



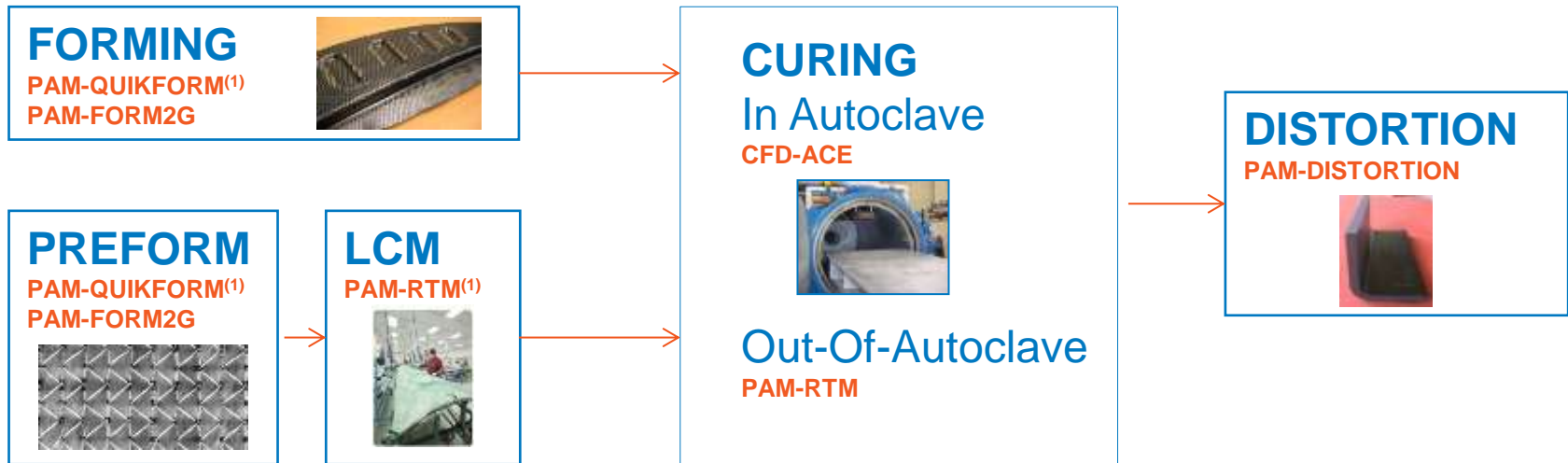
PAM-FORM 2G 2013

Thermoforming of dry textiles and prepregs

July 23rd, 2013
Mathilde Chabin

- Introduction to ESI Composites Manufacturing Suite
- PAM-FORM 2G product presentation
- References

- Introduction to ESI Composites Manufacturing Suite
- PAM-FORM 2G product presentation
- References



(1) Standalone version or CATIA V5 embedded

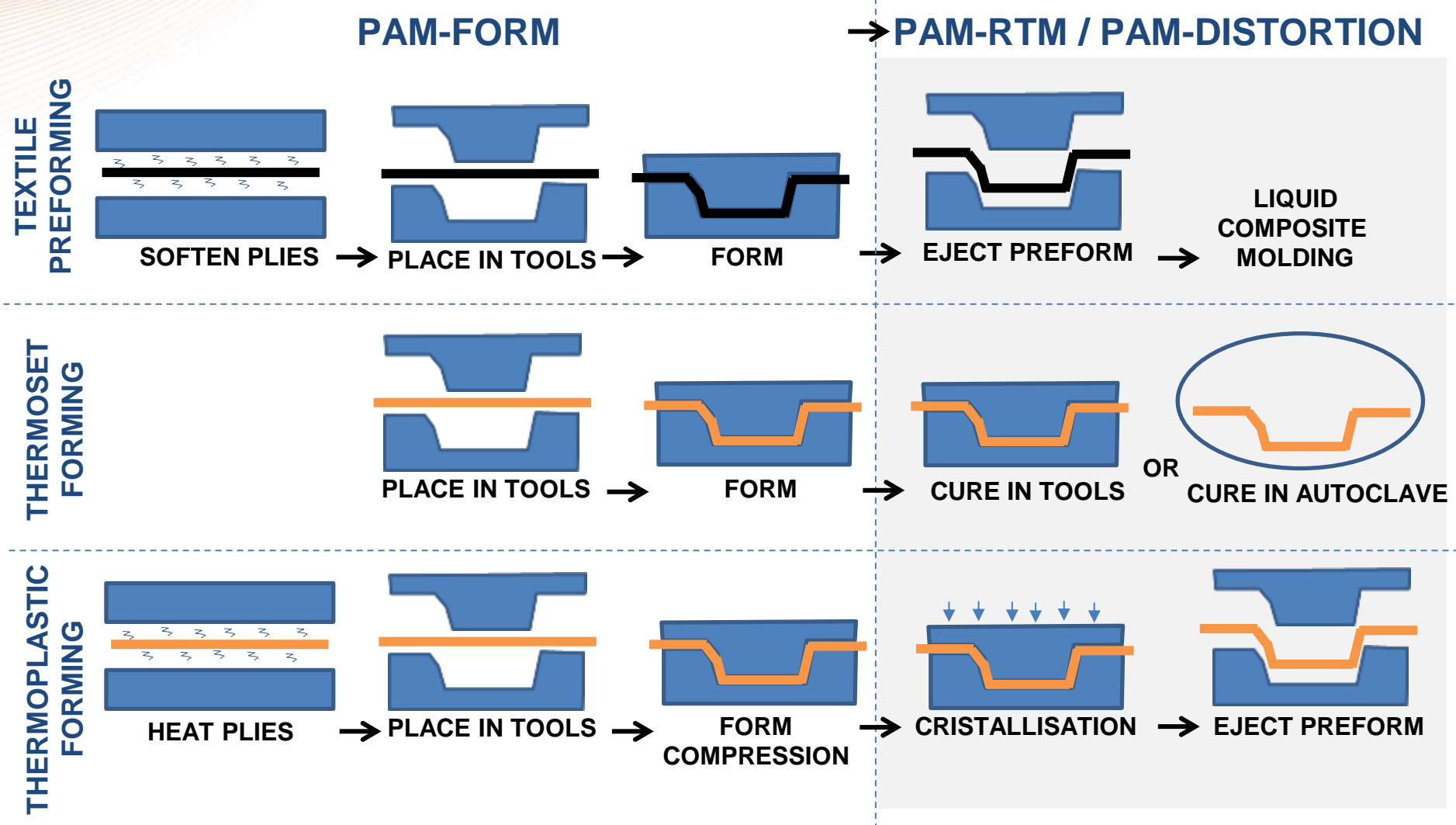
Note: ESI solution can use draping results from non-ESI applications as Fibersim, Composites Design by DS...

➔ ESI chain

- Introduction to ESI Composites Manufacturing Suite
- PAM-FORM 2G product presentation
- What is new in 2013 version
- References

PAM-FORM 2G

Process Schematic

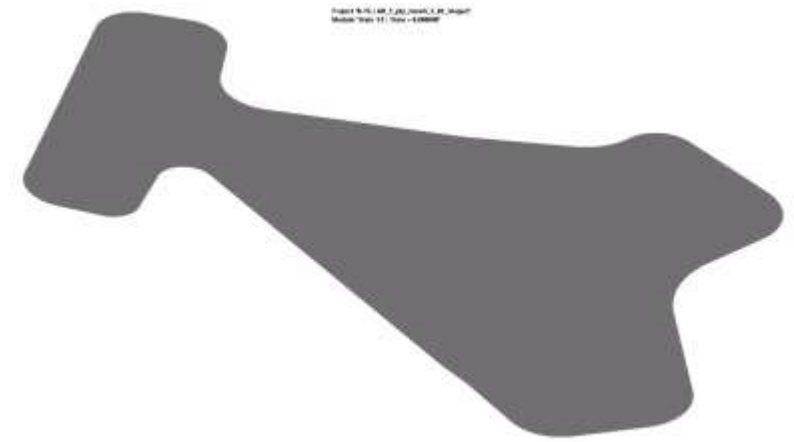


— **To define and optimize:**

- Forming strategy: stamping, thermoforming, diaphragm forming...
- Process parameters: tool velocity, holding system and force, temperature cycle, pressure cycle, material type and thickness for diaphragms...

