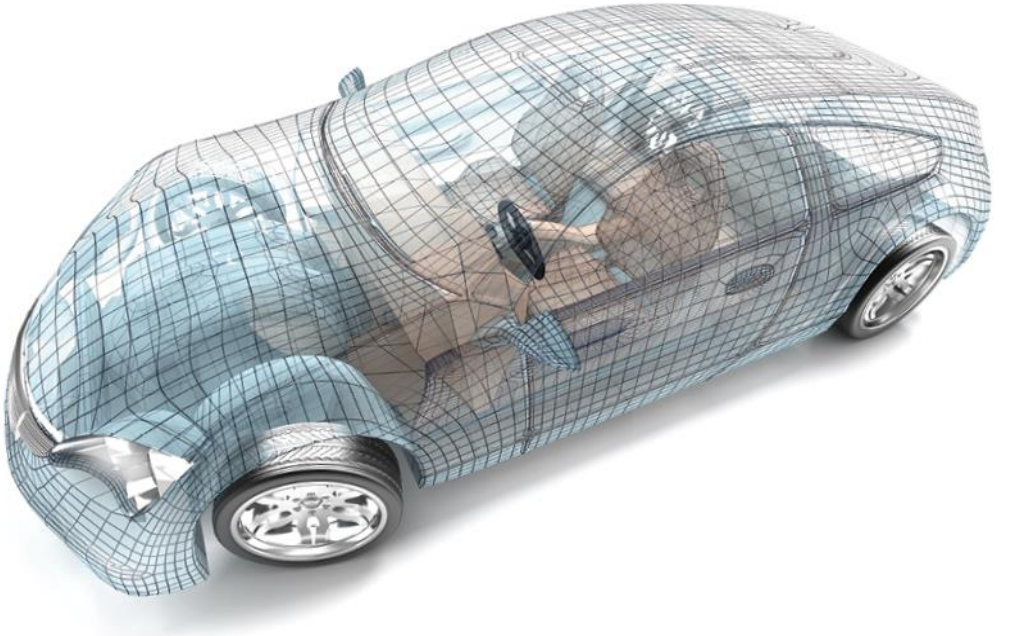
TCC 2020

THERMOPLASTIC COMPOSITES CONFERENCE

A VIRTUAL EVENT

APRIL 29 – MAY 1, 2020



A Holistic Approach to Automated Fiber Placement Manufactured Parts for Performance Evaluation

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Aerospace/Defense - Application Engineering
MSC Software/e-Xstream Engineering

Agenda

01 Workflow Overview
Multi-scale material modeling – Process/Structure coupled FEA

02 AFP Process Induced Microstructure – CAE Representation
Understand the AFP Process – CAE Process Simulation Software Data review

03 Effect of AFP Process on Local Microstructure
Accurate Definition of Microstructure on FEA Model

04 Material Modeling
Multi-Scale material modeling using Mean-Field Homogenization

05 Analysis Results
Stiffness Knock-down – Plaque and airplane wing

Presentation Objectives

- **Summarize** the main steps of the workflow presented
- **Recall** the concept of *Multi-scale Modelling* and its benefits
- **List** the major *AFP microstructure defects* mapped over FEA models
- **Recognize** opportunities to apply the workflow presented

Workflows Overview

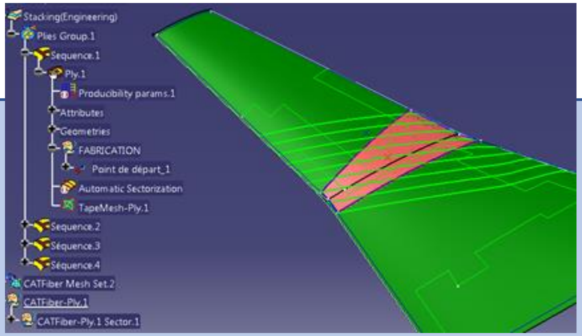
Multi-scale material modeling – Process/Structure coupled FEA

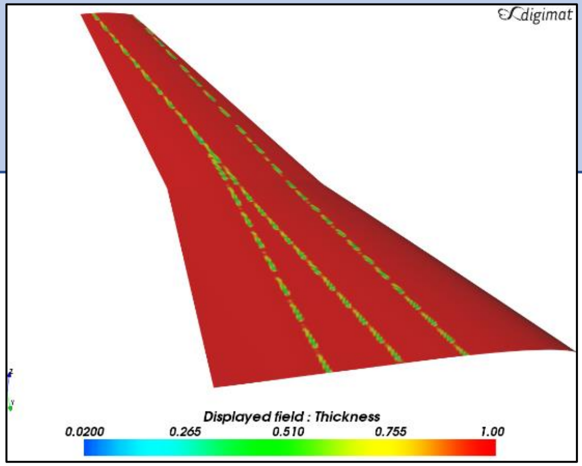
Workflow Overview - Coupling

Coupled Finite Element Analysis

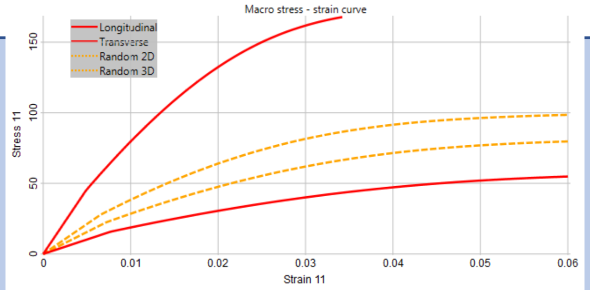
Bridge the gap between disciplines & scales for Representative Simulation

Manufacturing DATA



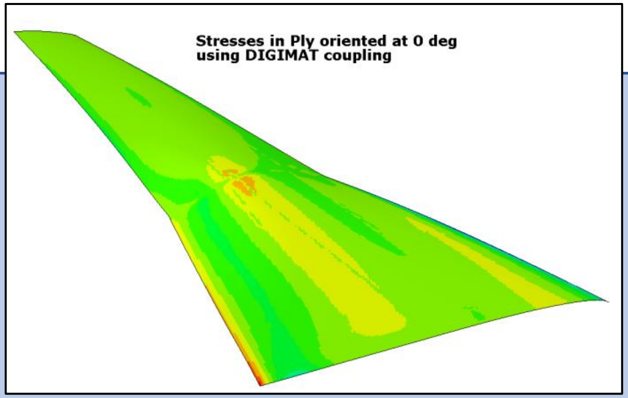


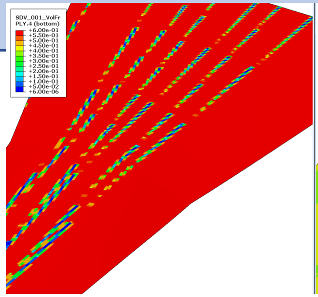
Material Model

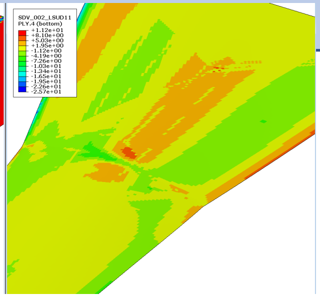


- Anisotropic material
- Mapping
- Multiscale FEA

Performance Evaluation



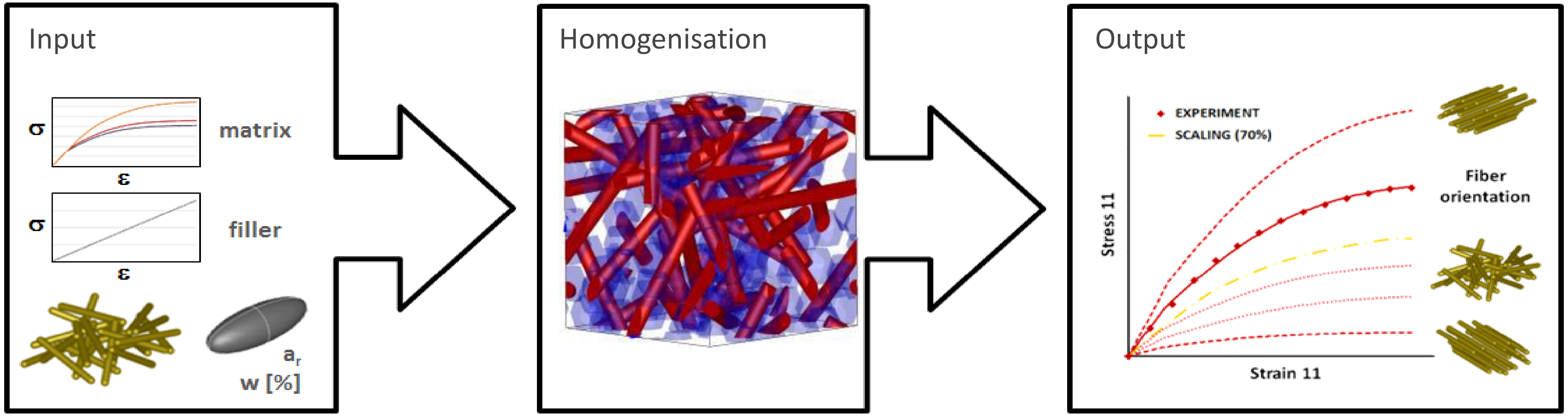




Workflow Overview – Multiscale Modeling

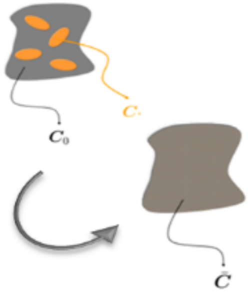
Multi-scale Modeling

Prediction of Non-Linear Anisotropic Macroscopic behavior from constituents' properties and microstructure



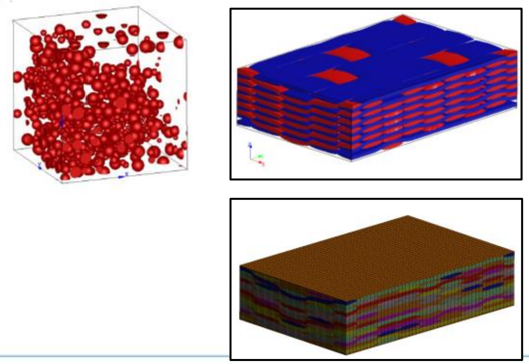
<u>Semi-Analytical method</u>

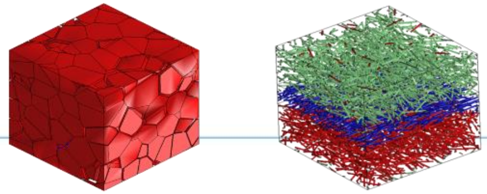
- Mean-Field homogenization
- Mori-Tanaka
- Fast model preparation/solution
- Easy coupling with FE solver



<u>RVE Direct Analysis method</u>

- Full-Field homogenization
- Build the accurate RVE geometry
- Compute it by FEM directly





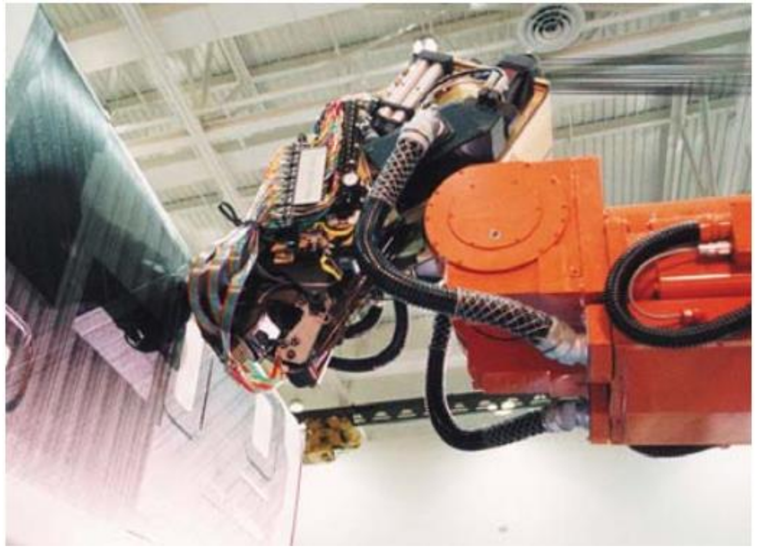
AFP Process Induced Microstructure – CAE Representation

