, D., Haufe, A., Feucht, M.: Possibilities to consider Bake-Hardening Effects of Aluminum Components in Finite Element Simulations, NAFEMS DACH, virtual event, 2020.

Further Capabilities

Grayscale Mapping

- Different grayscale ranges of an image can be handled using Envyo to map coresponding properties
- Method considers shells, solids and cohesive elements
- OpenCV library has been added to allow for automatic shape detection





DIGIBODY

Bundesministerium für Wirtschaft und Klimaschutz

Mercedes-Benz

DUPONT

inpro

ARENA2036

DYNA MORE

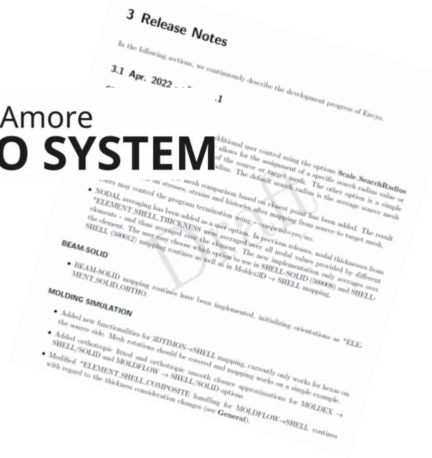
LWF

IFB Institut für Flugzeugbau

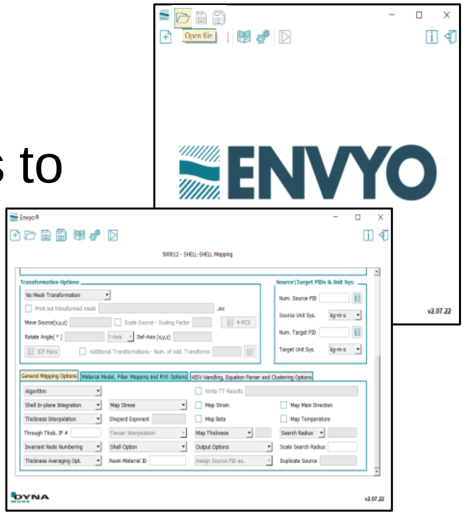
TÜVRheinland Genau. Richtig.

Future Development Plan

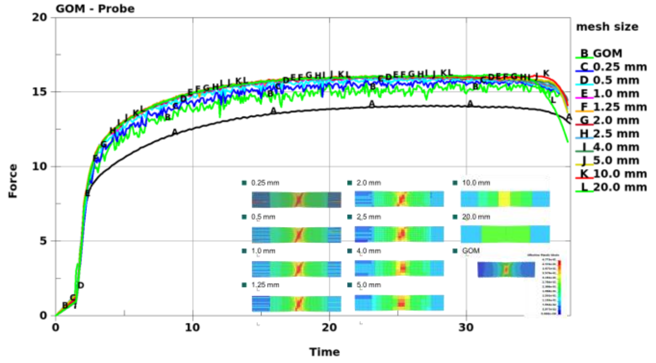
- Full integration into the DYNAmore ECO SYSTEM

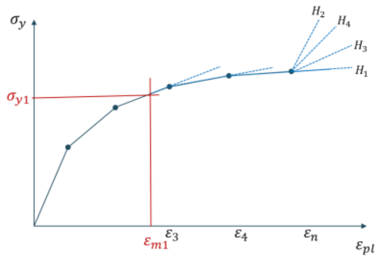


- 180+ customer and development examples inside our QA
- Improvements on GUI to help our users to define their mapping process

