Manufacturing Process Simulation of Fiber Reinforced Composites – Industrial software tools and state of the art in research

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Content

Manufacturing process simulation of fiber reinforced composites

- ESI Group – The company
- Introduction composite process chain
- Composite Manufacturing Process Simulation (MPS)
  - Forming simulation - PAM-FORM
  - Filling simulation - PAM-RTM
  - Distortion simulation - PAM-Distortion
- Visual Environment
  - Basics (Software Framework & Performance)
- Chaining of simulation tools
  - Industrial example
    - KTM Technologies (automobile part)
    - Snecma (Fan blade)
    - Premium AEROTEC GmbH (aeronautical part)

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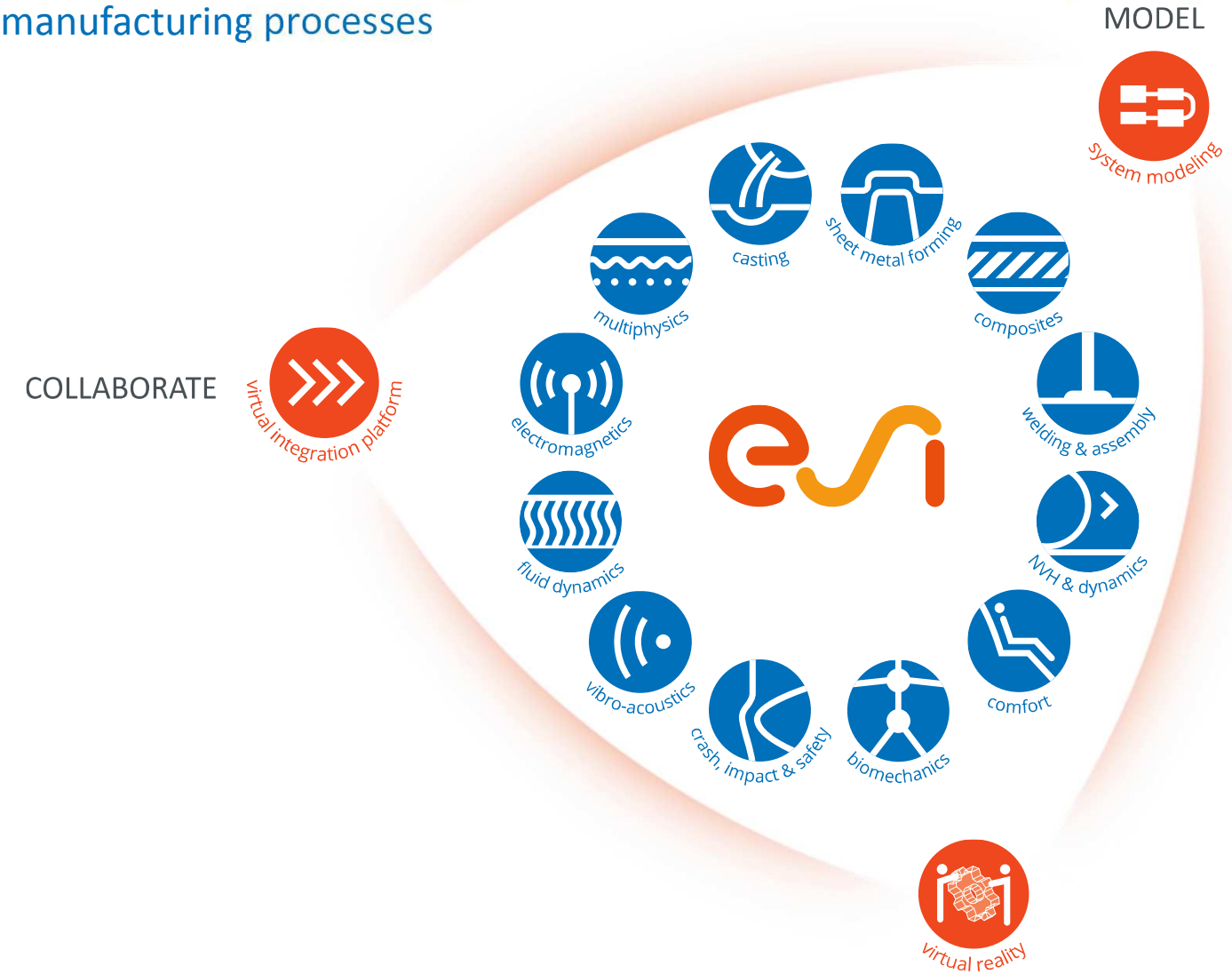
Virtual Product Engineering

World-leading editor of digital simulation software for virtual prototyping and manufacturing processes



ESI Around The World

More than **40** countries

32 subsidiaries

1000 people

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esi get it right®

ESI in Deutschland

- Foundation 1979
- 1986 first Crash simulation VW Polo
- ca. 110 employees
- ca. 13 Mio Euro
- 2 entity
  - ESI GmbH
  - ESI Software GmbH

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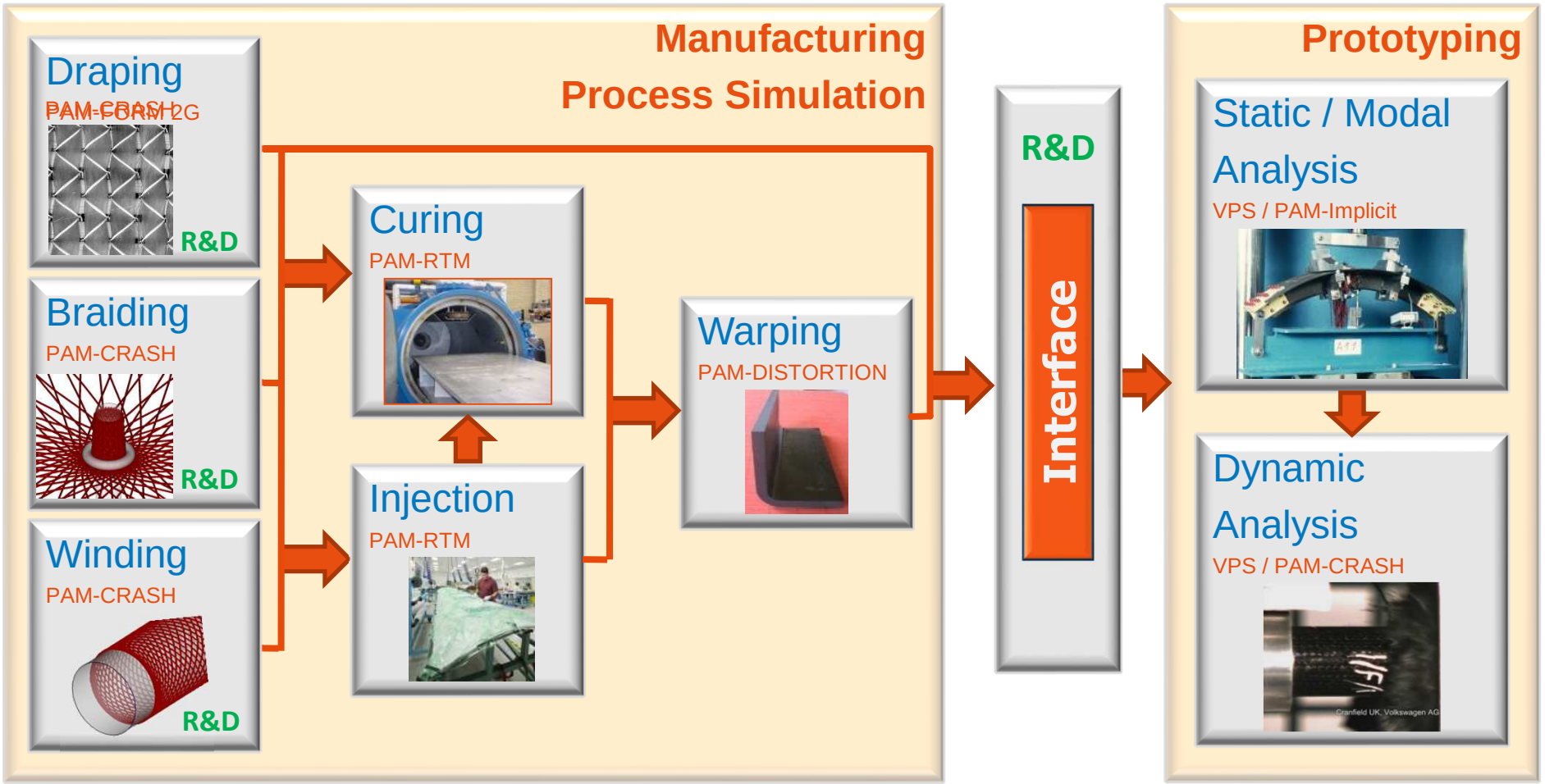
Introduction Process Chain / ESI Composites Solution

Simulation of composites- a closed process chain?



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ESI Composites Manufacturing Simulation Suite

PAM-FORM | **PAM-RTM** | **PAM-DISTORTION**

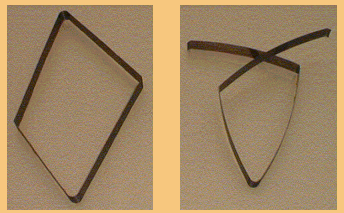
THERMOFORMING
of prepregs Thermosets & Thermoplastics

PREFORMING
of dry textiles

LIQUID COMPOSITES MOLDING
Injection or infusion

CURING
Out-Of-Autoclave or Autoclave

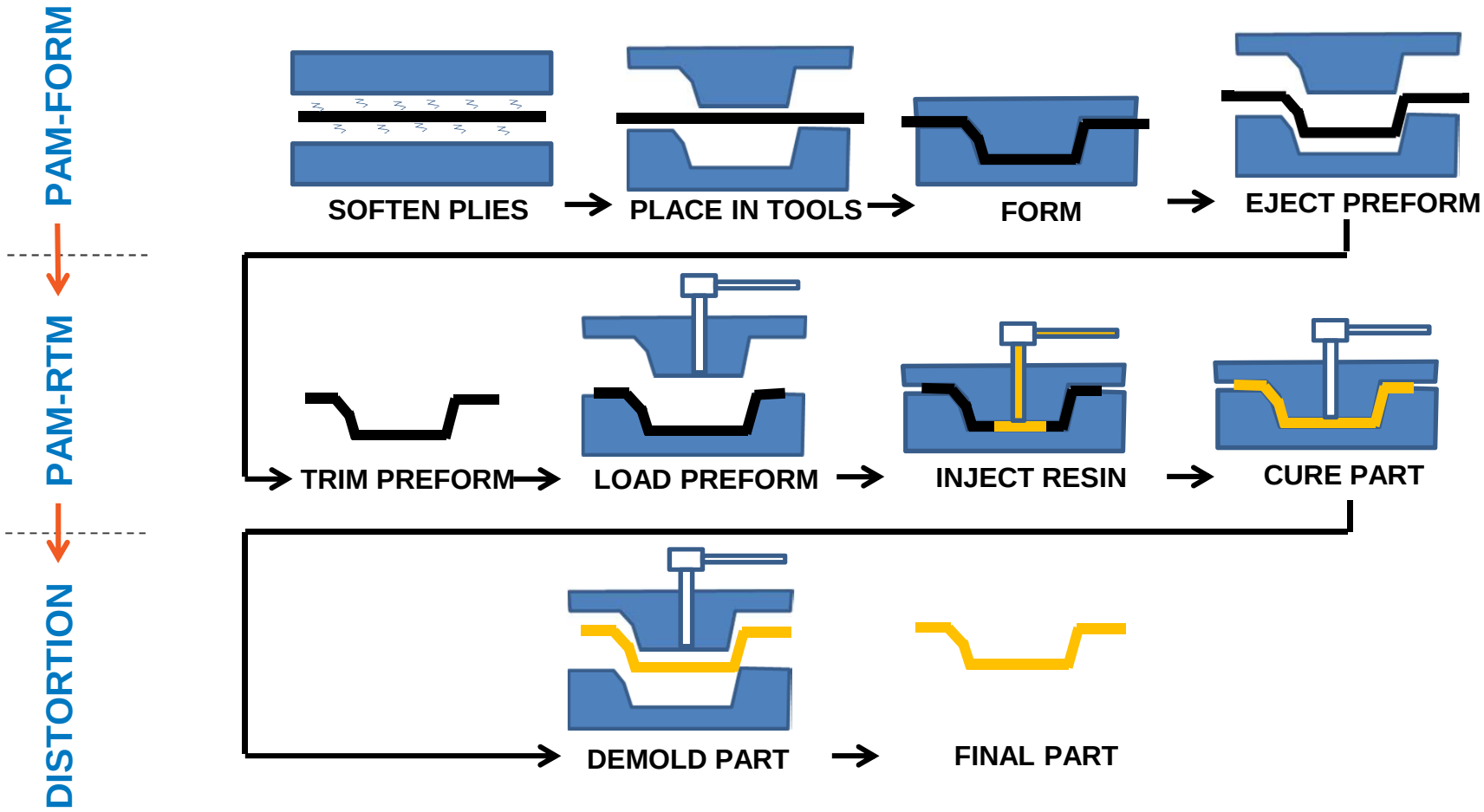
DISTORTION
Manufacturing induced residual stresses and distortion



Compensated Mold

MPS-Commercial Solutions

Liquid Composites Molding Process Chain



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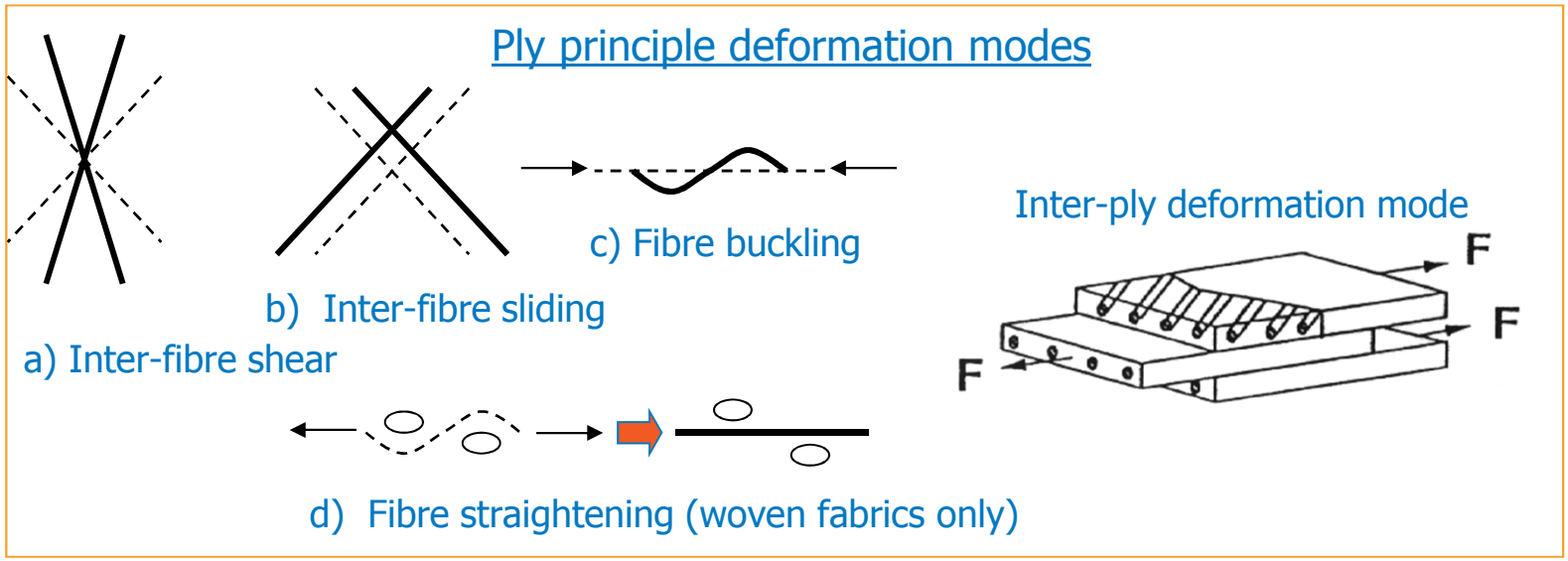
The main problematics

Material

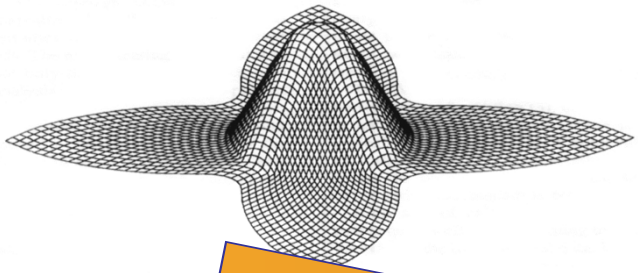
- Multi-material design
- Fabric deformation mechanisms are very different to metals