Understand the AFP Process – CAE Process Simulation Software Data review

Automatic Fiber Placement - Review

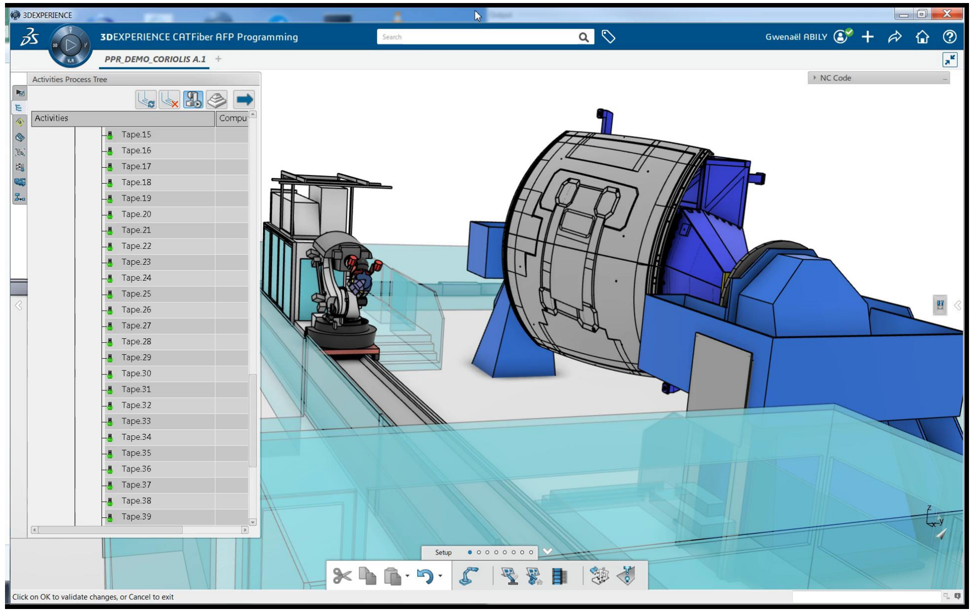
- **The Process:**

  Fast and efficient deposition process of carbon fiber material for large component applications



- **The control software:**

  drives the system and forms the design/manufacturing interface, bridging the gap between the part as-designed and the part as-manufactured

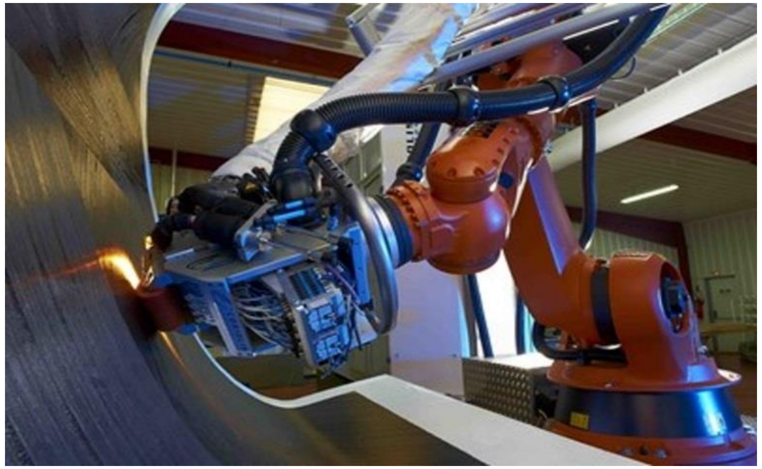


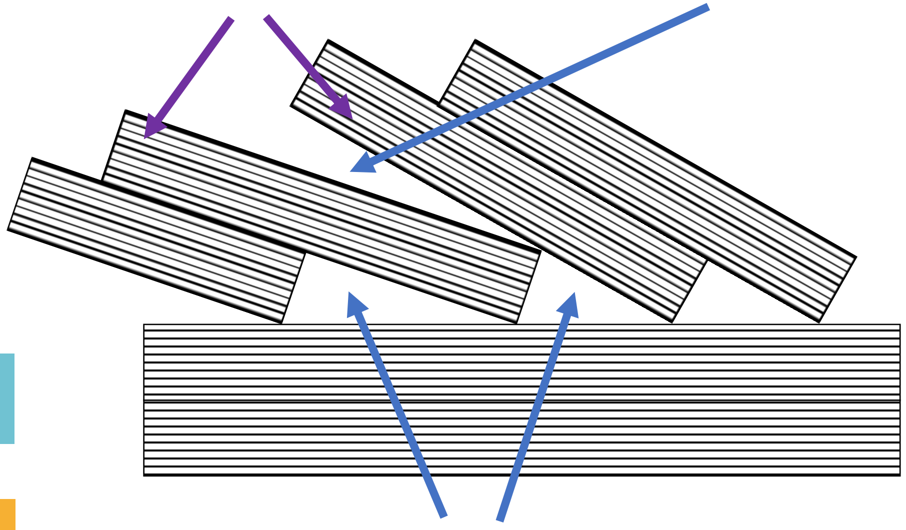
Courtesy of:

CORIOLIS composites

Linking Process & Microstructure

Strip deposition process generates composite structure containing specific microstructures





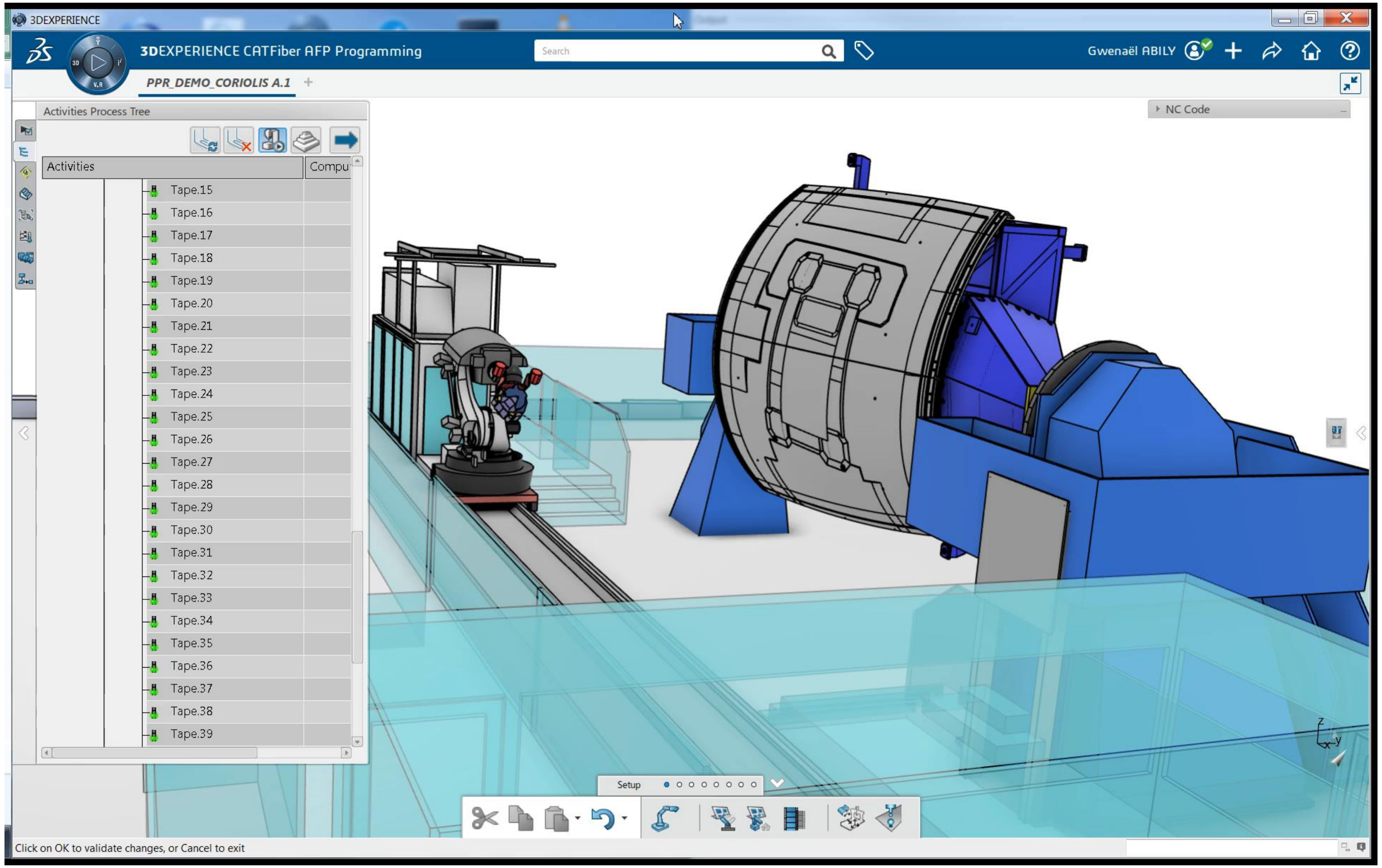
What are the effects of these defects on the over performance of the part?

How much defect can be tolerated within the design?

How simulation can help to automate the process?

Process Visualization – Control Software

Strip deposition process generates composite structure containing specific structures

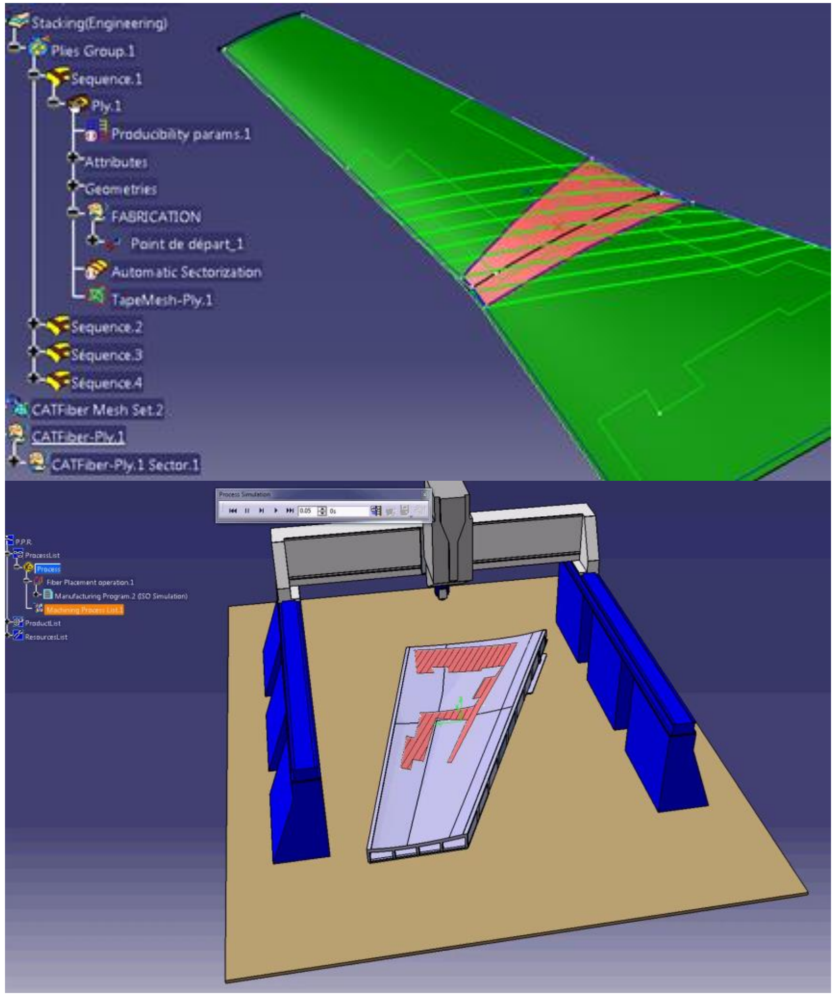


Courtesy of:

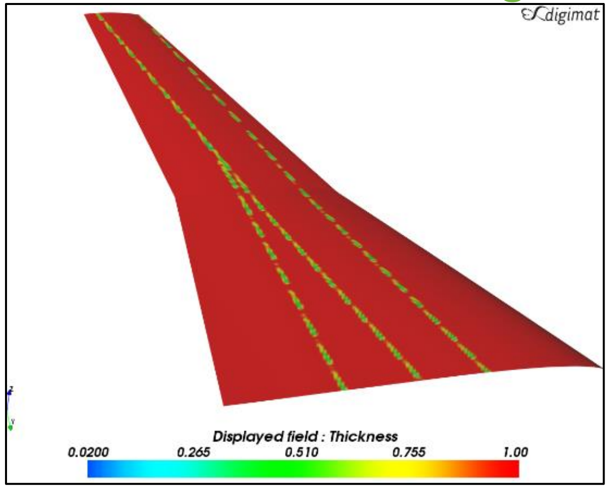
CORIOLIS composites

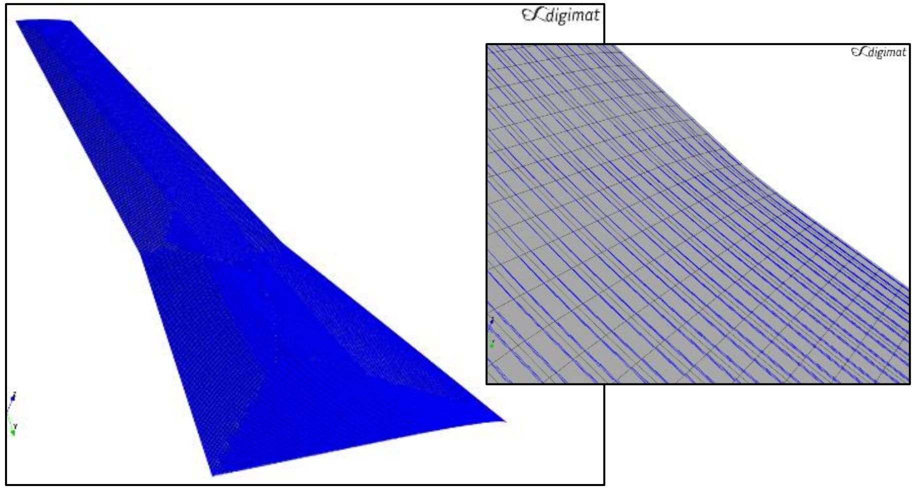
Design/Manufacturing Information Transfer to FEA

Design/Manufacturing Process



As-manufactured Composites Characteristics Transfer and Material Modeling



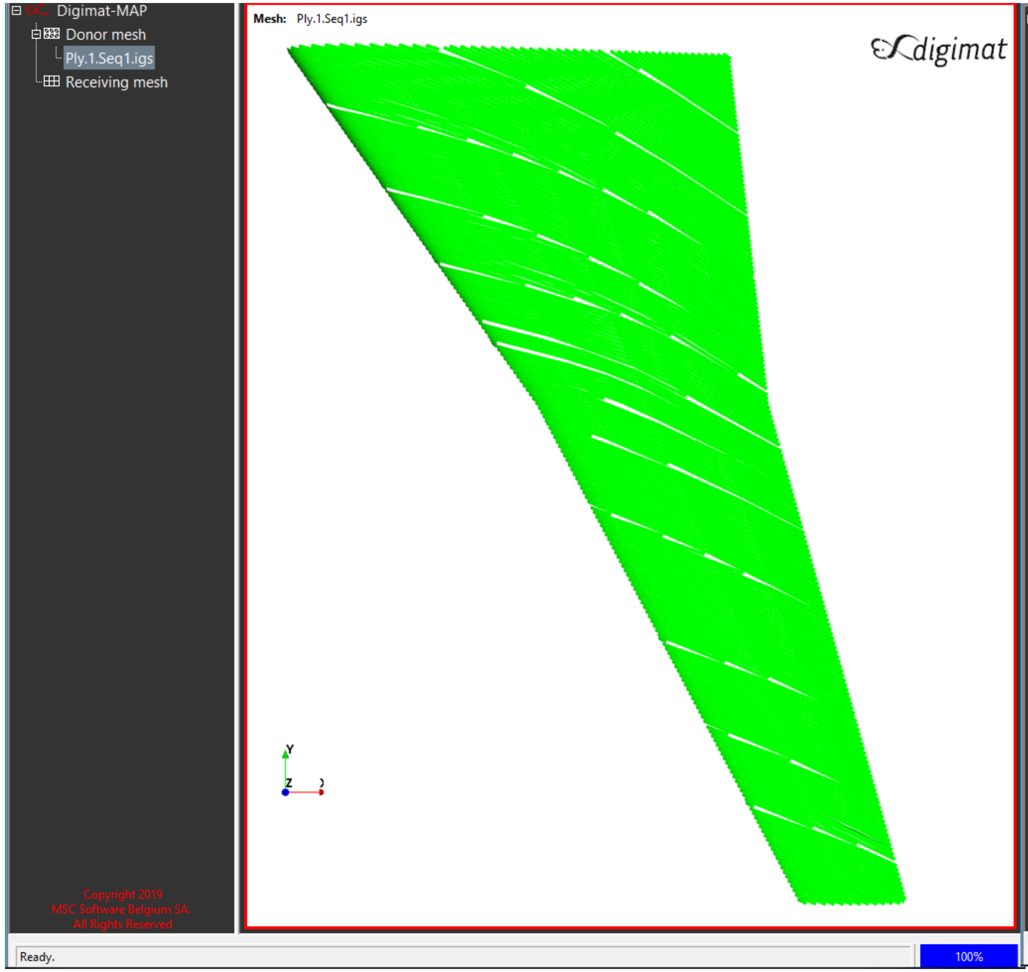


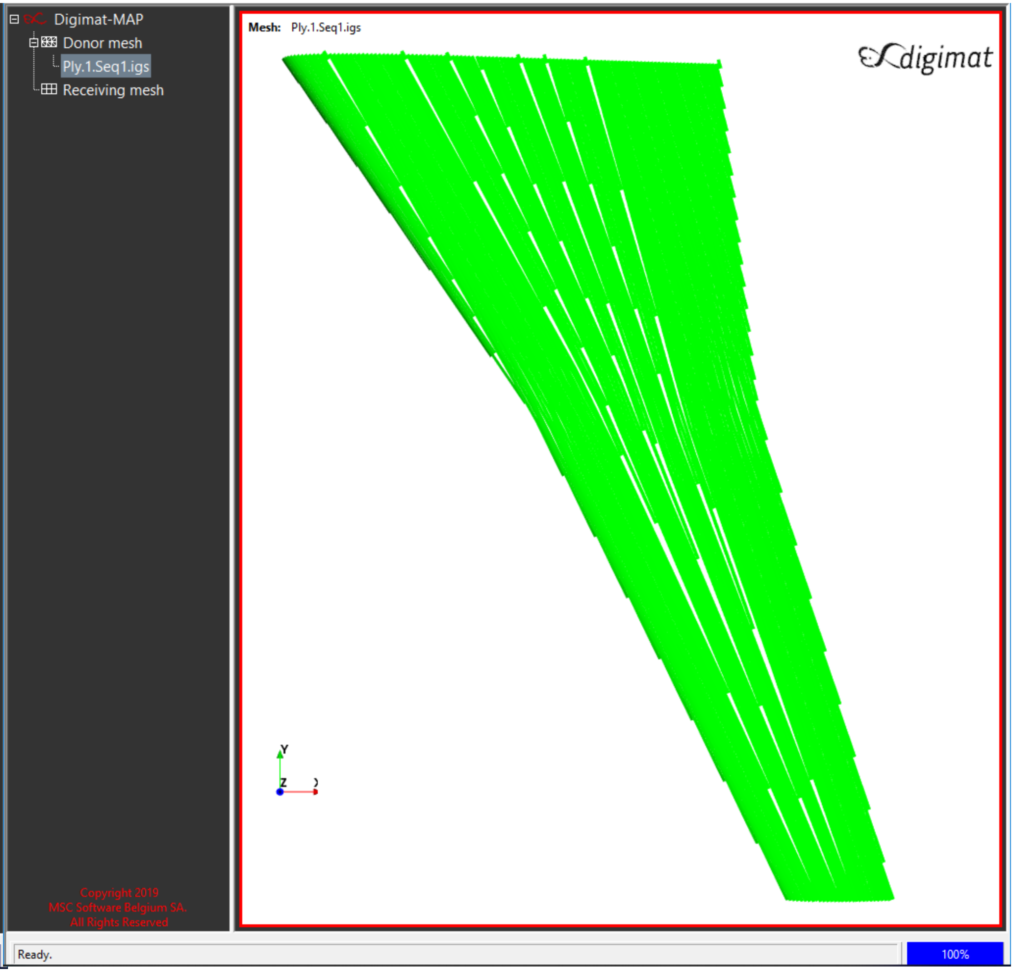
Mapping of Tape Information

Tape Strip position, orientation and geometry defined in .iges format exported from tape placement software (CATFiber in this case)

Iges files for the whole layup is imported into Mapping tool

Ply.1.45Cut.igs	IGS File
Ply.2.0.igs	IGS File
Ply.3.135Cut.igs	IGS File
Ply.4.90.igs	IGS File
Ply.5.45Cut.igs	IGS File
Ply.6.0.igs	IGS File
Ply.7.135Cut.igs	IGS File
Ply.8.90.igs	IGS File
Ply.9.90.igs	IGS File
Ply.10.135Cut.igs	IGS File
Ply.11.0.igs	IGS File
Ply.12.45Cut.igs	IGS File
Ply.13.90.igs	IGS File
Ply.14.135Cut.igs	IGS File
Ply.15.0.igs	IGS File
Ply.16.45Cut.igs	IGS File

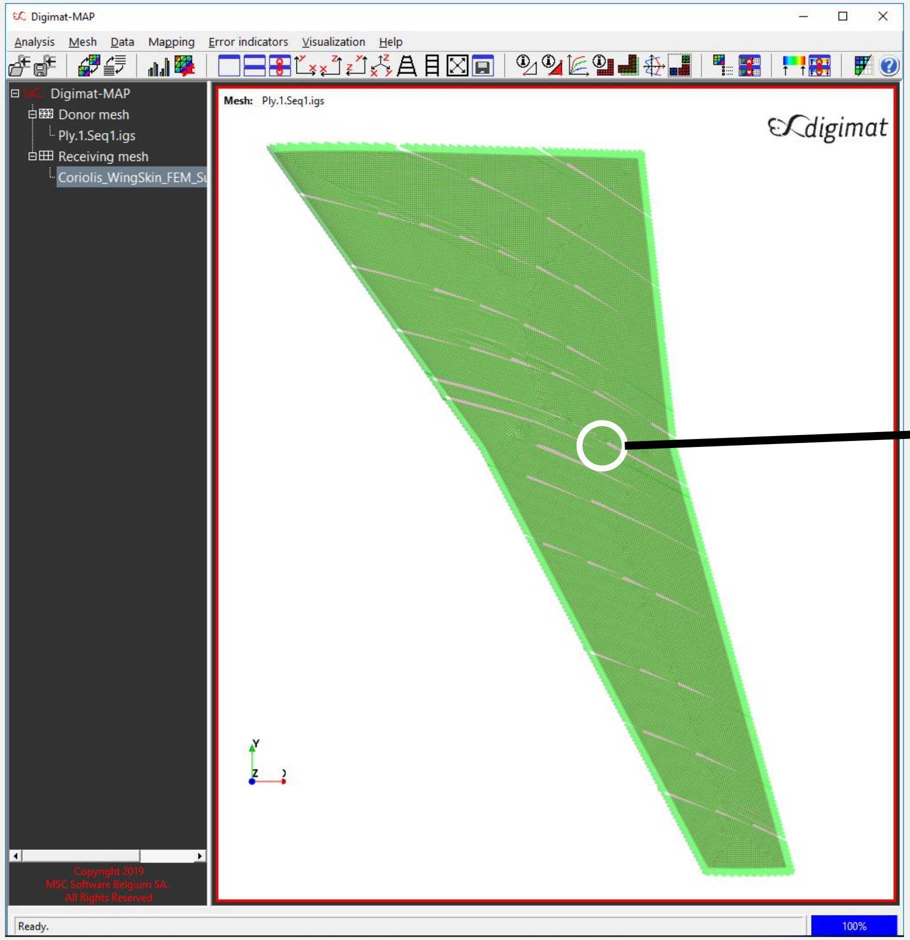


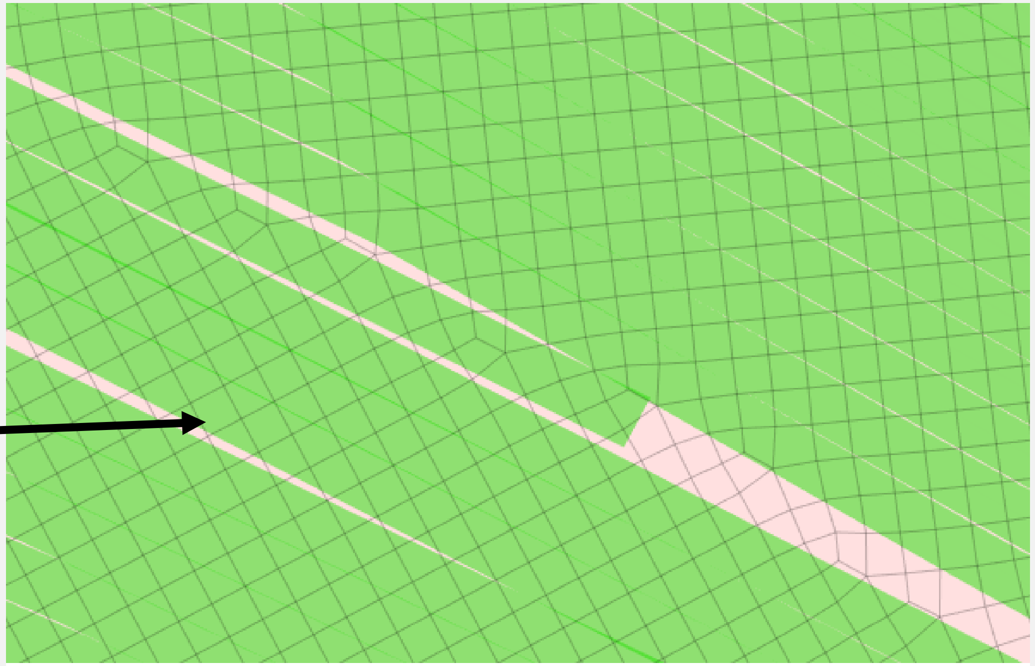


Tape Orientation and GAP Visualization

Transfer performed form IGES geometry to Receiving Mesh (i.e. FE Analysis mesh)