— **Through the prediction of:**

- Wrinkling
- Bridging
- Thickness
- Optimum flat pattern
- Final fiber orientation

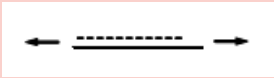








Automotive B-Pillar

— **With material models for NCF, UD and woven fabrics**

PAM-FORM 2G simulation

Material data requirements

DEFORMATION MODE	REPRESENTATION	SIMULATION INPUT	COMMENTS
Fiber extension		Young's modulus (E1, E2)	To be done for both fiber directions
Fiber buckling		Young's modulus = f(strain) (E1, E2)	To be done for both fiber directions
In-plane shear		Force/Displacement (G)	To be done for positive and negative shear
Bending		Simulations for Bending Stiffness calibration (B1, B2)	To be done for both fiber directions
Compaction		Thickness = f(pressure)	Can be done for different shear angles
Sliding		Friction coefficient	Can be temperature, velocity and pressure dependent To be done between plies and between plies and tools
In-plane shear viscosity		Viscosity	Can be temperature dependent

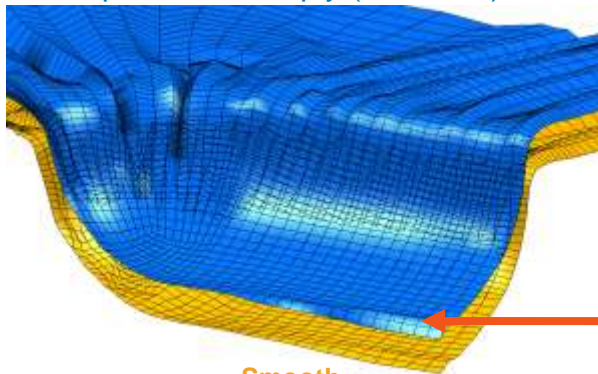
- Material data are needed for each ply of the laminate
- Data should cover temperature range of the process

PAM-FORM 2G simulation

Example 1: Wrinkling prediction

- UD thermoforming:
 - 20 plies of carbon unidirectional
 - thermoplastic matrix –APC2-AS4

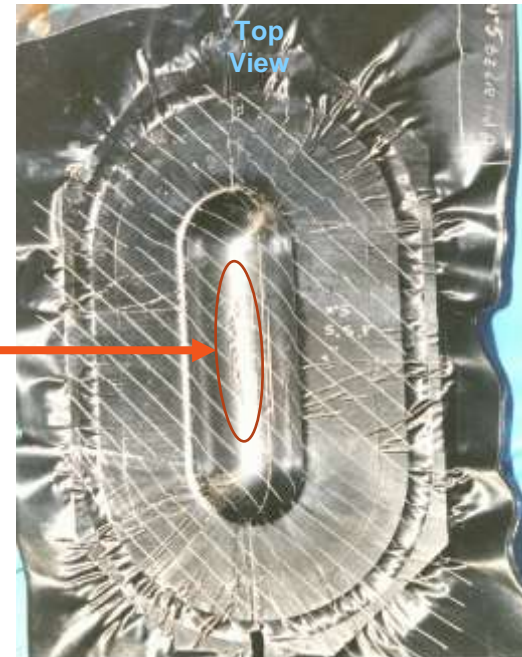
PAM-FORM2G simulation
Top and Bottom ply (End view)



Smooth surface



Bottom View



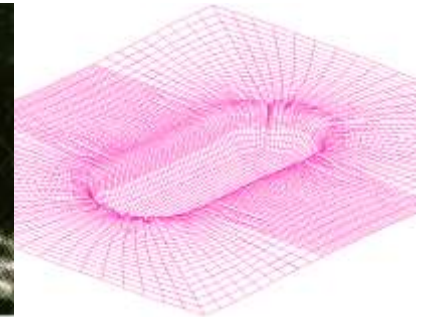
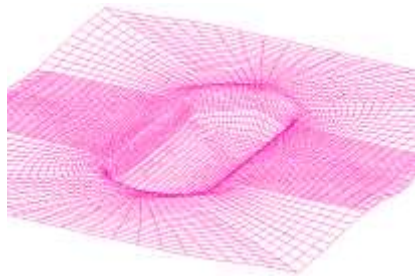
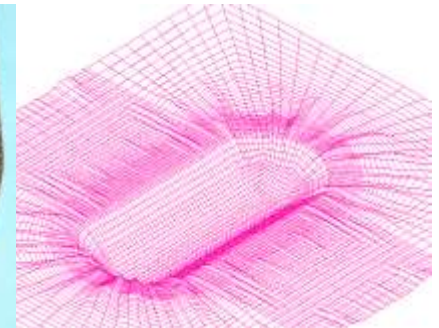
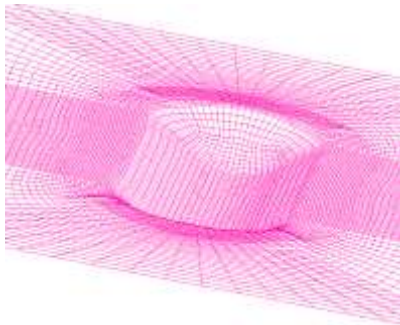
Top View