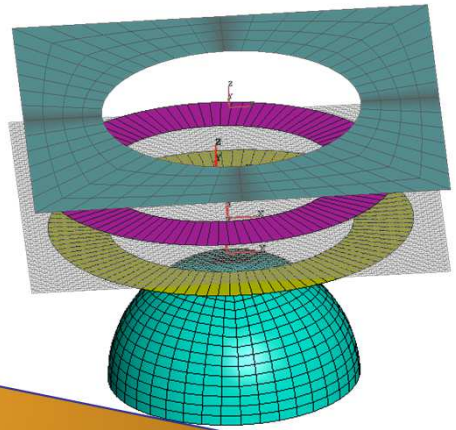


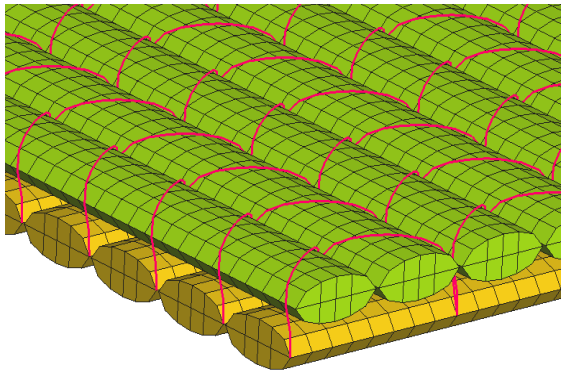
Available Methods Draping and Forming

Draping : PAM-QUIKFORM

FE : PAM-FORM / VPS







Kinematic methods

FE methods (macro-level)

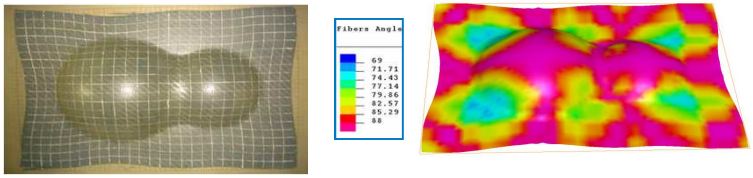
FE methods (meso-level)

LOW (OLD 1950+)

HIGH (NEW 2000+)

Effort/complexity
Input requirements
Modeling effort
CPU costs
Accuracy

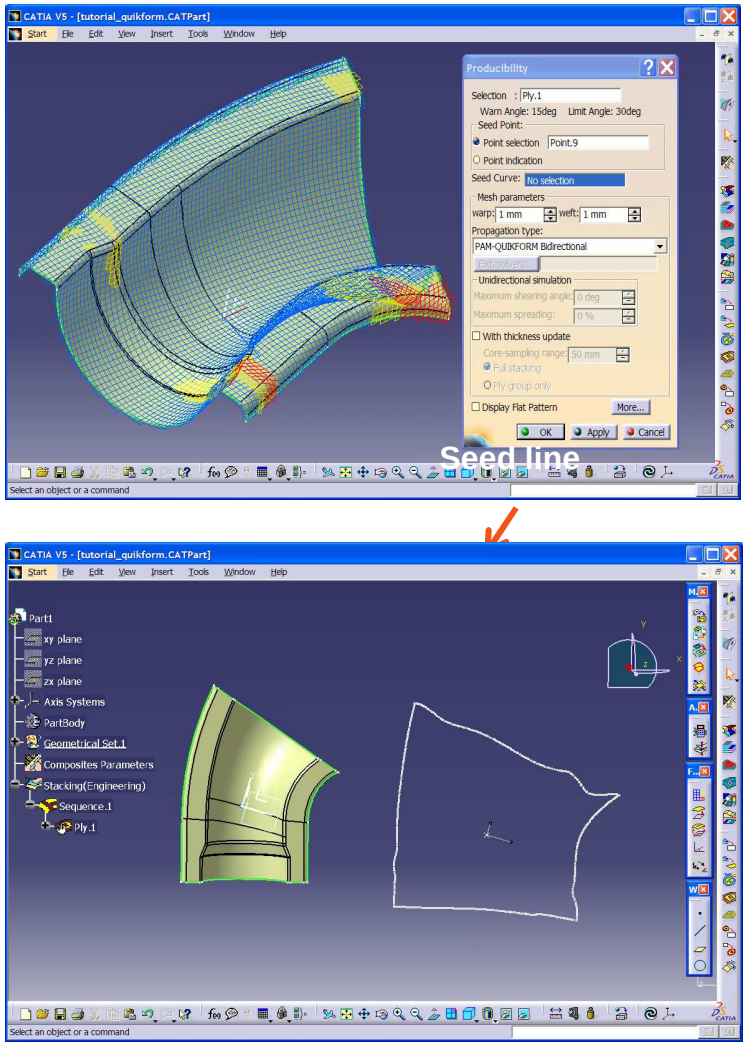
Kinematic Method using PAM-QUIKFORM



Experimental Simulation

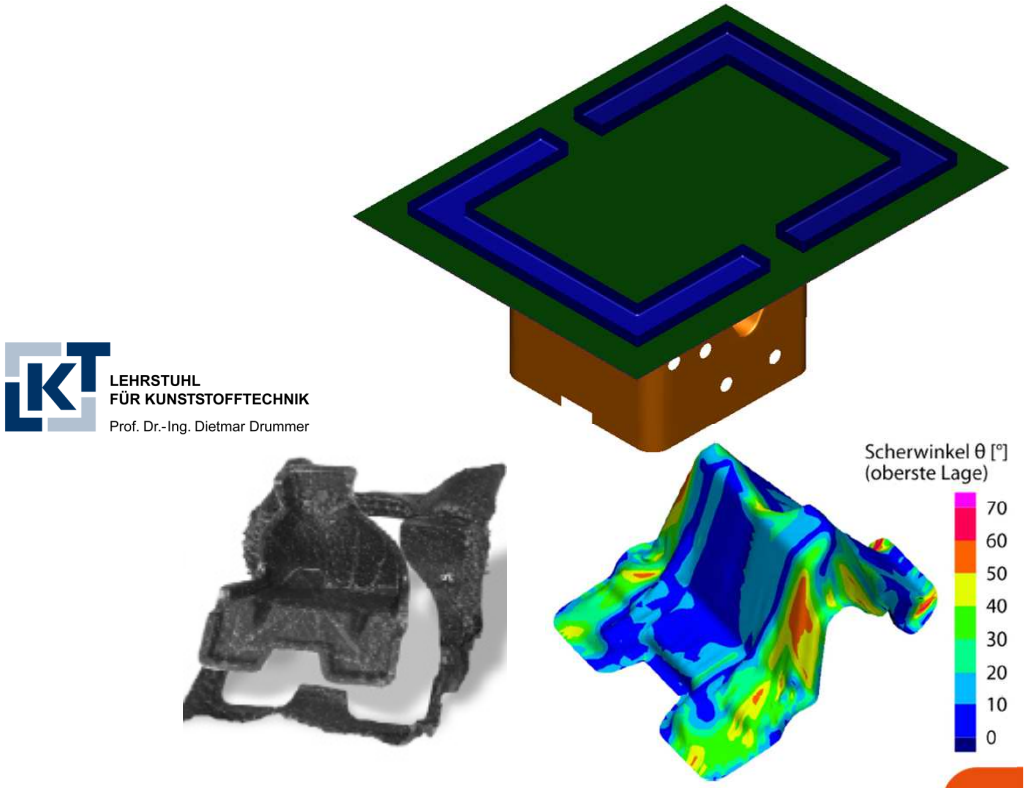
Courtesy: Cranfield University

- Deformation mechanism for
  - Fabric Textile
  - UD/ NCF Materials
- Draping strategy and part design feasibility with few seconds CPU Time
- Through the prediction of
  - Fiber Orientation
  - Shearing
  - Wrinkling
  - Flat pattern optimization



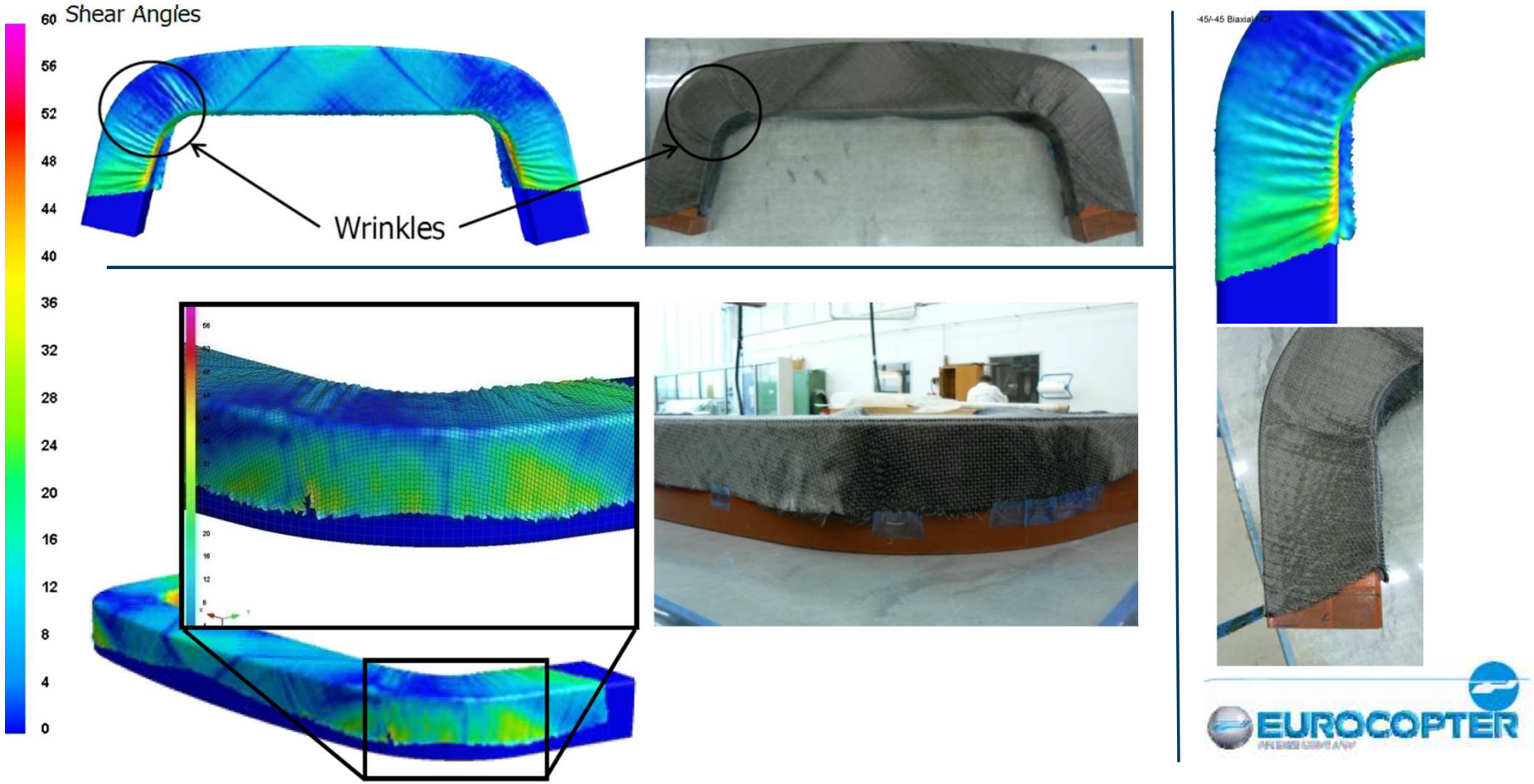
Forming simulation- PAM-FORM

- PAM-FORM can consider:
  - Different forming strategies:
  - Stamping, diaphragm (single or double) forming, thermoforming
  - Clamping conditions, process parameters, tool velocity, temperature, pressure
- to prediction:
  - Wrinkling
  - Bridging
  - Thickness
  - Optimum flat pattern
  - Contact pressure
  - Fiber orientation
  - Stresses and strains



Forming simulation- PAM-FORM

Example of Forming –Results of ± 45 NCF: Shear angles

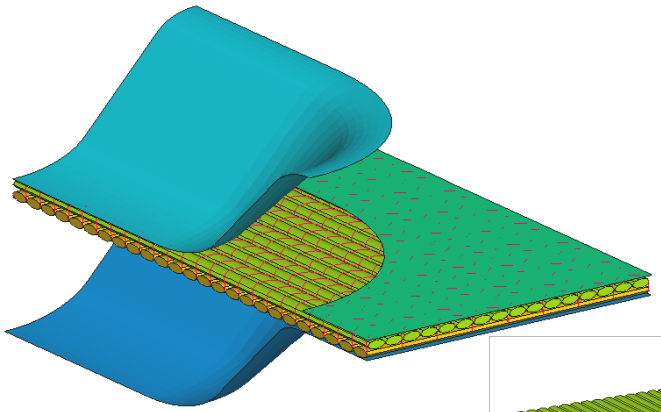


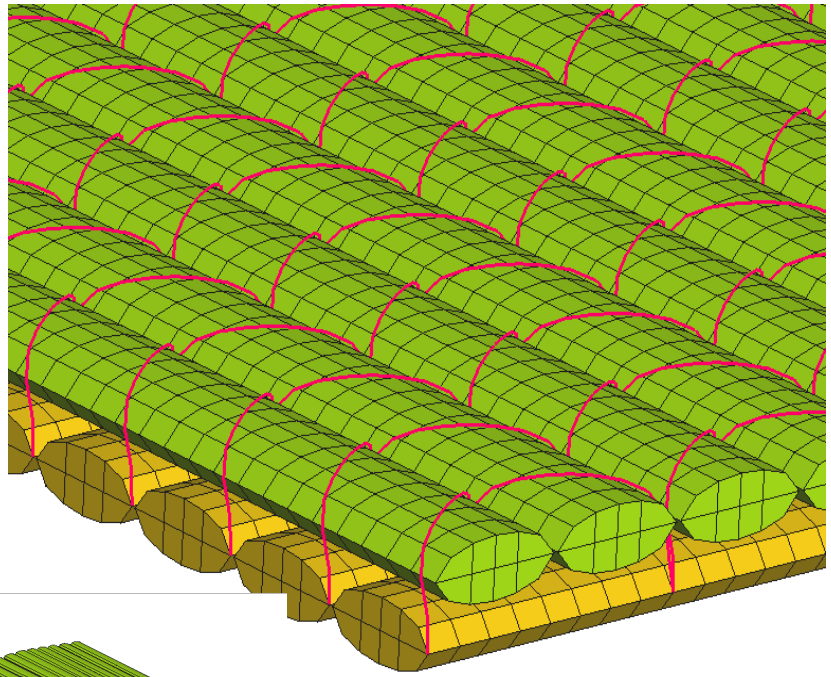
FE Methods (Micro Level)

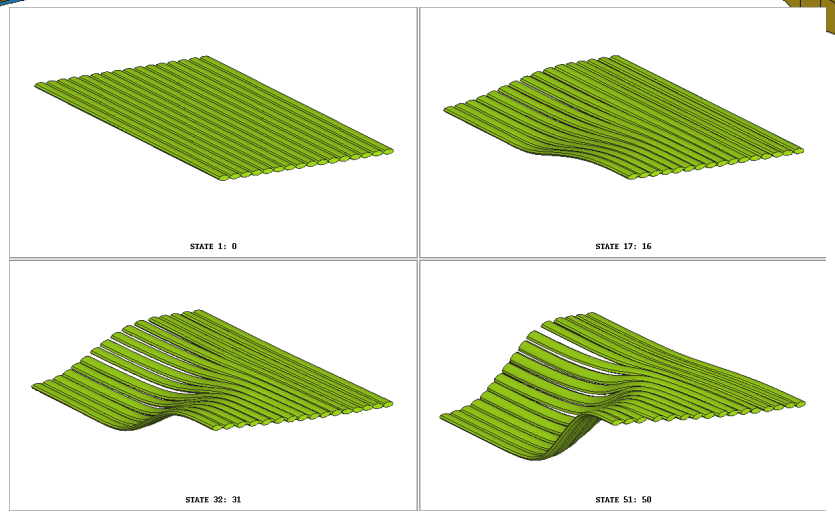
using PAM-FORM / VPS (Explicit)