A computed % of tape coverage and the fiber orientation for each ply are both obtained directly from tape placement software





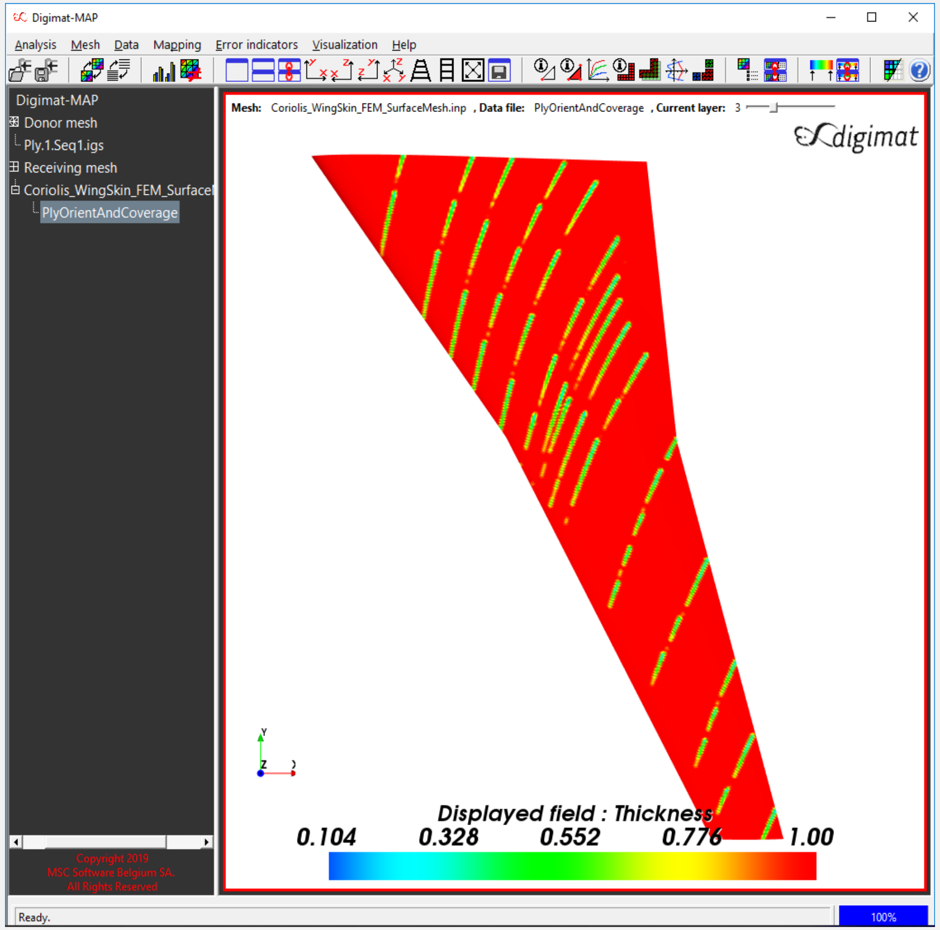
For each ply and for each Element, the following is computed:

- The % of coverage
- The fiber orientation based on the tow surface orientation

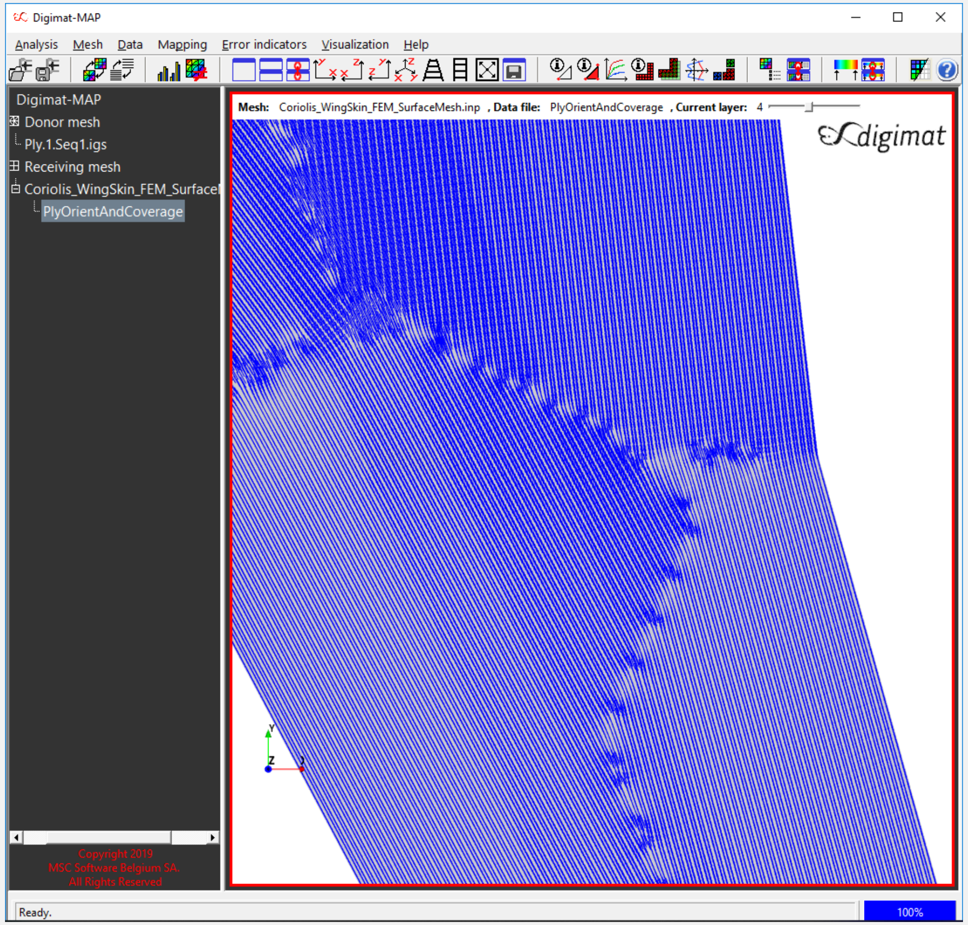
Translate GAP Into Microstructure Information

Usage of Digimat MAP to perform the mapping operation and compute the % of coverage and the fiber orientation per element per ply

Visualization of the % of Coverage per ply on the Analysis Mesh



Visualization of the Fiber Orientation per ply on the Analysis Mesh



Effect of AFP Process on Local Microstructure

Accurate Definition of Microstructure on FEA Model

Hard Tooling – Variable Volume Fraction

HARD TOOLING - The result of the mapping operation is written in an XML file to reflect the right consolidation conditions.

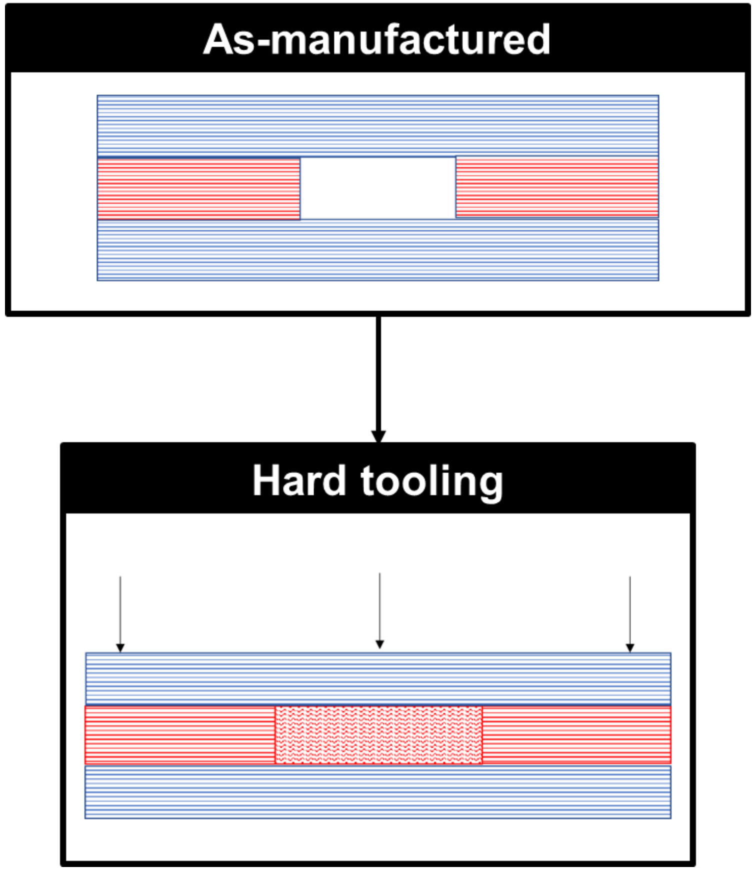
Hard Tooling -> Variable Fiber Volume Fraction

-> **Hard tooling spreads the cure pressure**

- Generates resin flow towards the gaps
- Keeping the overall laminate thickness constant

-> **Vicinity of the Gap**

- Modification wrt of the % of coverage of the fiber volume fraction
- Usage of local Vf to compute the local material properties



Hard Tooling – Variable Volume Fraction

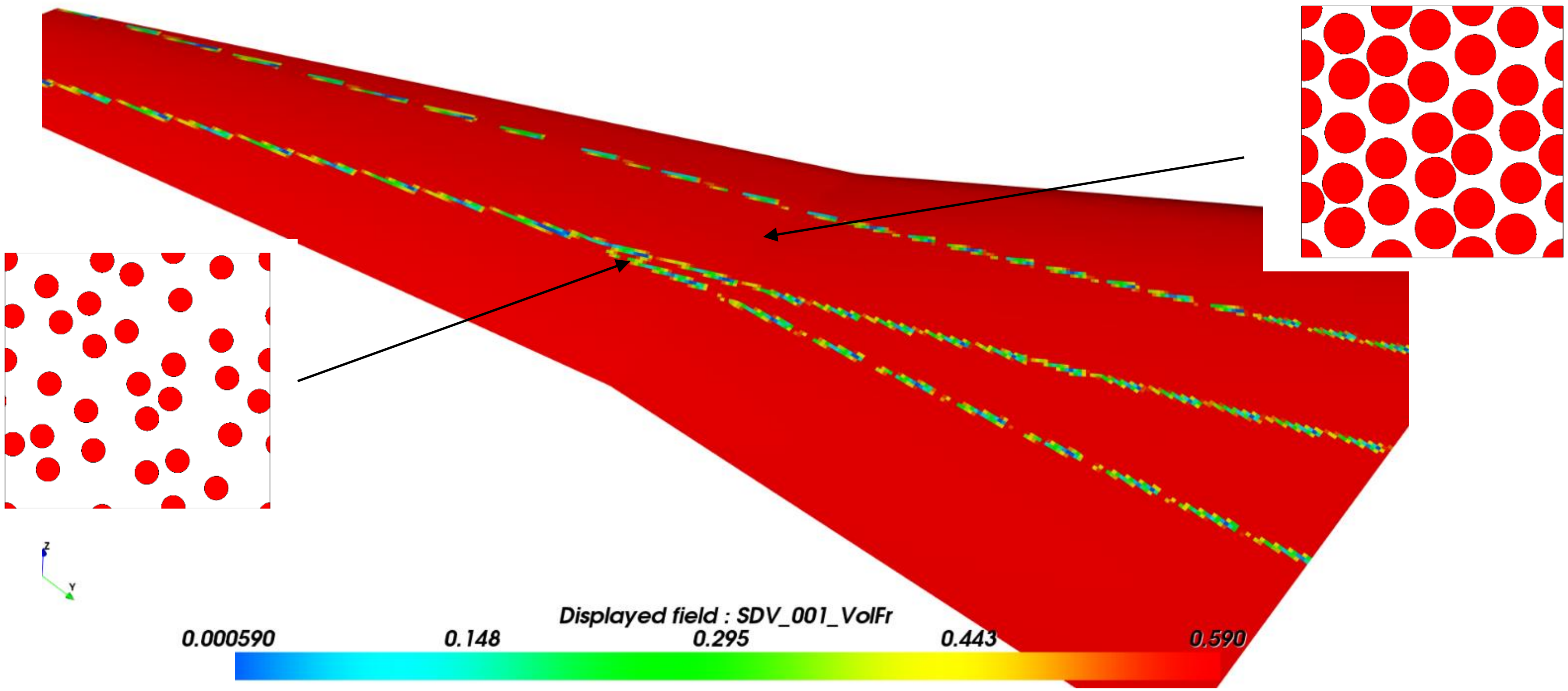
Visualizing the Hard tooling effect on Fiber Volume Fraction

