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Simulation for mass production of automotive composite structural components

Mathilde Chabin, Arthur Camanho (ESI Group)

November 2012

Lightweight automotive design

- To reduce CO_2 emissions (environmental awareness and regulation)
  - Weight-to-power ratio with power limited due to emission regulation

- To cut fuel consumption (selling argument)

- To increase autonomy

  Electrification of vehicle results in additional weight (battery) between 250 kg to 350 kg

  (BMW's MCV, JEC Composites Magazine No 61)

➔ *New concept in vehicle architecture and new production processes*

Composites in Automotive Industry

Statement

- Reduce weight using composites material
  - Carbon fibers is about 50% lighter than Steel and 30% lighter than Aluminum
  - Composites are already widely used in automotive industry for non structural components

Renault Espace composites
Started in 1984
Up to 400 vehicles/day

Non structural components
Mostly Short fibers – SMC process

  - Industrial wants to extend the use of composites to structural components; Mechanical requirements can only be reached with continuous fiber composites

Composites in Automotive Industry

Automotive structural components

- However…
  - Missing know-how and experience on continuous fiber composites design and manufacturing for automotive applications
  - Technology transfer from Aeronautics but industry constraints are different!

- Specific automotive constraints:
  - Production time cycle
  - Process automation
  - Cost of finished part
  - Performances (Crash, Safety…)
  - Recycleability (european regulation ex:REACH)

Composites in Automotive Industry

Automotive structural components / Supporting examples

- <u>Collaborative program "defi composites", LC4 project</u>

  "Low cost Carbon fiber chassis, adapted to automotive production time cycle and safety requirements"

<u>Target (First prototype End 2011):</u>

- integration of safety standard of constructors
- 1000 chassis/day
- Less than 1000 Euros/chassis

- <u>BMW backrest in the M3 CSL</u>

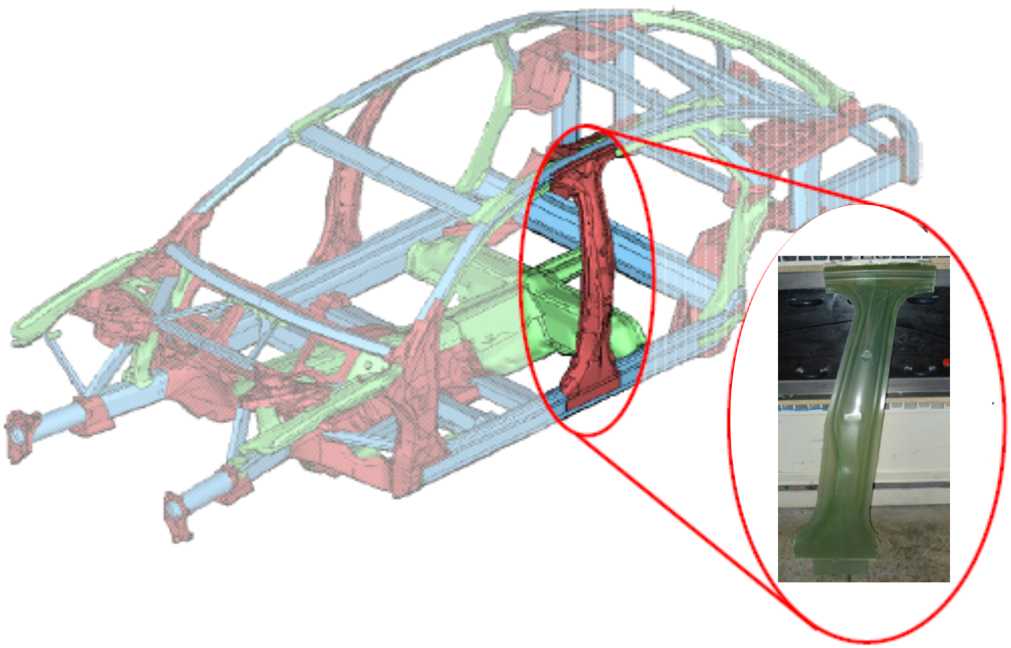
  6 dies in 2005 with expensive try-outs because of material cost, manufacturing processes

  <u>2011 target:</u> 2 dies maximum!

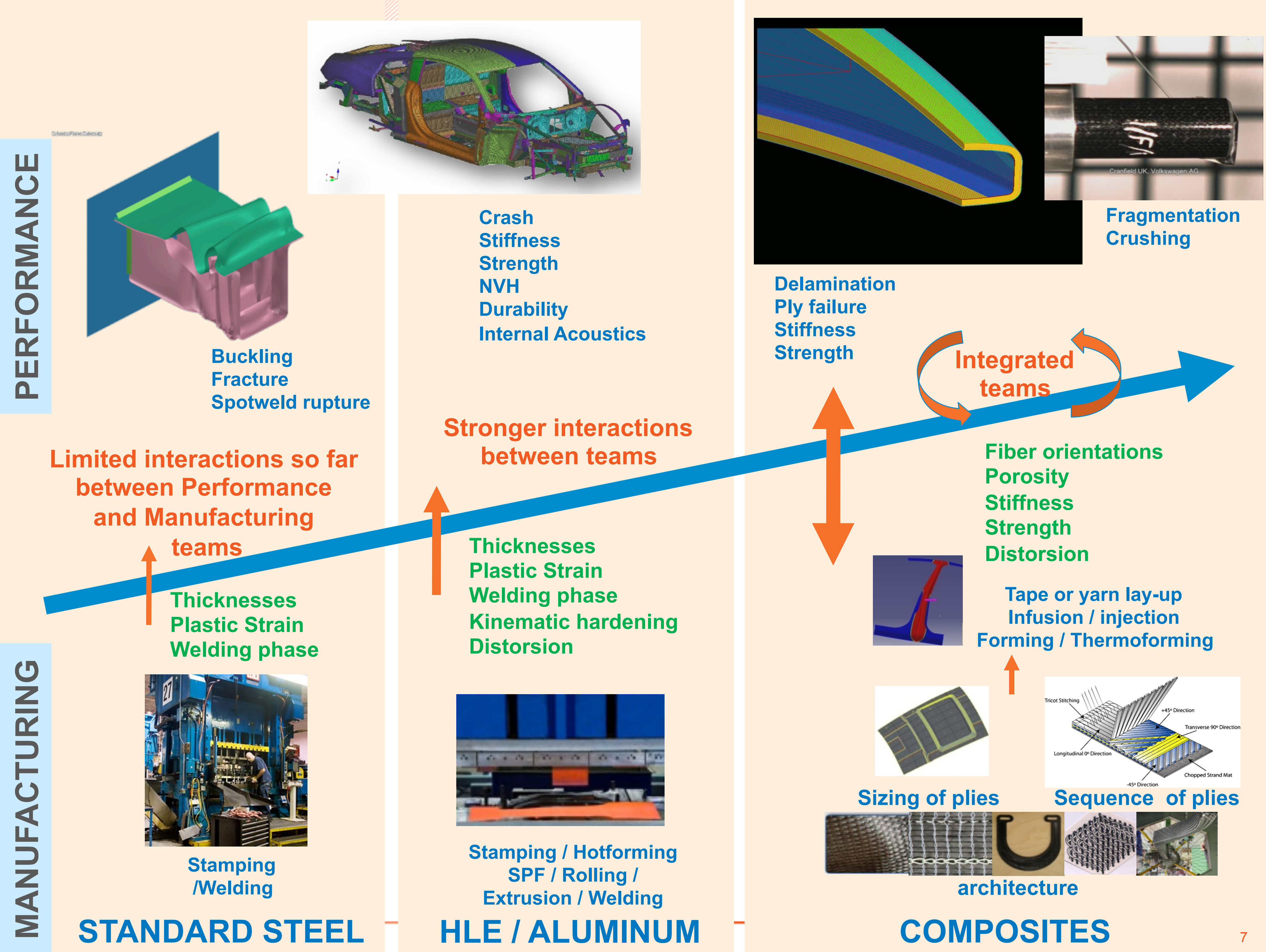
Composites in Automotive Industry

Automotive structural components / pain point

- Current practices lay on expensive trials



RTM B-Pillar:
~ 100kEuros / Die
~ 300 Euros in material per test


PERFORMANCE
MANUFACTURING
Buckling
Fracture
Spotweld rupture
Crash
Stiffness
Strength
NVH
Durability
Internal Acoustics
Cranfield UK, Volkswagen AG
Fragmentation
Crushing
Delamination
Ply failure
Stiffness
Strength
Integrated teams
Limited interactions so far between Performance and Manufacturing teams
Stronger interactions between teams
Fiber orientations
Porosity
Stiffness
Strength
Distorsion
Thicknesses
Plastic Strain
Welding phase
Thicknesses
Plastic Strain
Welding phase
Kinematic hardening
Distorsion
Tape or yarn lay-up
Infusion / injection
Forming / Thermoforming
Tricot Stitching
+45° Direction
Transverse 90° Direction
Longitudinal 0° Direction
Chopped Strand Mat
-45° Direction
Sizing of plies
Sequence of plies
architecture
Stamping /Welding
Stamping / Hotforming
SPF / Rolling /
Extrusion / Welding
STANDARD STEEL
HLE / ALUMINUM
COMPOSITES

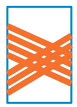
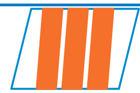
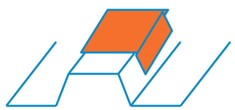
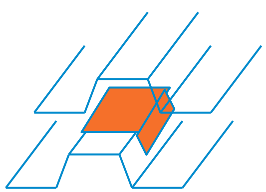
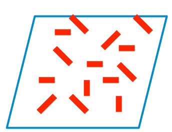
Agenda of the technical presentations

- Manufacturing (10:30-12:30)
- Assembly (14:00-15:00)
- Physics of materials (15:00-16:00)
- Performances (16:00-17:00)

Composites Manufacturing Simulation for “As Built” Structural Analysis

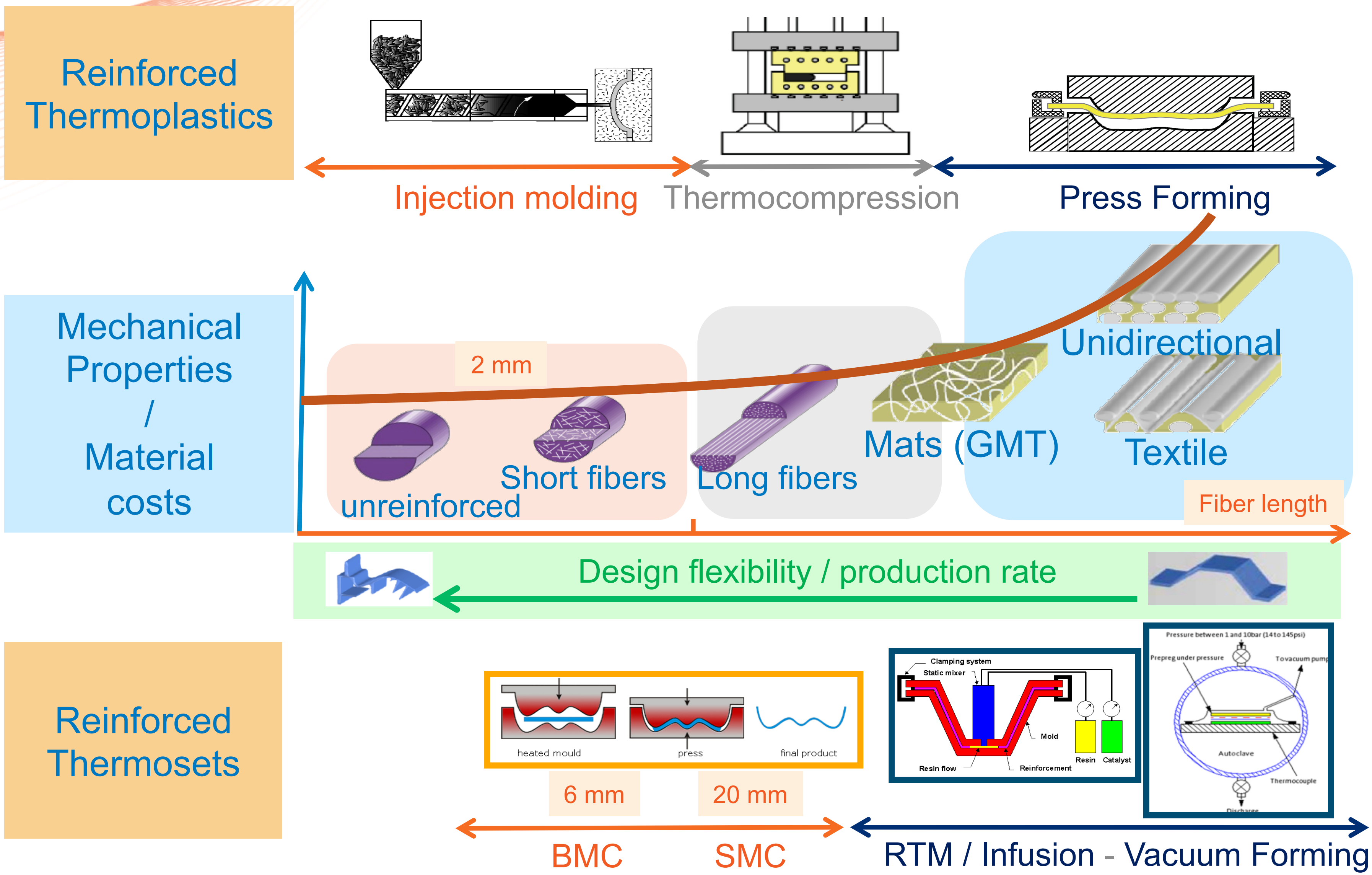
Composites in Automotive Industry

Automotive structural components: Material/Manufacturing

Fibers	Manufacturing technologies			Production time cycle	Process Automation	Material cost	Mechanical Performances
CONTINUOUS		Filament winding					
		Tape or yarn laying					
		Textile: Manual lay-up			Manual		
		Pre-pregs: Manual lay-up			Manual		
		Textile: -Stamping -Diaphram forming					
		Pre-pregs: -Stamping -Diaphram forming	TP			Expensive raw material but no storage concern and recycling possibility	
			TS			Expensive raw material, storage condition and short life duration	
SHORT		SMC BMC LFT GMT					Non structural components

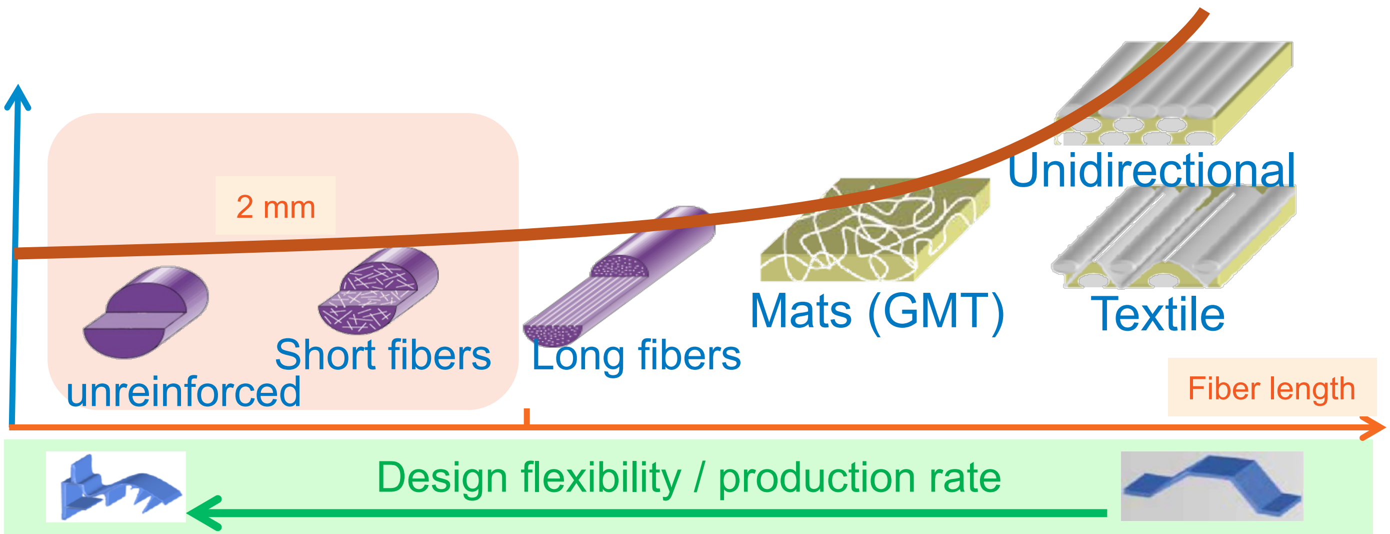
Automotive structural components

Composites materials and processes



Short Fiber Injection (1/2)