R&D

- Meso-Mechanical models:
  - NCF draping simulation





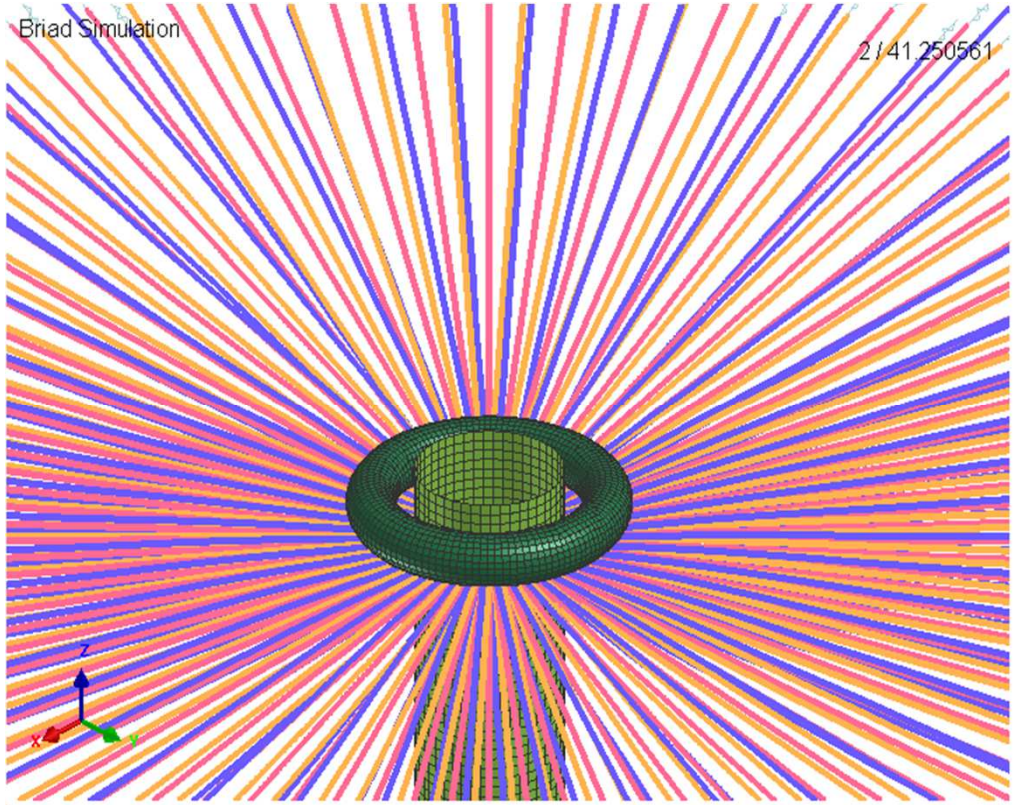


Courtesy Airbus UK & ESI GmbH (FALCOM Project)

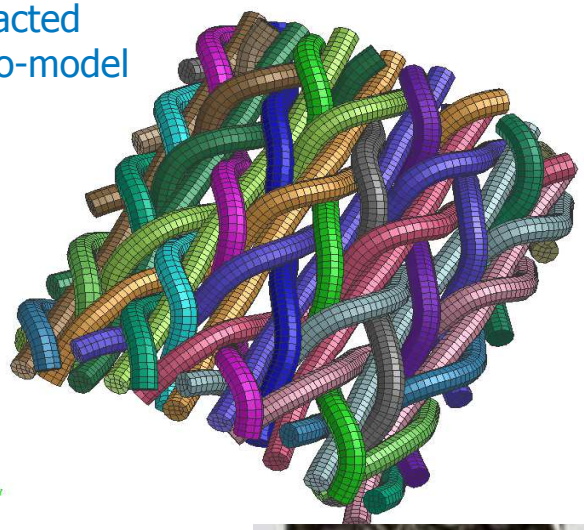
Braiding

Tri-axial Meso modelling Modell

R&D



Extracted meso-model



Braiding Simulation with PAM-CRASH
176 axis and off-axis yarns

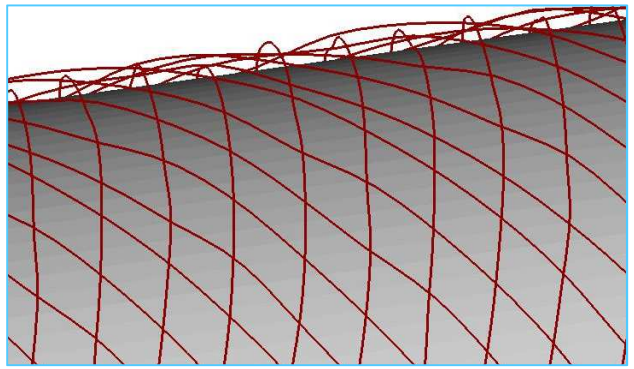
IFB

Filament Winding

Creation of 3D Fibre Architecture

R&D

- **Base: 3D position fibres**



FACHHOCHSCHULE GIESSEN FRIEDBERG

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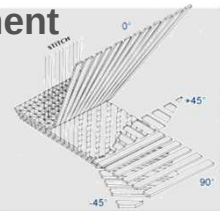
Filling simulation- PAM-RTM

PAM RTM, assumptions and prediction

Reinforcement
- Permeability K
- Density
- Heat conductivity
- Specific Heat



Resin
- Viscosity μ
- Density
- Heat conductivity
- Specific Heat capacity
- Enthalpy
- Kinetics Modeling

Resin & Reinforcement
- Capillarity
- Micro-Macro void function

Mold
- Heat conductivity tensor
- Specific heat capacity
- Density

Equations
- Flow of resin inside porous medium
- Heat exchanges inside reinforcement and mold
- Chemical reaction of resin
- Reinforcement deformation in case of infusion

For non-isothermal process only;
for resin velocity optimization only

PAM-RTM

Optimized
- Injection strategy
- Injection pressure or flow rate
- Molding temperature
- Location of injection gates, vents and vacuum ports
- Flow media position

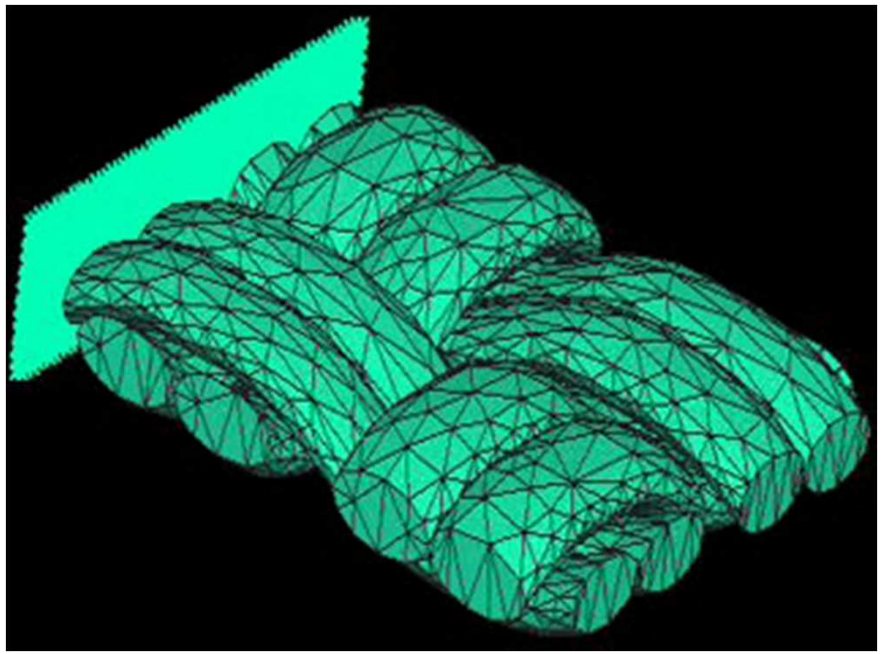
Prediction of
- Injection strategy
- Dry spots
- Filling and curing times
- Flow front velocity/Fiber washing
- Pressure applied to the mold

Liquid Composites Molding

3D Permeability (Constant or function of porosity)

Experimental

Simulation (FPM/CFD)



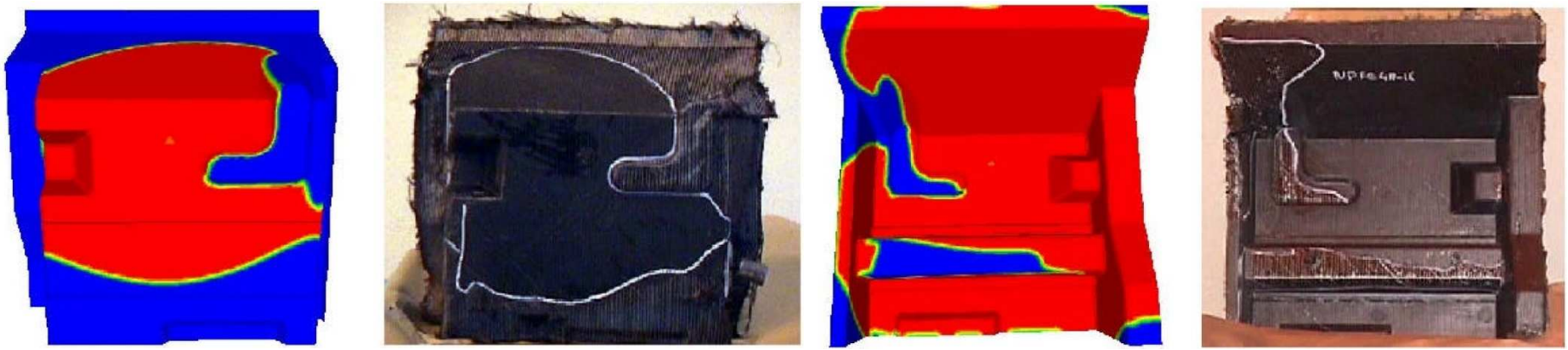
ÉCOLE POLYTECHNIQUE MONTRÉAL

$$K = \frac{v.L.\eta}{\Delta P}$$

Darcy's law

Filling simulation- PAM-RTM

Example of Resin flow front analysis



Mold filled to 40%

Mold filled to 80%

Mold filled to 100%

0% injected

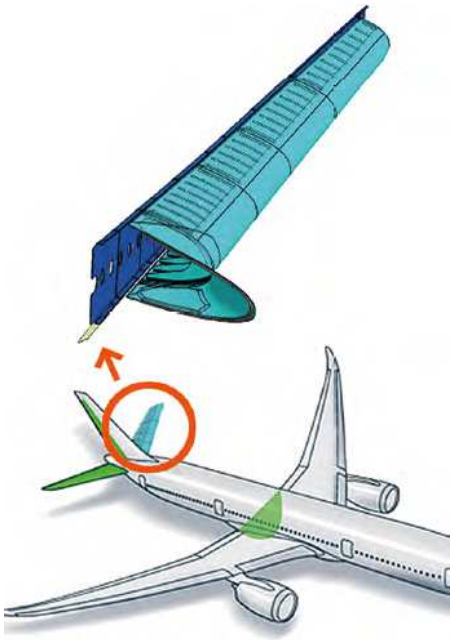
100% injected

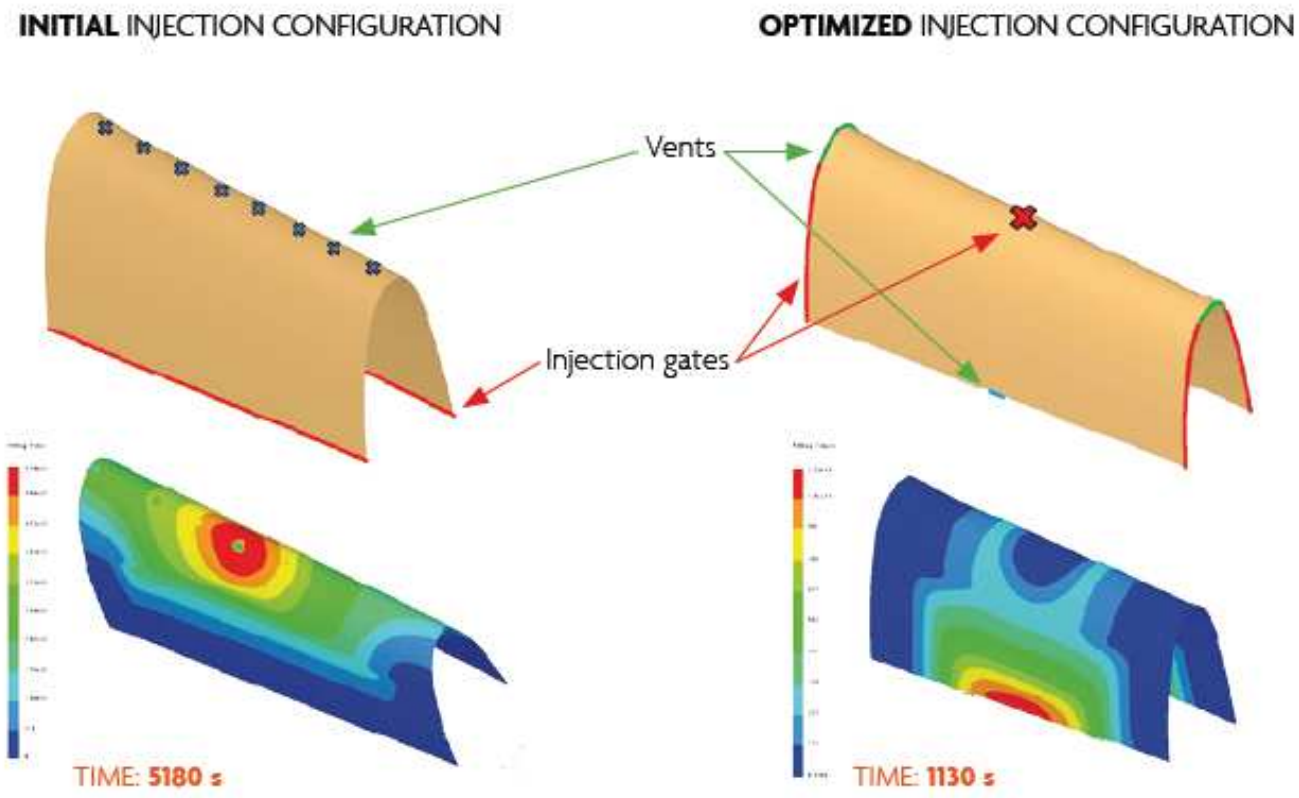
TECABS

Ecole d'Ingénieurs Centre de Recherche Mines de Douai LILLE EUROREGION

Filling simulation- PAM-RTM

To minimize filling time through process strategy





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Distortion simulation - PAM-Distortion

Shape distortions and residual stresses and where they come from

Draping Preforming

prepreg

dry preform

- Laminate lay-up
- Draping / forming effect

Injection Curing

Autoclave

RTM

- Thermal expansion
- Chemical shrinkage
- Cure temperature and uniformity of the field
- Tool thermal expansion

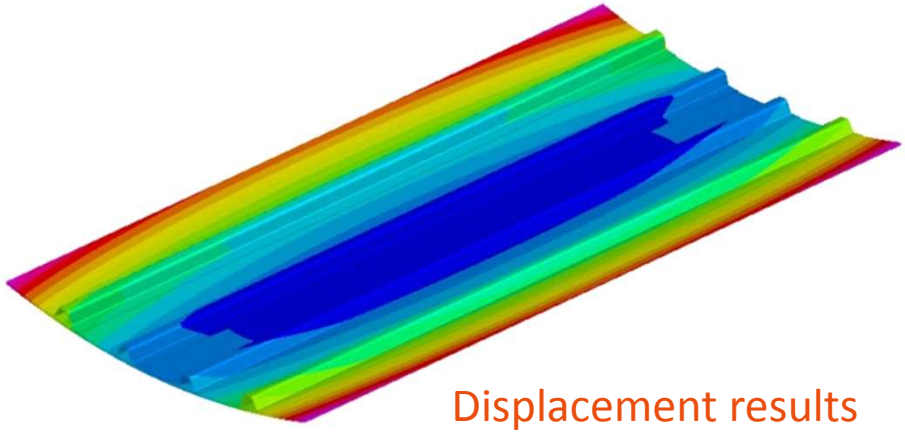
Demolding

- Defect
  - Warpage
  - Delamination

Internal stresses generation

Distortion simulation - PAM-Distortion

- To define and optimize:
  - Stacking definition
  - Curing process
  - Mold material and design
  - Mold geometrical compensation