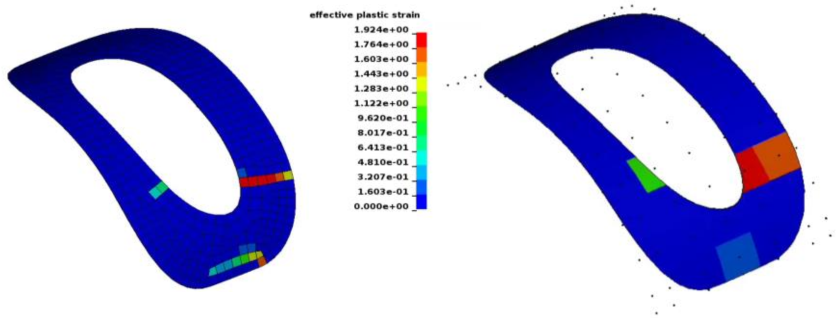


- GOM image data consideration for simulation





- Mapping to IGA simulation data



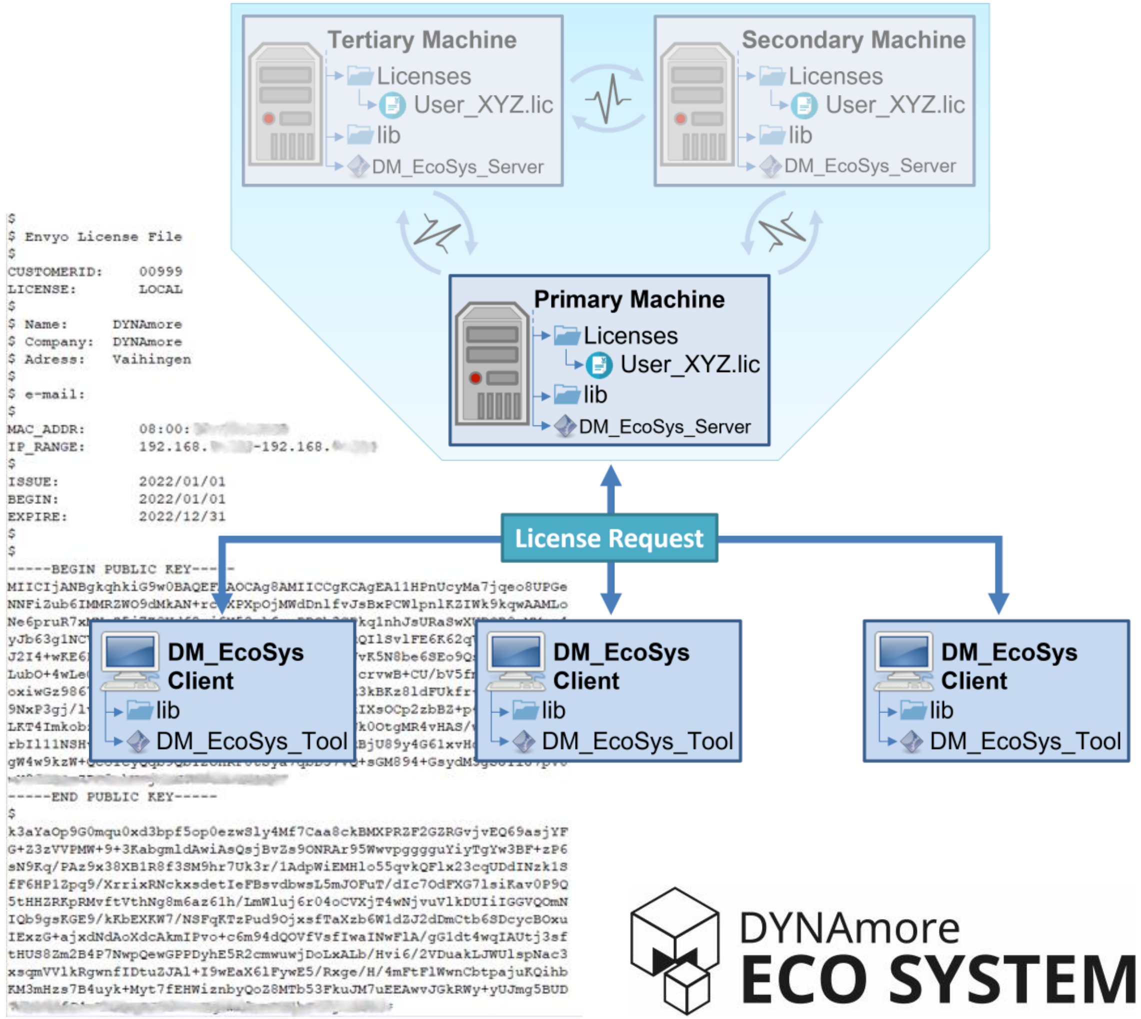
Future Development Plan

New Licensing Scheme

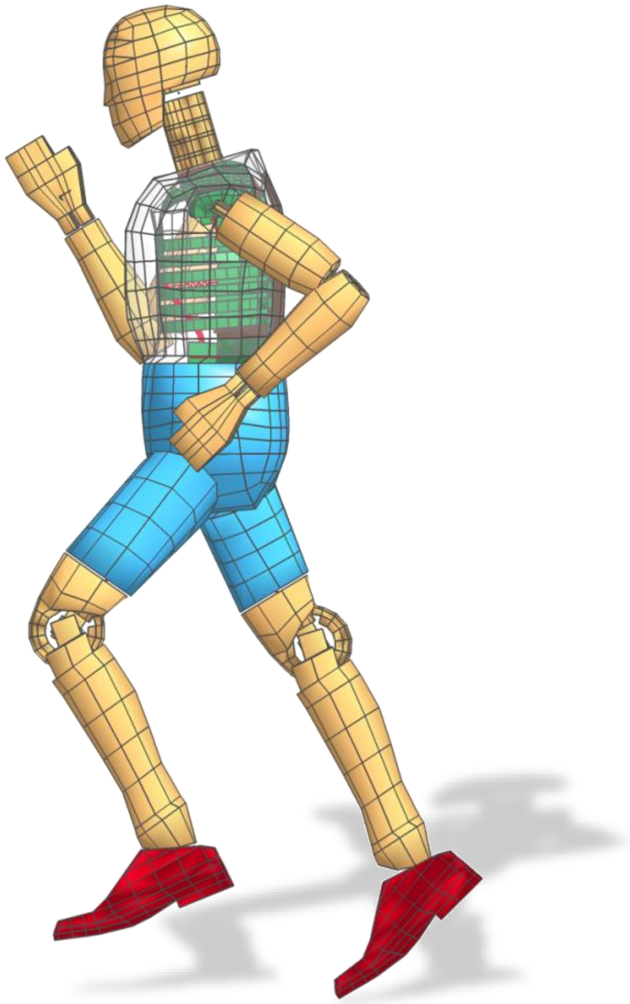
- License file verification will be updated to allow for a more flexible version distribution