Mechanical Properties / Material costs



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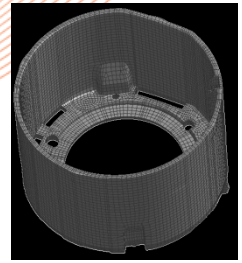
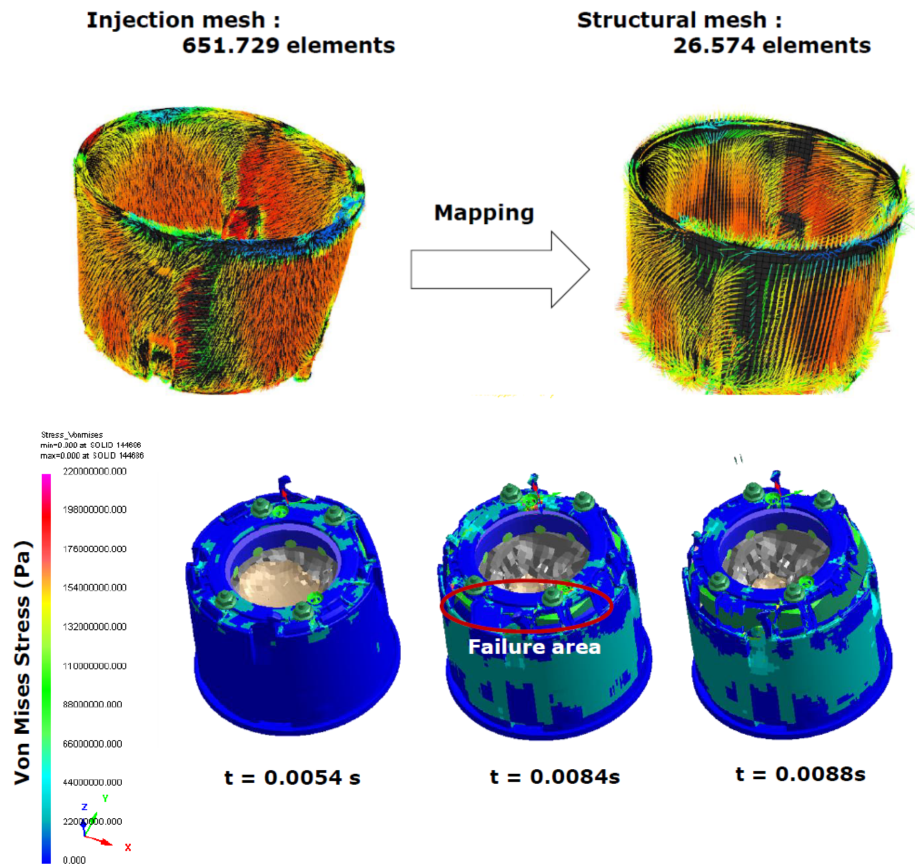


Short Fibers Injection (2/2)

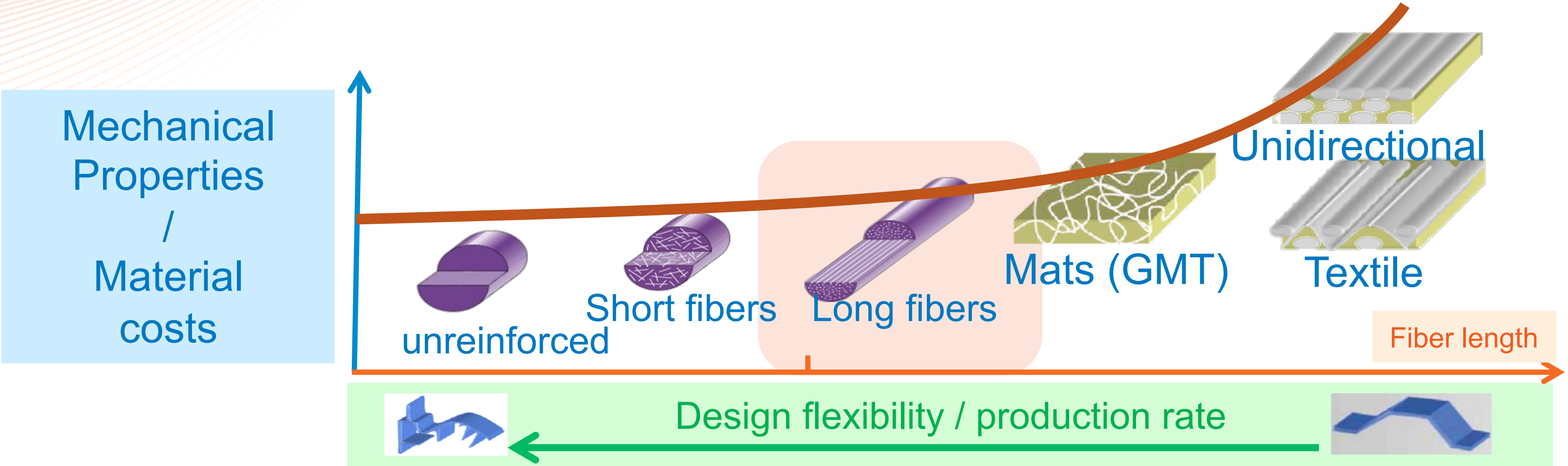
- Driver Airbag container: Polyamide matrix / Glass fiber-30% mass fraction

- Modeling:
  - Injection analysis to get fiber orientations
  - Identification of ElastoViscoPlastic Material model with DIGIMAT material model
  - VPS failure analysis using Digimat model



Courtesy of TRW Automotive Safety Systems GmbH and DSM

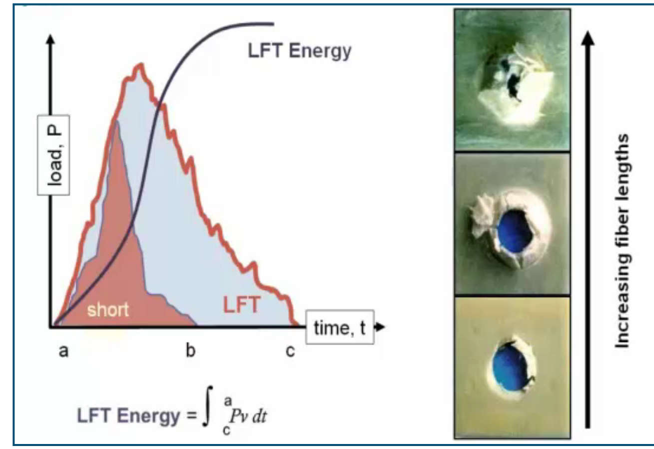
LFT: Long Fiber Thermoplastic (1/2)



- From 8 metallic parts to 1 plastic part
- LFT decrease weight & cost

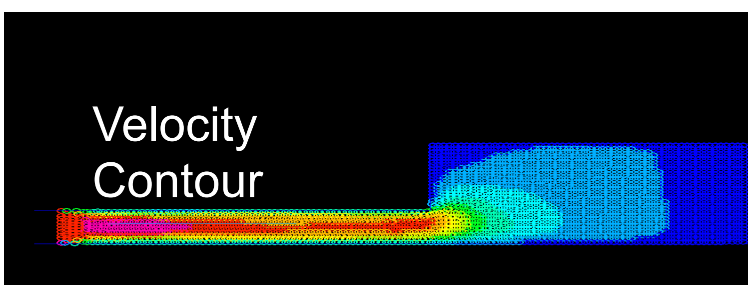
LFT: Long Fiber Thermoplastic (2/2) Fiber orientations and damage

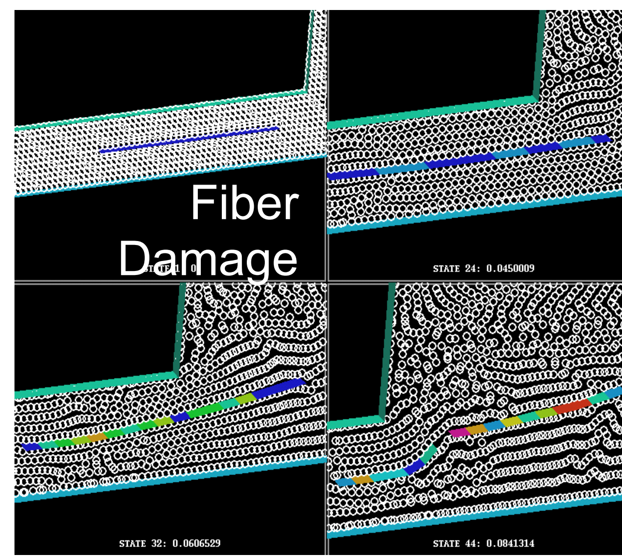
- Fluid flow with fibers transport
  - will give final stiffness & strength



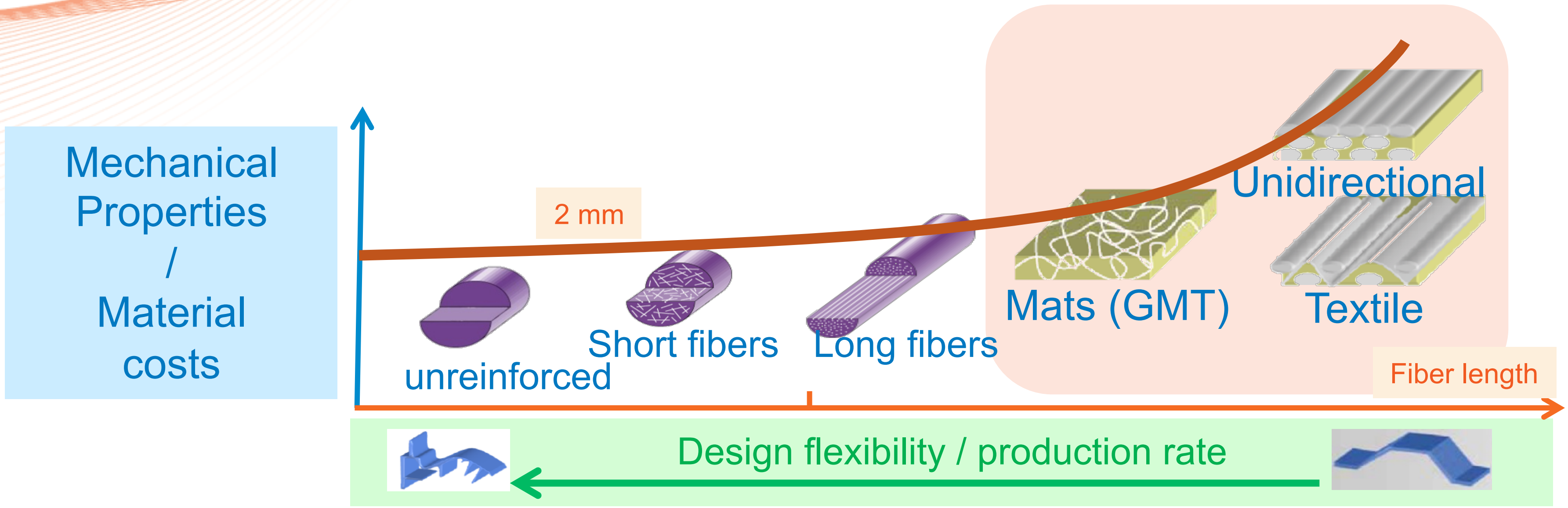
- Modeling
  - TP modeled with SPH (meshless method)
  - Fiber modeled with beam elements
  - Fiber interactions handled through contact algorithms

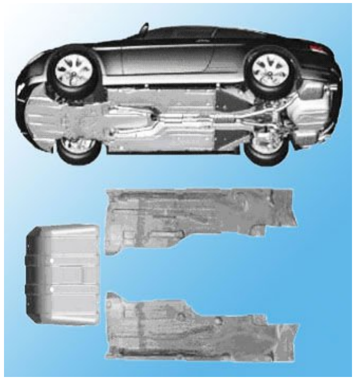
- **Phenomenae not well known !**
  - **ESI Ready to engage a cooperative investigations**





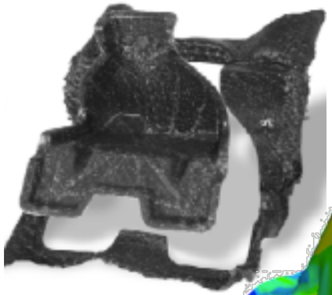
Thermoforming (1/7)

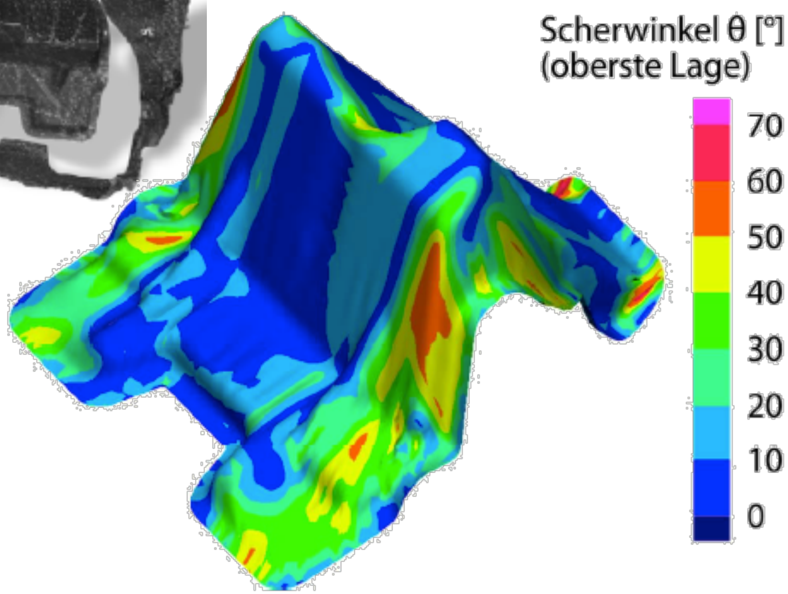




Thermoforming simulation using PAM-FORM (2/7)