Displacement results

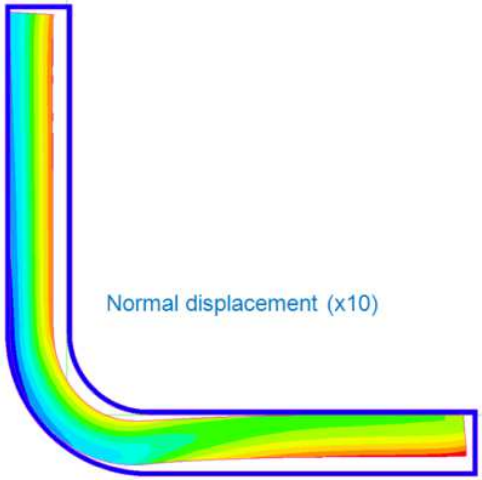
Fuselage Panel example

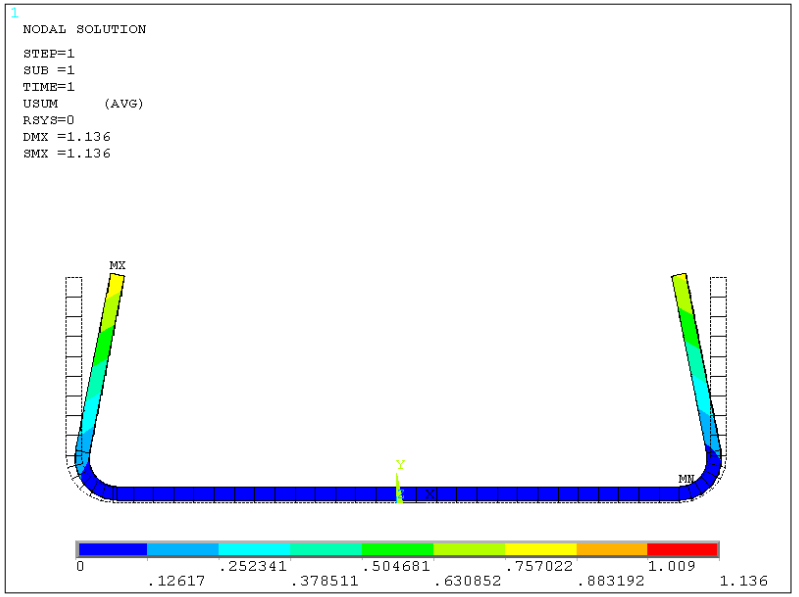
- Through the prediction of:
  - Internal stresses during curing
  - Residual stresses after demolding
  - Deformation during curing
  - Deformation after demolding

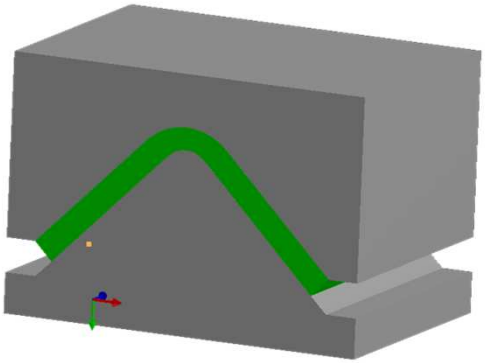
- Taking into account
  - Material history during curing process (temperature and degree of cure)
  - Thermal and mechanical interaction with mold

Distortion simulation - PAM-Distortion

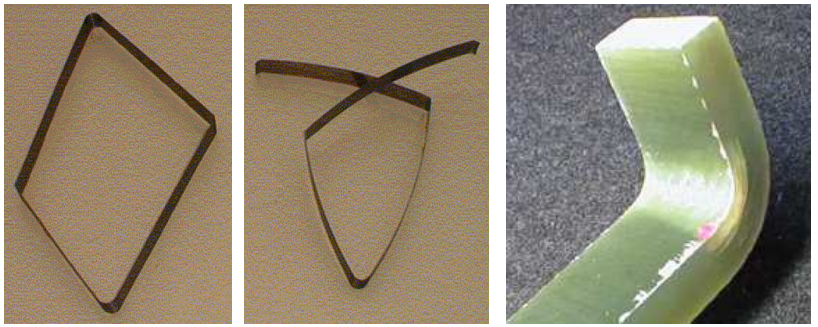
Example of a Distortion analyses







Courtesy: SWEREA SICOMP



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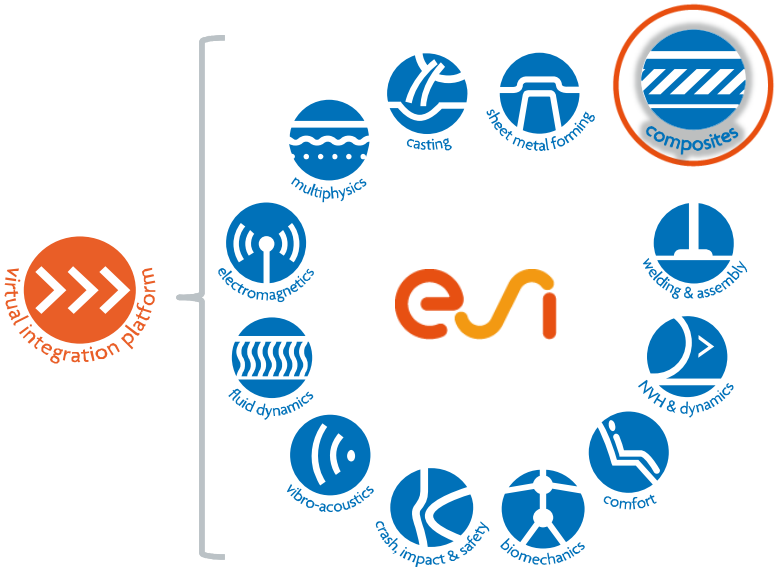
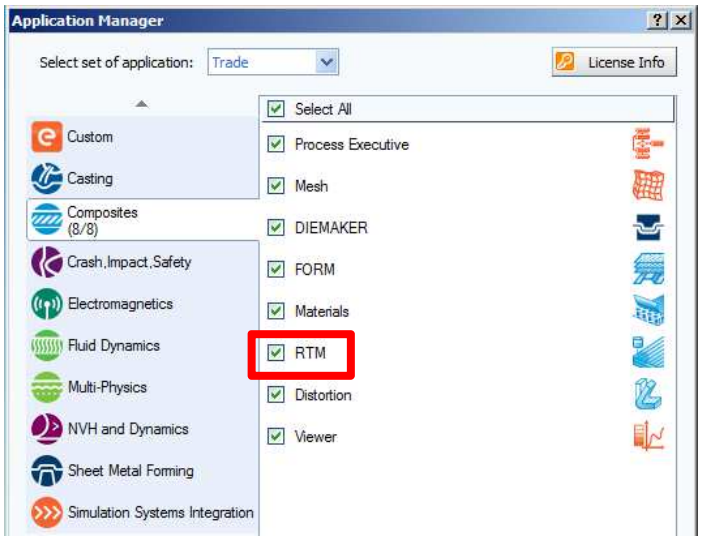
Visual Environment

Enhancement for Composites



Release Jan 2015



Basics

Software Framework & Performance (1/2)

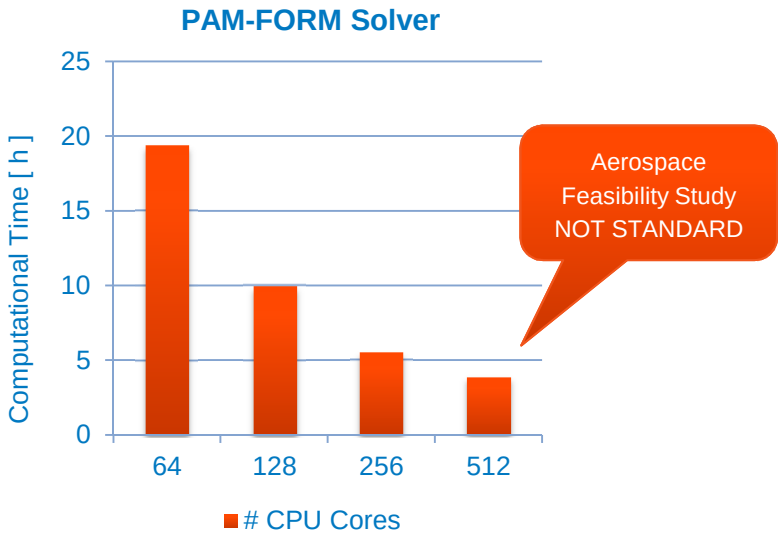
- ESI is permanently integrating and improving it's End to End Virtual Prototyping Solution (SOLVER and GUI Framework)
  - GUI: Visual Environment Frame with derived dedicated Apps. / for HIGH END Visualization ICIDO VD Software
  - SOLVER: Explicit and Implicit Solver (Single Core) for Manufacturing and Virtual Performance as well as CFD and mesh-less Methods (FPM/SPH) for multi-physics Apps.

- ESI is offering a Solution Toolkit with open interfaces
  - ASCII and XML for input/output
  - ERF container (HDF5-Format / http://www.hdfgroup.org/HDF5) for output

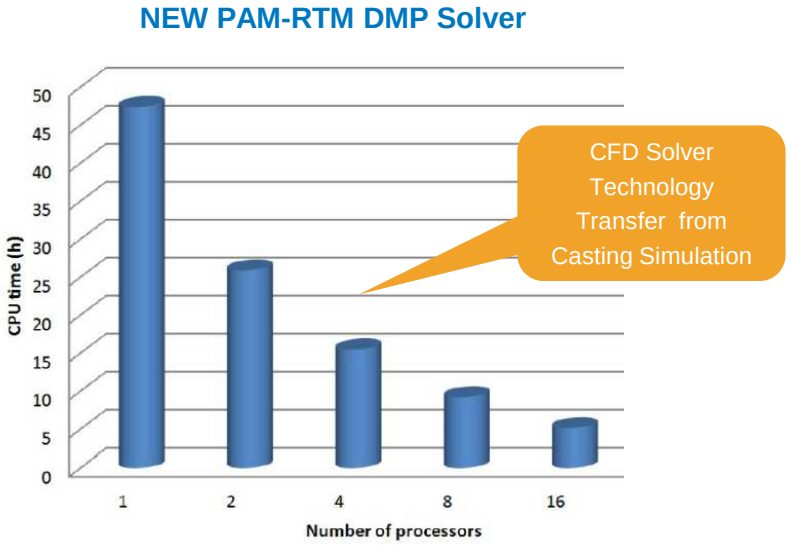
Basics

Software Framework & Performance (2/2)

- Computational performance is a key success factor
  - Parallel processing (8, 16, 32, 64 CPU Cores) with real scalability is mandatory in order get appropriate response times



Draping (PAM-FORM DMP)
- C-Channel
- 10 Meters /100 plies
- 7.8M Shell Elements



LRI Process (PAM-RTM DMP)
- Aeronautical part
- 2.5 Meters / 10 plies
- 1.25M 3D Elements

General Benefits of the migration to Visual-Environment

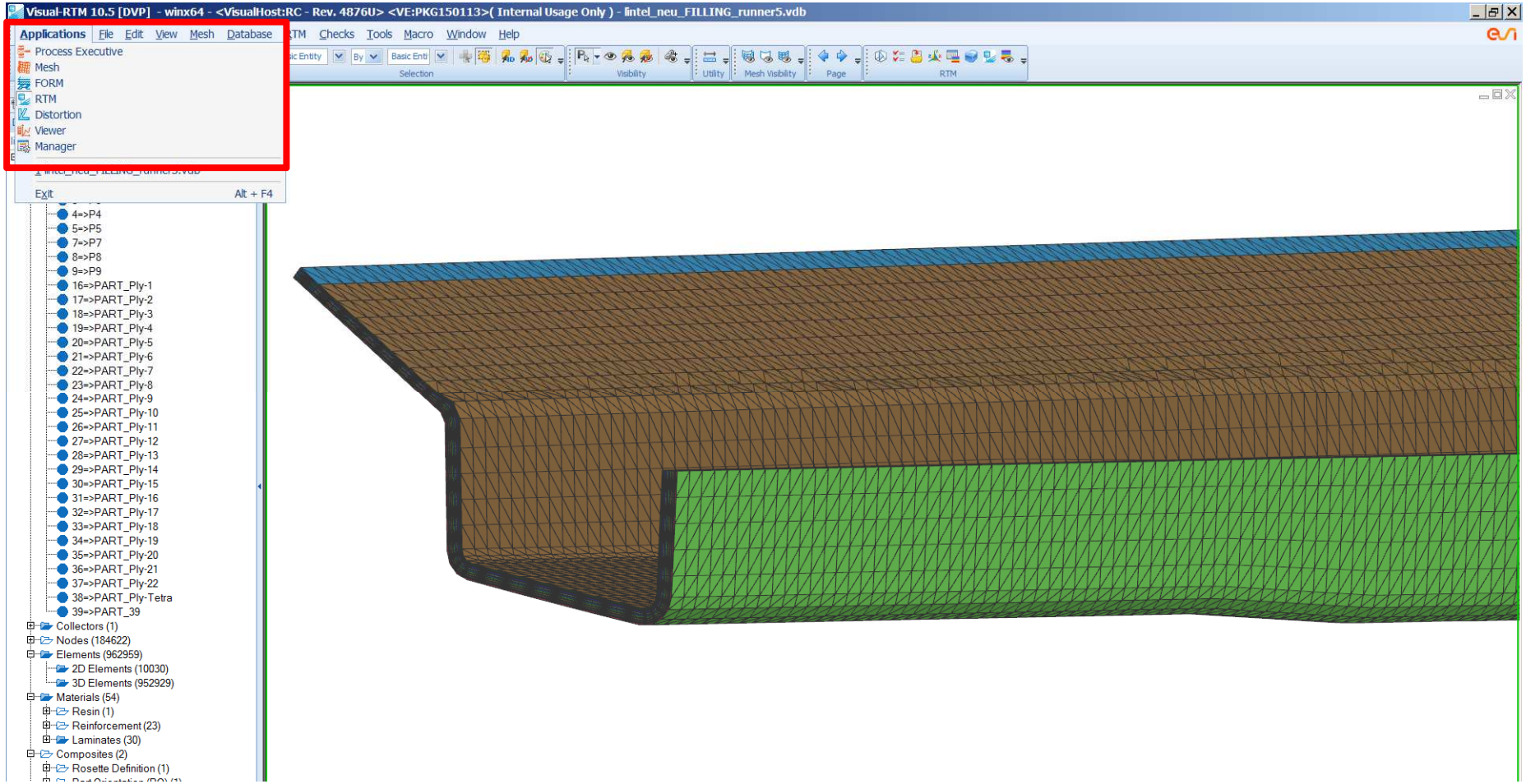
- Fully integrated environment for all 3 applications:
  - PAM-FORM, PAM-RTM, PAM-DISTORTION

- Common :
  - **Material database** management
  - **HDF5** format for simulation results
    (ERF file replacing *.DSY, *.THP, *.res, etc…)
  - Post-processing application: **Visual-Viewer**

- Access to Visual platform functionalities:
  - **Python scripting** for automation of process modeling
  - Advanced meshing capabilities through **Visual-Mesh**