Fiber Volume Fraction varies within each ply:

- From Pure Resin to FVF of reference

Composite Properties

- Vary based on Fiber Volume Fraction



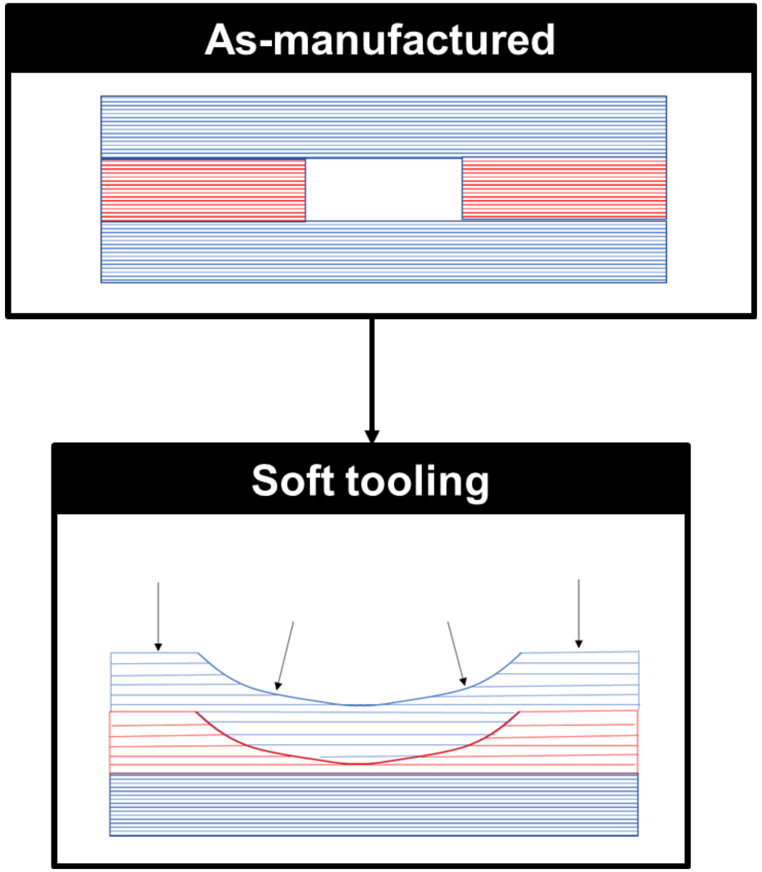
Soft Tooling – Variable Laminate Thickness

SOFT TOOLING - The result of the mapping operation is written in an XML file to reflect the right consolidation conditions.

Variable Ply Thickness → Soft Tooling

Uniform Cure Pressure

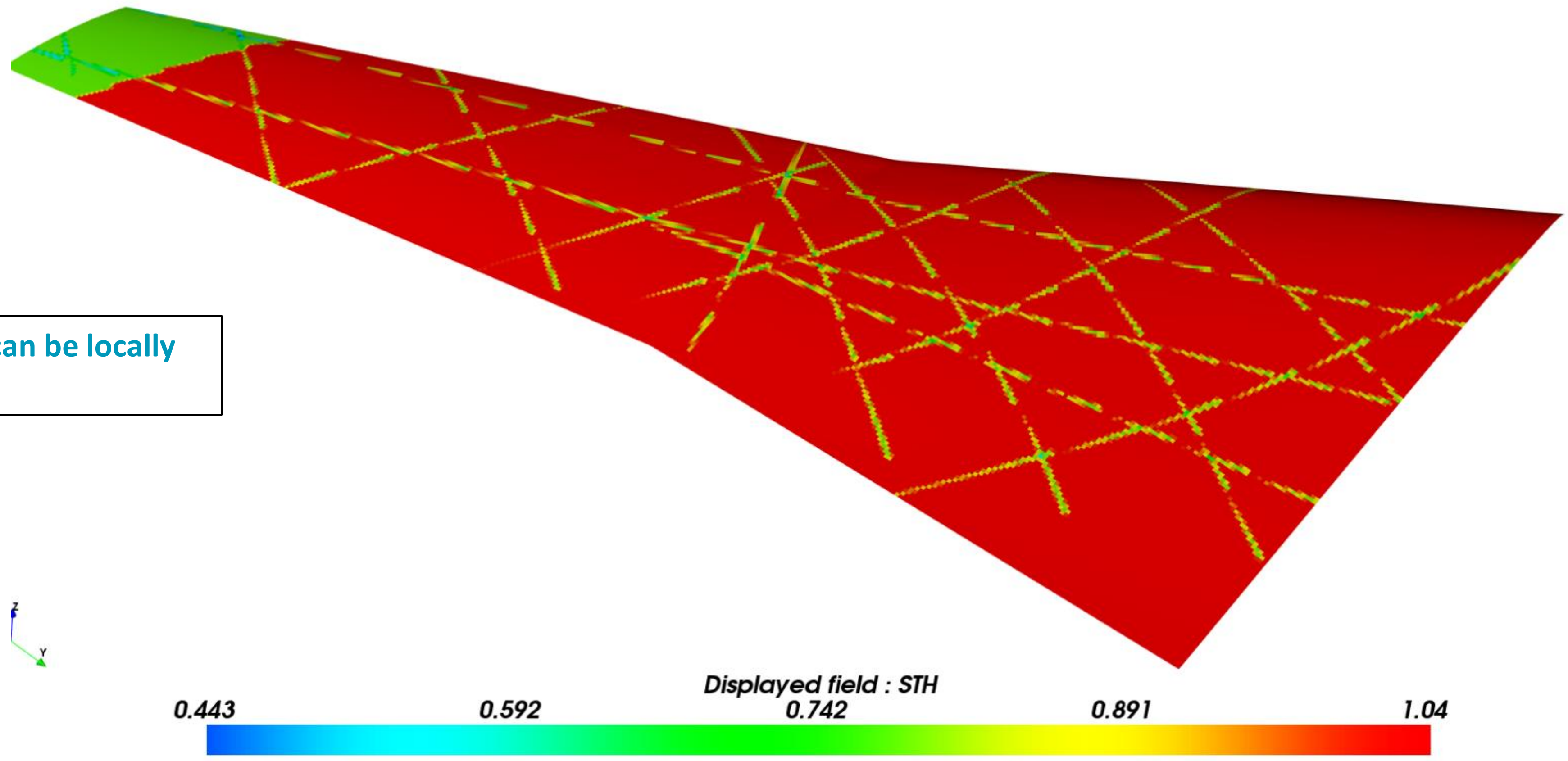
- local difference in overall laminate thickness due to soft tool
- Far from the gap → Ply thickness remains unchanged
- Vicinity of the gap → Modification wrt of the % of coverage of the ply thickness to reflect the overall laminate thickness changes



Soft Tooling – Variable Laminate Thickness

Visualizing the soft tooling effect on ply thickness

Total Laminate Thickness can be locally decreased of 55%



FEA Model Definition Using 2D Shell

The results of the mapping operation are used to create the *SHELL SECTION COMPOSITE commands cards that can be included in the Analysis mesh

Generates files containing the *shell section cards and the material cards

```
**
**  -- Definition of SHELL SECTION
**
*include, input=Micro2_Analysis1_AbaqusInclude.inp
*End Part
**
**
** ASSEMBLY
**
*Assembly, name=Assembly
**
*Instance, name=PART-1-1, part=Structural_Mesh
*End Instance
**
*End Assembly
**
** MATERIALS
**
*INCLUDE, input=Micro2_Analysis1.aba
** ----------------------------------------------------------
**
** STEP: Step-1
```

Local Orientation is defined through a XML file

- Shell section are created with the modified ply thickness

  OR

- Variable Fiber Volume Fraction can be used with a Digimat Material

Material Properties are defined through a Digimat Material Card

- Material model contains fiber orientation depency
- Material model has Volume Fraction depency

```
*elset, elset=SetSection-0
230273,230274,230275,230276,230277,230278,230279,230280,230281,230282,230283,230284,
230289,230290,230291,230292,230293,230294,230295,230296,230297,230298
*Orientation, name=Orientation-1, definition=offset to nodes, system=rectangular
2,3
3,0
*Shell section, elset=SetSection-0, composite, orientation=Orientation-1
0.125,3,Digimat_Material,0,PLY.1
0.125,3,Digimat_Material,0,PLY.2
0.103,3,Digimat_Material,0,PLY.3
0.125,3,Digimat_Material,0,PLY.4
0.125,3,Digimat_Material,0,PLY.5
0.125,3,Digimat_Material,0,PLY.6
0.050,3,Digimat_Material,0,PLY.7
0.125,3,Digimat_Material,0,PLY.8
0.125,3,Digimat_Material,0,PLY.9
0.125,3,Digimat_Material,0,PLY.10
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0.125,3,Digimat_Material,0,PLY.13
0.086,3,Digimat_Material,0,PLY.14
0.125,3,Digimat_Material,0,PLY.15
0.125,3,Digimat_Material,0,PLY.16
******************************************************************************
```

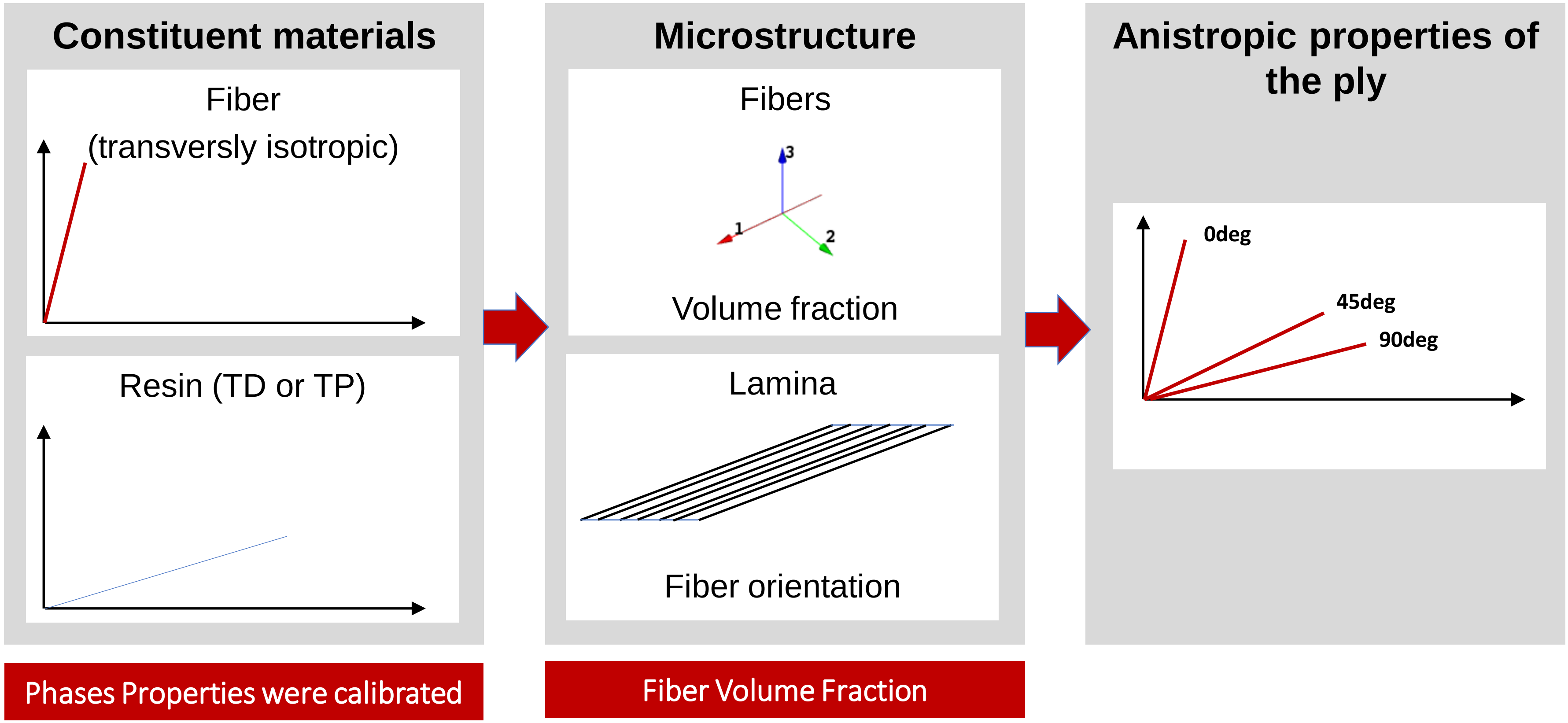
Material Model Generation – UD Material

Multi-Scale material modeling using Mean-Field Homogenization

Tape Anisotropic Stiffness Multi-scale Definition

Mean-field homogenization applied to Representative Volume Elements to calibrate lamina anisotropic stiffness