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



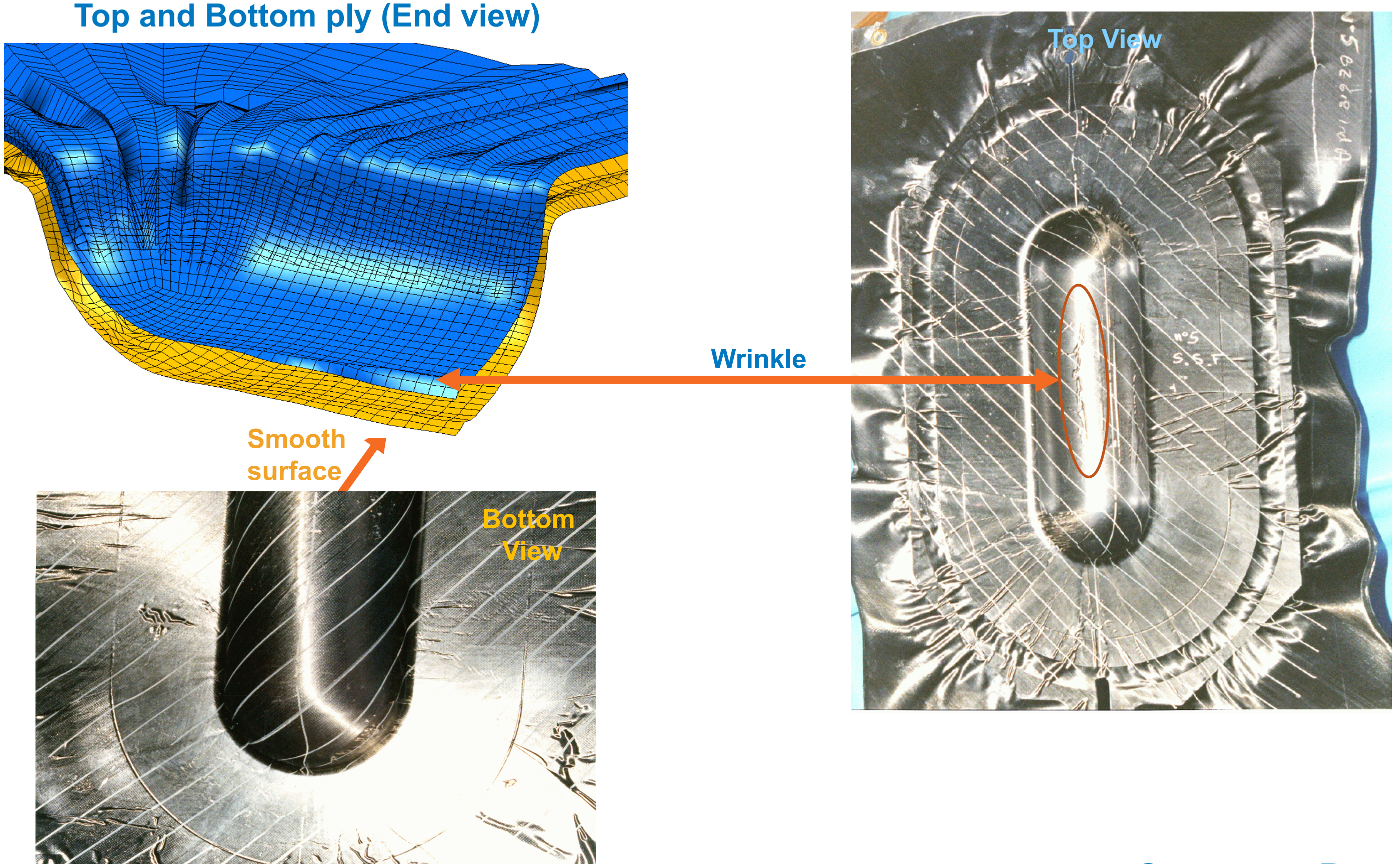


Courtesy: LKT Erlangen-Nürenberg

Ex1: Wrinkling prediction / forming (3/7)

- UD thermoforming / 20 plies / APC2-AS4 (thermoplastic matrix, carbon unidirectional reinforcement) / Quasi-Isotropic lay-up

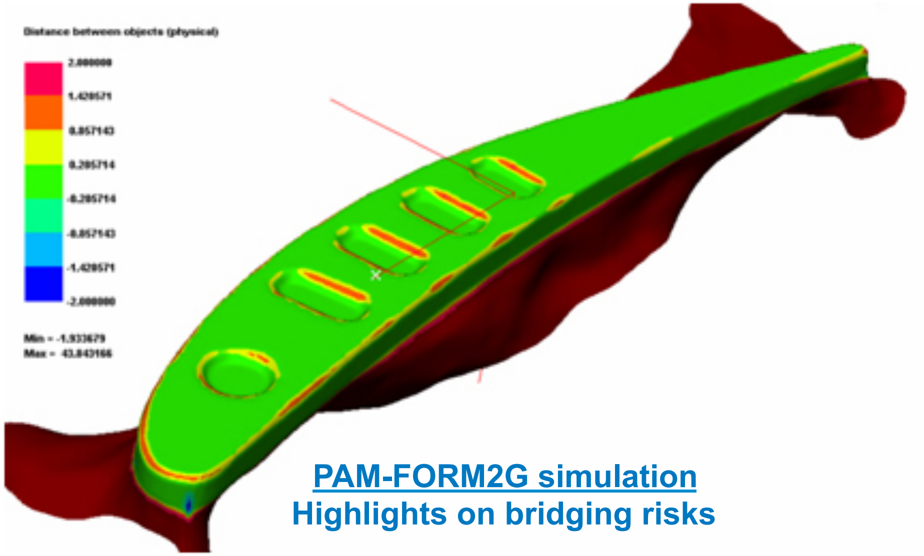
PAM-FORM2G simulation
Top and Bottom ply (End view)



Courtesy: Dassault Aviation

Ex2: Bridging risk prediction (4/7)

- Fabric / 6 plies / PPS Matrix



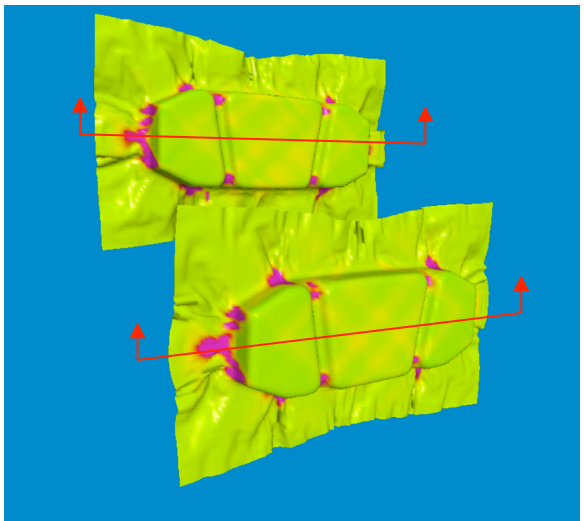
PAM-FORM2G simulation
Highlights on bridging risks

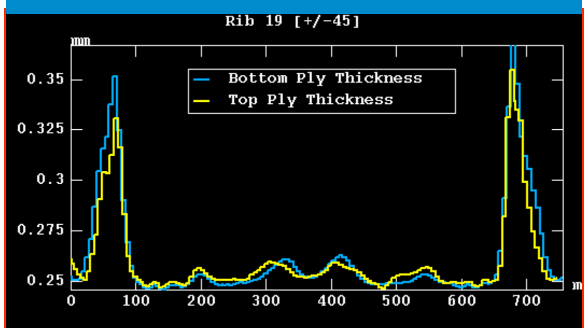
Courtesy: Delft University of Technology

Ex3: Prediction of laminate thickness and thickness per ply (5/7)

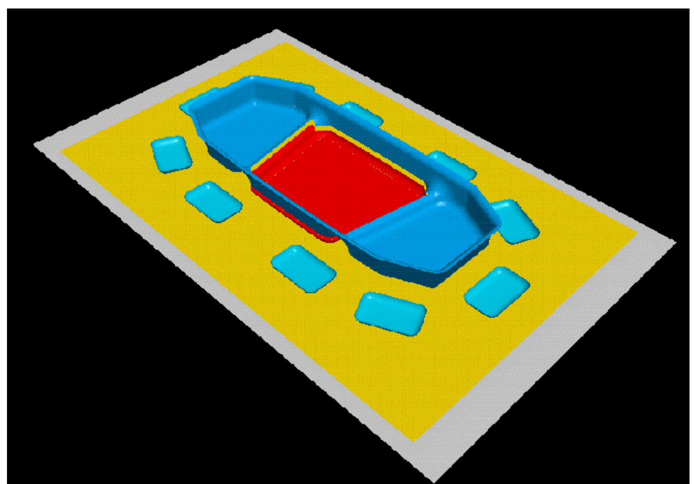
- Wing box: UD and Fabrics / 8 plies

Thickness per ply
determined with PAM-FORM2G

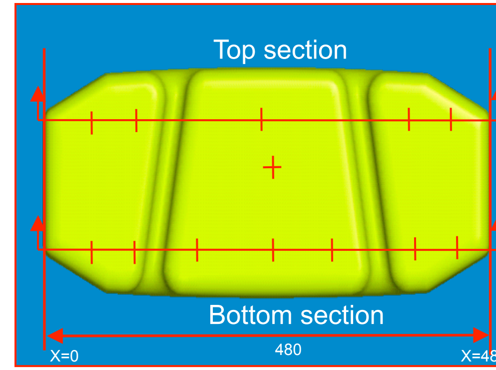


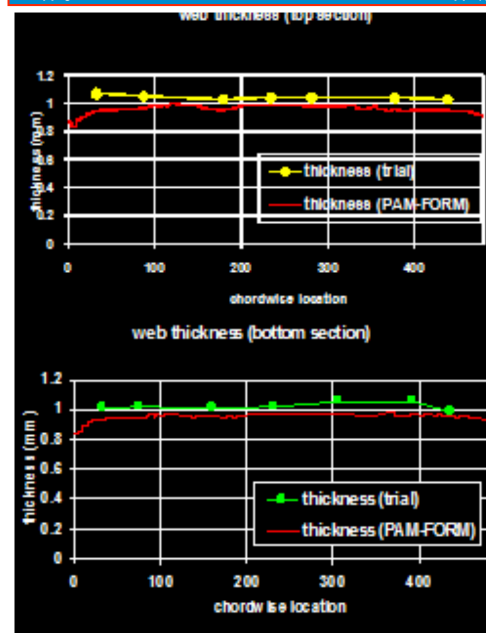


Complex clamping conditions
determined with PAM-FORM2G



Laminate thickness
Ultrasonic measurement versus simulation

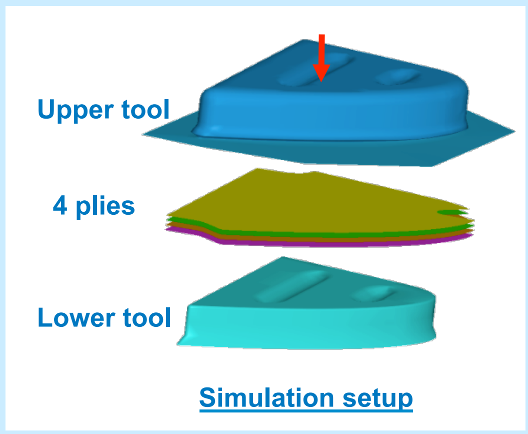


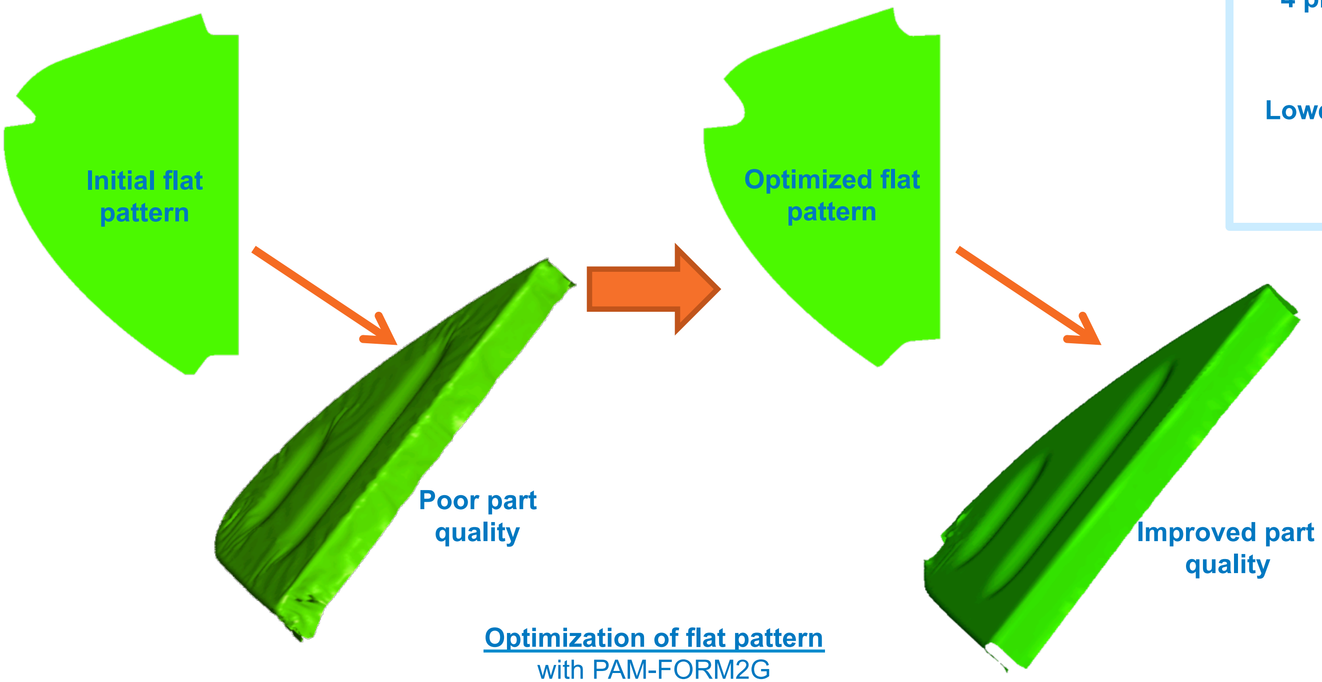


Courtesy: Airbus UK

Ex4: Flat pattern optimization (6/7)

- J-RIB: 4 plies / thermoforming

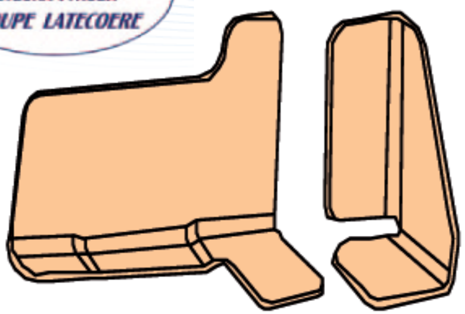




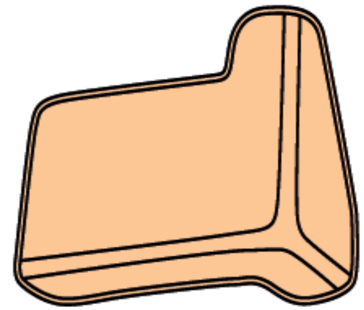
Optimization of flat pattern
with PAM-FORM2G

Courtesy: Airbus UK

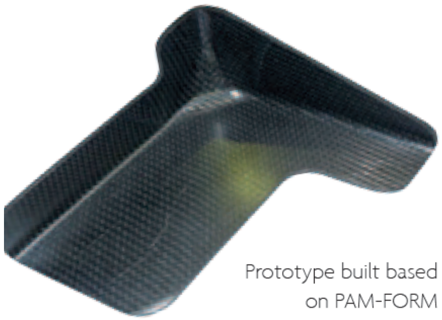
Ex5: Integrated shape and tooling optimization (7/7)