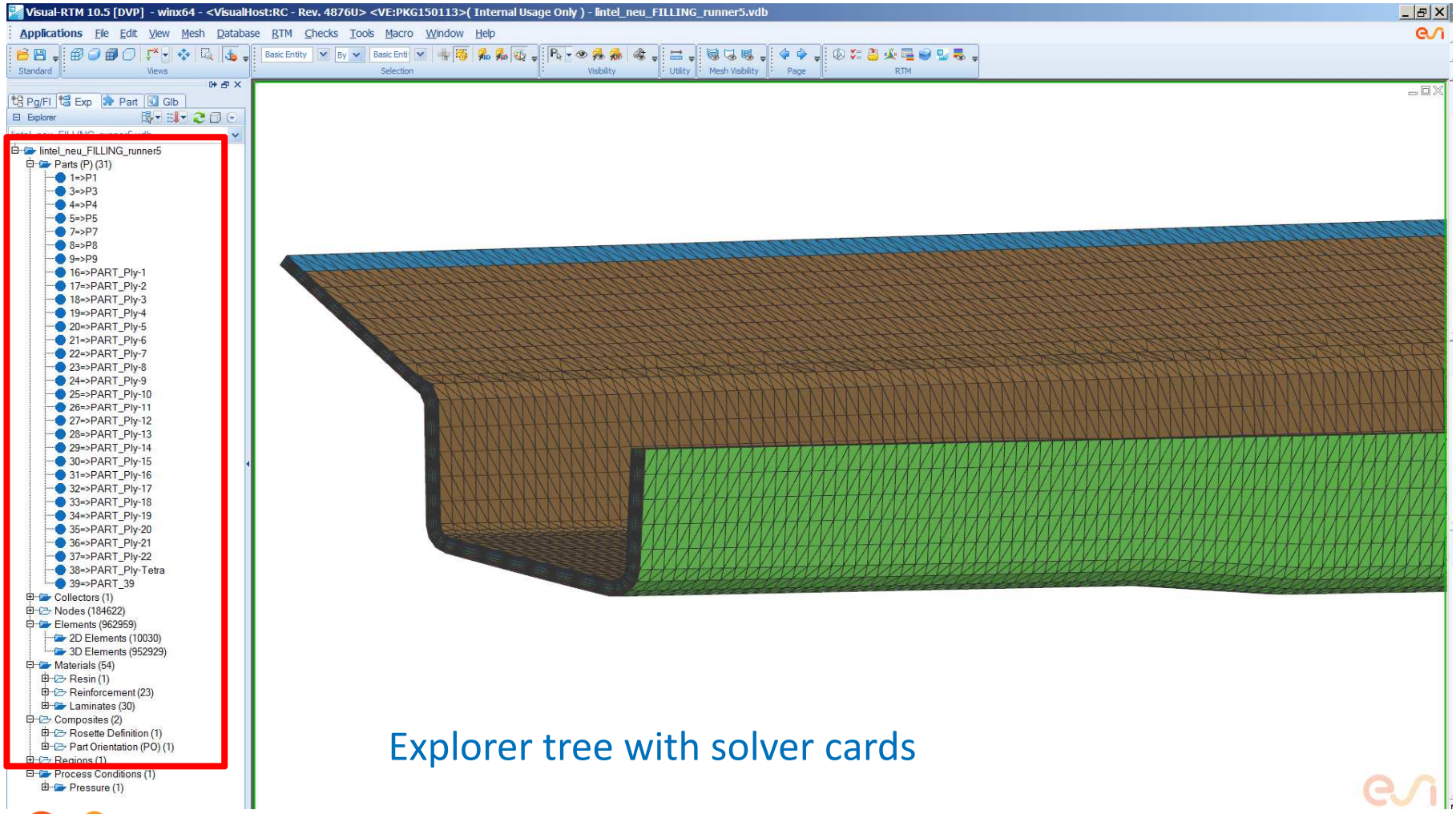
All applications in the same environment

(FORM, RTM, DISTORTION)



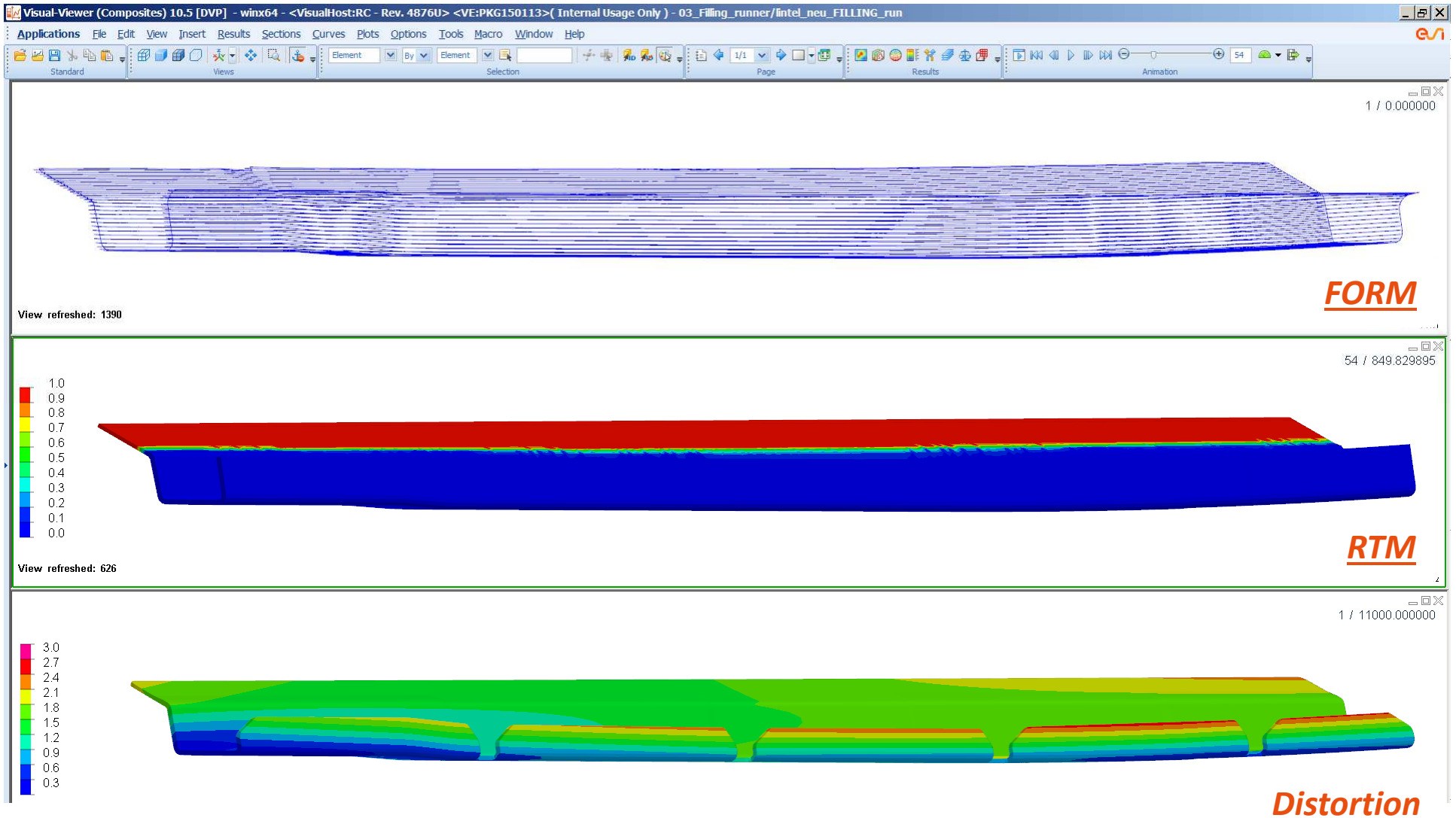
All applications in the same environment

(FORM, RTM, DISTORTION)

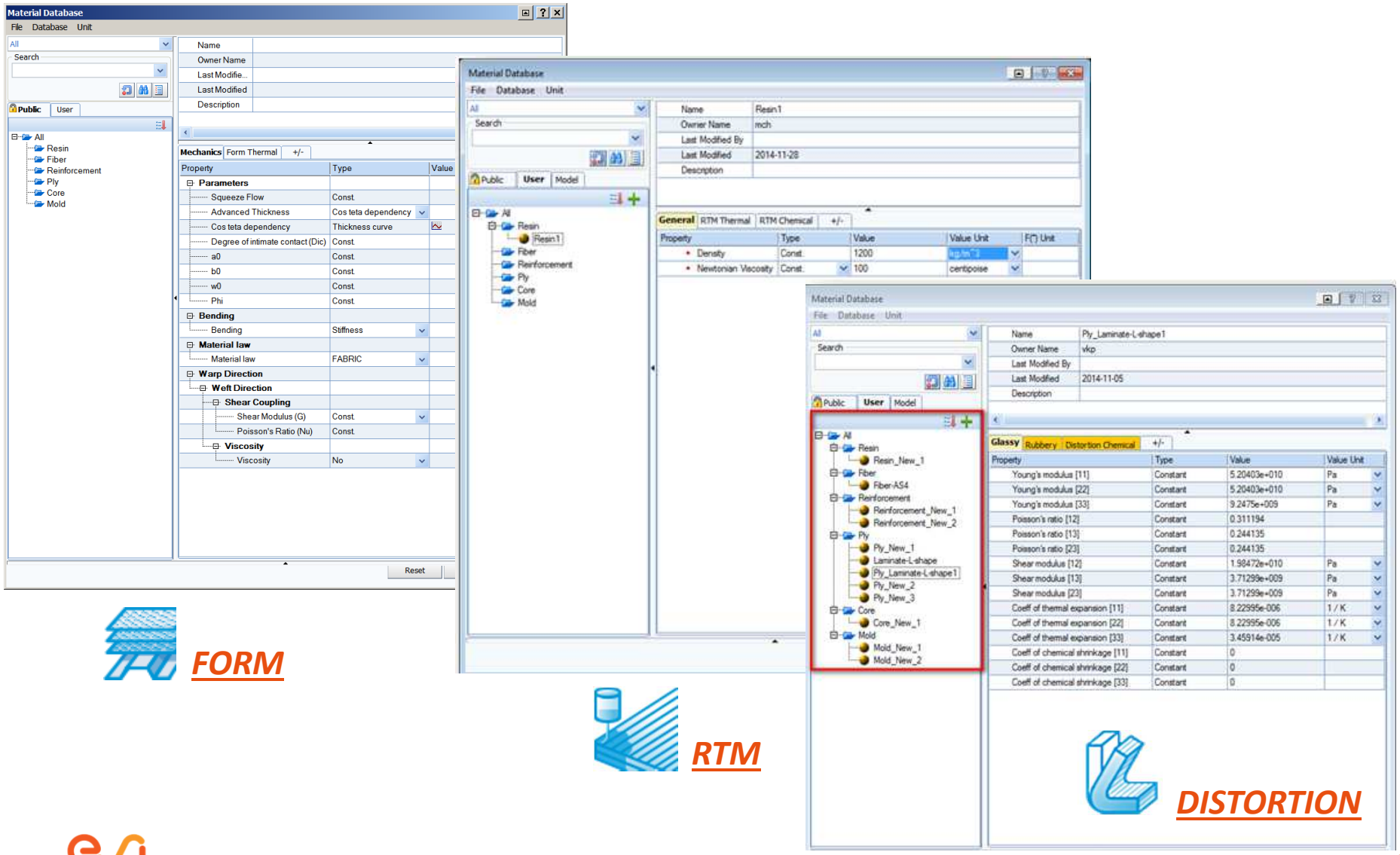


Explorer tree with solver cards

One unique Viewer for post-processing all applications

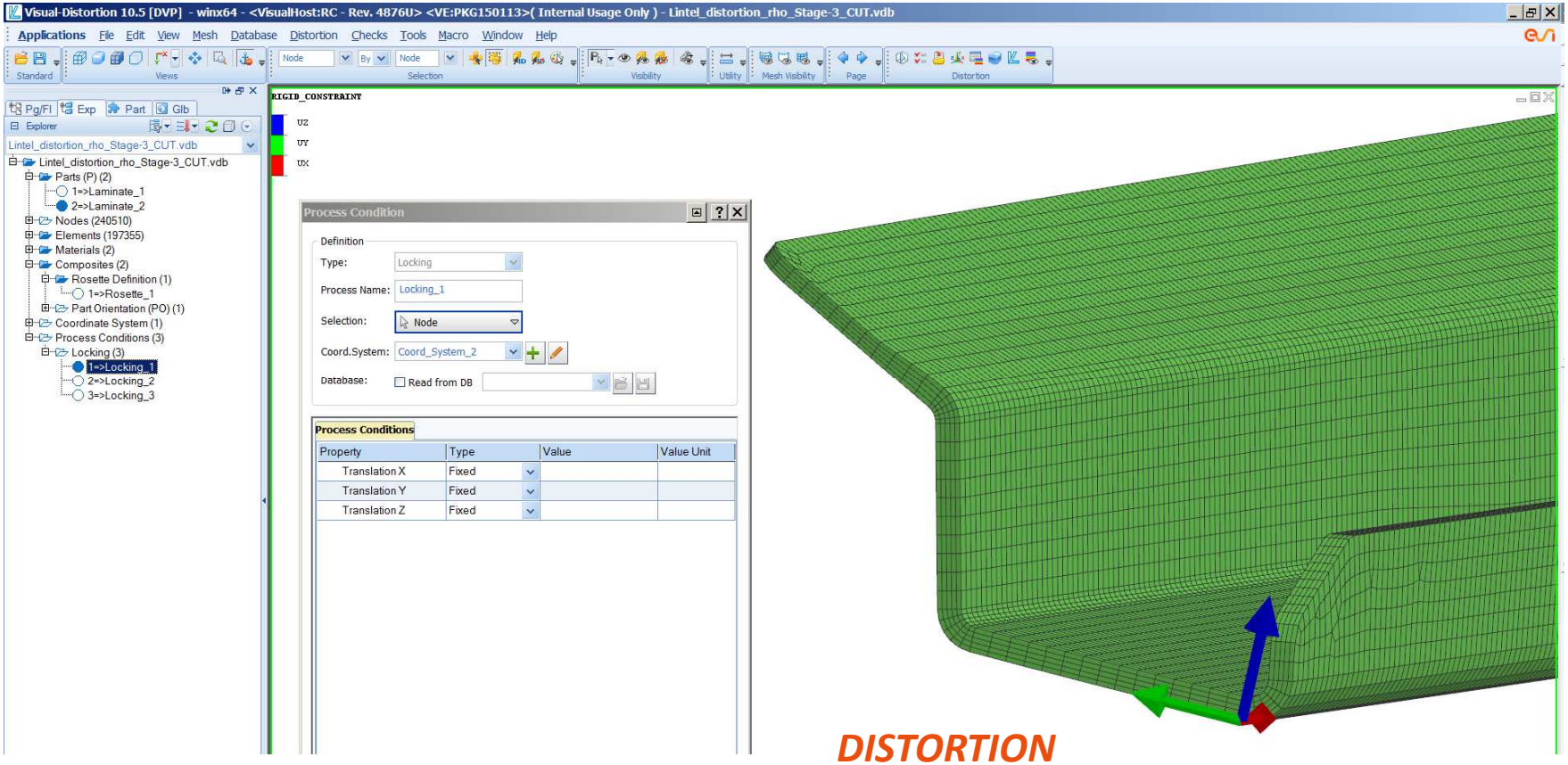


Common Material Database for all applications



Advisor for easy setup creation (process oriented)