- Licensing models will remain:
  - Node-locked
  - Server
  - Server Triad

- Environment variable `DM_ECOSYS_NETWORK` and `DM_ECOSYS_NETWORK_PORTS` have been established to have one server/client system at the customer for the whole DYNAmore Ecosystem



Thank You



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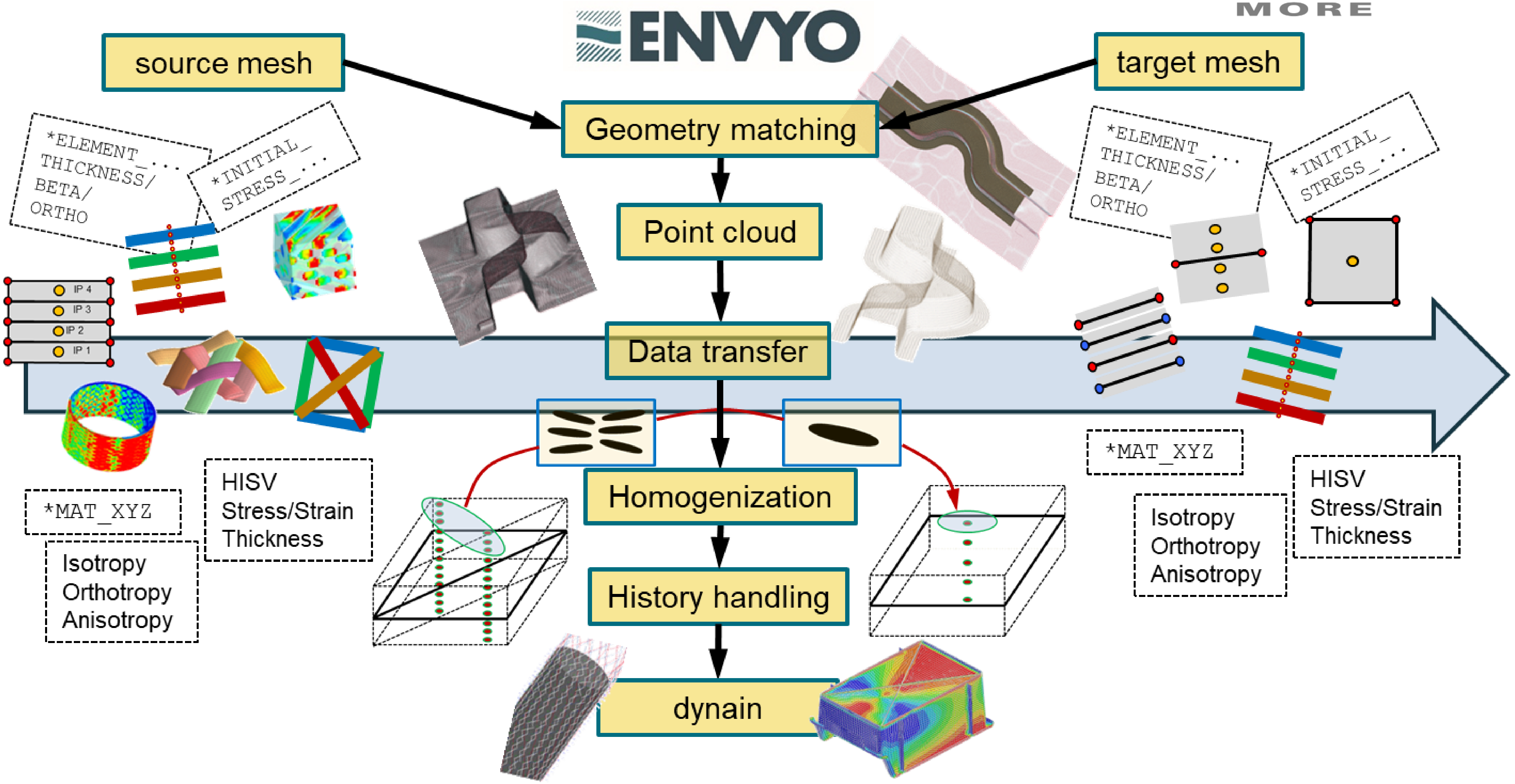

ENVYO
source mesh
target mesh
Geometry matching
Point cloud
Data transfer
Homogenization
History handling
dynain
*ELEMENT_...
THICKNESS/
BETA/
ORTHO
*INITIAL_
STRESS_...
IP 4
IP 3
IP 2
IP 1
*MAT_XYZ
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Orthotropy
Anisotropy
HISV
Stress/Strain
Thickness
*ELEMENT_...
THICKNESS/
BETA/
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