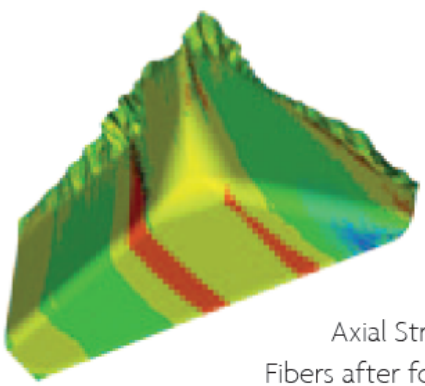
Standard shape



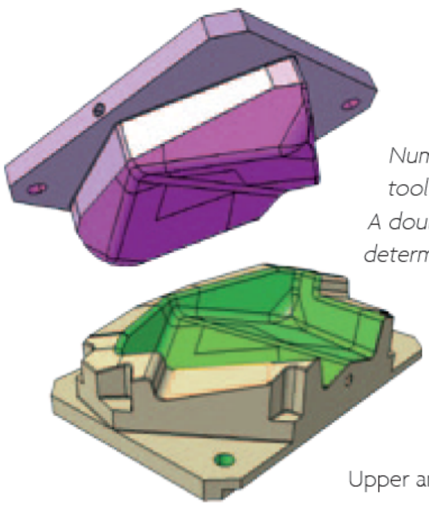
Integrated shape



Prototype built based on PAM-FORM computations



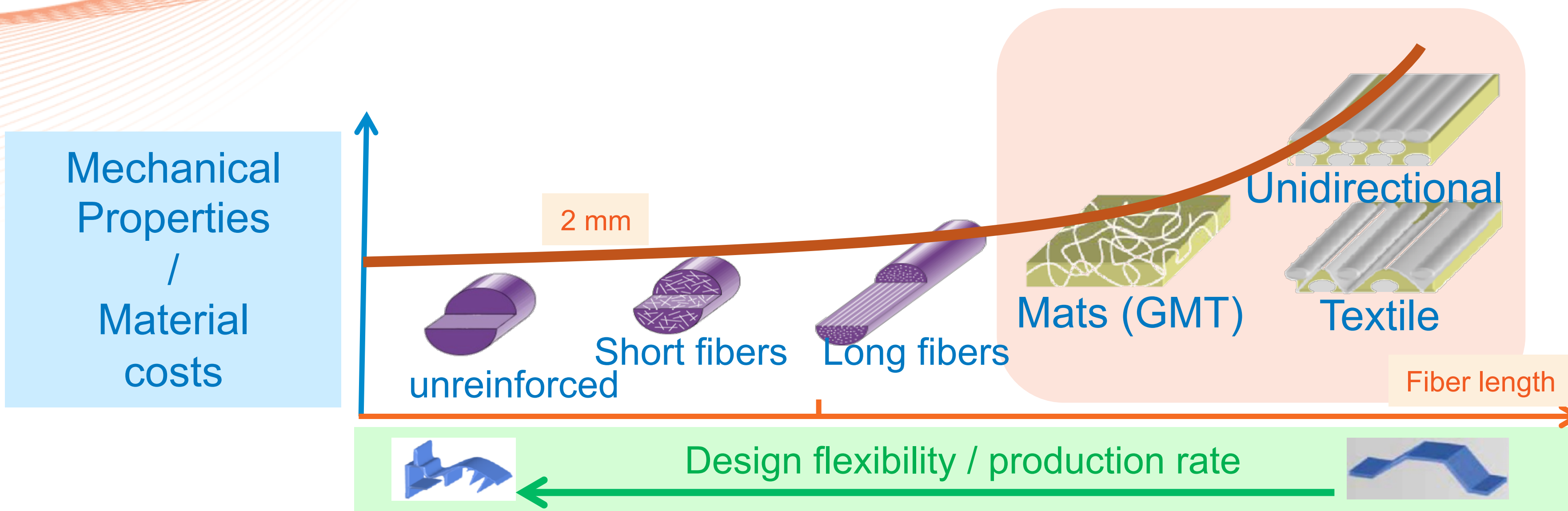
Axial Strain on Fibers after forming

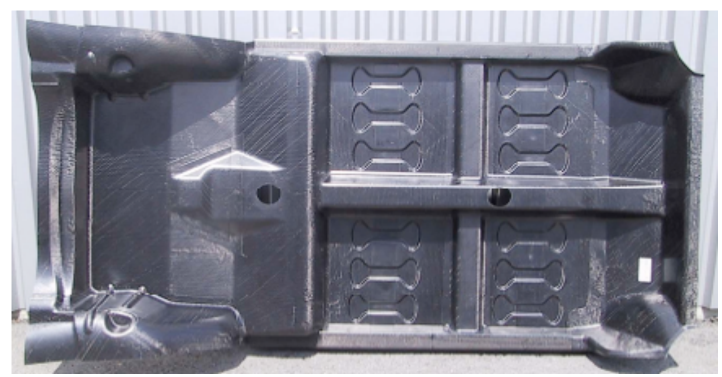


Numerous variants for the tool shape were evaluated. A double part die design was determined with PAM-FORM.

Upper and lower forming tools

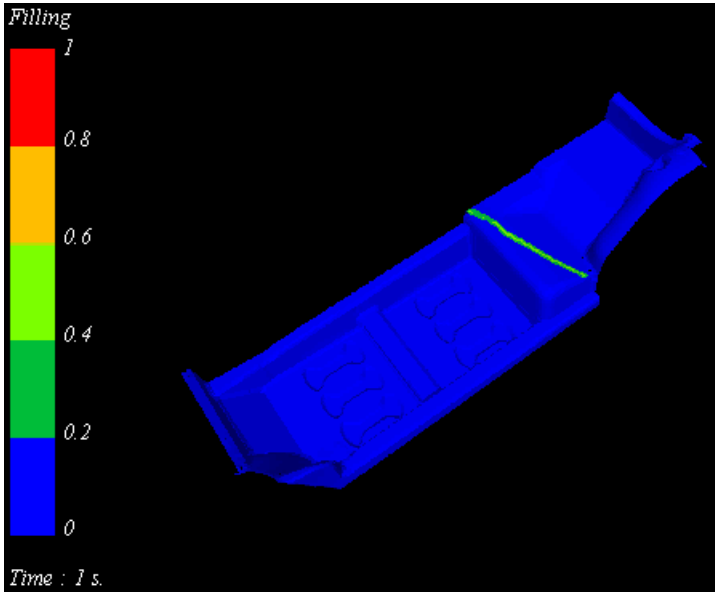
Liquid Composites Molding (LCM) RTM / Infusion (1/13)





Liquid Composites Molding Simulation (2/13)

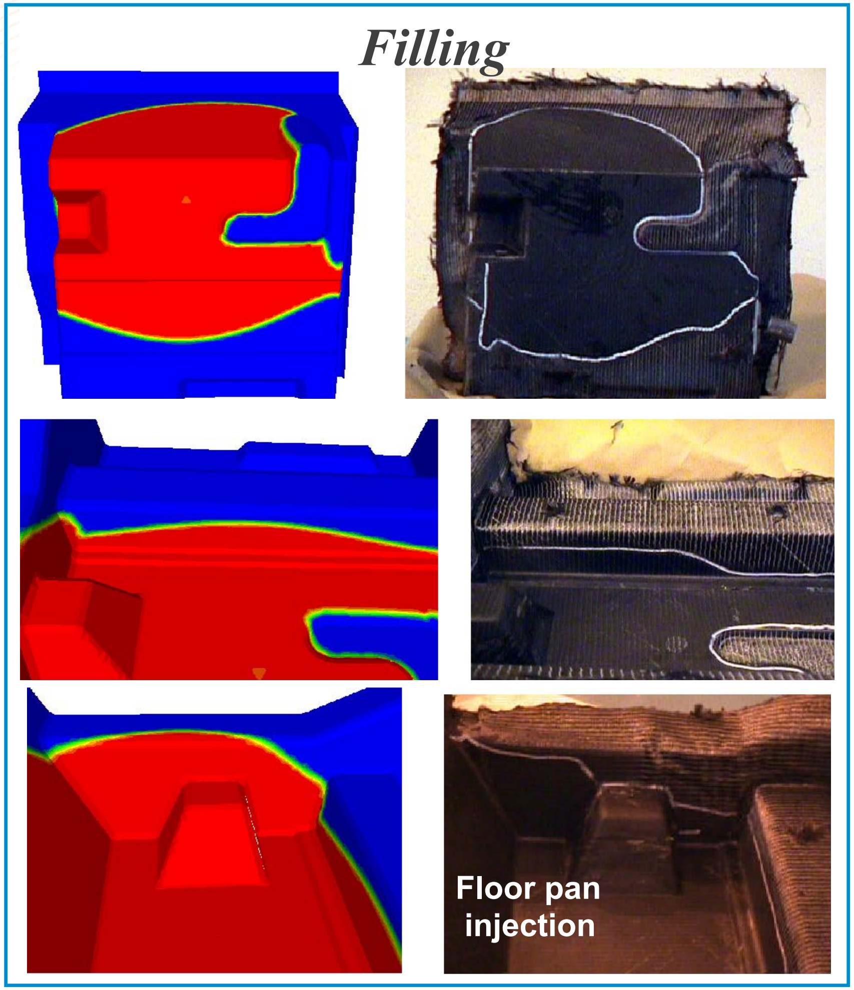
- PAM-RTM can evaluate and optimize
  - Injection strategy (**RTM, VACUUM INFUSION, VARTM**…)
  - Injection pressure and flow rate
  - Injection gates, vents and vacuum ports location
  - Molding temperature
  - Flow media
- Through the prediction of
  - Dry spots
  - Filling and curing times
  - Flow front velocity / Fiber washing
  - Pressure in the mold

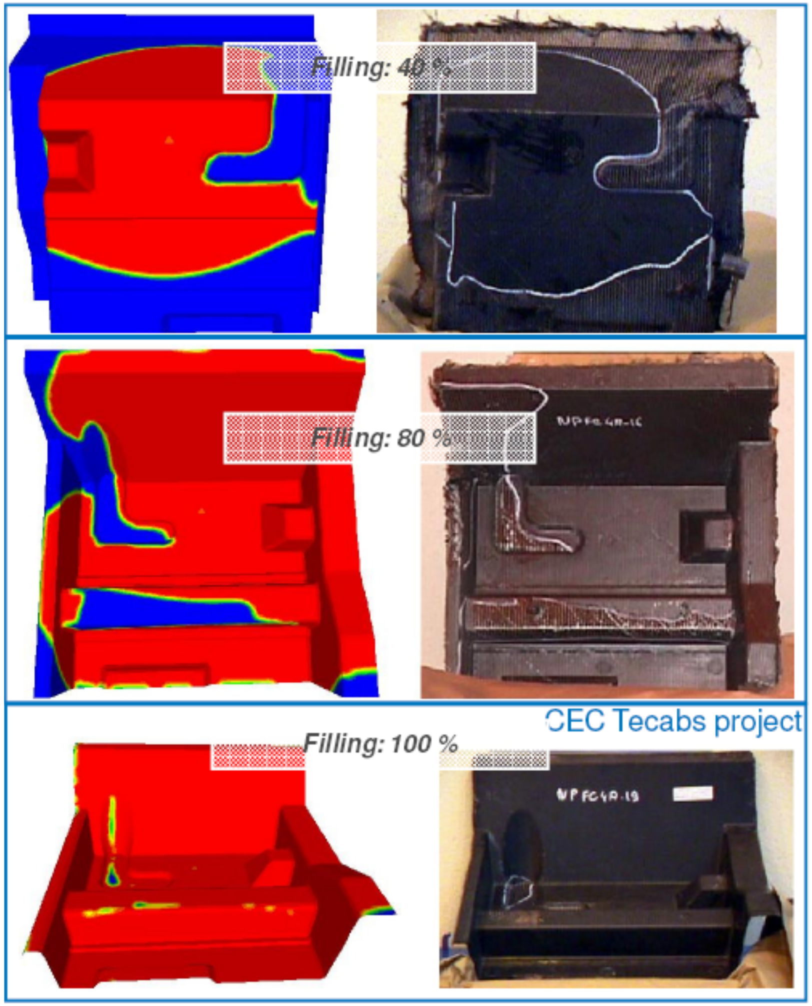


- Taking into account
  - Fiber angle variation (permeability variation) of the preform

Ex1: Resin flow front analysis (3/13)

- NCF floor pan injection

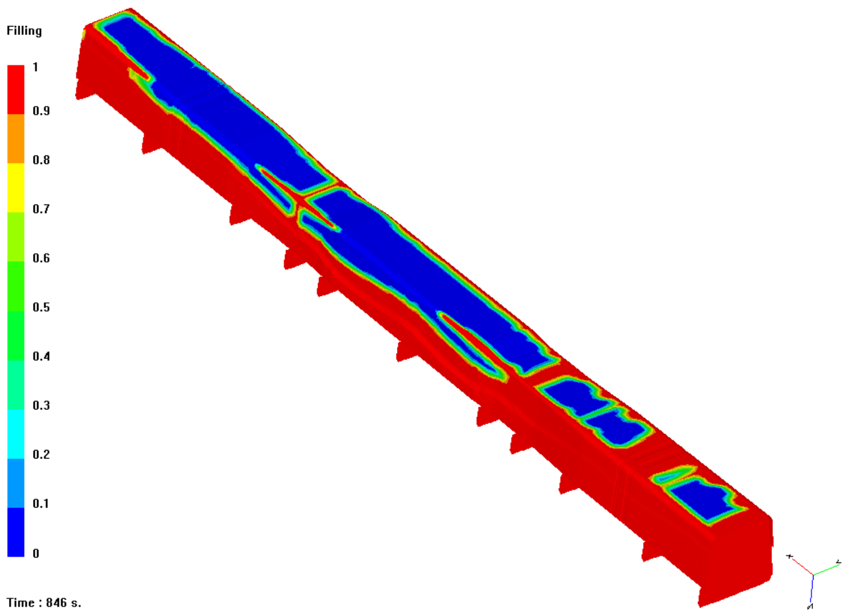


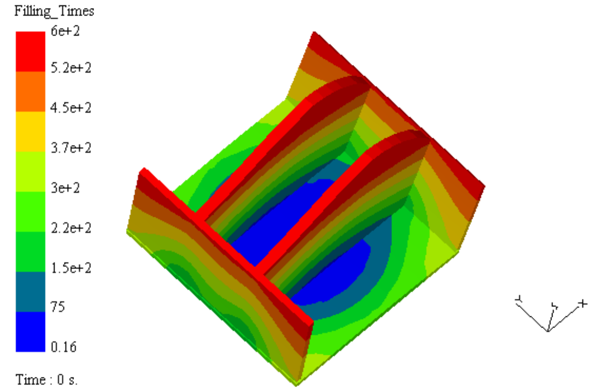


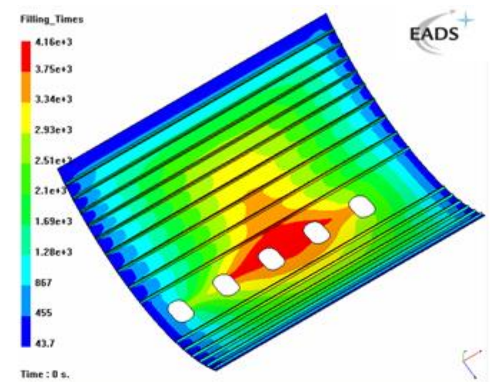
TECABS: RENAULT – Mines Douai

Ex2: Degree of filling, filling and curing time prediction (4/13)

'With this application, Airbus is introducing the numerical simulation of manufacturing liquid composite molding processes. It is seen as a major breakthrough that will help us to remain at the cutting edge of the technology in the composite material field' adds Gilles Debril, Airbus Concurrent Engineering, Composite Project Manager.





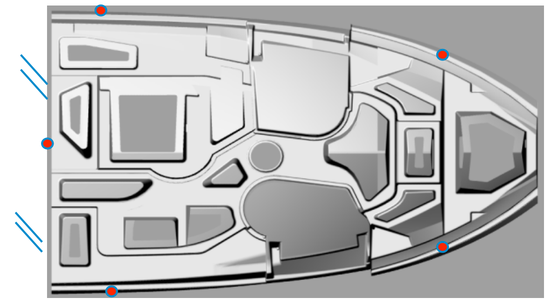


Filling time

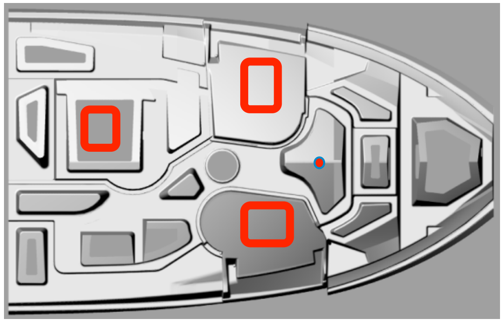
Courtesy: EADS Innovation work,

Ex3: Complex injection strategy definition (5/13)

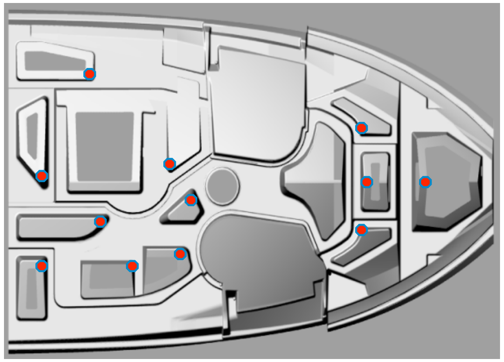
- Inner liner for hull reinforcement
  - Very complex part including high shapes (1.2m)
  - Injection analysis allows determination of injection strategy (injection points/channels and vents location as well as open/closing sequence) to minimize:
    - Dry spots
    - Filling and curing times
    - Fiber washing
    - Pressure in the mold