Wrinkle

PAM-FORM 2G simulation

Example 2: Process definition

- Woven fabrics thermoforming: impact of punch velocity



PUNCH VELOCITY= 5.mm/s

PUNCH VELOCITY=40.mm/s

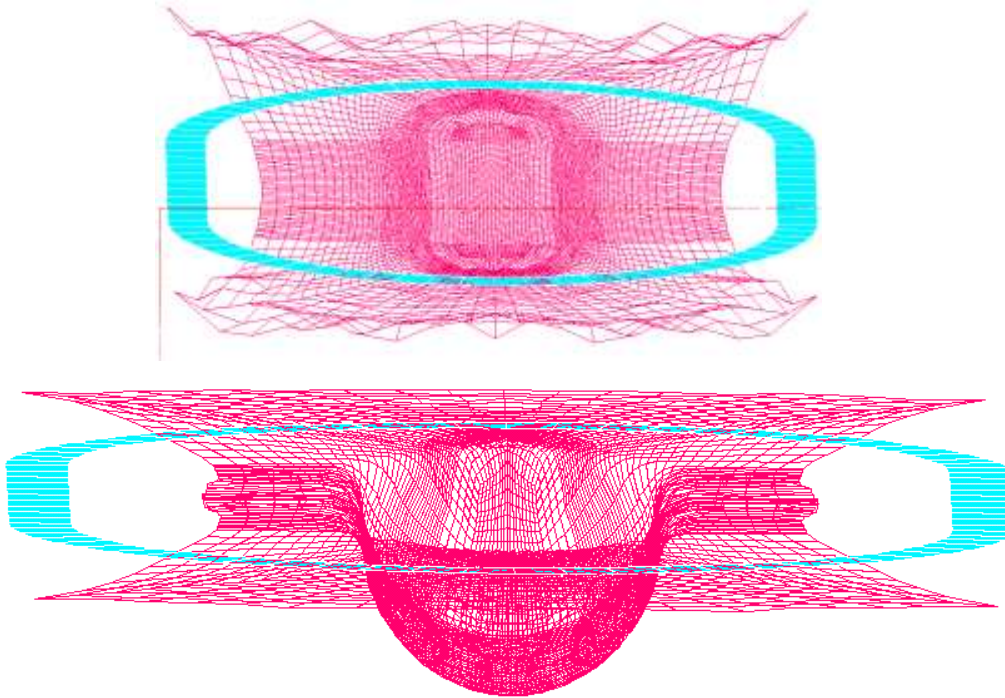
PEI-CETEX; 8 plies

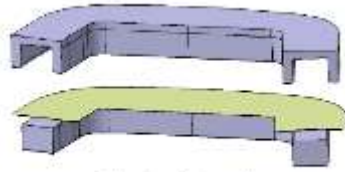
Courtesy: Dassault Aviation

PAM-FORM 2G simulation

Example 3: Material definition

- Clamping system definition
- Laminate definition





Stamping tools and reinforcement

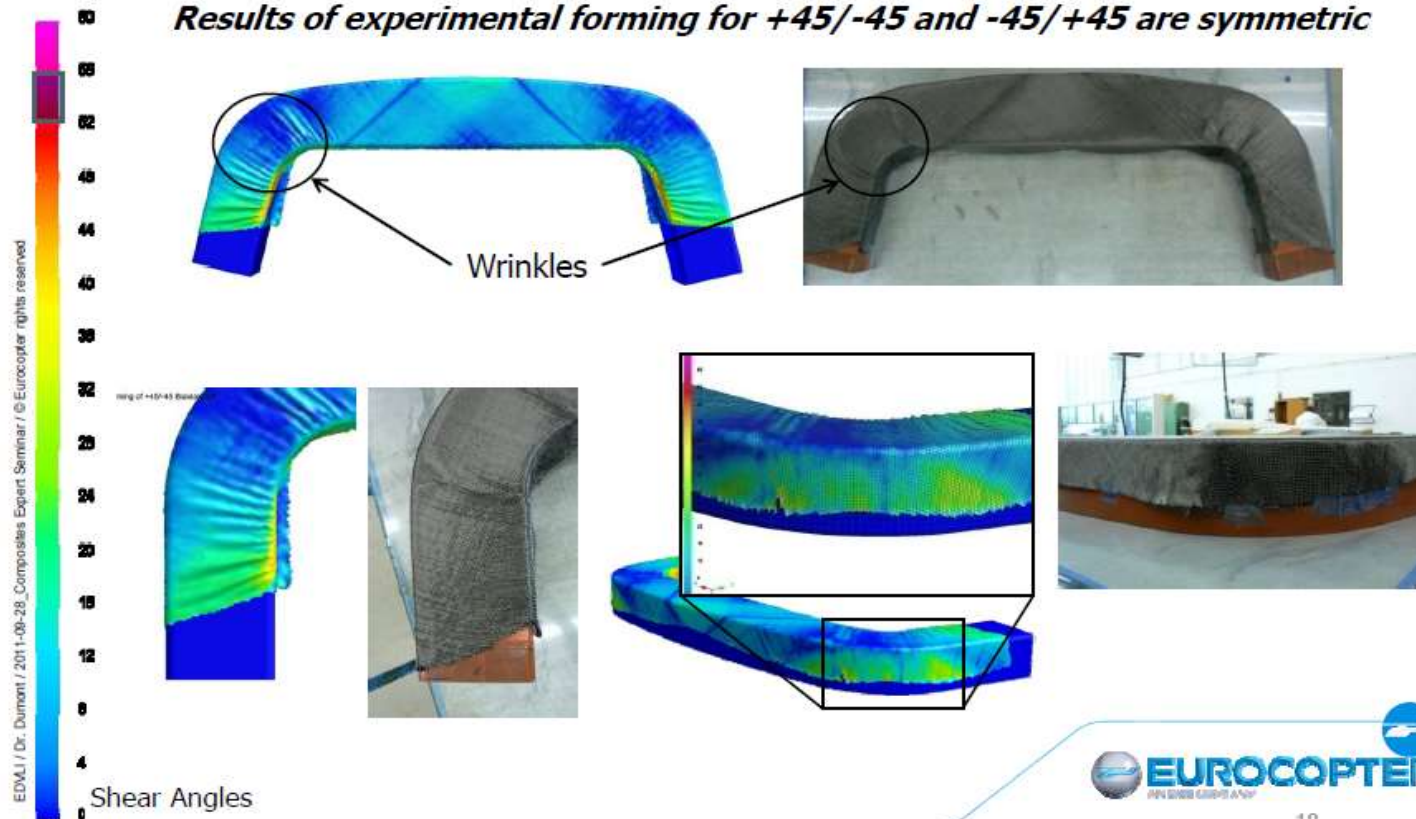
PAM-FORM 2G simulation

Example 4: Shearing prediction on preform

thinking without limits

Forming – Results of ± 45 NCF: Sh. angles

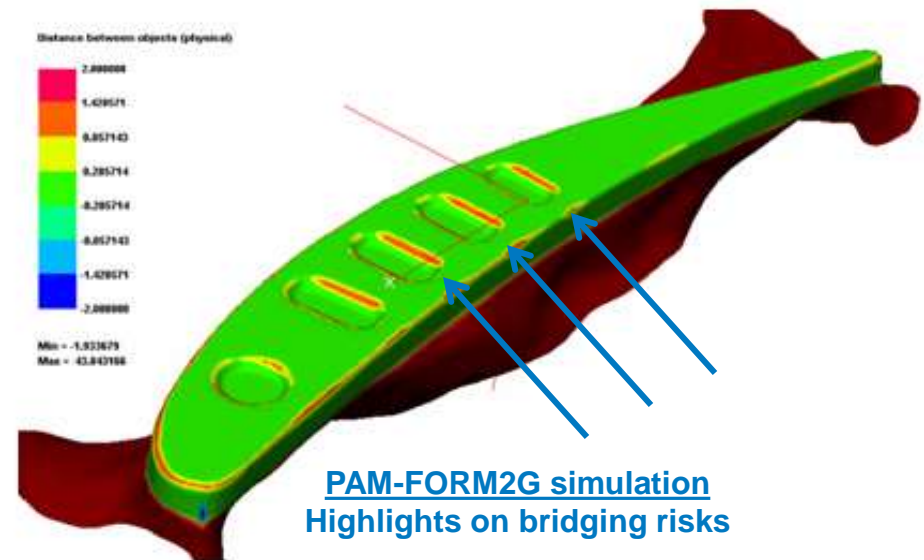
Results of experimental forming for $+45/-45$ and $-45/+45$ are symmetric



PAM-FORM 2G simulation

Example 5: Bridging prediction

- Fabric / 6 plies / PPS Matrix



- Introduction to ESI Composites Manufacturing Suite
- PAM-FORM 2G product presentation
- **References**

Some References

- AUDI
- Lamborghini
- Bilcare
- BMW
- DLR
- DOW
- EUROCOPTER
- GE
- Mercedes-Benz
- Letov
- Minoru Kasai
- NCC
- VW
- Visteon



www.esi-group.com

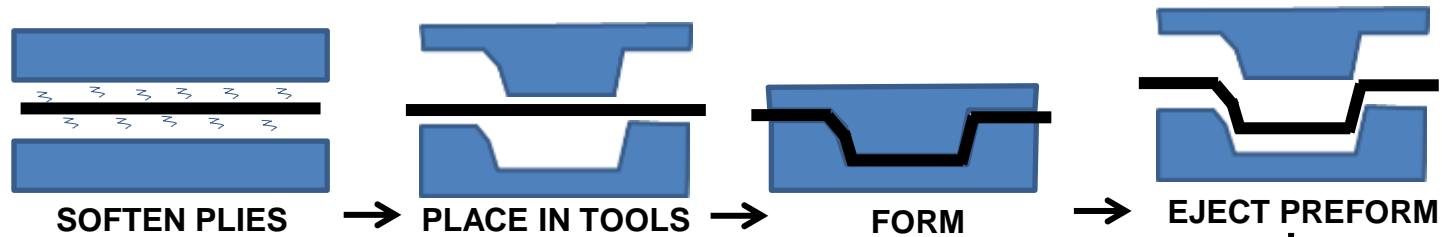


PAM-RTM 2013

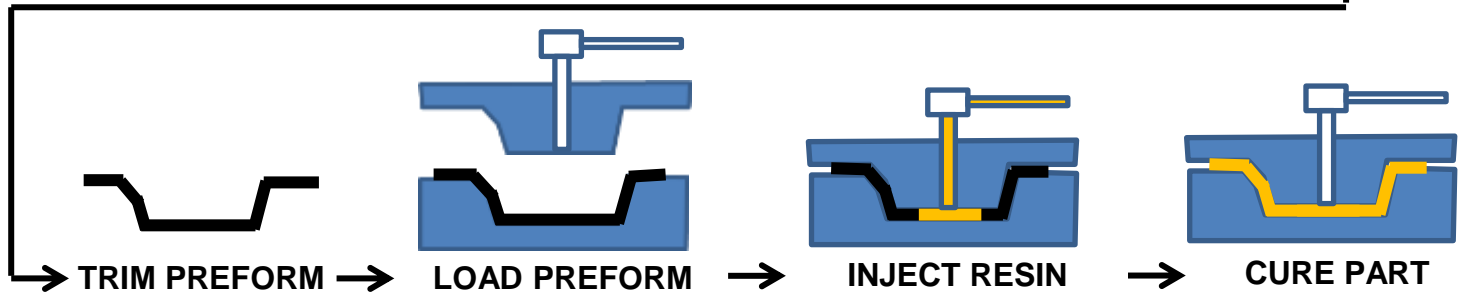
Product presentation

Liquid Composites Molding *Process Schematic*

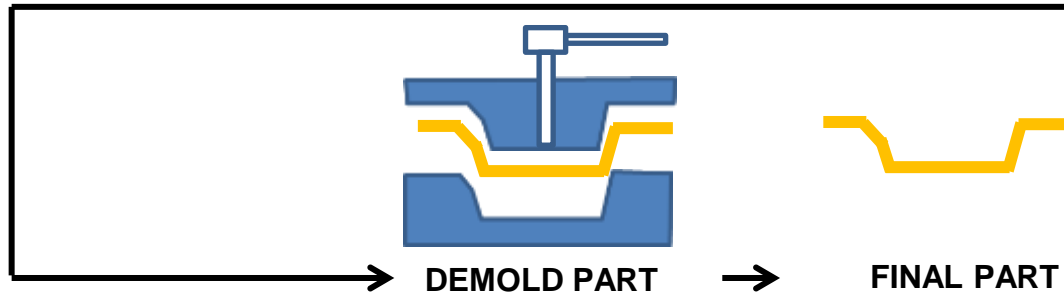
PAM-FORM 2G



PAM-RTM



SYSPLY

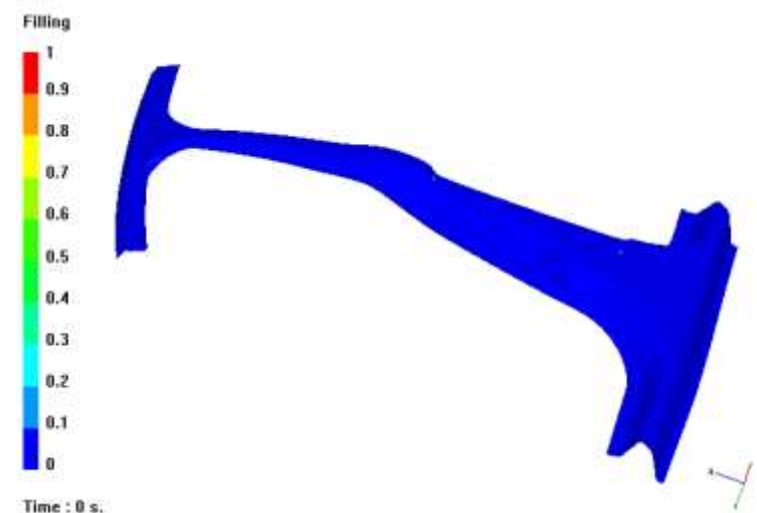


● To define and optimize:

- LCM strategy (RTM, CRTM, VARI...)
- Location of injection gates, vents and vacuum ports
- Size, type and location of flow media
- Temperature cycle

● Through the prediction of:

- Filling and Curing time
- Dry spots
- Flow front velocity
- Pressure in the mold



B-Pillar injection

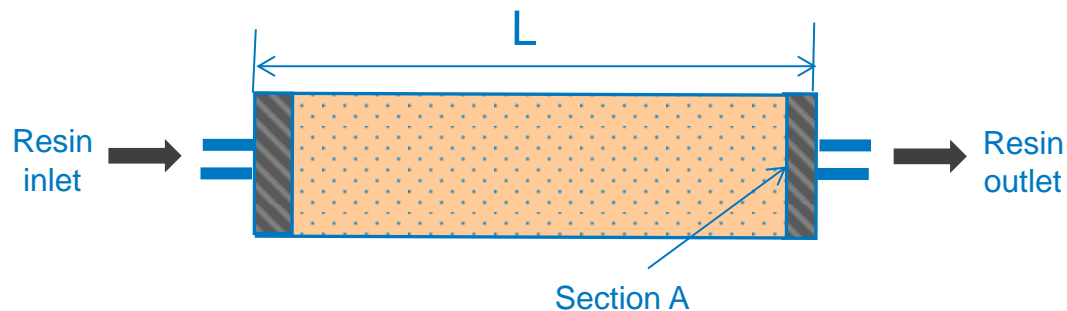
● Taking into account

- Fiber angle variation (permeability variation) of the preform

- Resin flow in a porous medium using

DARCY'S LAW

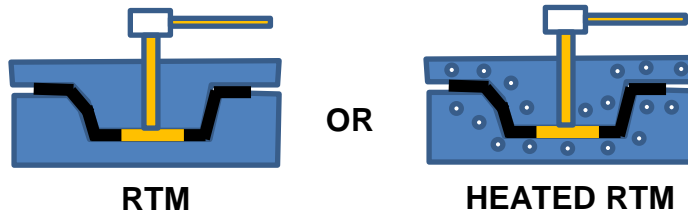
$$q = \frac{Q}{A} = \frac{K}{\mu} \cdot \frac{\Delta p}{L}$$