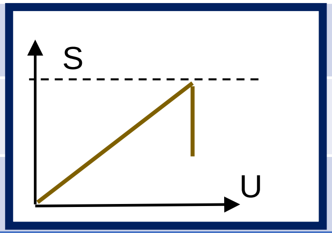
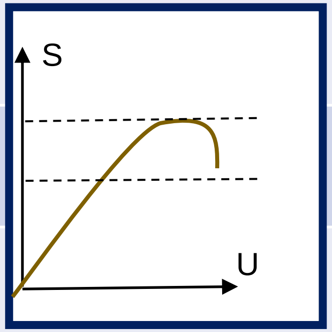
- The material model is built from constituent properties
- The composite is built from Constituents



Continuous Fiber Composite Progressive Failure

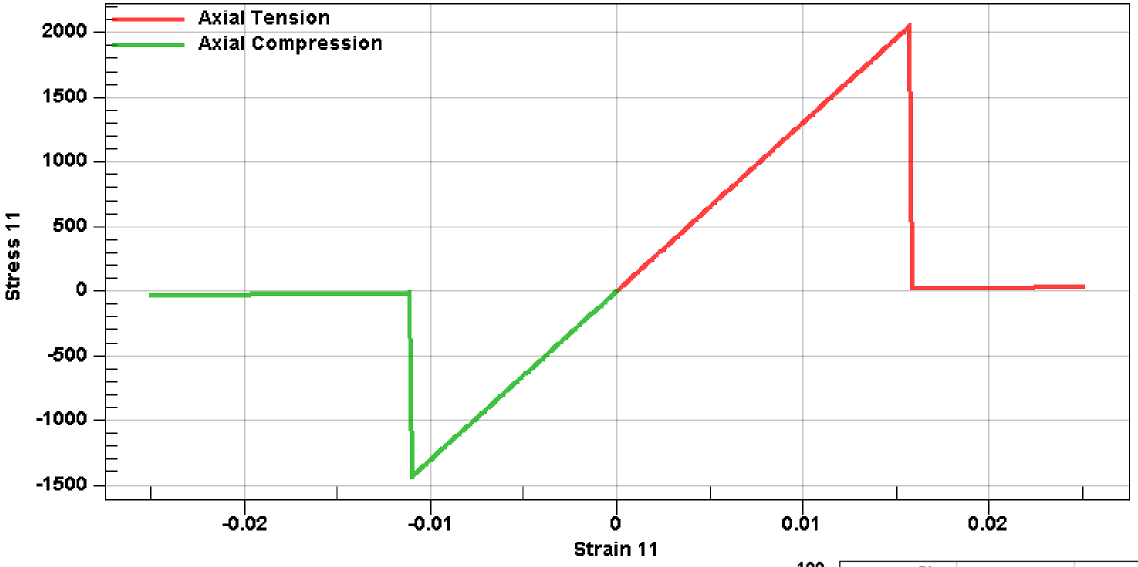
Lamina may exhibit different failure behaviors with respect to the loading directions that request to be calibrated

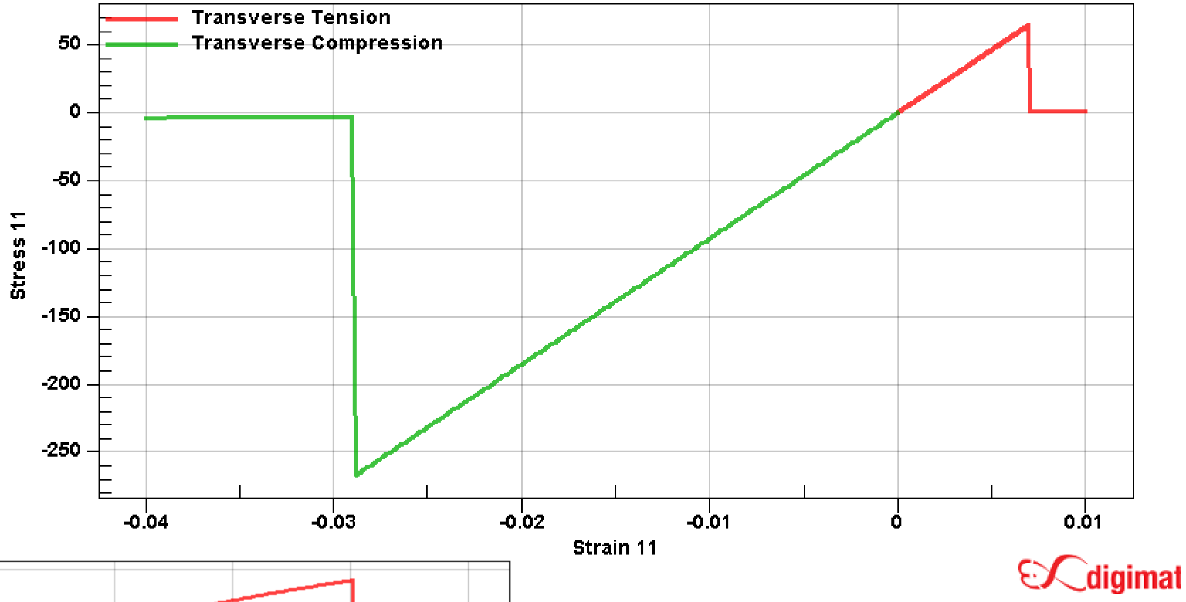
➢ Example: For a UD, the behavior below are commonly observed

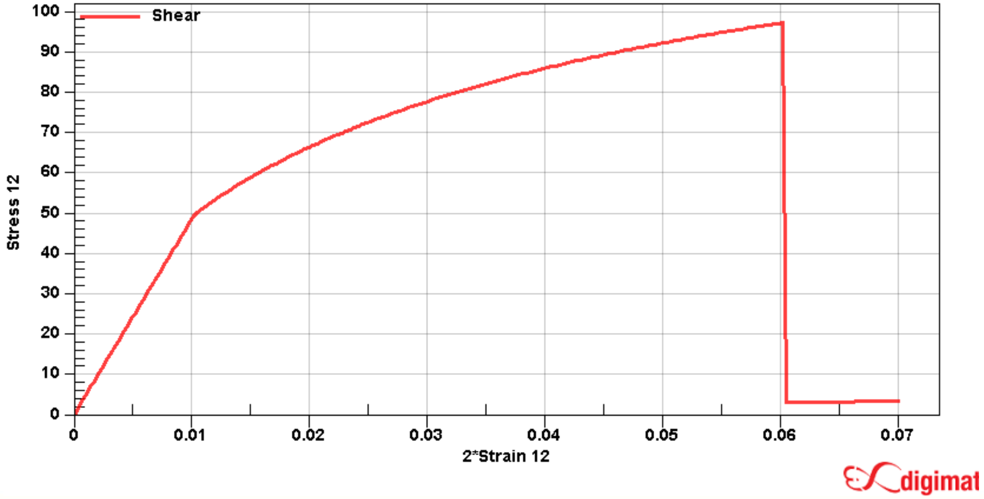
Direction	Stiffness and Failure	Typical shape of the response
Axial Tensile	**Linear behavior until brittle failure**	
Transverse tensile	**Linear behavior until brittle failure**	
Axial Compressive	**Non-linear behavior with progressive loss of stiffness until failure**	
Transverse compressive	**Non-linear behavior with progressive loss of stiffness until failure**	
In-plane shear	**Non-linear behavior with progressive loss of stiffness until failure**	

Ply Strength Results

Use of different damage laws allows representing a non-linear behavior with linear materials.



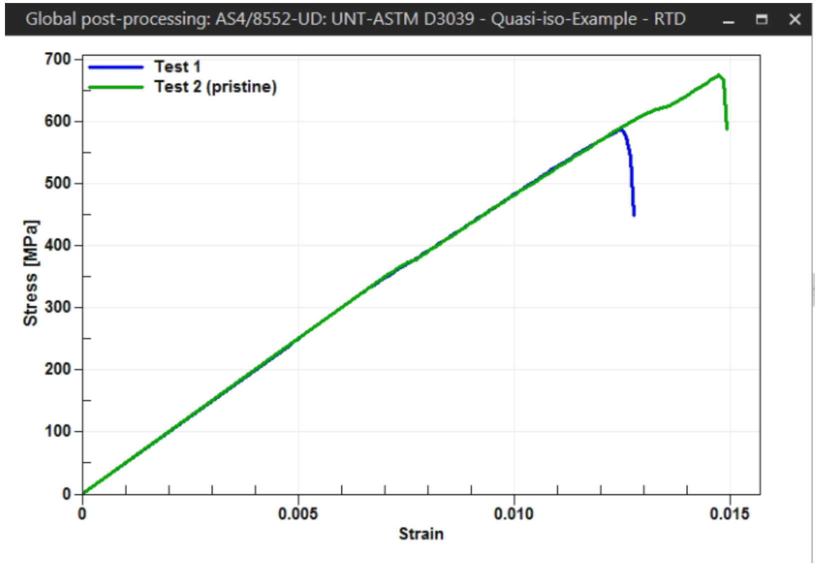




Coupon Strength Results

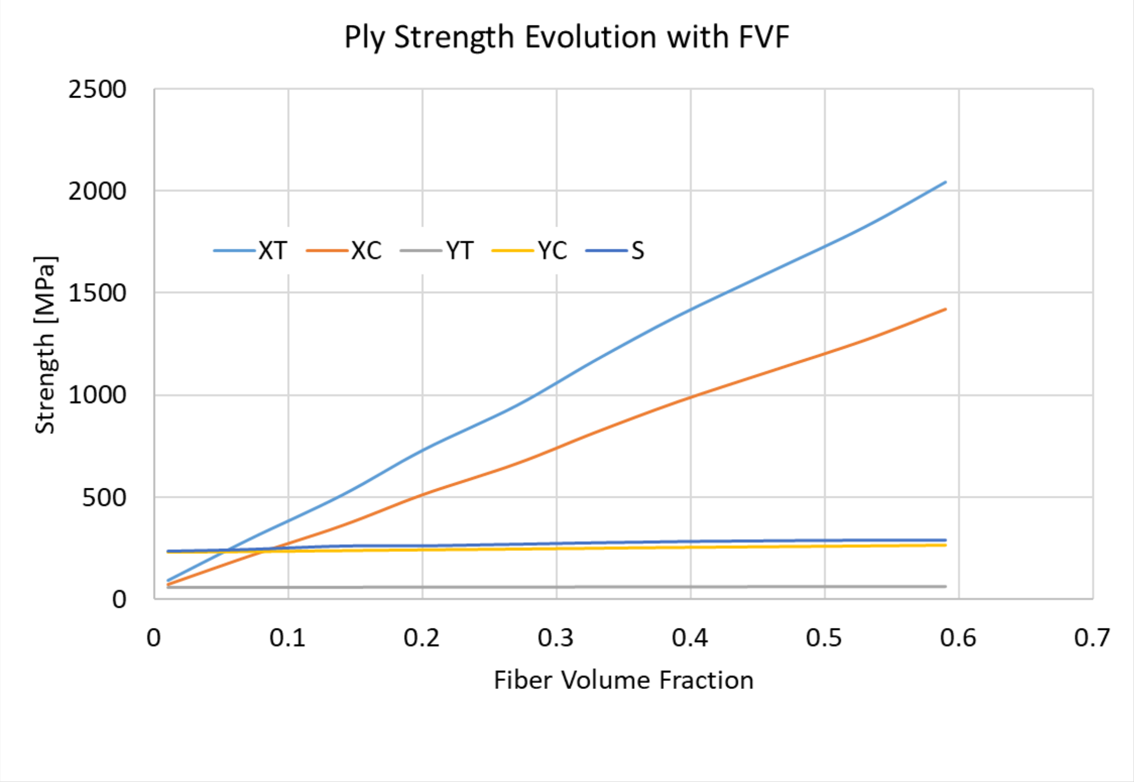
Evolution of Ply Strength with fiber volume fraction using mean-field homogenization