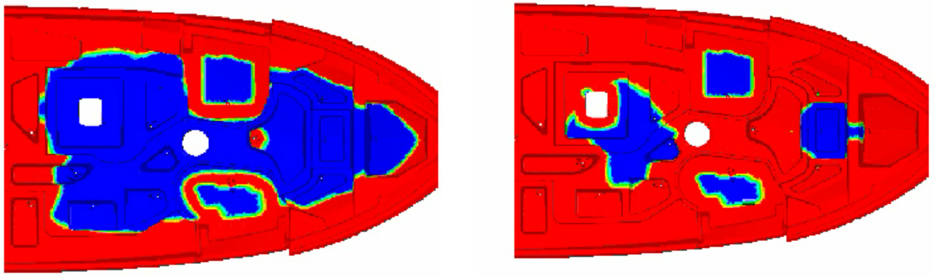
Initial injection points



Secondary injection points/channels



Vents location

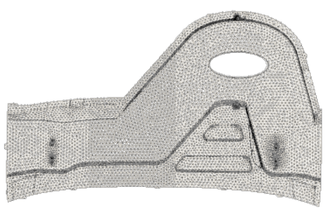


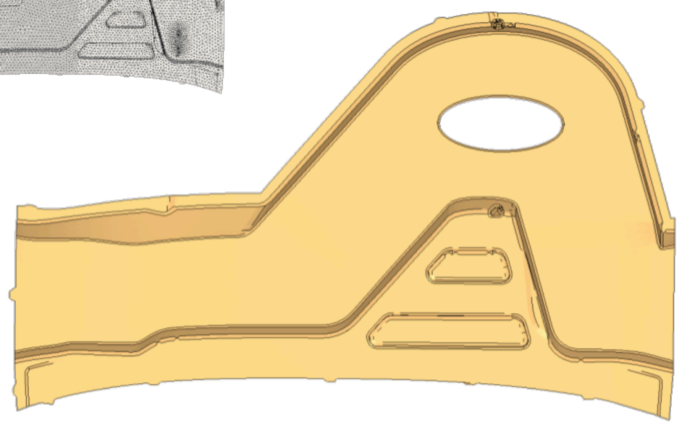
Flow front during injection
With PAM-RTM

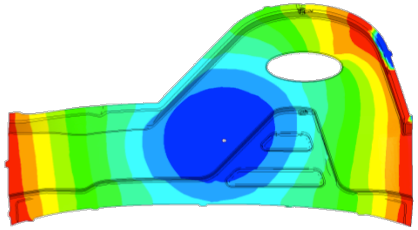
VISIT http://www.esi-group.com/products/composites-plastics/pam-rtm/references **for complete video presentation** **Courtesy:** PPE & Azimut

Ex4: Quick estimate of optimum injection strategy (6/13)

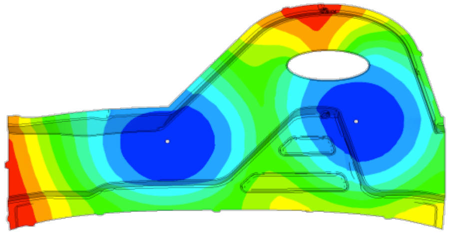
- Automatic estimate of injection point location and filling time



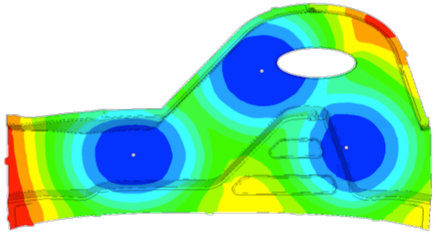




192 secondes



93 secondes

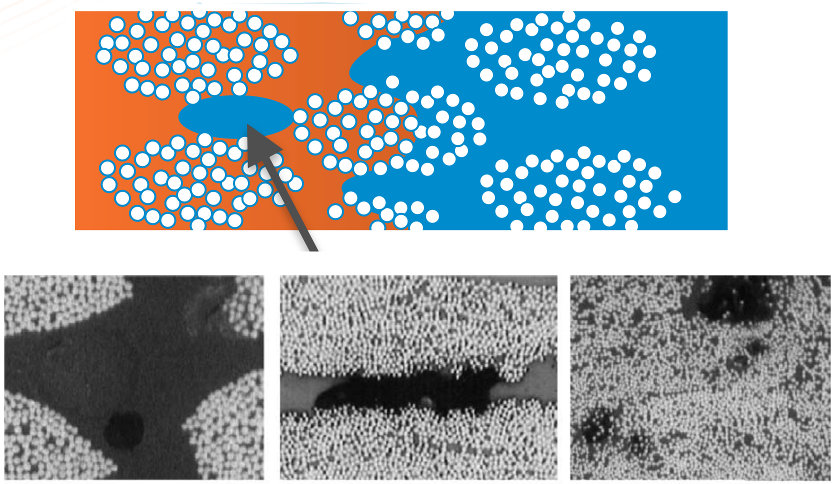


62 secondes

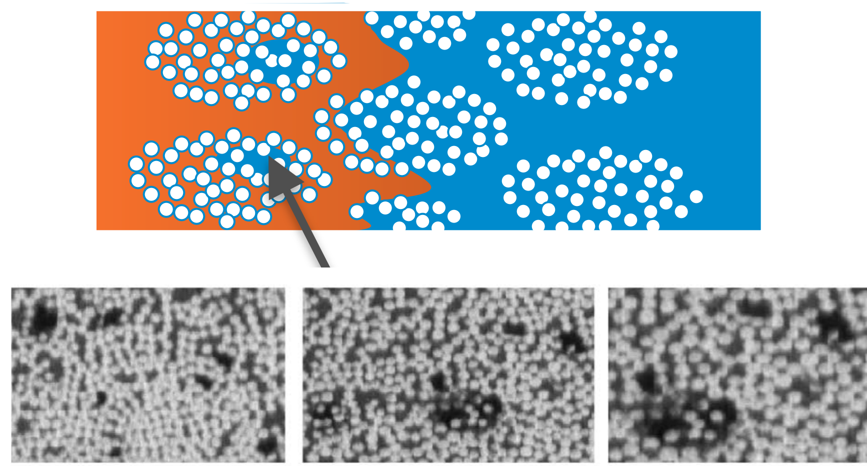
Ex5: Porosity reduction (7/13)

Low resin flow front velocity

High resin flow front velocity



a



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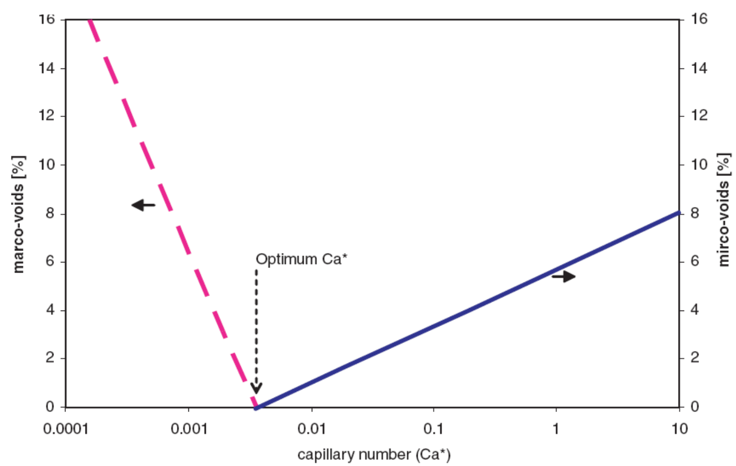


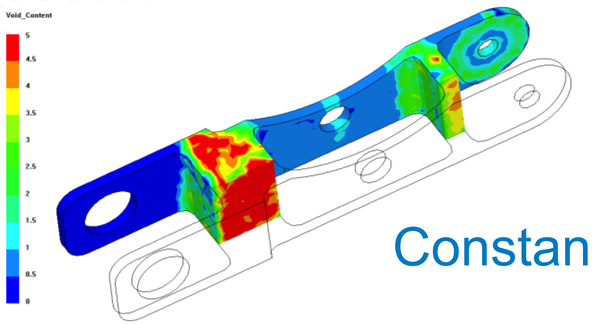
$$Ca = \frac{\mu \, v}{\gamma}$$

École Polytechnique Montréal

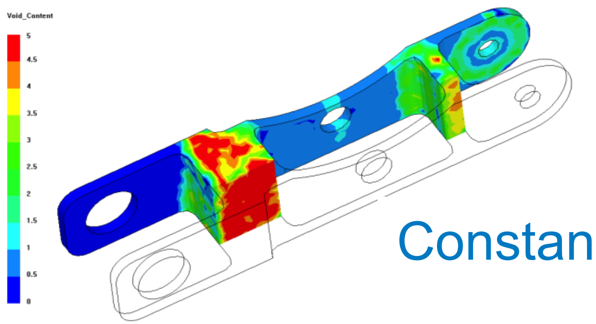
Chaire sur les Composites à Haute Performance

Ex5: Porosity reduction (8/13)

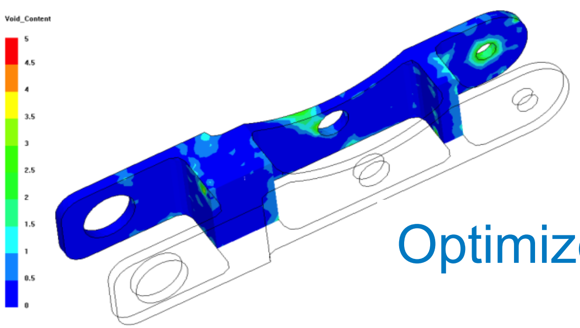
Void content for different Injection strategies



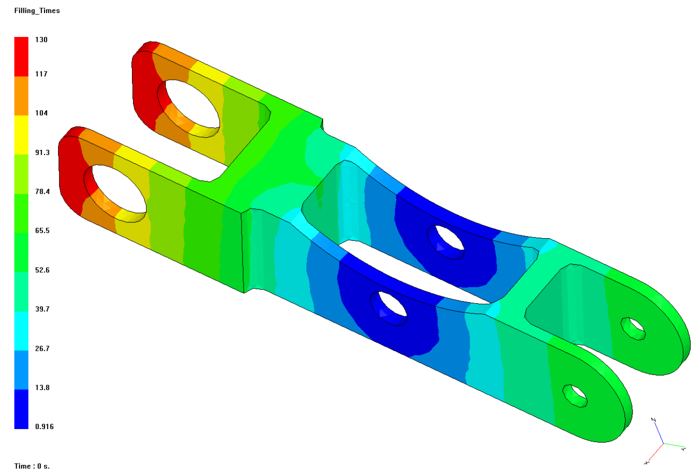
Constant pressure



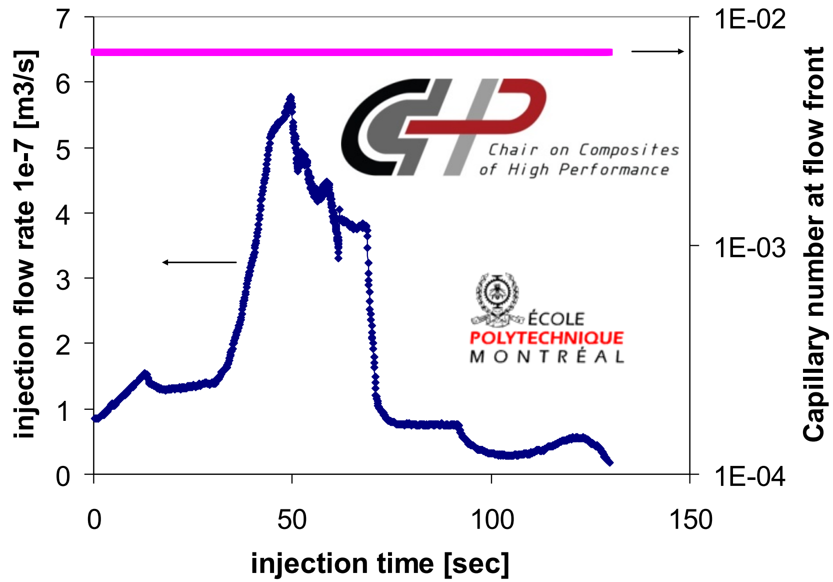
Constant flow rate



Optimized flow rate



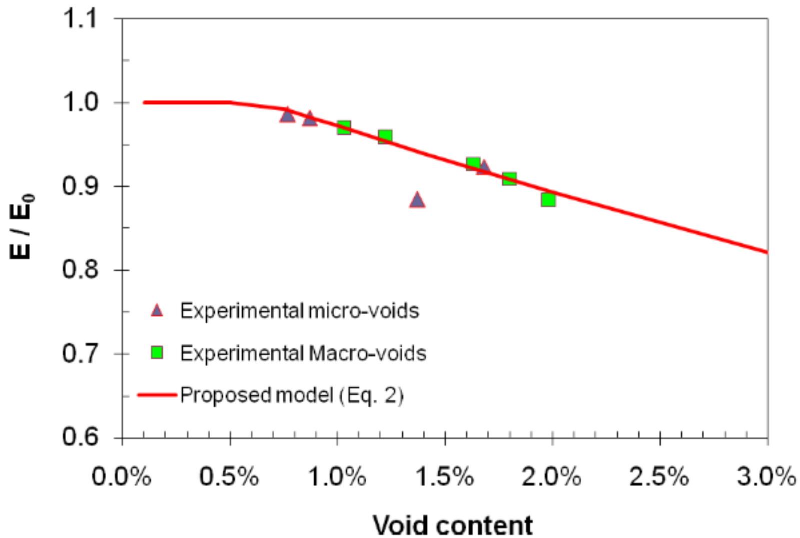
Optimized flow rate profile

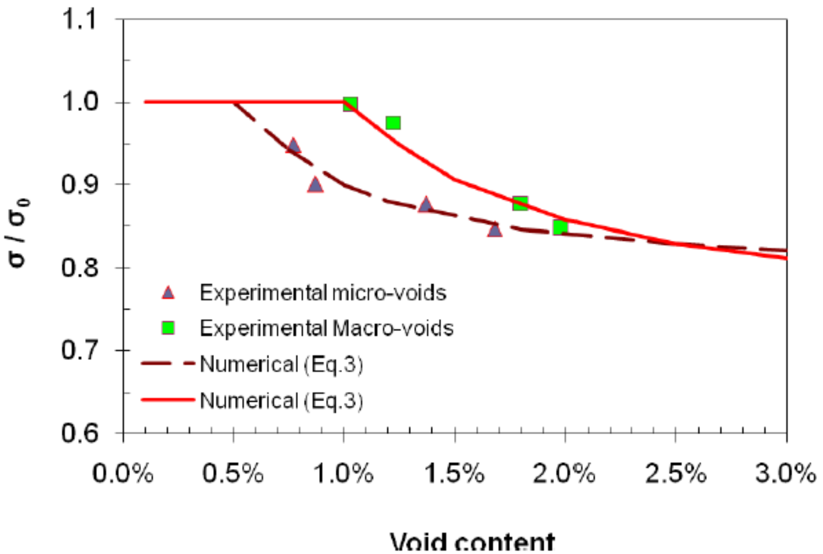


Ex5: Effect of Voids on Mechanical Properties (9/13)

- $E/E_0=A_E*\exp(B_E/x)$
- $\sigma/\sigma_0=A_T*\exp(B_T/x)$
- Where x = void content in %

Possible reuse of RTM simulation results in part performance assessment



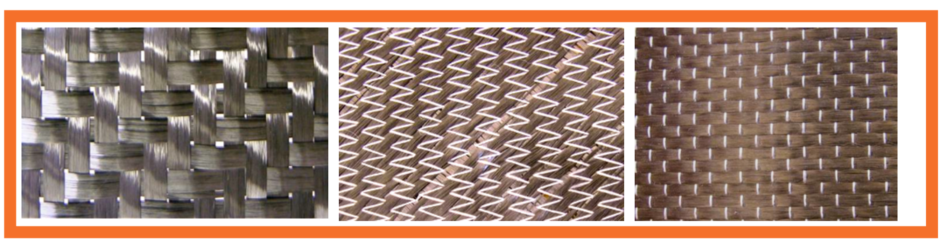


Leclerc Jean-Sebastien; Edu Ruiz, Porosity Reduction using Optimized Flow Velocity in Resin Transfer Molding, Elsevier Composites Part A

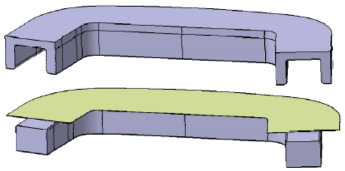
Ex 6: Pre-forming simulation / TECABS (10/13)

- TECABS project floor pan (VW, SOTIRA, AIREX, …) :