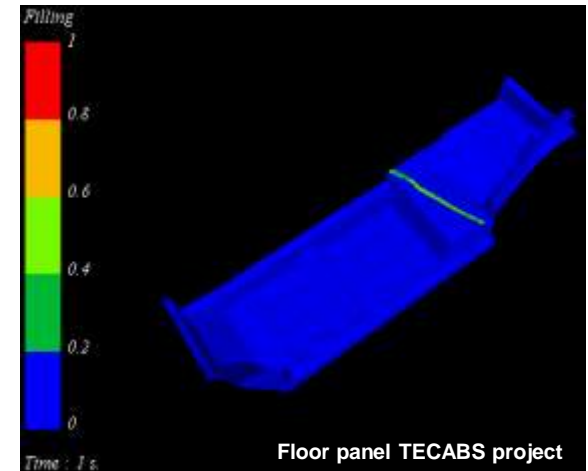
Liquid Composites Molding

Process variants with PAM-RTM

RTM: Resin Transfer Molding



Material data for simulation

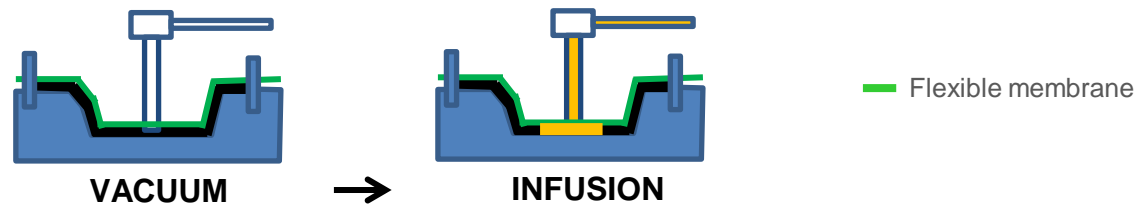


	RTM	HEATED RTM (<i>added data</i>)
Reinforcement	Permeability tensor (K1,K2,K3) <i>Constant OR f(shear angle)</i>	Density <i>Constant</i> Specific heat <i>Constant OR f(temperature)</i> Thermal conductivity tensor (K1, K2, K3) <i>Constant OR f(temperature)</i> Effective conductivity tensor (K1, K2, K3) <i>Constant OR f(temperature) OR f(temperature, degree of cure)</i>
Resin	Density <i>Constant</i> Viscosity <i>constant OR f(time) OR f(material age)</i>	Viscosity <i>f(temperature) OR f(temperature, degree of cure) OR User defined</i> Specific heat <i>Constant OR f(temperature) OR f(temperature, degree of cure)</i> Heat conductivity <i>Constant OR f(temperature) OR f(temperature, degree of cure)</i> Enthalpy <i>constant</i> Curing Kinetics <i>5 models including Kamal-Sourour OR User Defined</i>

Liquid Composites Molding

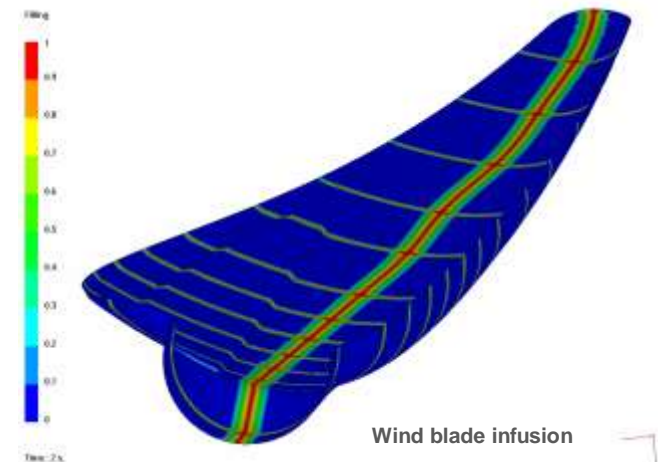
Process variants with PAM-RTM

- VARI:** Vacuum Assisted Resin Infusion



- Material data for simulation (added data)

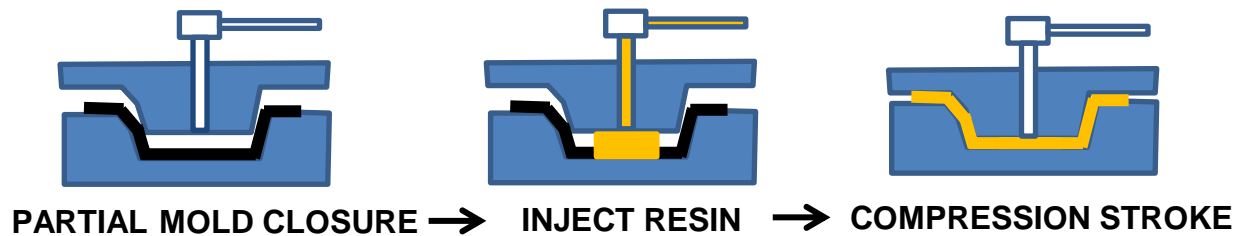
	VARI (added data)
Reinforcement	Permeability tensor (K_1, K_2, K_3) $f(\text{fiber content})$ Compressibility curve $\text{Pressure of compaction} = f(\text{fibre content})$



Liquid Composites Molding

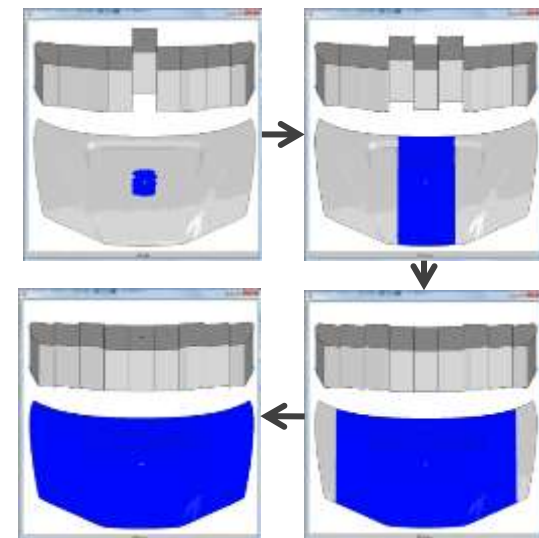
Process variants with PAM-RTM

— CRTM: Compression Resin Transfer Molding



— Material data for simulation

	CRTM
Reinforcement	Permeability tensor (K_1, K_2, K_3) f (fiber content)

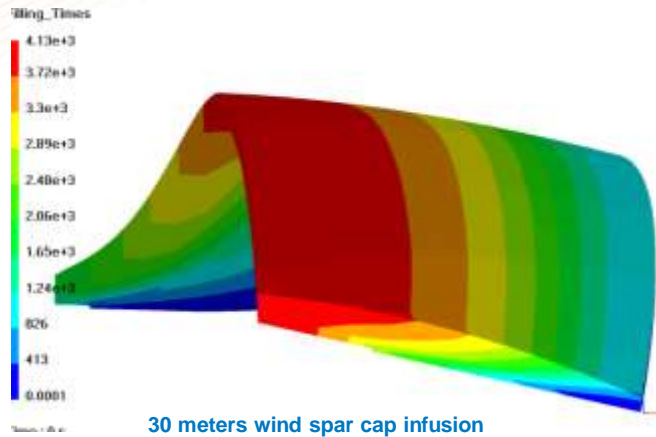


Automotive hood – A-CRTM
 Courtesy: CCHP of Ecole Polytechnique of Montréal

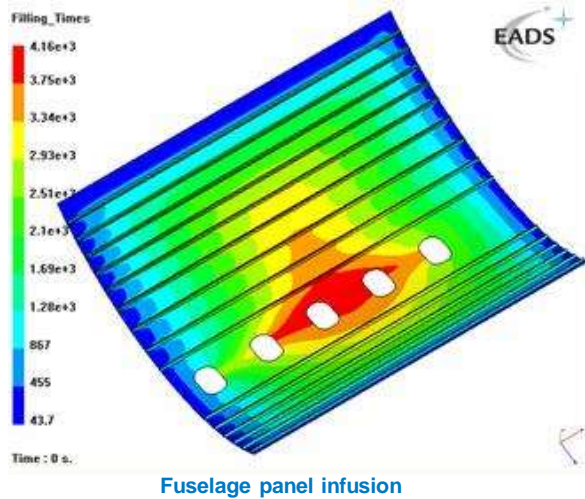
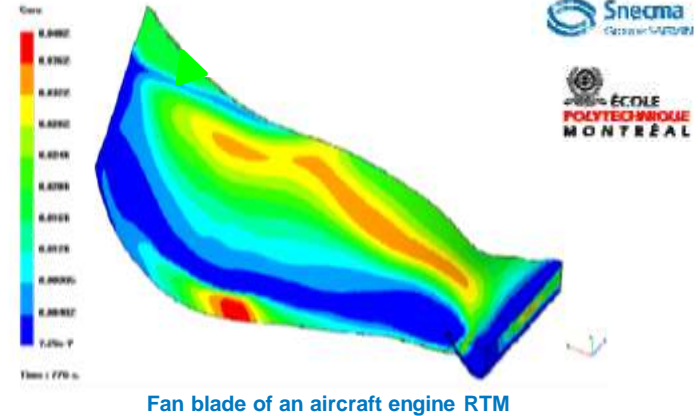
PAM-RTM simulation