User still has access to solver cards

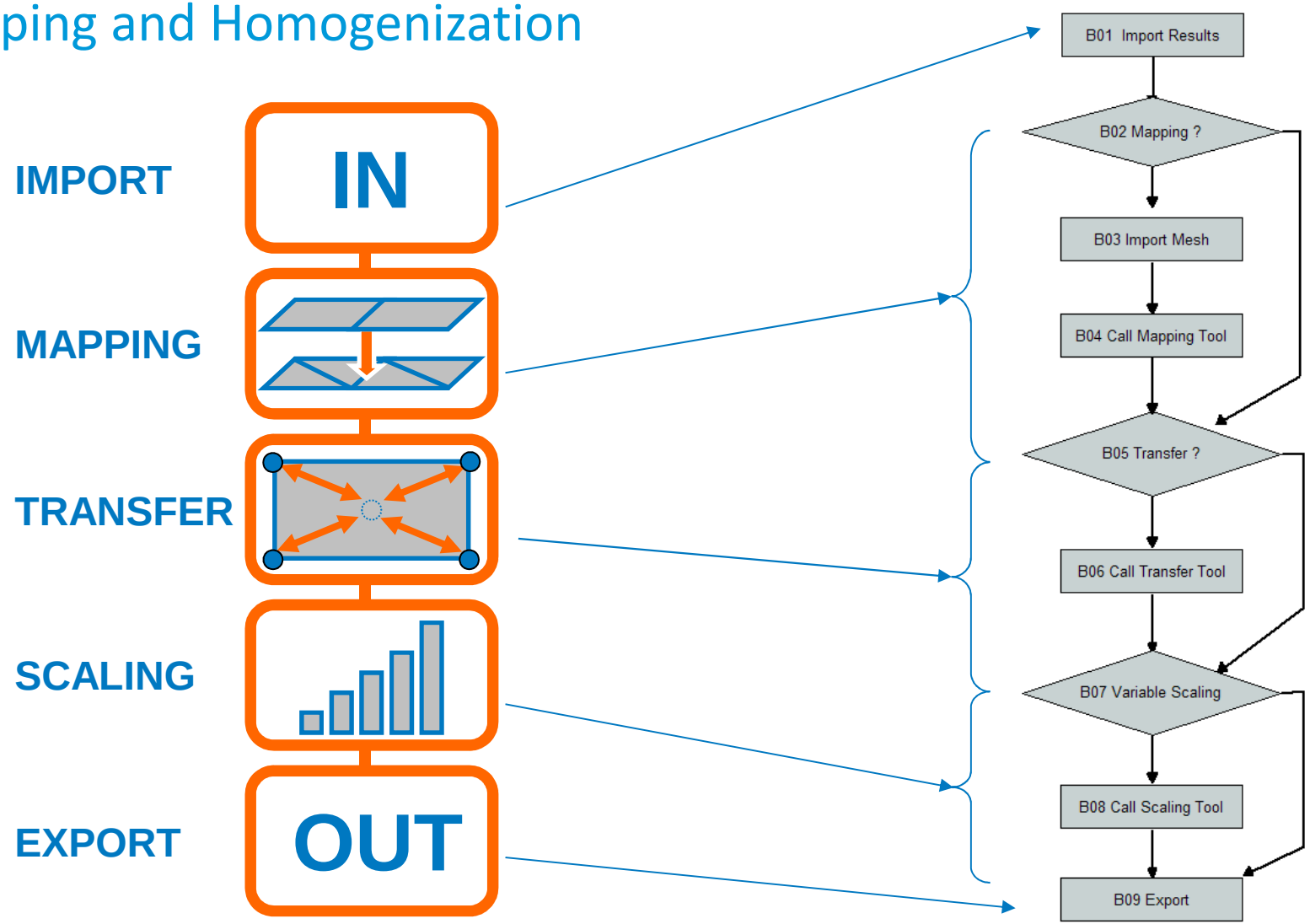


DISTORTION

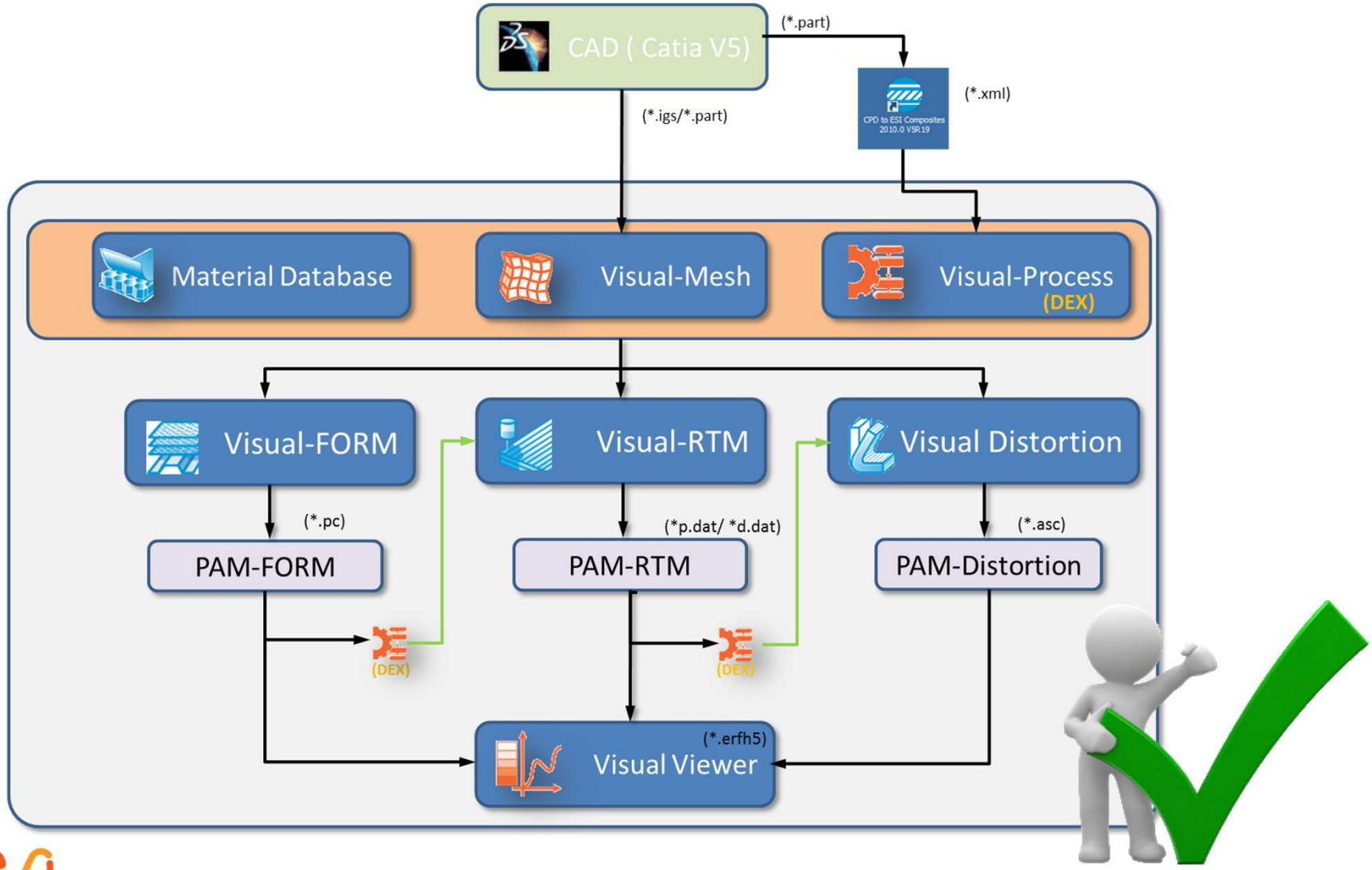
Visual Process (DEX)

(DEX)

Mapping and Homogenization



Workflow for Composite Process Simulation chain



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    - PAG (aeronautical part)

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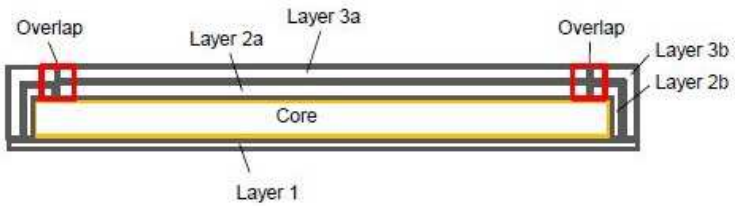
KTM Race Car Application Front Splitter

Front Splitter

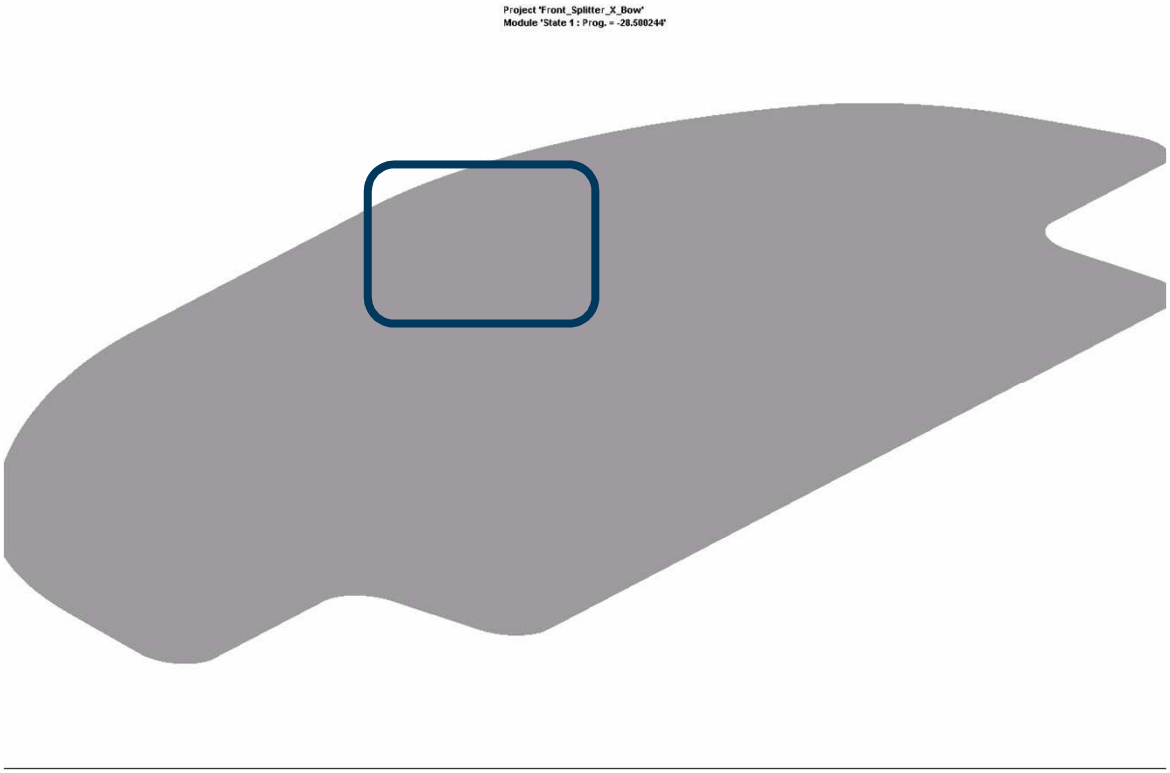
Laminate definition

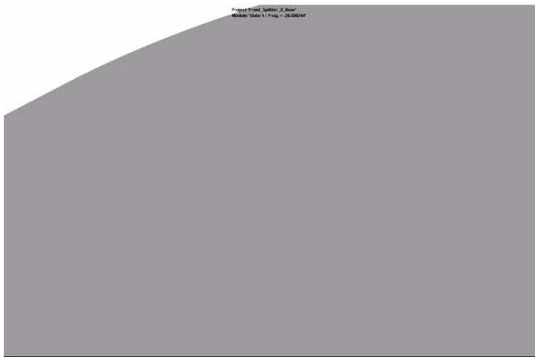


Fiber: Tenax–J STS 40 F13 24 K 1800 tex; Binding type: plain
Resin+ Hardener: EpikoteResin04695/1 and EpikureCuringAgent 05357
Core: Büfadur67 –15, PUR Foam

Zoom-in on structure

Pre-forming of upper plies with PAM-FORM

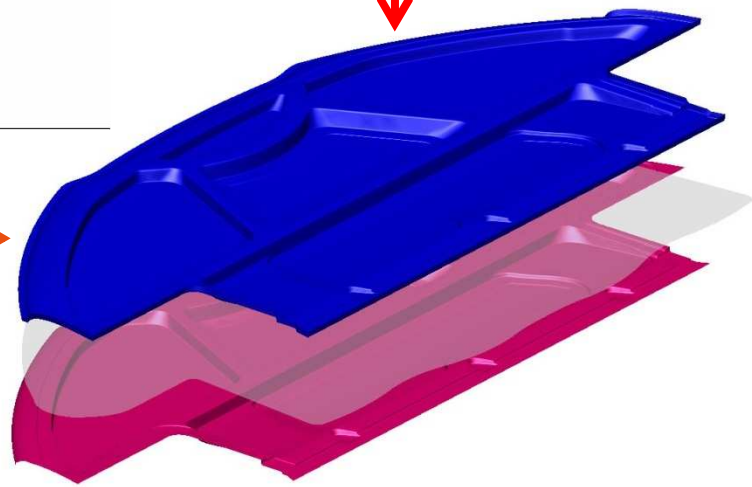




Upper tool's displacement

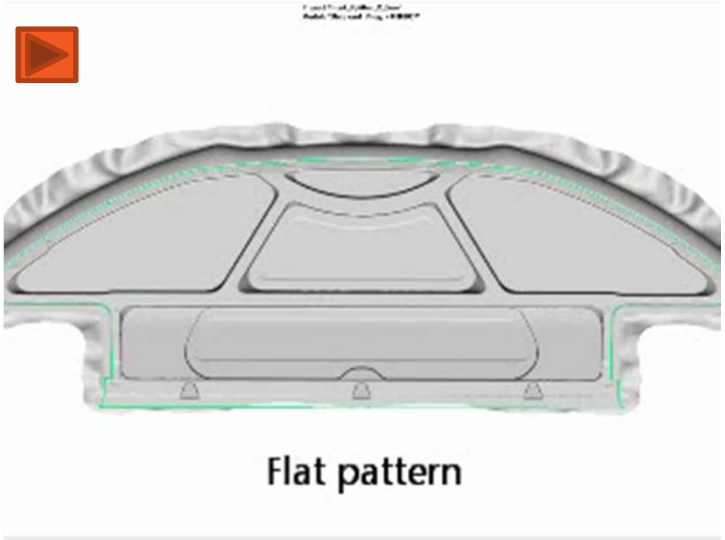
Upper tool

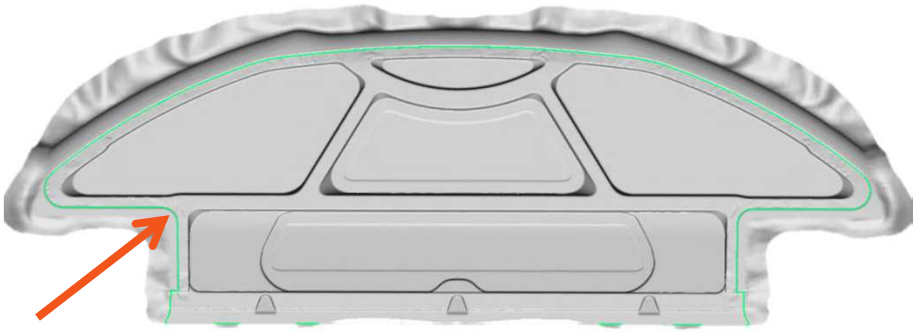
Lower tool (lock)