- PAM-FORM helps to Define & Optimize:
  - The process
  - The holding system
  - The plies geometry



Ex 7: Pre-forming simulation / Eurocopter (11/13)

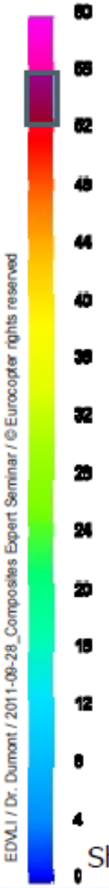


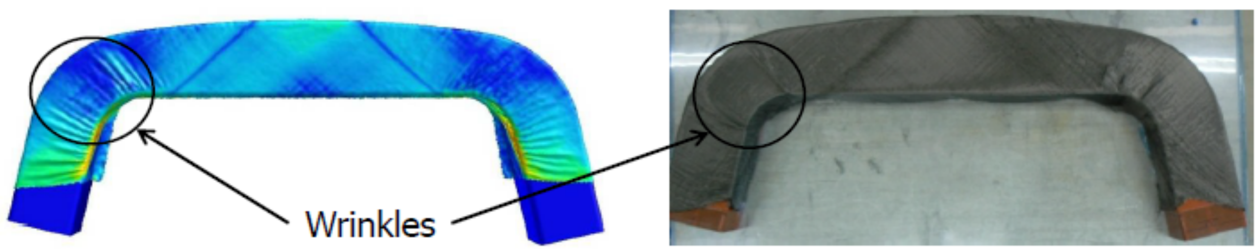
Stamping tools and reinforcement

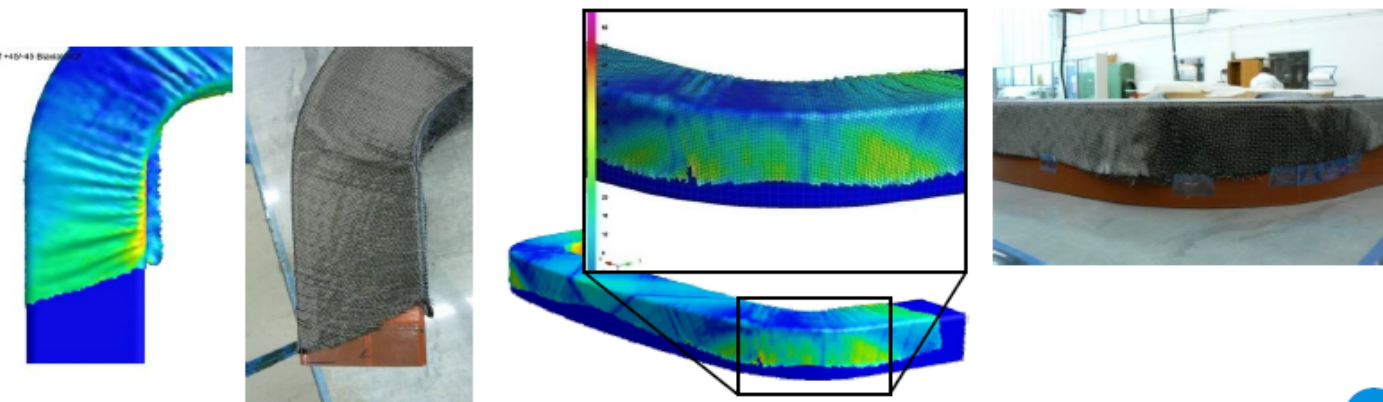
thinking without limits

Forming – *Results of ±45 NCF: Sh. angles*

Results of experimental forming for +45/-45 and -45/+45 are symmetric



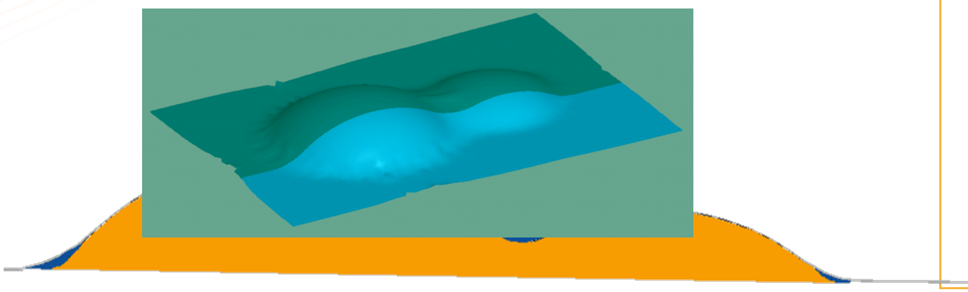


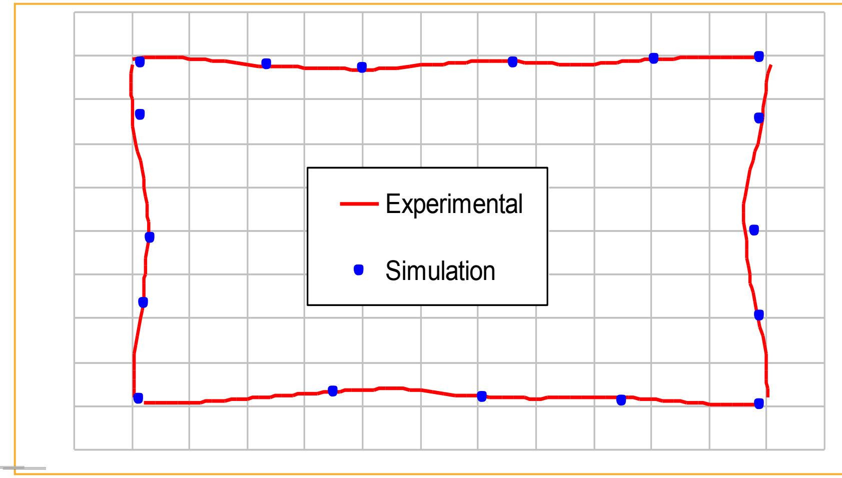


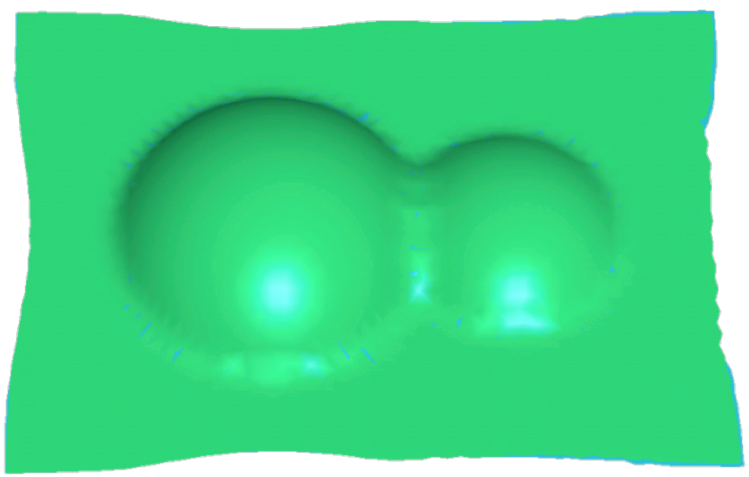
EUROCOPTER

Ex 8: Non Crimp Fabric Draping (12/13)

0° - 90 ° FIBRE ORIENTATION







Simulation results

Experimental results

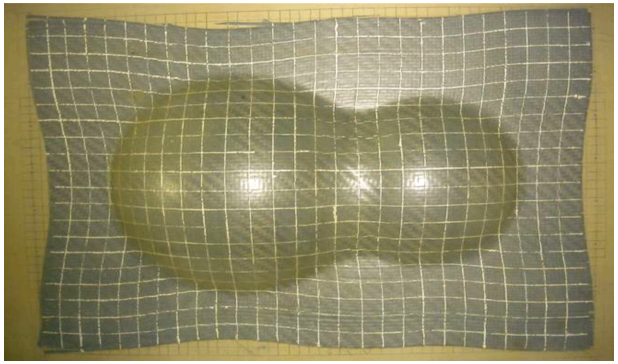
Cranfield U.

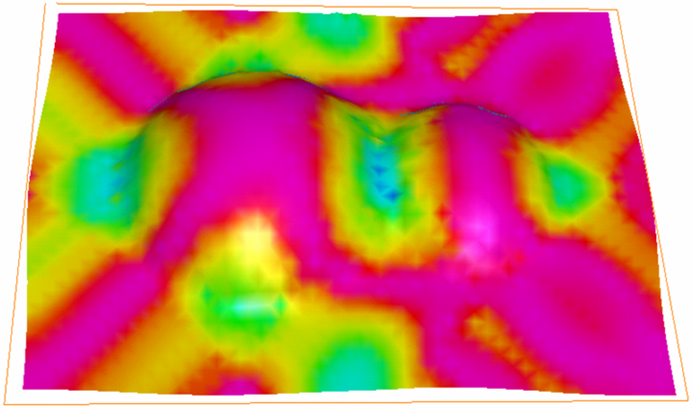
www.esi-group.com

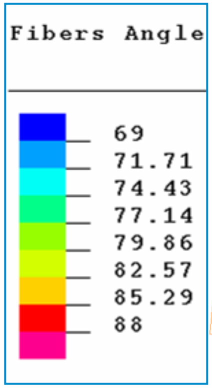
Ex 8: Non Crimp Fabric Draping (13/13)

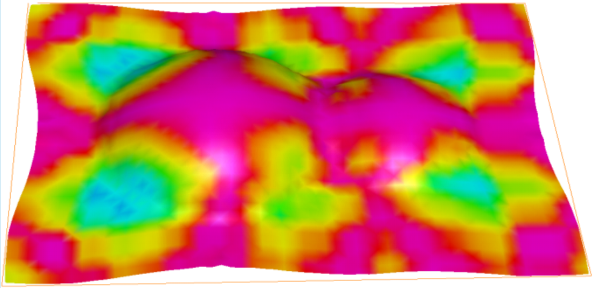
±45° fibre orientation to mould symmetry

0° - 90° fibre orientation to mould symmetry



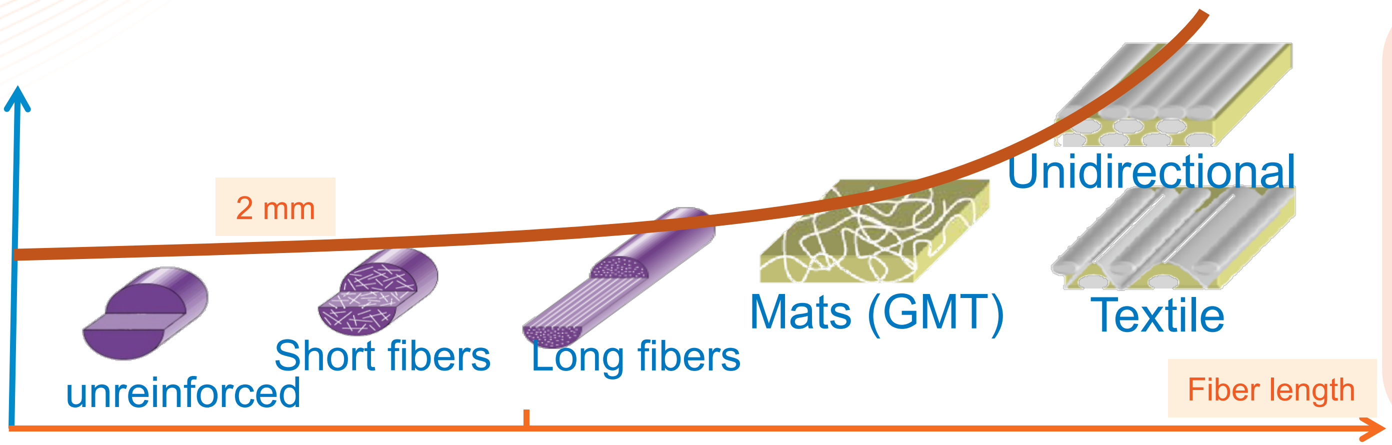




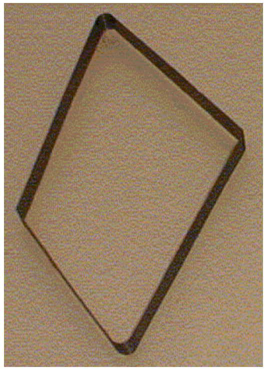


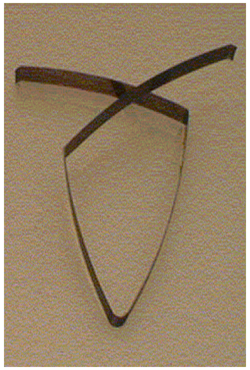
Cranfield U.

Distortions (1/2)

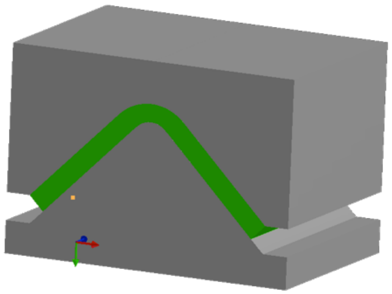


After Manufacturing



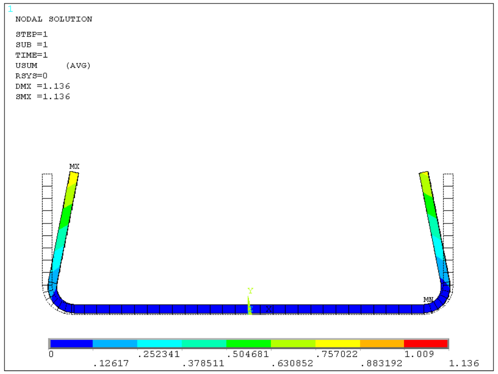


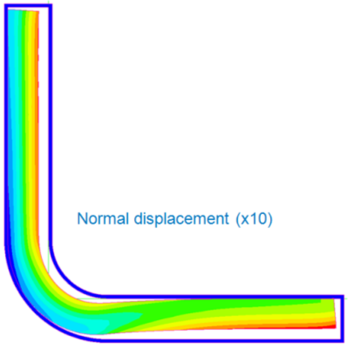
Distortion Analysis (2/2)



Sources of Distortion

- Lay-up
- Draping effects
- Thermal expansion
- Chemical shrinkage
- Cure temperature and uniformity
- Tool thermal expansion





Simulation Status

- Laboratory validation accounting for all these parameters performed in European or French collaborative projects (MAAXIMUS, LCM-SMART).
- ESI ready to engage a cooperative investigation

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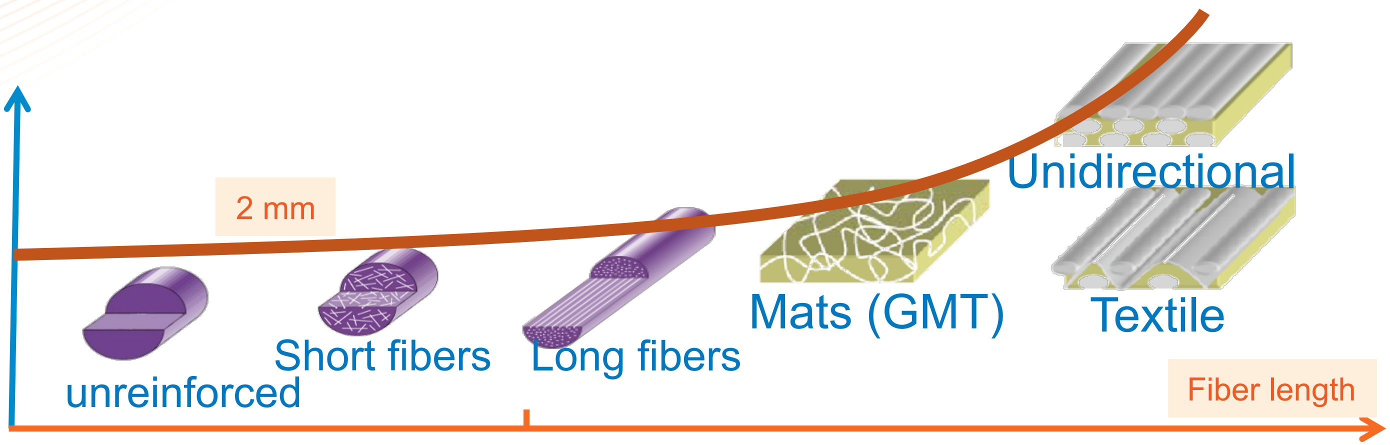
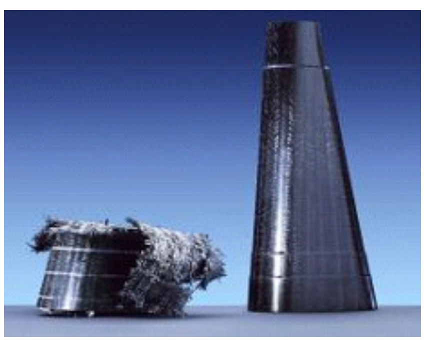
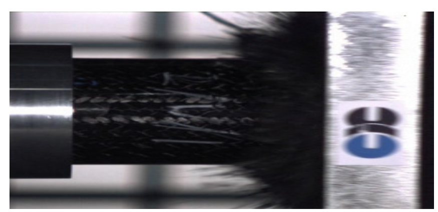
Crash worthiness (1/8)