Post-Processing examples

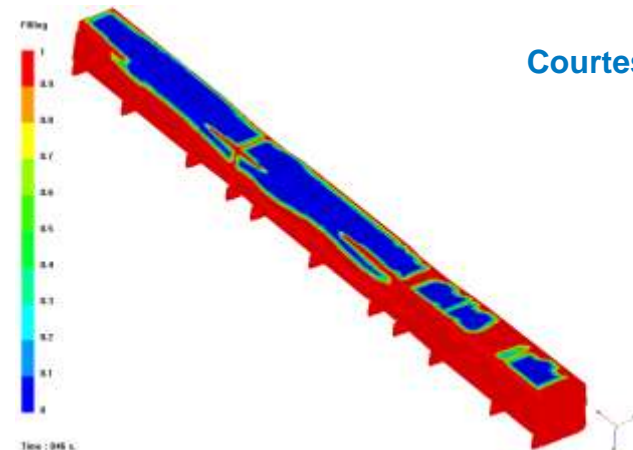
Filling time



Curing time



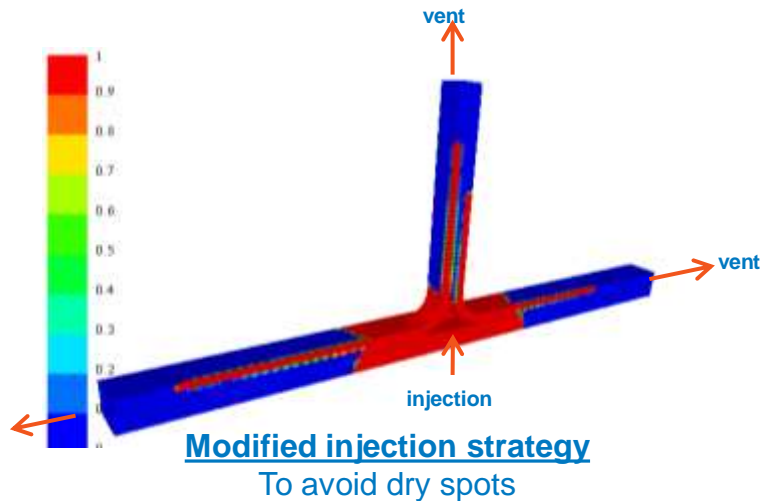
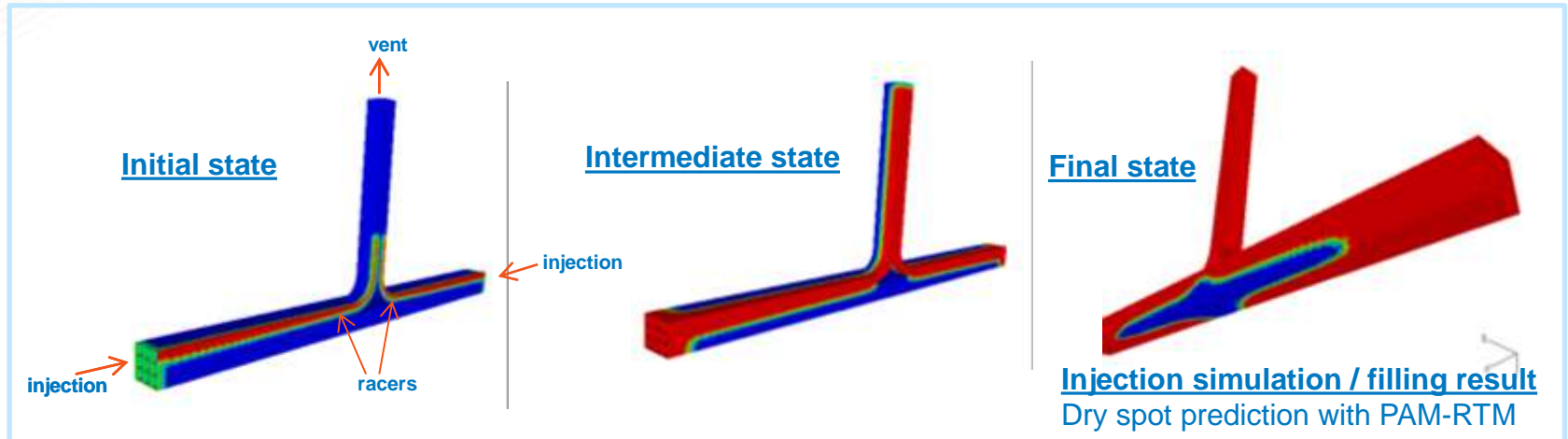
Filling degree



PAM-RTM simulation

Post-Processing examples

■ Dry spots



Final part

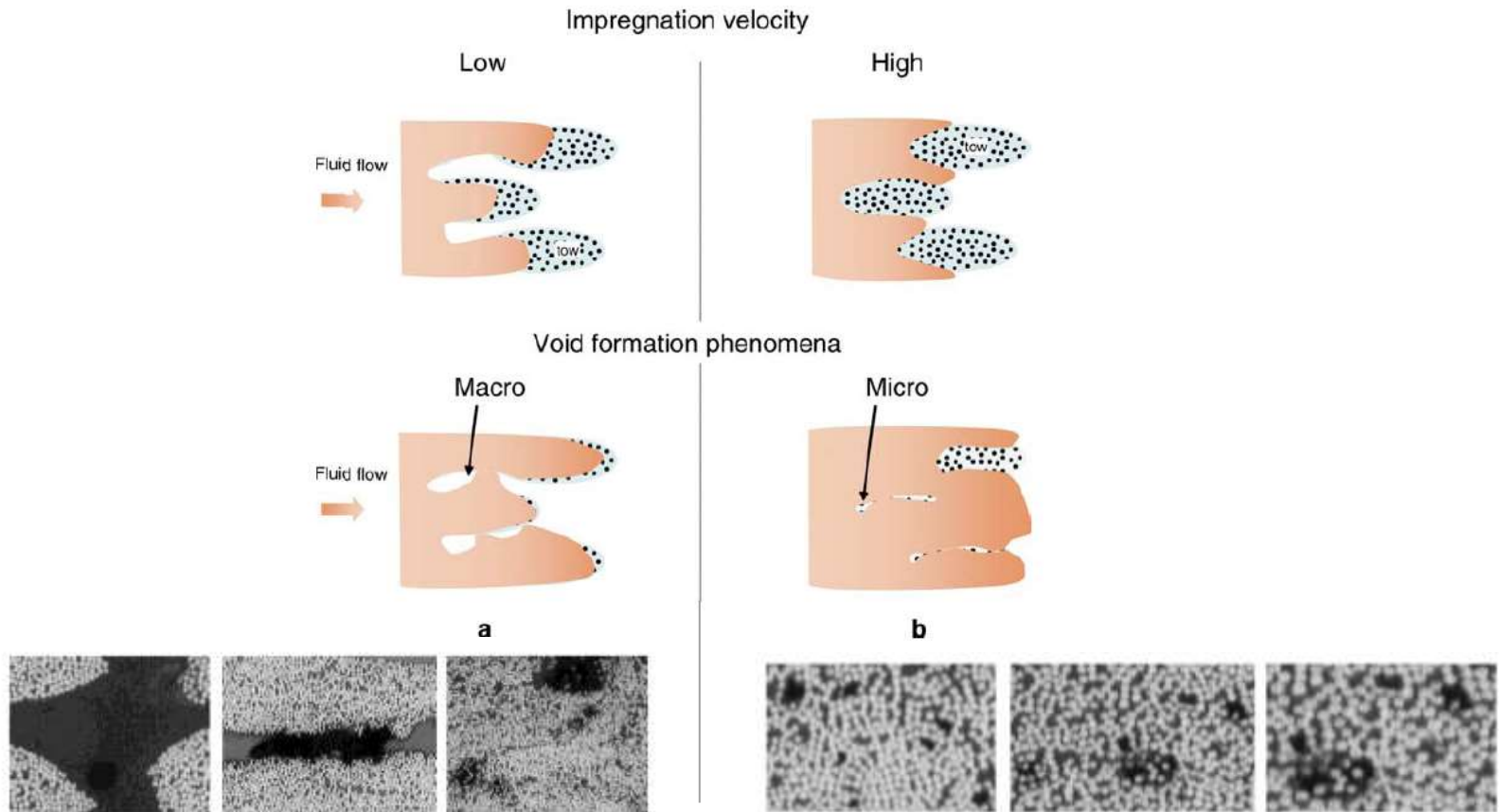
Courtesy: Cranfield University

PAM-RTM simulation

Additional functionalities

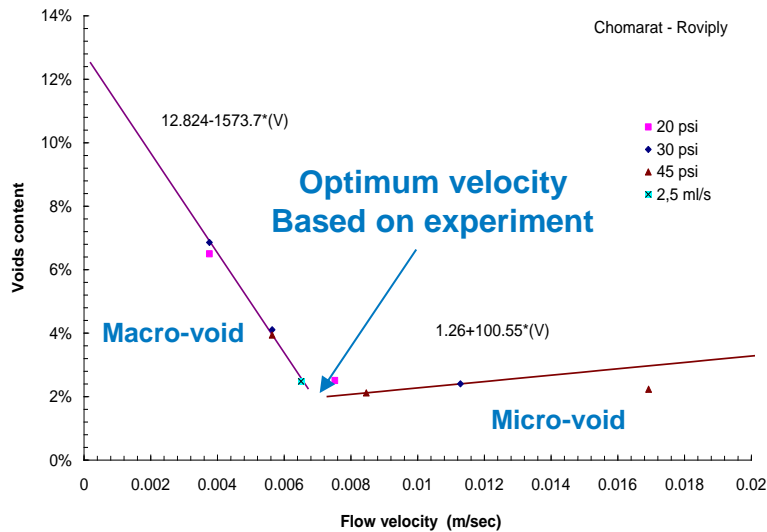
■ Porosity prediction and reduction:

- Principle: Critical impregnation velocity: $\max \|\vec{v}_{front}\| \leq \|\vec{v}_{crit}\|$

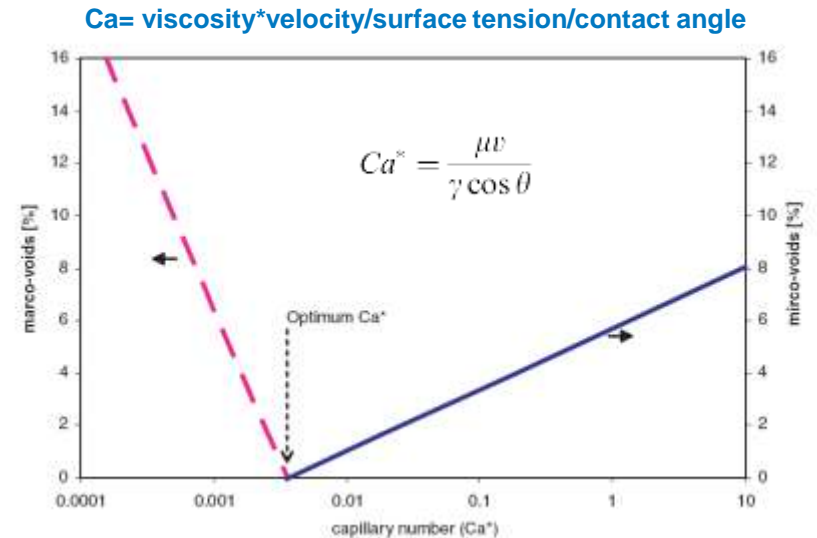


Porosity prediction and reduction:

- PAM-RTM input data:

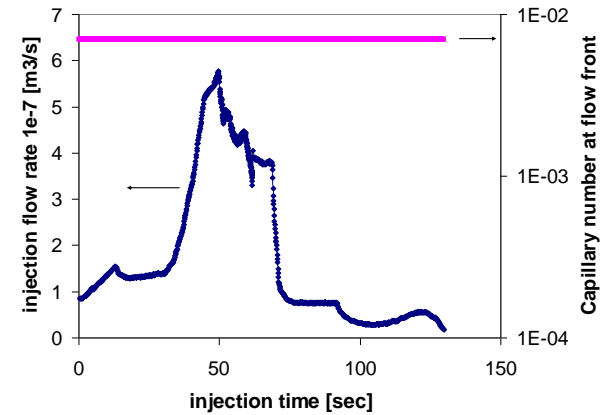
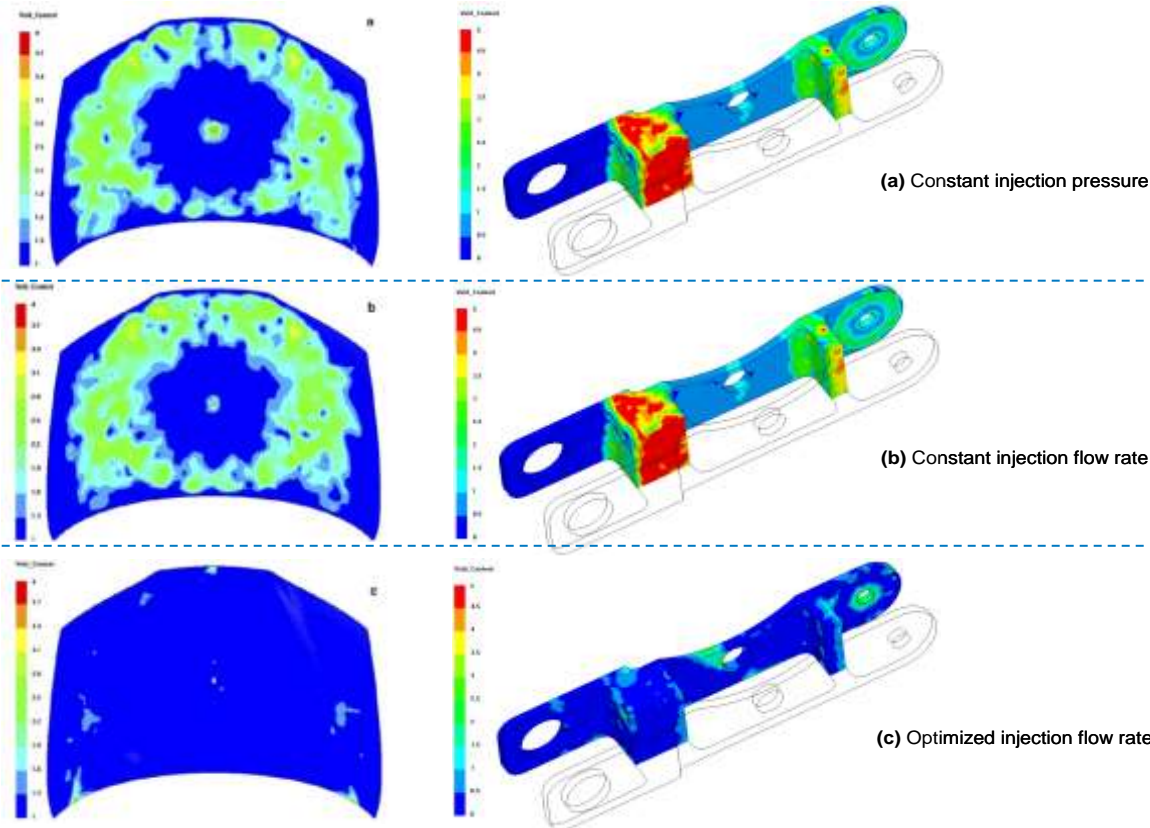


Experimental data



PAM-RTM input curve

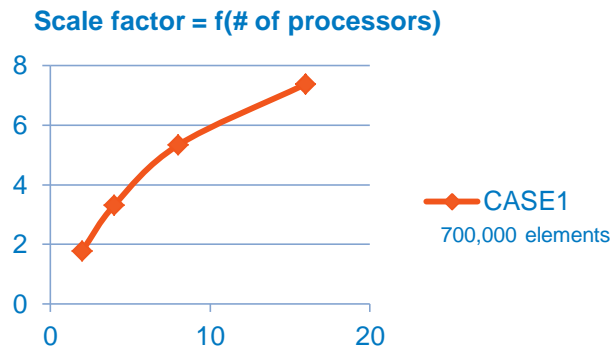
- Porosity prediction and reduction:
 - PAM-RTM output: injection flow rate curve



PAM-RTM simulation

Additional functionalities

- **Trigger manager** that allows conditional opening of the gates
- **DMP** solving capability that highly decrease the computation time when increasing the number of processors

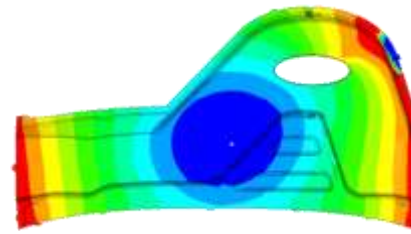
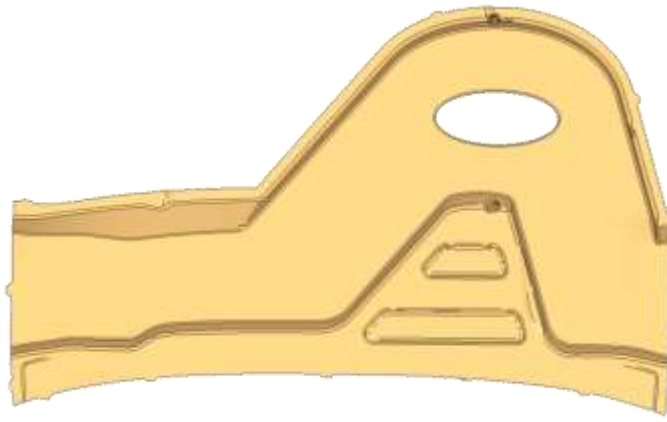


- **Gravity** effect on resin flow

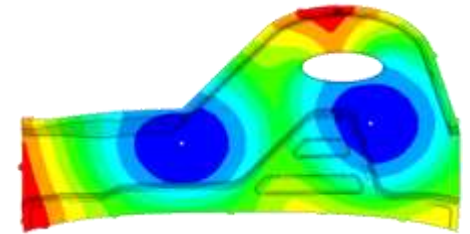
PAM-RTM simulation

Additional functionalities

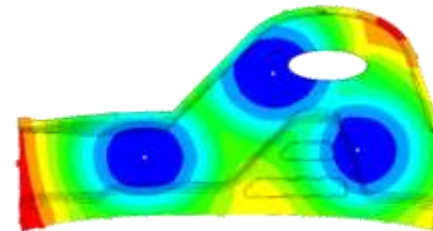
- One shot simulation (few seconds) for estimation of last points to be filled and filling time
- Automatic estimate of injection point location