Pre-forming simulation for flat pattern optimization

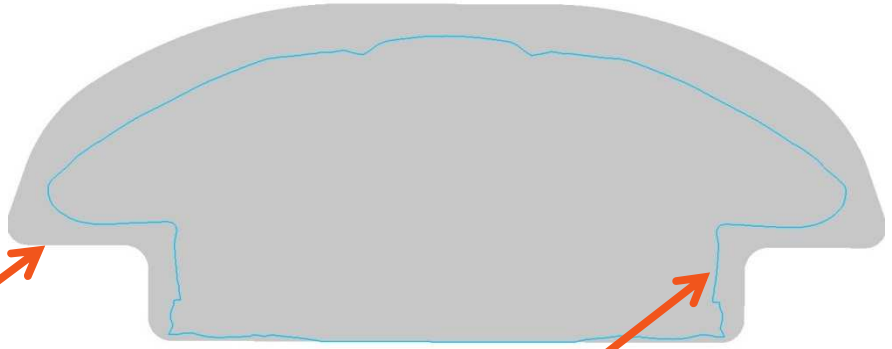
Flat pattern optimization





Trim-line

Reverse engineering
to optimize initial ply pattern

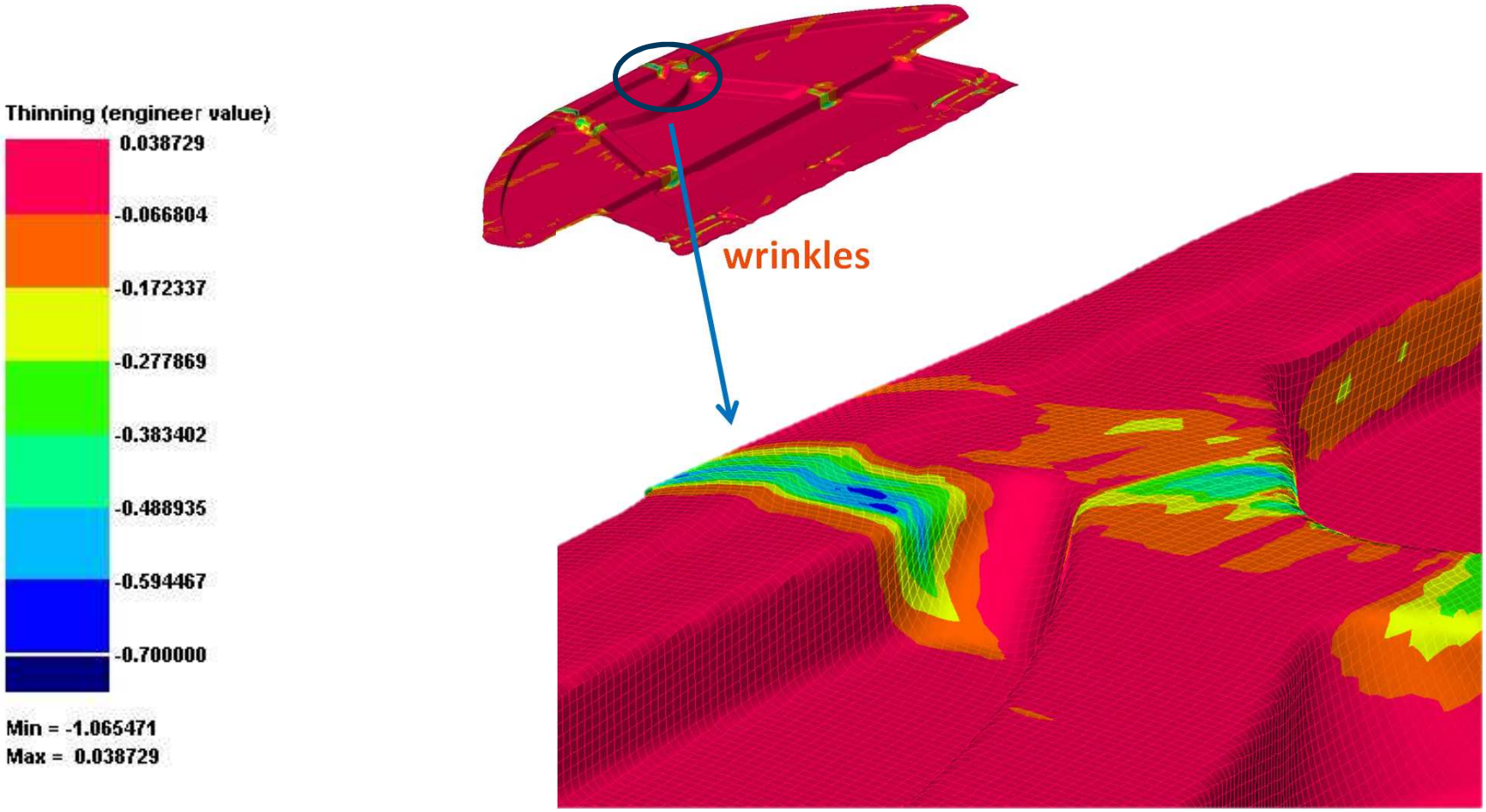


Initial ply contour

Optimized ply contour

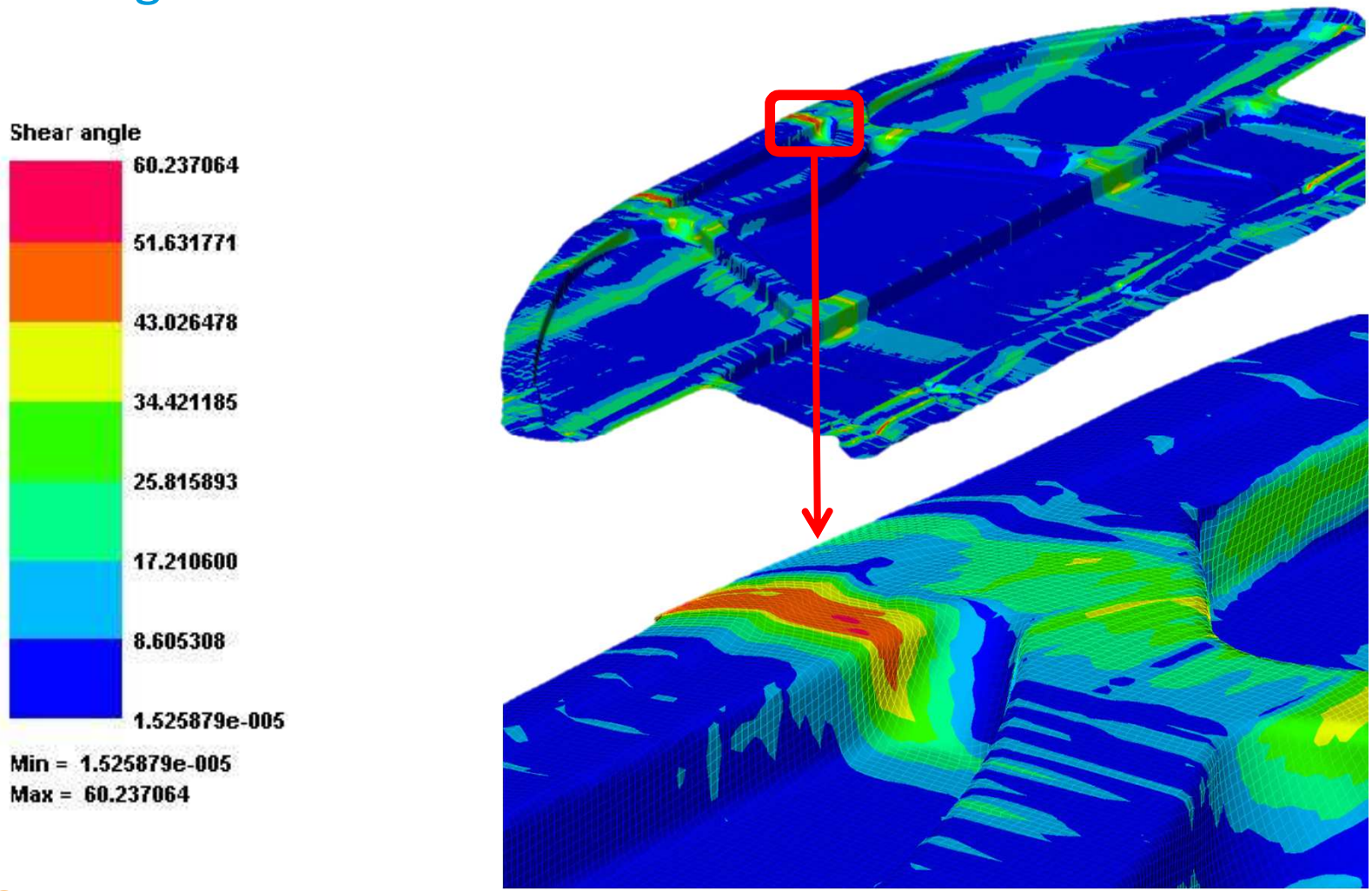
Pre-forming simulation to predict and optimize thickness

Thinning contour



Pre-forming simulation to predict and optimize shearing

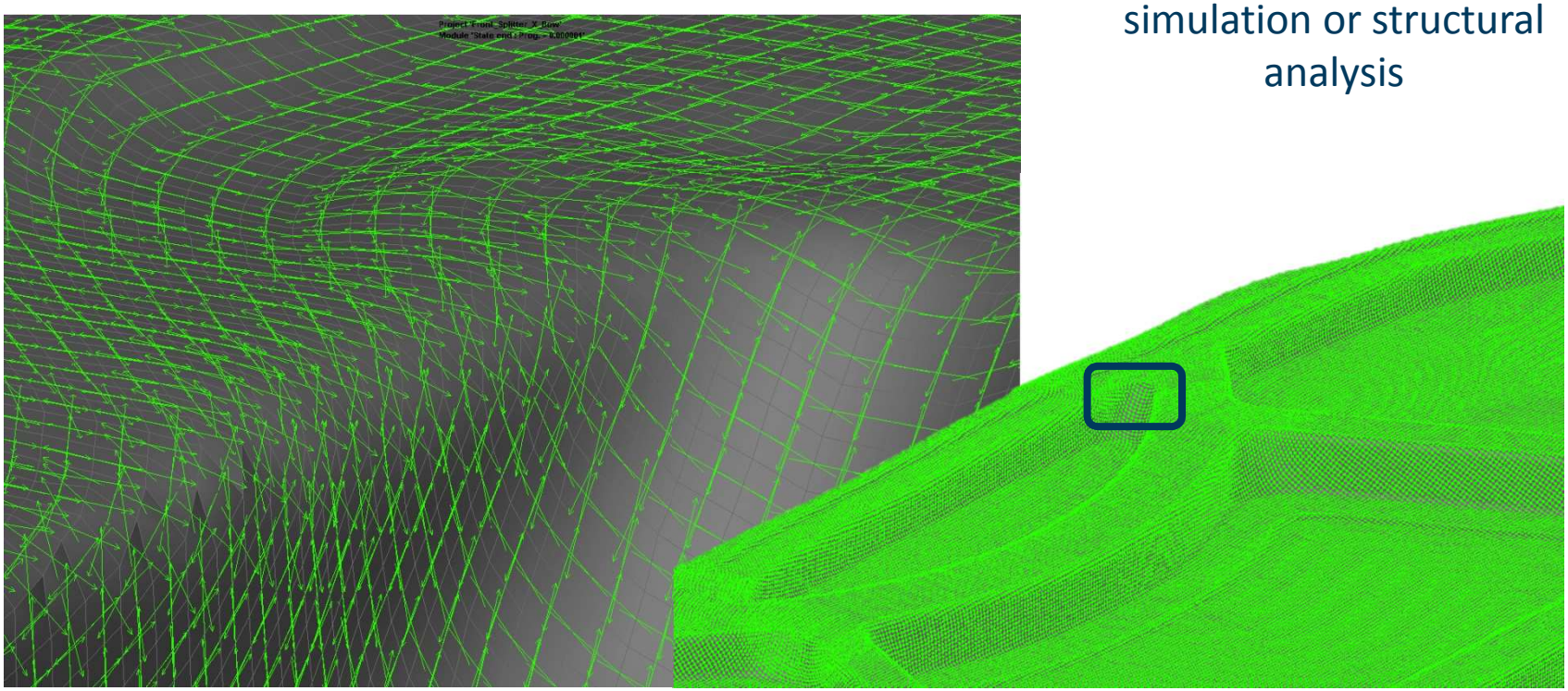
Shear angle



Pre-forming simulation to predict and optimize fiber orientations

Fiber orientation

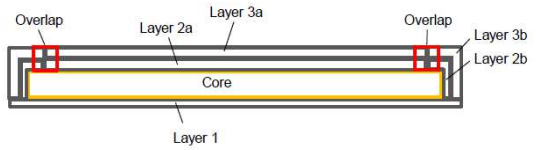
Export your ***fiber orientation*** for injection simulation or structural analysis



Injection simulation to predict and optimize

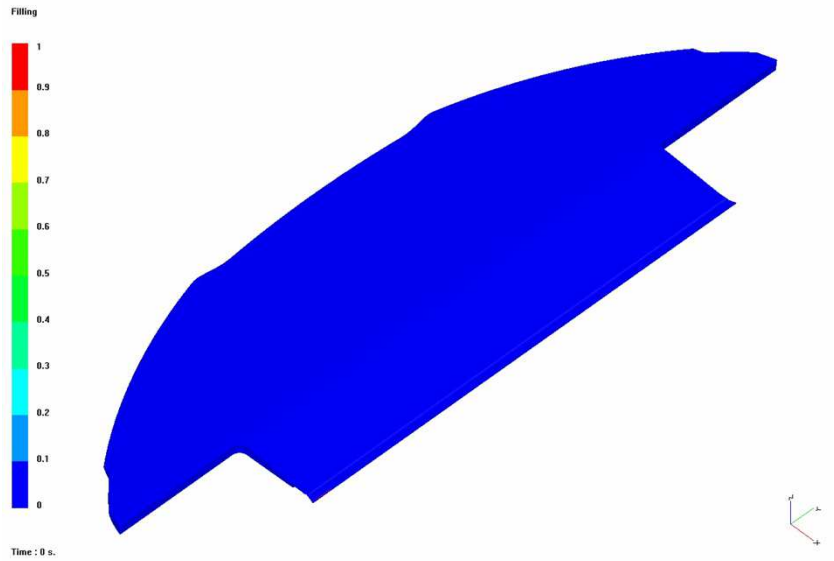
Dry spots, porosities...

- 3D injection taking into account fiber orientations (impact on permeability) from preforming simulation

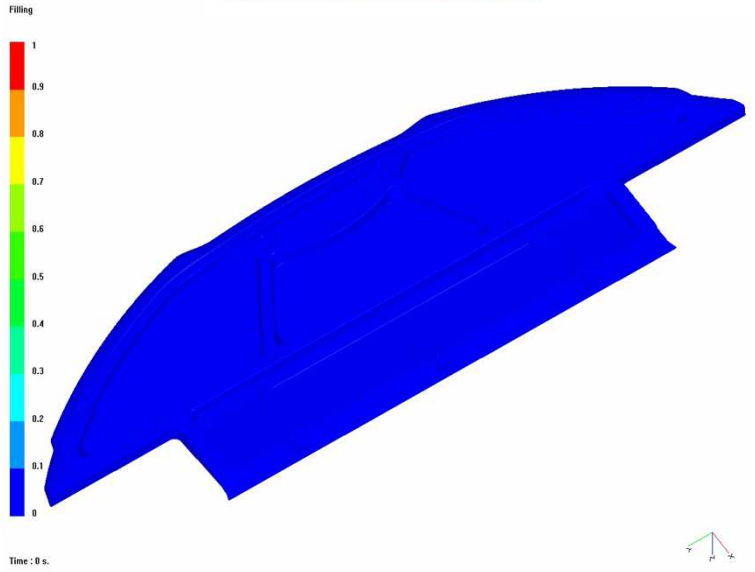


Lay-up

Layer Number	Material	Angle
Layer 1	Tenax – J STS 40 F13	0°/90°
Layer 2a	Tenax – J STS 40 F14	0°/90°
Layer 2b	Tenax – J STS 40 F15	0°/90°
Layer 3a	Tenax – J STS 40 F16	0°/90°
Layer 3b	Tenax – J STS 40 F17	0°/90°



Bottom view

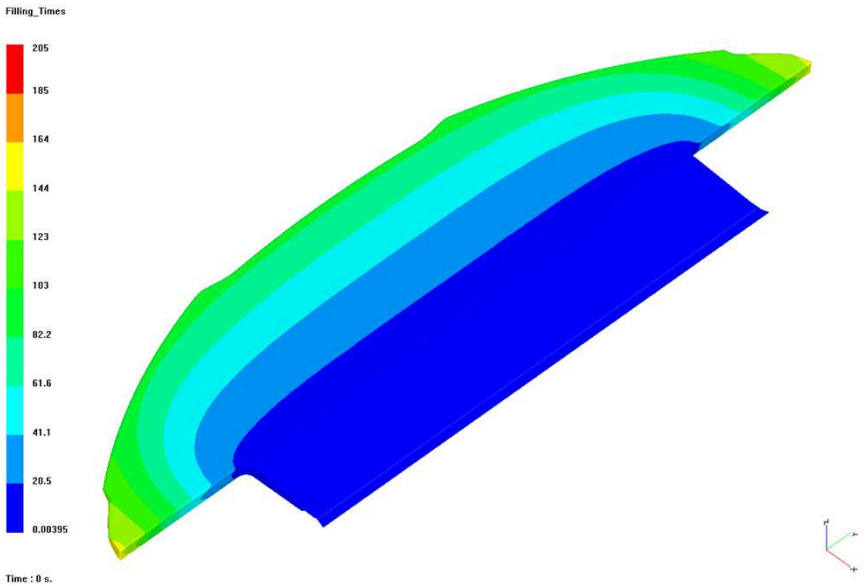


Top view

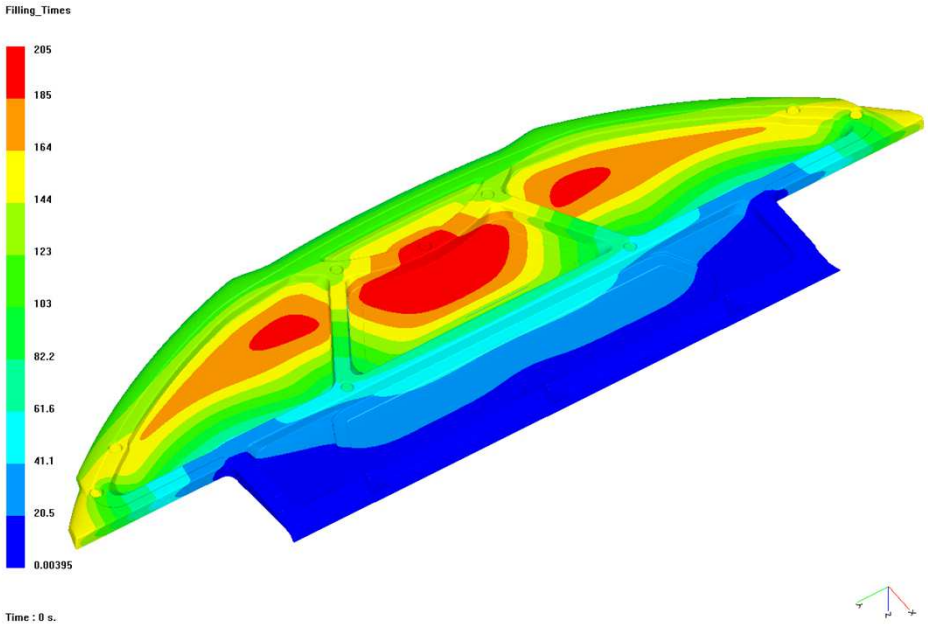
Resin Flow front during injection

Injection simulation to predict and optimize filling time

Filling time



Bottom view



Top view

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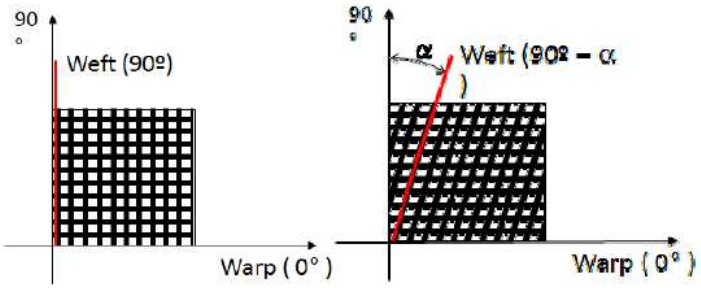
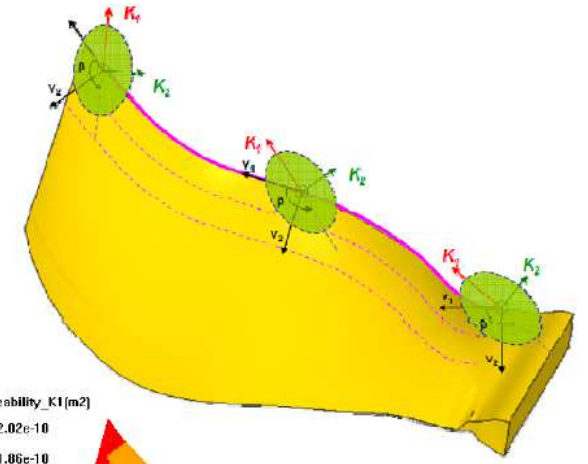
Draping Influence on RTM Process