Assembly

Crash

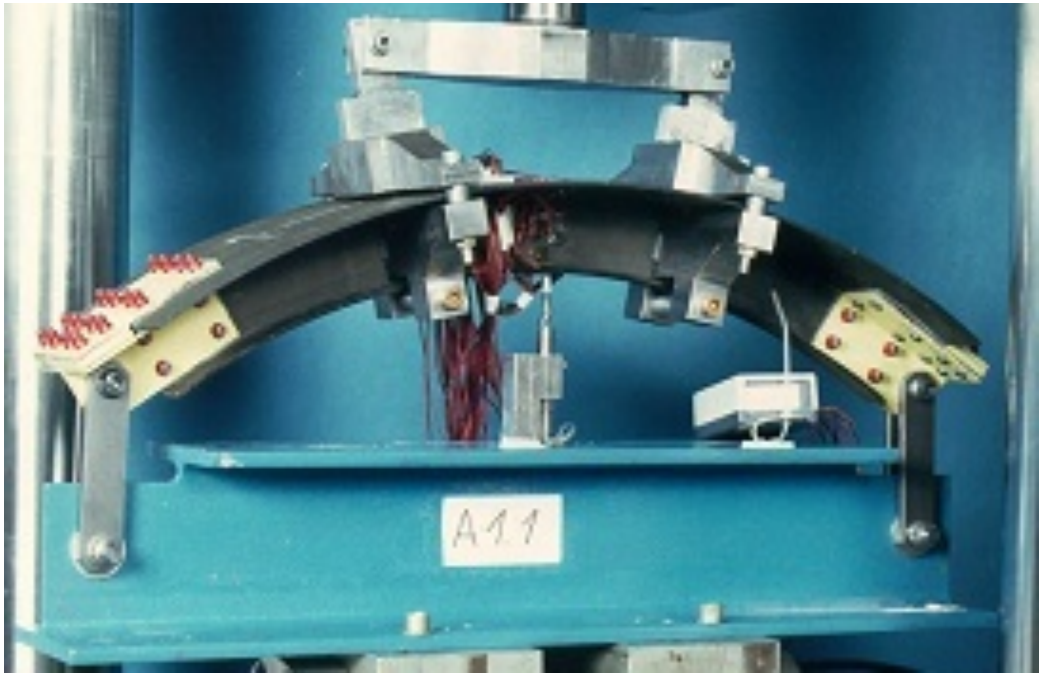


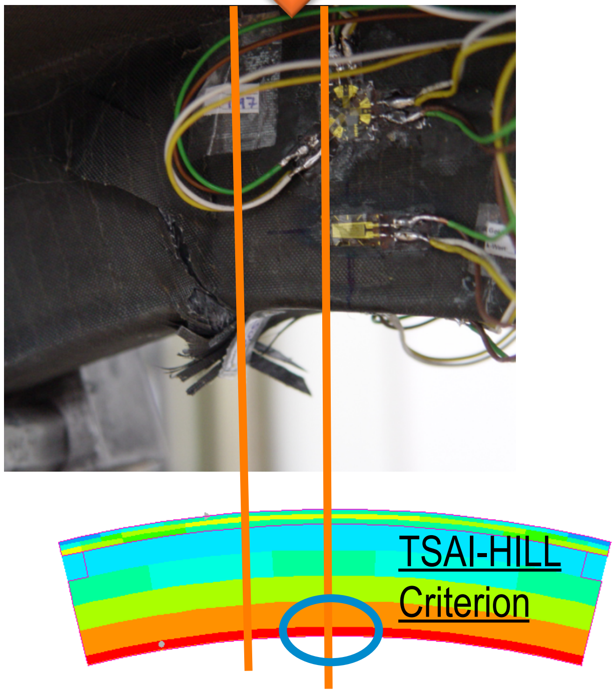


Ex1: Preforming Effects on Air Frame Rupture Analysis (2/8)

- Simulation assumed uniform stiffness
- Stiffness is influenced by draping

Discrepancy between experiment and simulation





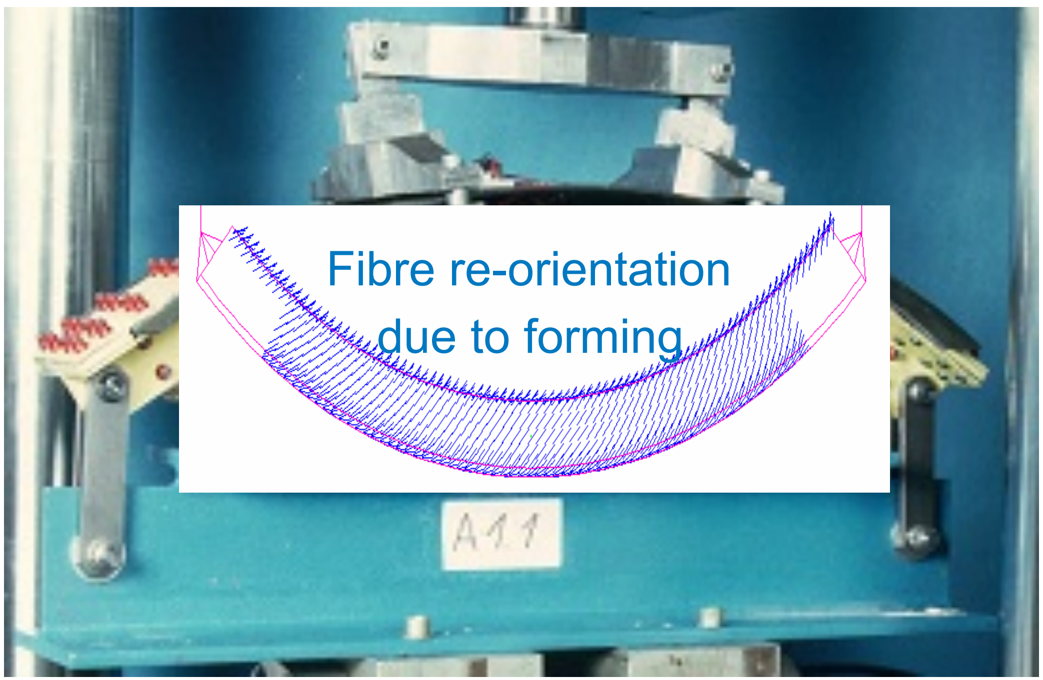
Courtesy of EADS-M (EC FALCOM project)

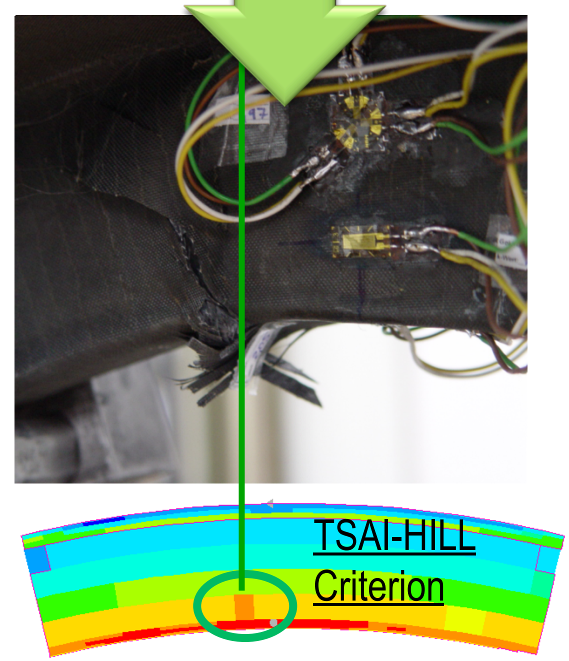
Maximum

Ex1: Preforming Effects on Air Frame Failure Analysis (3/8)

- Simulation assumed uniform stiffness
  - Stiffness is influenced by draping

Accounting for preforming leads to the correct location of failure



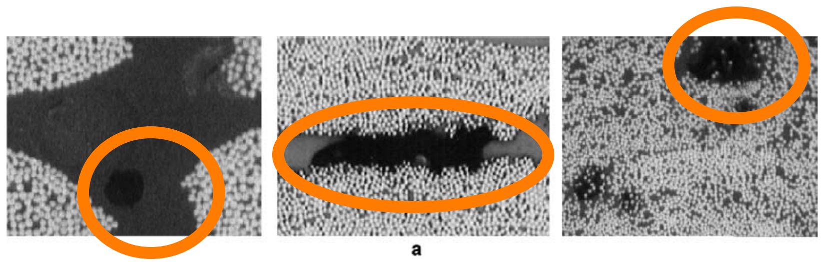


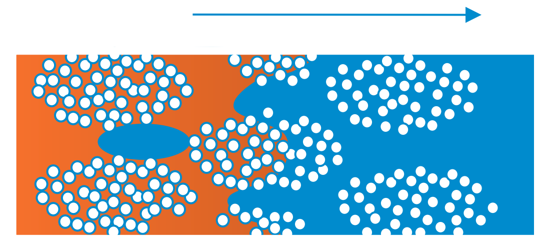
Maximum

Courtesy of EADS-M (EC FALCOM project)

Ex2: Effects of Injection conditions onto Mechanical Performance (4/8)

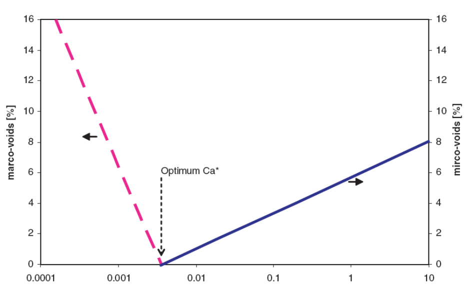
- For high performance composites, formation of micro-voids inside the fiber tows should be minimized (J. Bréard)
  - Macro voids Inter-tow

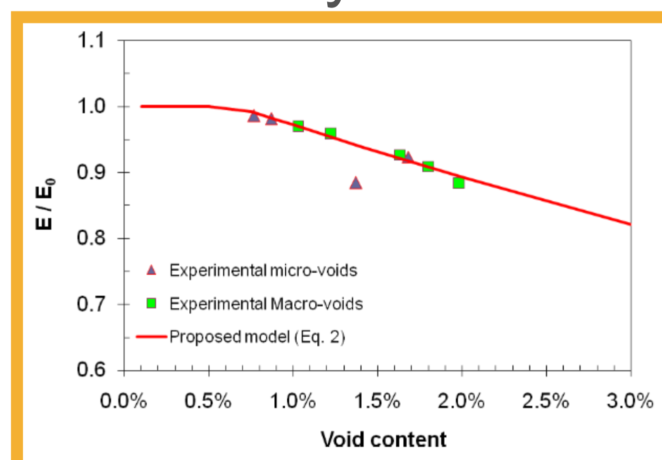




  - Micro voids intra-tow
- Micro-voids are highly related to the resin velocity
- Critical impregnation velocity

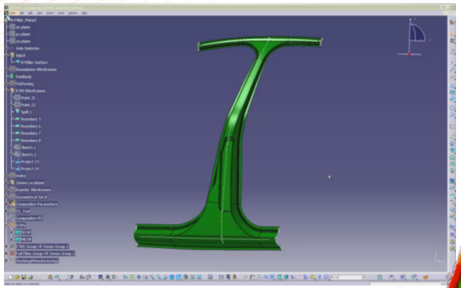
$$Ca = \frac{\mu \ v}{\gamma}$$

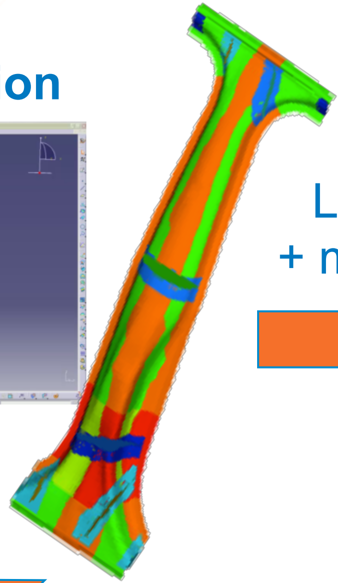




Ex2: Influence of Porosities on Stiffness & Strength

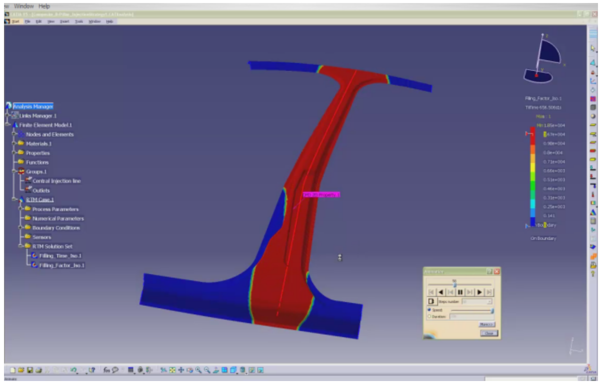
Lay-up definition





Lay-up
+ material

Draping and RTM Model



Draping and
Porosity effect
on mechanical
properties

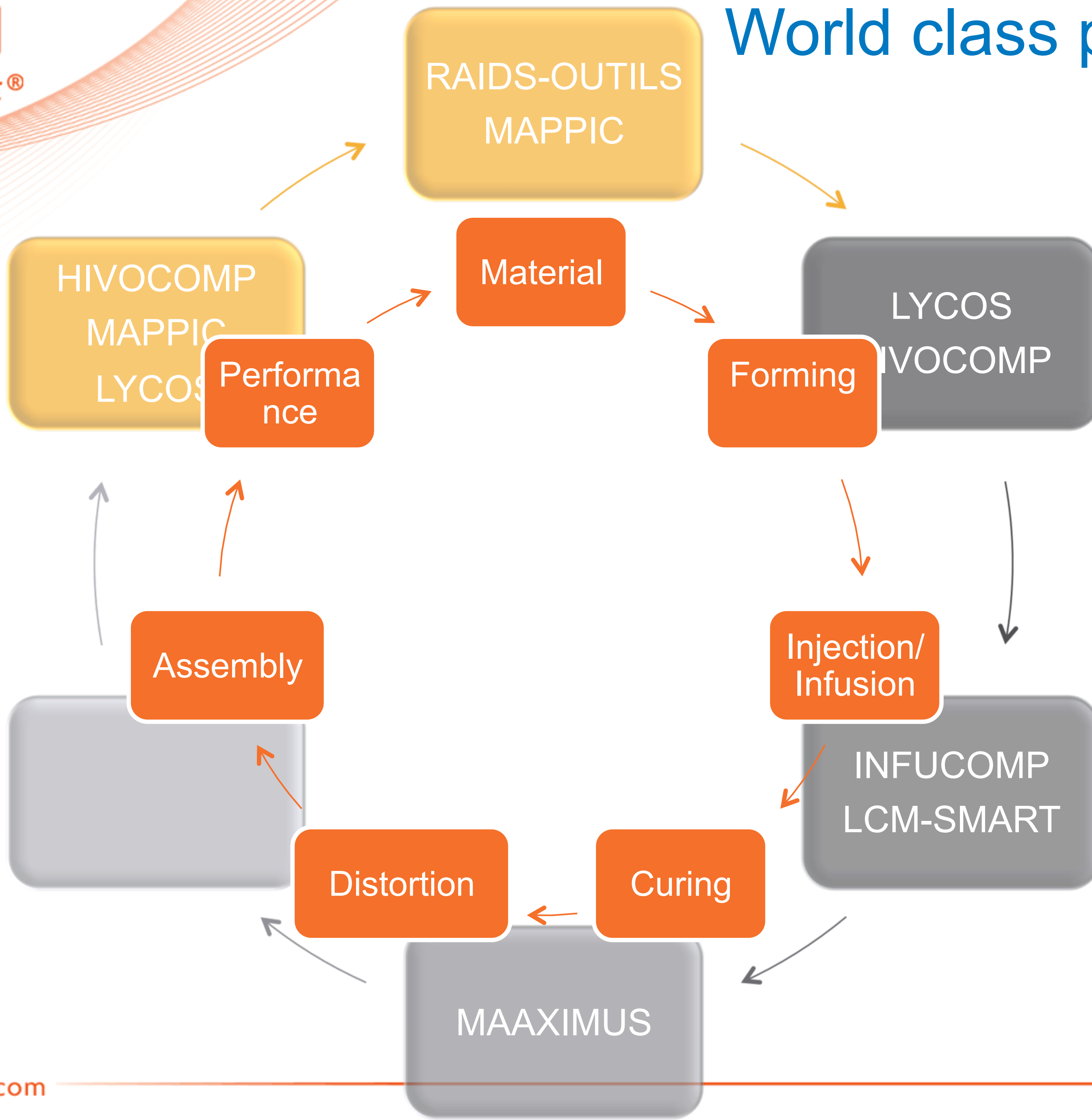
Strength analysis

Design
Iteration

Benefits of ESI Solution

- Help to optimize production time cycle by a better understanding and control of the process
- Help to reduce production cost by evaluating new composites manufacturing strategies
- Detect and correct manufacturing defects that would impact the structural performances of the part
- Allow realistic description of the formed part, enabling a predictive mechanical performance simulation