192 secondes



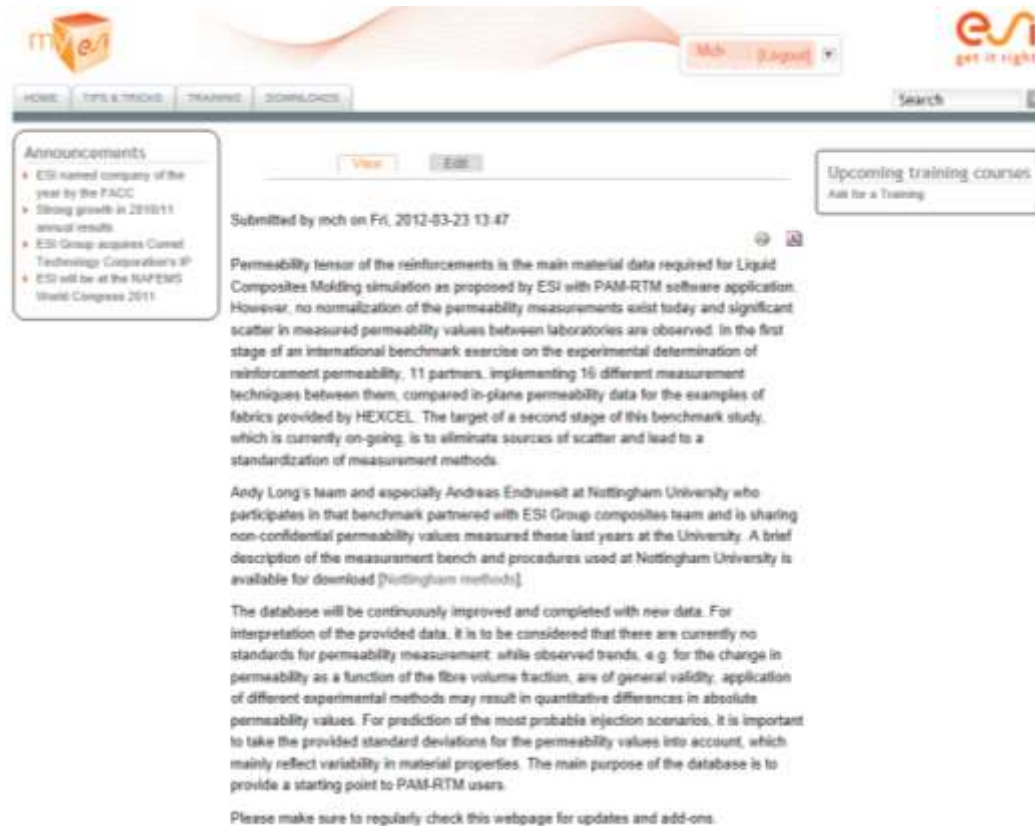
93 secondes



62 secondes

- Consolidation of DMP solver:
 - Permeability as a function of shear angle
 - Trigger manager
 - Reporting improvements
 - Results sampling on sensors
 - Specific heat and effective thermal conductivity - $f(T, \alpha)$
- Material database

- Based on [Nottingham University](#) data available on ESI customer portal: [MyESI](#)



Submitted by mch on Fri, 2012-03-23 13:47

Permeability tensor of the reinforcements is the main material data required for Liquid Composites Molding simulation as proposed by ESI with PAM-RTM software application. However, no normalization of the permeability measurements exist today and significant scatter in measured permeability values between laboratories are observed. In the first stage of an international benchmark exercise on the experimental determination of reinforcement permeability, 11 partners, implementing 16 different measurement techniques between them, compared in-plane permeability data for the examples of fabrics provided by HEXCEL. The target of a second stage of this benchmark study, which is currently on-going, is to eliminate sources of scatter and lead to a standardization of measurement methods.

Andy Long's team and especially Andreas Endruweit at Nottingham University who participates in that benchmark partnered with ESI Group composites team and is sharing non-confidential permeability values measured these last years at the University. A brief description of the measurement bench and procedures used at Nottingham University is available for download [Nottingham methods].

The database will be continuously improved and completed with new data. For interpretation of the provided data, it is to be considered that there are currently no standards for permeability measurement; while observed trends, e.g. for the change in permeability as a function of the fibre volume fraction, are of general validity, application of different experimental methods may result in quantitative differences in absolute permeability values. For prediction of the most probable injection scenarios, it is important to take the provided standard deviations for the permeability values into account, which mainly reflect variability in material properties. The main purpose of the database is to provide a starting point to PAM-RTM users.

Please make sure to regularly check this webpage for updates and add-ons.

REINFORCEMENTS DATA

- CARBON 3d angle-interlock 12K.xls
- CARBON 3d orthogonal.xls
- CARBON DCFP 24K 115 mm.xls
- CARBON DCFP 24K 28 mm.xls
- CARBON DCFP 3K 28 mm.xls
- CARBON triax braid 0 45.xls
- CARBON triax braid 0 60.xls
- CARBON triax braid 0 70.xls
- CARR REINFORCEMENTS 3839I.xls
- CHOMARAT Tissu Roving 900T.xls
- COTECH EDX 424.xls
- CS INTERGLAS 04367.xls
- CS INTERGLAS 91945.xls
- CS INTERGLAS 92115.xls
- CS INTERGLAS 92125.xls
- FORMAX FGE 101.xls
- FORMAX FGE 104.xls
- FORMAX FGE 196 HD.xls
- FORMAX FGE 117.xls
- FORMAX FGE 360.xls
- GLASS twill 3x1.xls
- GLASS twill 800.xls
- HEXCEL 01113 1000 TF970.xls
- HEXCEL 46330 D 1000.xls
- HEXCEL G0926 tw E01 1F.xls
- HEXCEL G0986 1200.xls
- HEXCEL G1164 AT250 TCT.xls
- HEXCEL NBB90 HR 1270 0400 G C1.xls
- OWENS CORNING ELPB567.xls
- OWENS CORNING U 1140R1750550 UDIMAT.xls
- OWENS CORNING Unifilo 750 450.xls

FLOW MEDIA DATA

- ARTECH knitflow 105 HT.xls

PAM-RTM simulation

Workflow example (1/4)