Draping of fabric

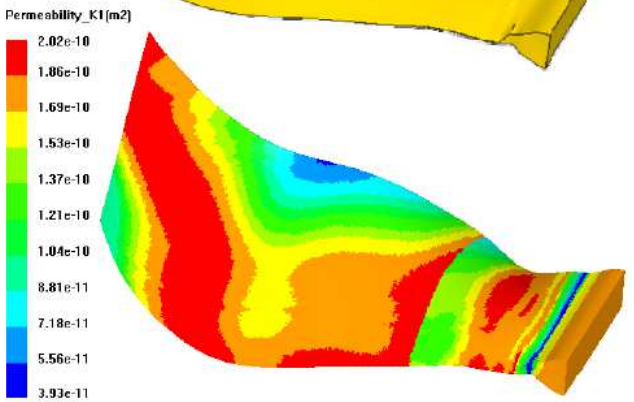


Draping of blade reinforcement



LEAP56™ engine

Composite fan blade



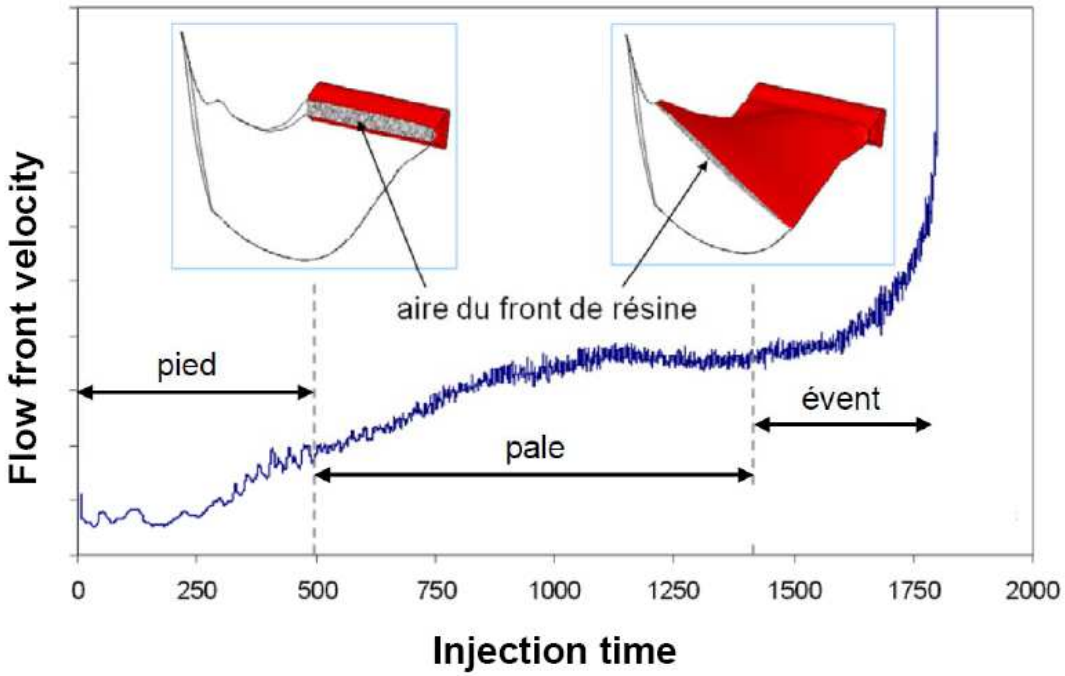
ÉCOLE POLYTECHNIQUE MONTRÉAL

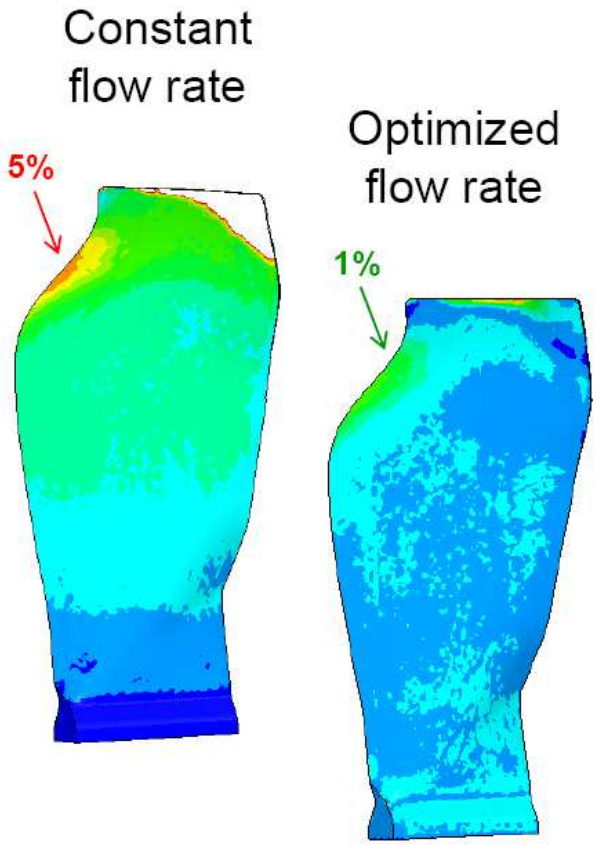
bruno.dambrine@snecma.fr / edu.ruiz@polymtl.ca

Snecma Groupe SAFRAN

'Presented at JEC2010 Composites Simulation Forum'

Porosity of the RTM process in structure calculation





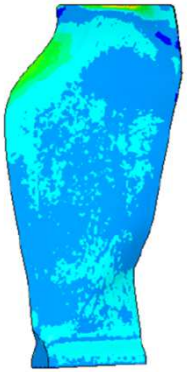
Optimization of injection flow rate to minimize micro/macro-voids formation in resin transfer molded composites

E. Ruiz [a], V. Achim [a], S. Soukane [a,*], F. Trochu [a], J. Bréard [b]

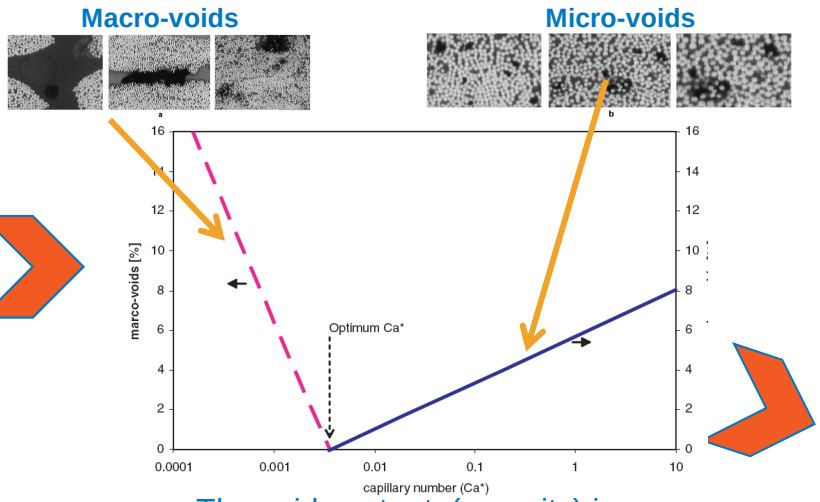
Composites Science and Technology 66 (2006) 475–486

bruno.dambrine@snecma.fr / edu.ruiz@polymtl.ca

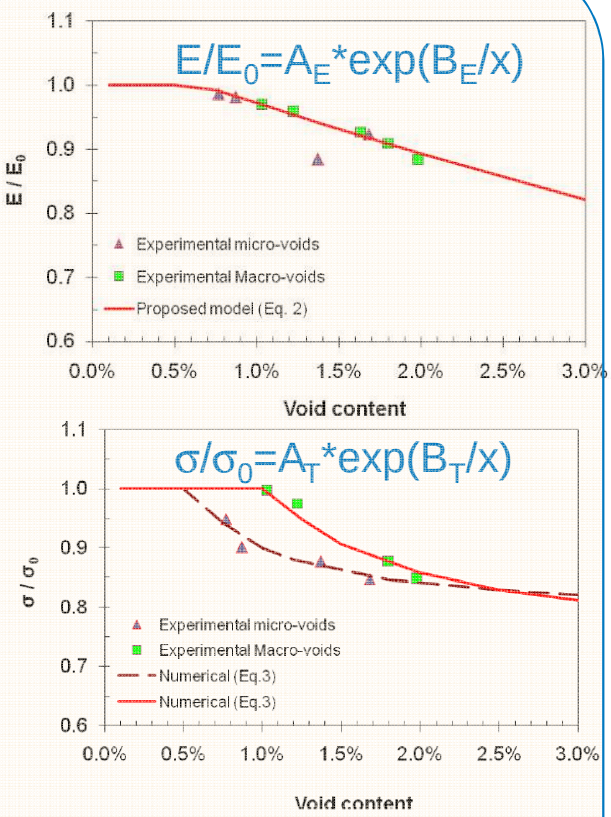
Porosity of the RTM process in structure calculation



RTM simulation takes into account local permeabilities due to fiber angels as well as porosities



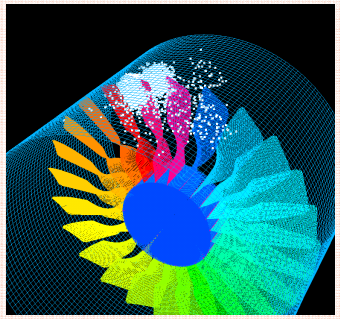
The void content (porosity) is determined from the RTM simulation (Void%=f(flow front velocity))



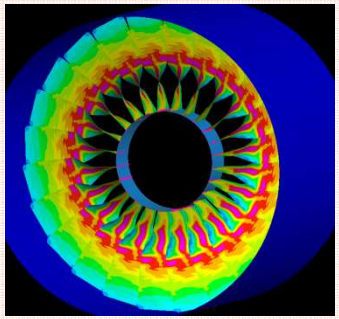
Porosity will affect Mechanical properties of the part

Resulting Stiffness and Damage analysis

accounting for mechanical properties resulting from manufacturing



Bird strike



Centrifugal pre-stress

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M.A.I Design Project

01.07.2012 bis 30.06.2015

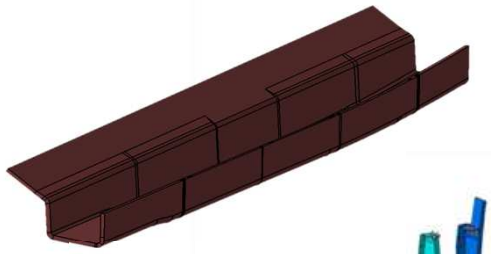
- Key Issue
  - Development of robust processes for the pro-duction of **industrial** FRC parts

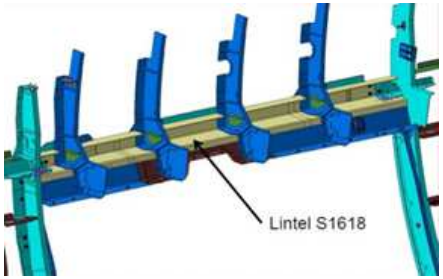
Budget

- MAI Design: 5.2Mio€
- ESI GmbH: 0.7Mio€ (40% founded by German government)

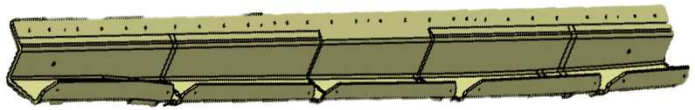
Lintel demonstrator

- Koppelung der Simulationen:
  - Drapiersimulation
  - PID Simulation
  - Mechanische Simulation
- Validierung anhand statischen Test





After machining



Drapiersimulation (AP2)

Ablegewinkel, Drapierbarkeit — *Eurocopter*

PID-Simulation (AP2)

Winkelverformungen, Eigenspannungen — *PAG, ESI*

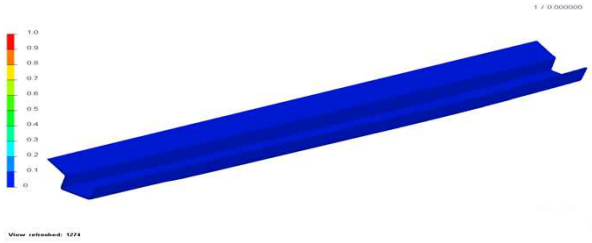
Strukturmechanische Simulation (AP3)

Statische Traglast, Beullast — *CADCON, HSA*

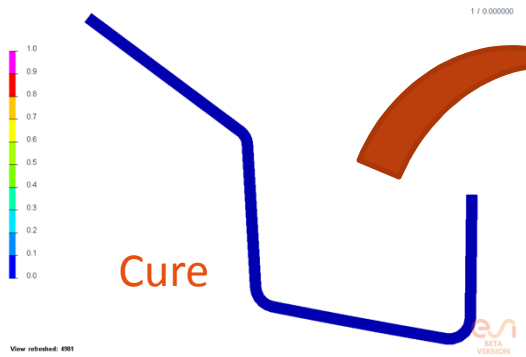
Statischer Drucktest (AP4)

Statische Tragfähigkeit — *PAG*

Example of Composite Manufacturing Chain (Lintel)



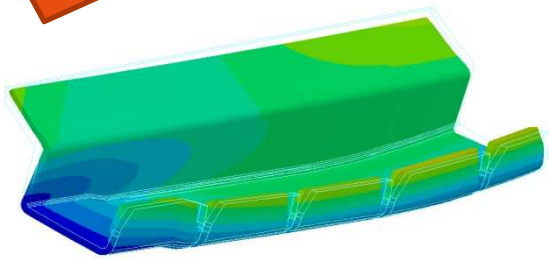
3D Heated RTM – filling analysis
(Visual-RTM)



Cure

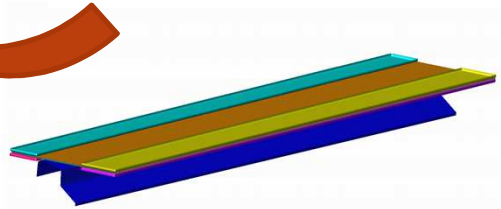
3D Curing analysis
(Visual-RTM)

Temperature
& Degree of Cure history



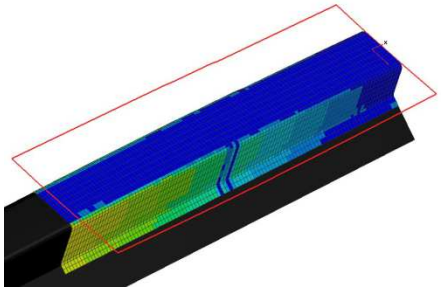
3D Distortion analysis
(Visual-Distortion)

Shearing of fibers



Multi-2D forming analysis
(Visual-FORM)

Flat pattern



Multi-2D Draping analysis
(Visual-FORM)

THANK YOU FOR YOUR ATTENTION

QUESTIONS ?

YOUR CONTACT AT ESI:

get it right®

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Team Leader – Virtual Manufacturing
Composites & Plastics

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