World class projects



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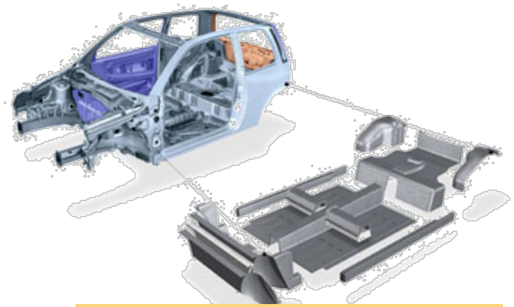
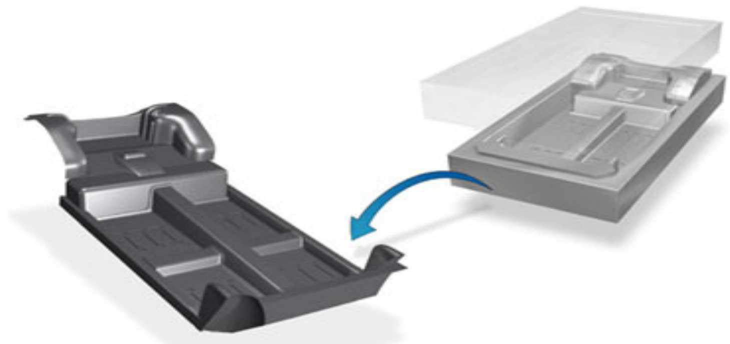
Automotive projects EU projects

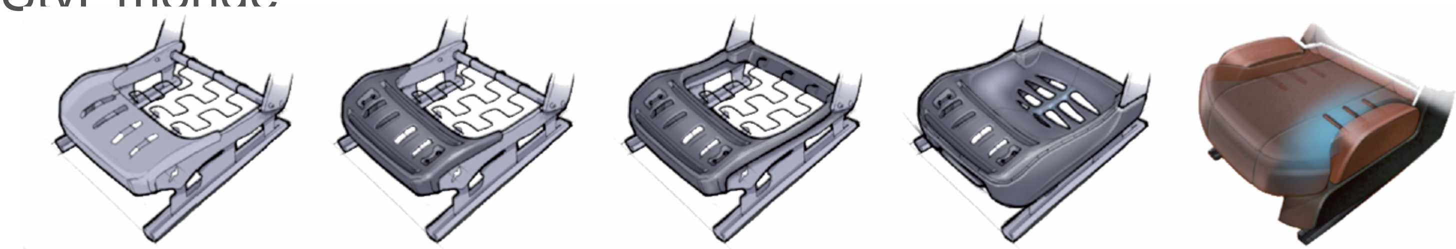
- EC / TECABS
  - Floor pan
  - Link form to crash



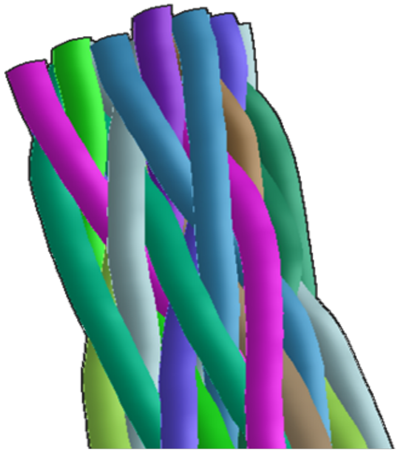


28 Metallic parts → 8 Preforms + 5 Foam cores

- FR / MATSIESA2
  - Thermoplastics forming for dash panels / on-going
  - Partners: Visteon, Renault, Chomarat
- FR / LYCOS
  - CFRP Thermoplastics seat structures / on-going
  - Partners: Faurecia, Rhodia, Activetech, Prodhag, RJP Modelage, Styl'monde

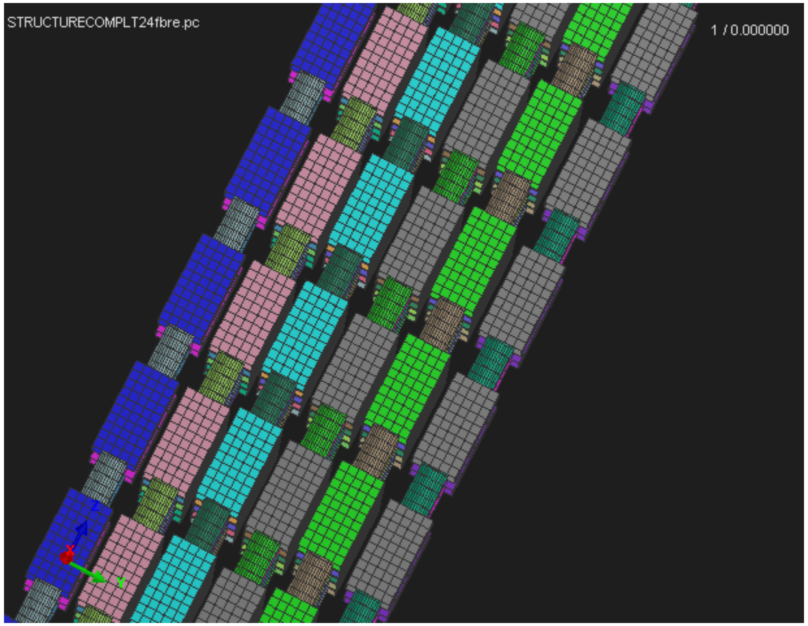


RAID-OUTILS (1/2)



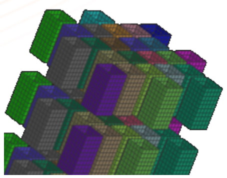
- New Textile technology for Stiffeners
  - Partners: EADS, Hutchinson, CETIM, etc

- ESI tasks: Mechanical properties / permeability prediction through simple braiding simulation



RAID-OUTIL (2/2)

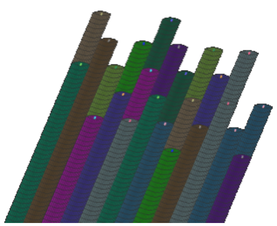
- Permeability prediction on a Unit Cell:



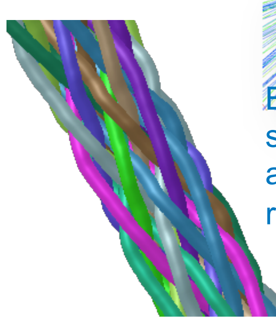
Braiding tools

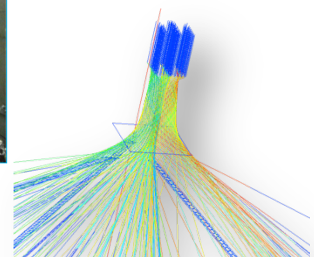
Kinematics

Constraints



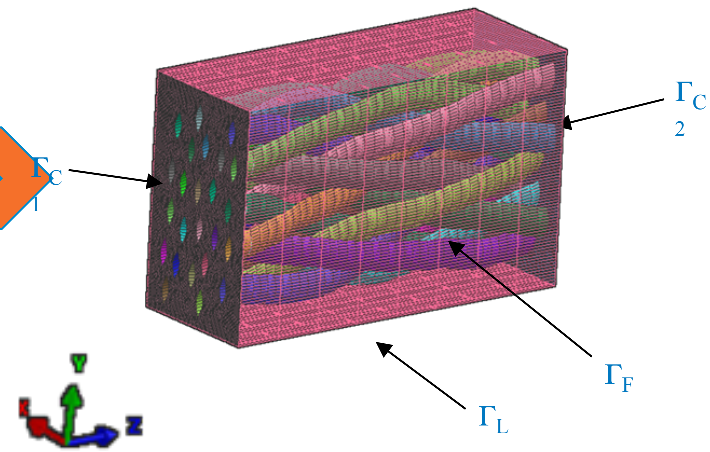
Fibers



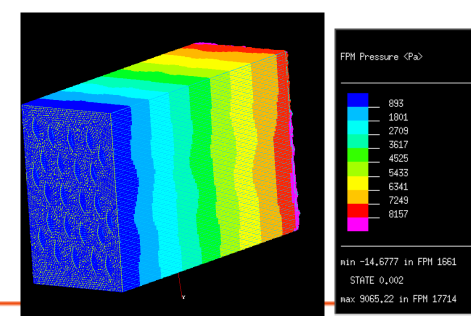


Braiding/weaving simulation for accurate geometrical representation

FPM simulation:
Injection in z direction
Imposed velocity, viscosity and pressure at borders



Result: Pressure gradient



Darcy's law

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

- HIVOCOMP EC FP7 Project with CRF

  Advanced materials enabling **HIgh-VOlume** road transport applications of lightweight structural **COMP**osite parts

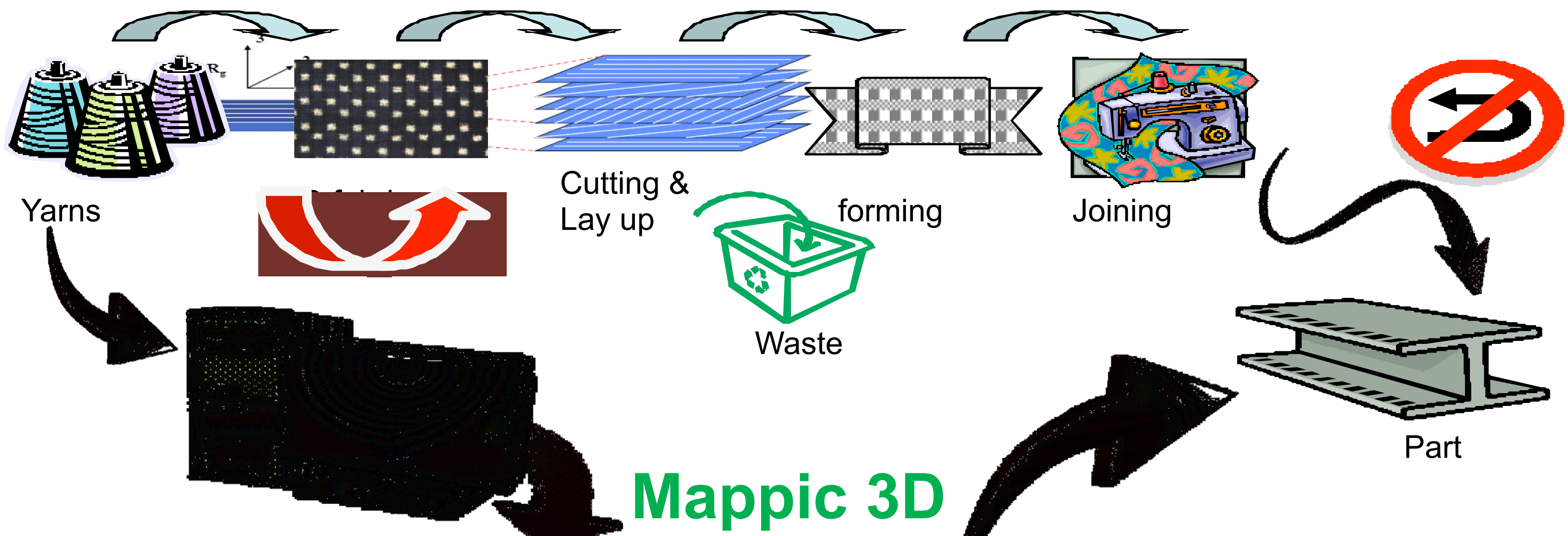
- Objectives
  - Achieve **radical advances** in two materials

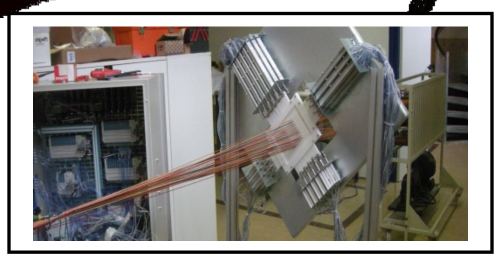
1. advanced polyurethane **(PU) thermoset matrix materials**
2. thermoplastic **self-reinforced polymer composites incorporating continuous carbon fibre reinforcements (Hybrid/SRC)**

  - Assure that these material innovations can be **successfully translated into high-impact industrial applications**
    - Hybrid B-pillar (PU/Hybrid-SRC), composite B-pillar (PU), front structure (PU), side closure (PU), seat frame (Hybrid-SRC) and suitcase (Hybrid-SRC)

Mappic 3D (1/3)

: One-shot Manufacturing on large scale of 3D upgraded automotive panels and stiffeners for lightweight thermoplastic textile composite structures





two technologies : panels and stiffeners
Reduction of cost : 38 %
Reductio n of time production : 25 %

Process simulation to get local porosities (2/3)

+ compression and temperature

Braiding simulation + draping
(Thermoplastics filament inside)

Intra yarn simulation of thermoplastics diffusion
FPM (Local model)
of the melted thermoplastic filaments
Prediction of intra yarn porosity

Local model
Numerical experiment
Statics
Rupture
Mapping of properties

Inter-yarn diffusion (FPM)
Prediction of inter yarn porosity

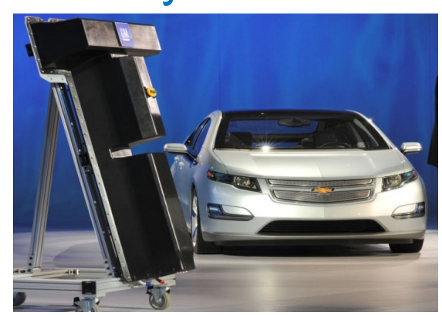
Prediction of performance based upon manufacturing (3/3)

Braiding simulation
Local fiber orientation

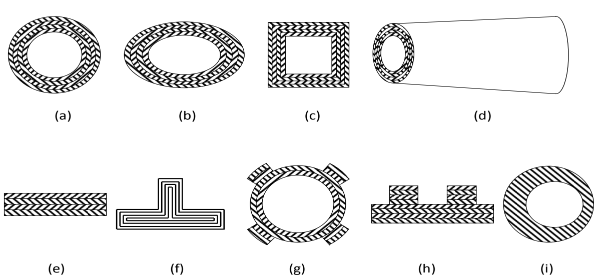
Local properties
Porosities

Mapping

Battery containers



Stiffeners



Plastic oil pan

VPS Statics, NVH and crash performance

Composites partnerships and network

- RTM
  - POLY MONTREAL
  - ECN
- CURING
  - Cranfield U.
- DRAPING
  - INSA LYON
- DISTORTION
  - SWEREA SICOMP
- MECHANICAL PERFORMANCE
  - IFB
  - KUL

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