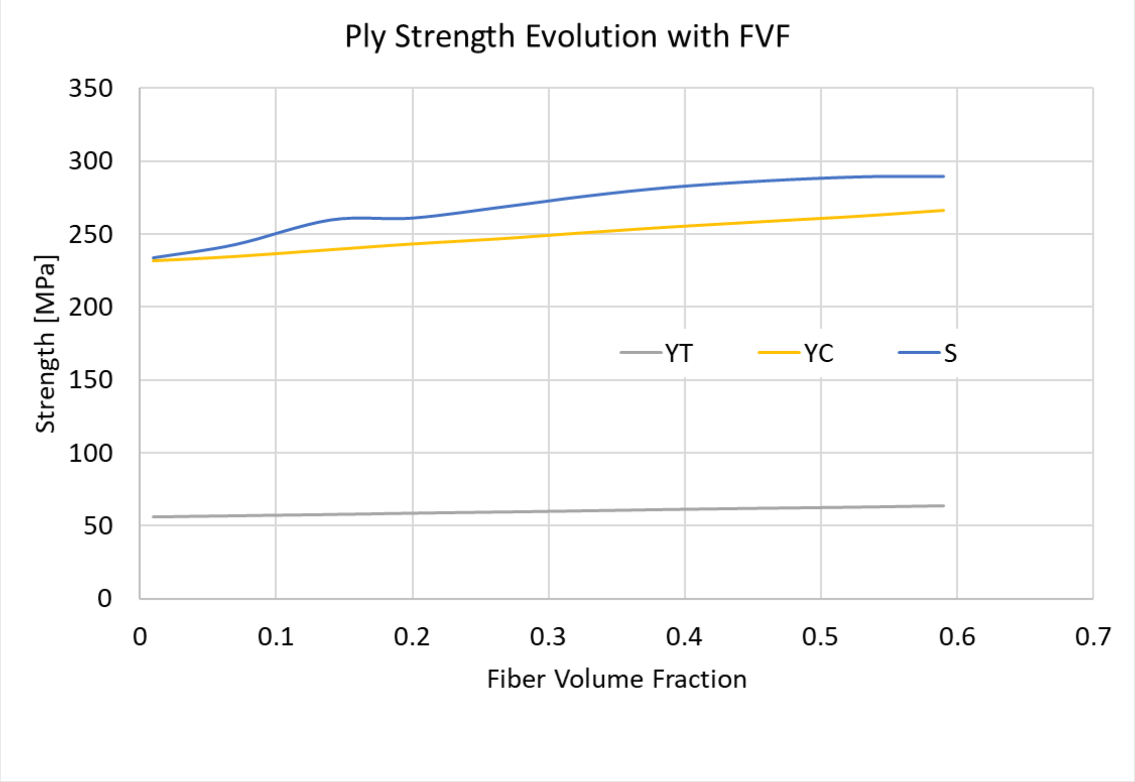
Fiber	Matrix	Layup	Test	Conditions	Experimental [MPa]	Digimat [MPa]	KDF
AS4	8552	[45/0/-45/90]2s	UNT	RTD	611.	675.	
AS4	8552	[45/0/-45/90]2s + Gaps all plies	UNT	RTD		516.9	0.76
AS4	8552	[45/0/-45/90]2s + Gaps Plies 45/-45	UNT	RTD		586.2	0.87
AS4	8552	[45/-45/0/45/-45/90/45/-45/45/-45]s	UNT	RTD	439.	412.	
AS4	8552	[45/-45/0/45/-45/90/45/-45/45/-45]s + Gaps all plies	UNT	RTD		294	0.71
AS4	8552	[45/-45/0/45/-45/90/45/-45/45/-45]s + Gap plies 45/-45	UNT	RTD		337.	0.94
AS4	8552	[0/45/0/90/0/-45/0/45/0/-45]s	UNT	RTD	1050.	1136.	
AS4	8552	[0/45/0/90/0/-45/0/45/0/-45]s + Gaps + all plies	UNT	RTD		698.	0.61
AS4	8552	[0/45/0/90/0/-45/0/45/0/-45]s + Gaps plies 45/-45	UNT	RTD		1076.	0.82



GAP Impact on Coupon Strength

Evolution of Ply Strength with fiber volume fraction using mean-field homogenization





Analysis Results

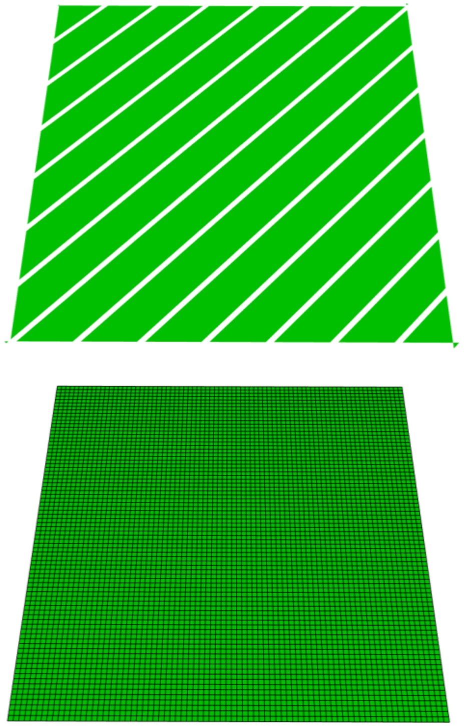
Stiffness Knock-down – Plaque and Airplane wing

AFP Manufactured Plaque - Stiffness Evaluation

Assessment if the GAP effect on the bending stiffness of a simple plaque

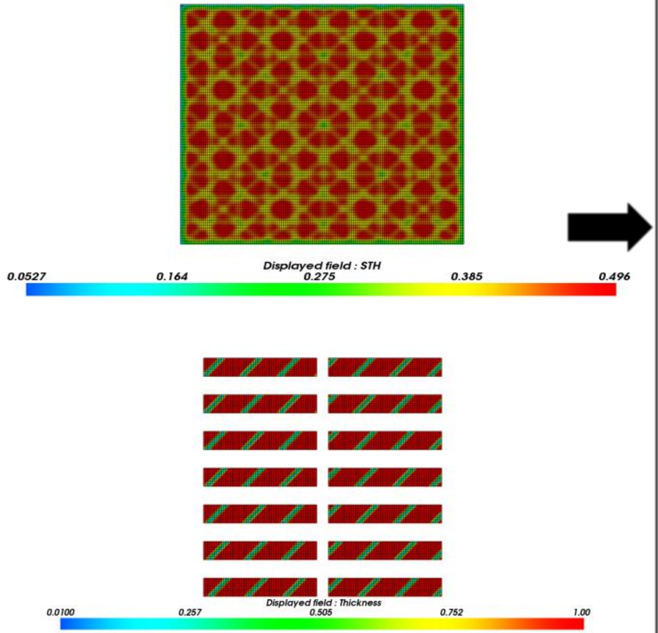
- Comparison between effect of gaps/no gaps applied on the following laminate - [45/0/-45/90]2s