Ply lay-up
Fibers orientation
Material definition

Import

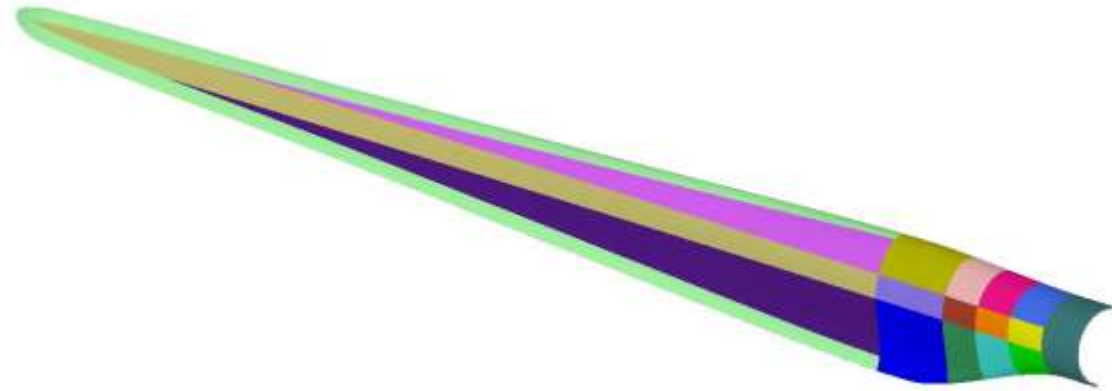


Zones



PAM-RTM

Solid mesh creation
and zones definition

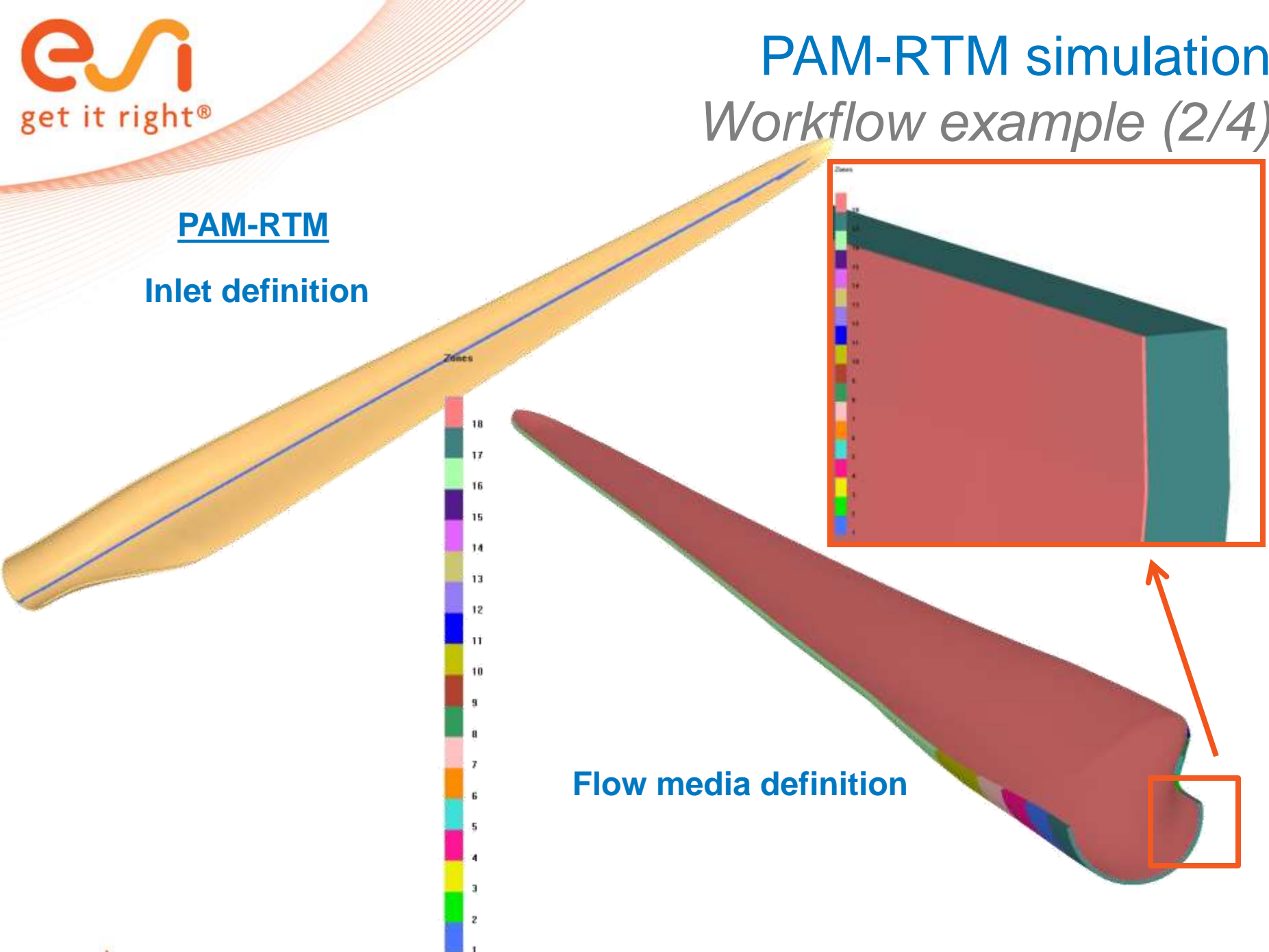


PAM-RTM simulation

Workflow example (2/4)

PAM-RTM

Inlet definition



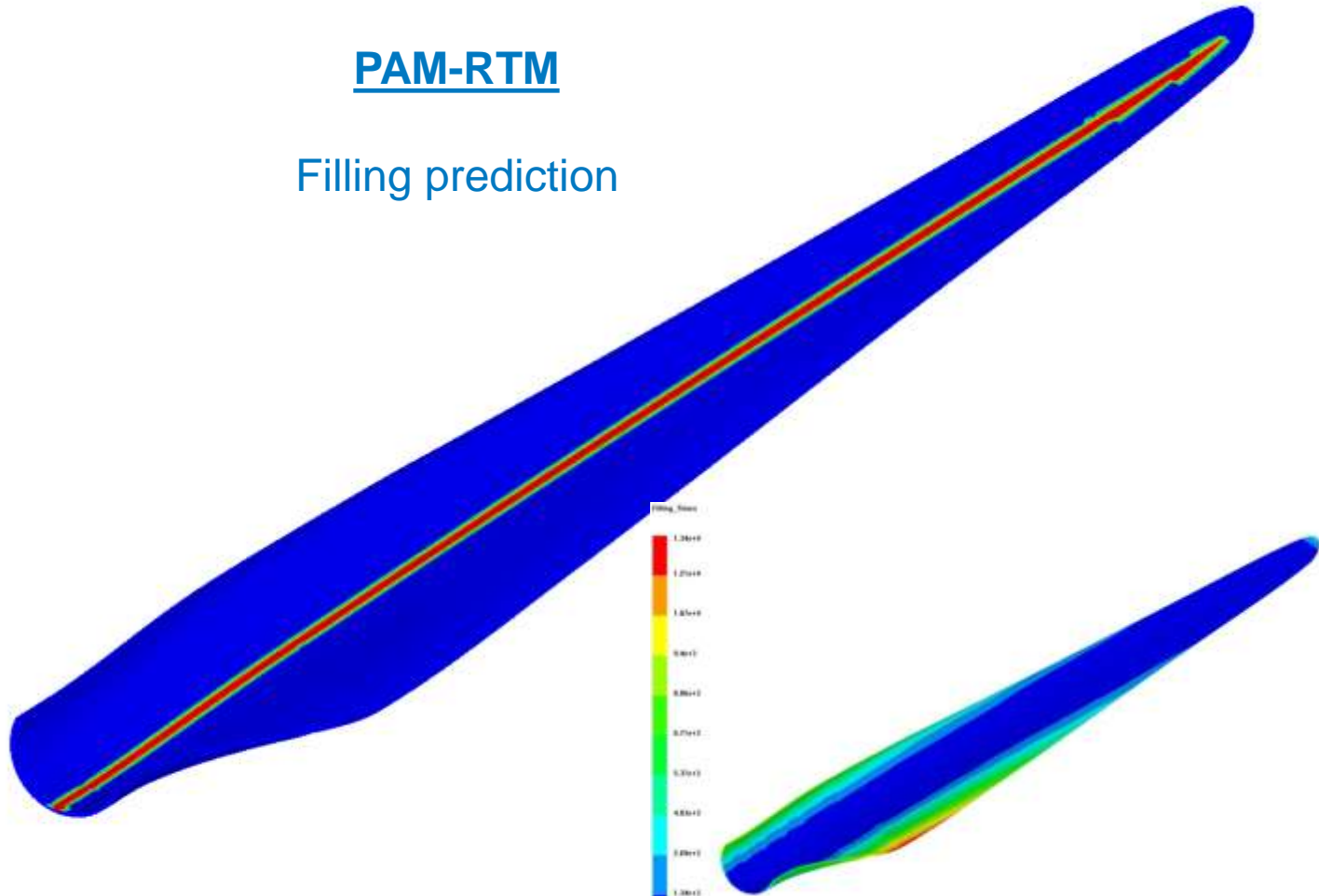
Flow media definition

Filling



PAM-RTM

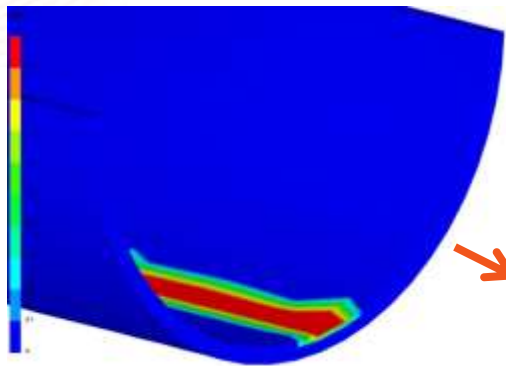
Filling prediction



Time, s

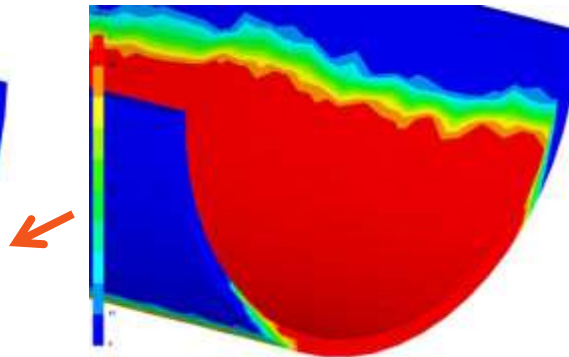
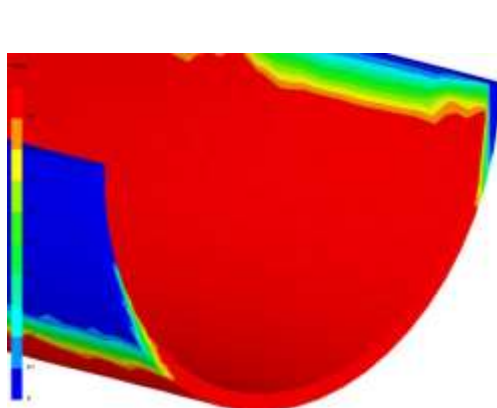
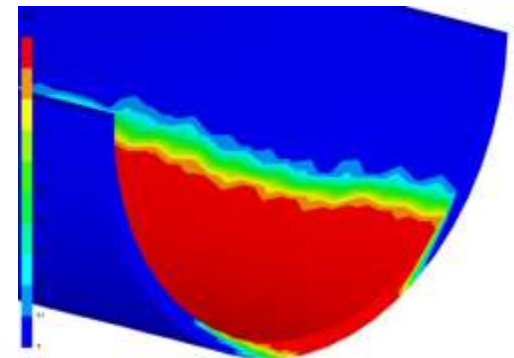
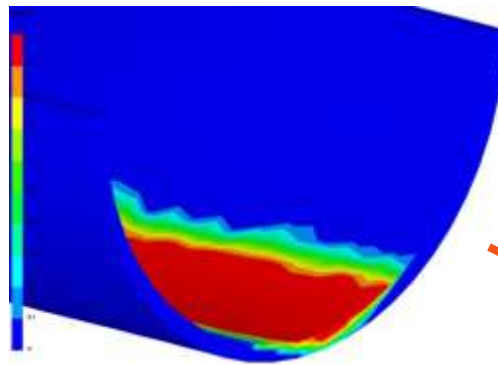


Time : 0 s.



PAM-RTM

Zoom-in on flow media
influence on resin flow front



Some References

- Aston Martin
- BOMBARDIER
- BMW
- CCAT
- Dassault-Aviation
- DOW
- EADS
- GE R&D
- GE India Technology Center
- Hexcel
- M-Torres
- ONERA
- PPE
- Snecma and Snecma Propulsion Solide (Safran Group)
- TECSIS, IPT, FURG, Unifei
- Volkswagen, VZLU
- Ecole des Mines, Ecole Polytechnique de Montréal, Ecole Polytechnique de Nantes, KU Leuven, Politecnico di Milano, Shanghai Jiaotong University, TU Clausthal, TU Delft, TU Munchen, University of Cranfield, University of Nottingham, Wichita State University...

<http://www.esi-group.com/products/composites-plastics/pam-rtm/success-stories>



www.esi-group.com