GAP/No-GAP Laminate

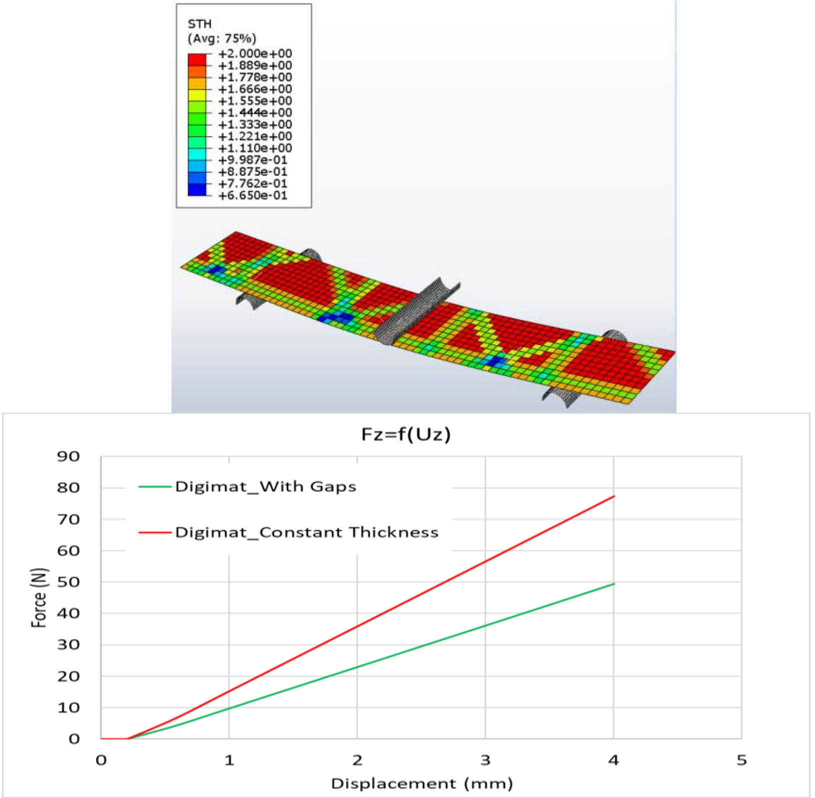


Map GAPs on the Analysis Mesh

Variable thickness or Variable FVF
Orientation from manufacturing



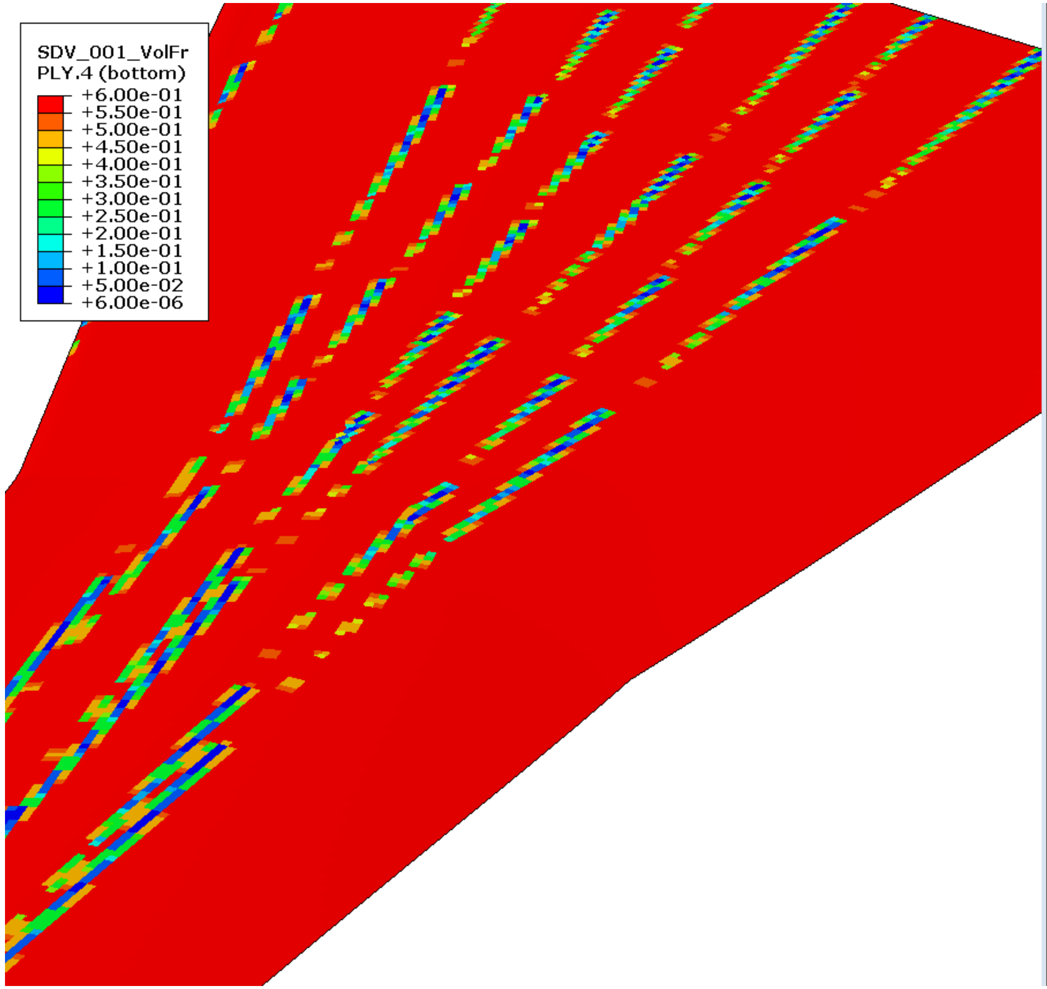
Coupled Analysis using GAP information

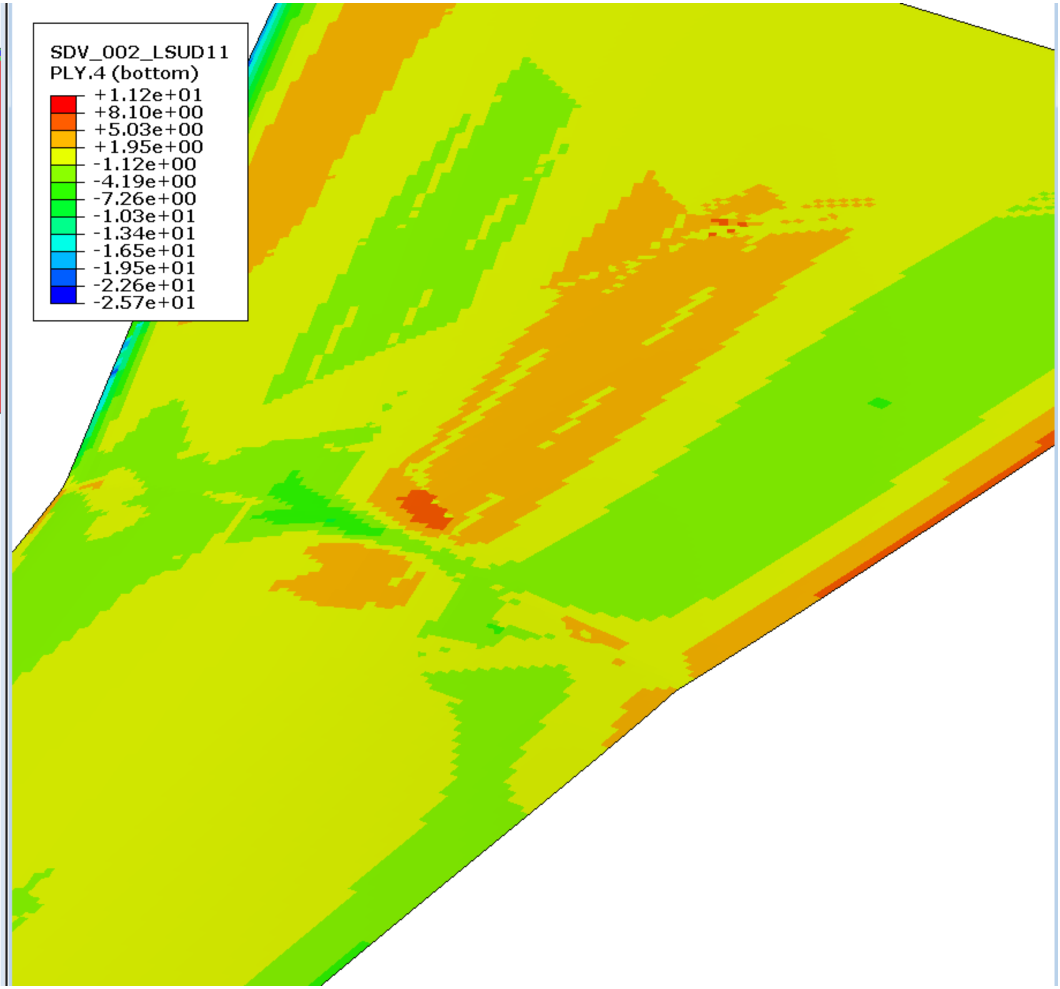


AFP Manufactured Wing - Stiffness Evaluation

Assessment if the GAP effect on the bending stiffness of an airplane wing

- Comparison between GAP position and Stiffness/stress results after load application on the Wing tip



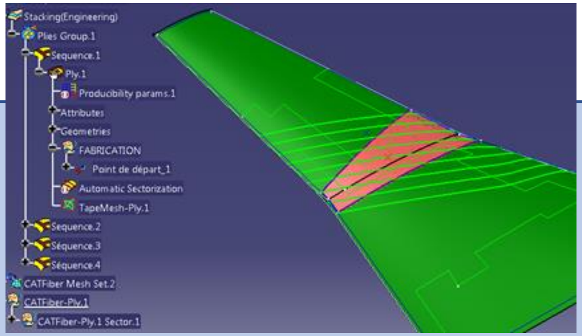


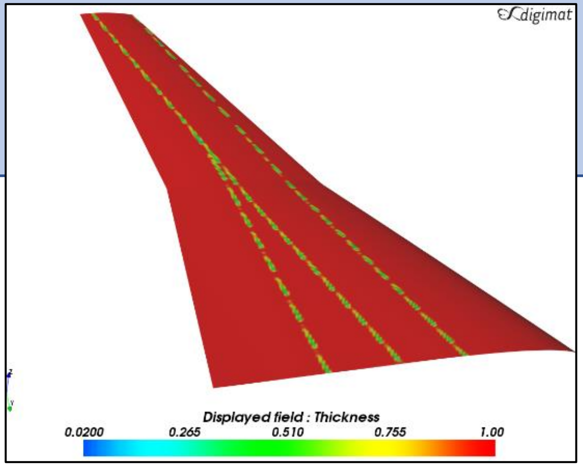
Summary

Coupled Finite Element Analysis

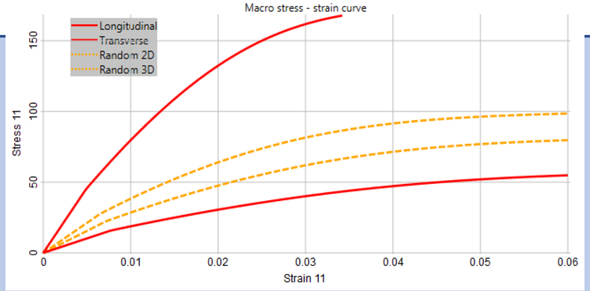
Bridge the gap between disciplines & scales for Representative Simulation

Manufacturing DATA - Mapping



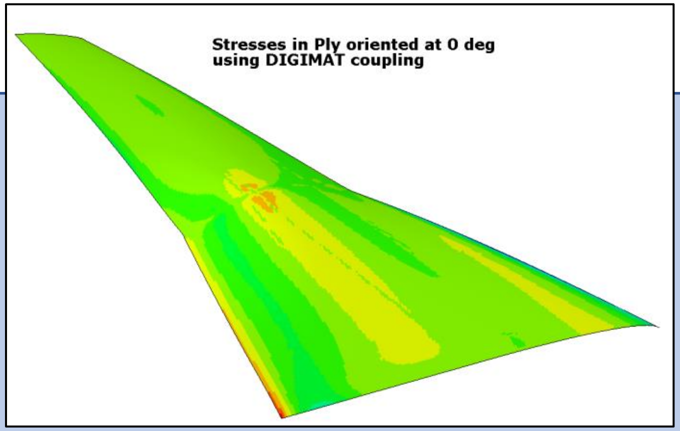


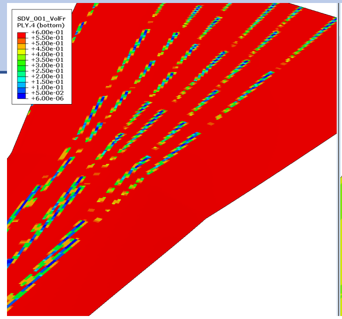
Material Model Generation

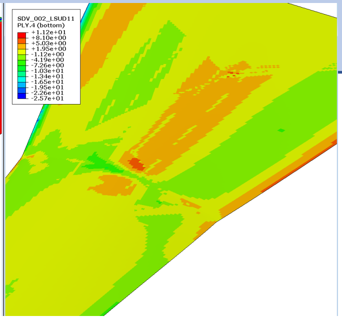


- Anisotropic material
- Mapping
- Multiscale FEA

Performance Evaluation

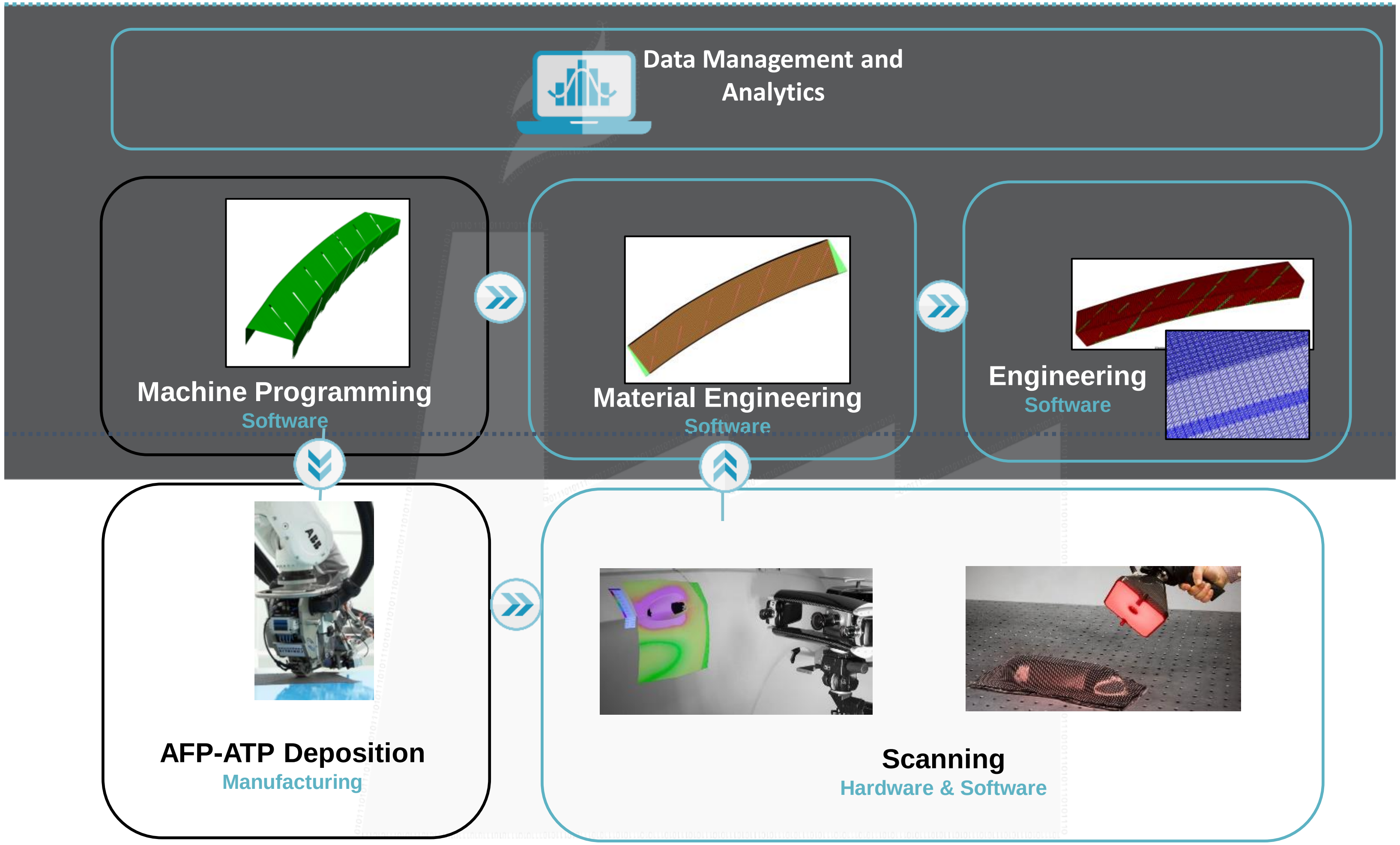






Digital Thread Application

Digital Thread Applied to AFP-ATP Components for Real Time Performances



OUTCOMES

- ❑ **As-programmed** part's performances
- ❑ **As-manufactured** part's performances
- ❑ Analyze deviation including defects & thicknesses between as-programmed & as-manufactured part

BENEFITS

- ❑ Access real time the performances of the part
- ❑ Optimize the deposition strategy prior to manufacturing
- ❑ Optimize the deposition strategy based on in-situ measurement

Contact Info

Thank you!!

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