PAM-FORM 2G 2013

Thermoforming of dry textiles and prepregs

July 23rd, 2013
Mathilde Chabin

CONTENT

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

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ESI Composites Manufacturing Suite

FORMING
PAM-QUIKFORM(1)
PAM-FORM2G

PREFORM
PAM-QUIKFORM(1)
PAM-FORM2G

LCM
PAM-RTM(1)

CURING
In Autoclave
CFD-ACE

Out-Of-Autoclave
PAM-RTM

DISTORTION
PAM-DISTORTION

(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

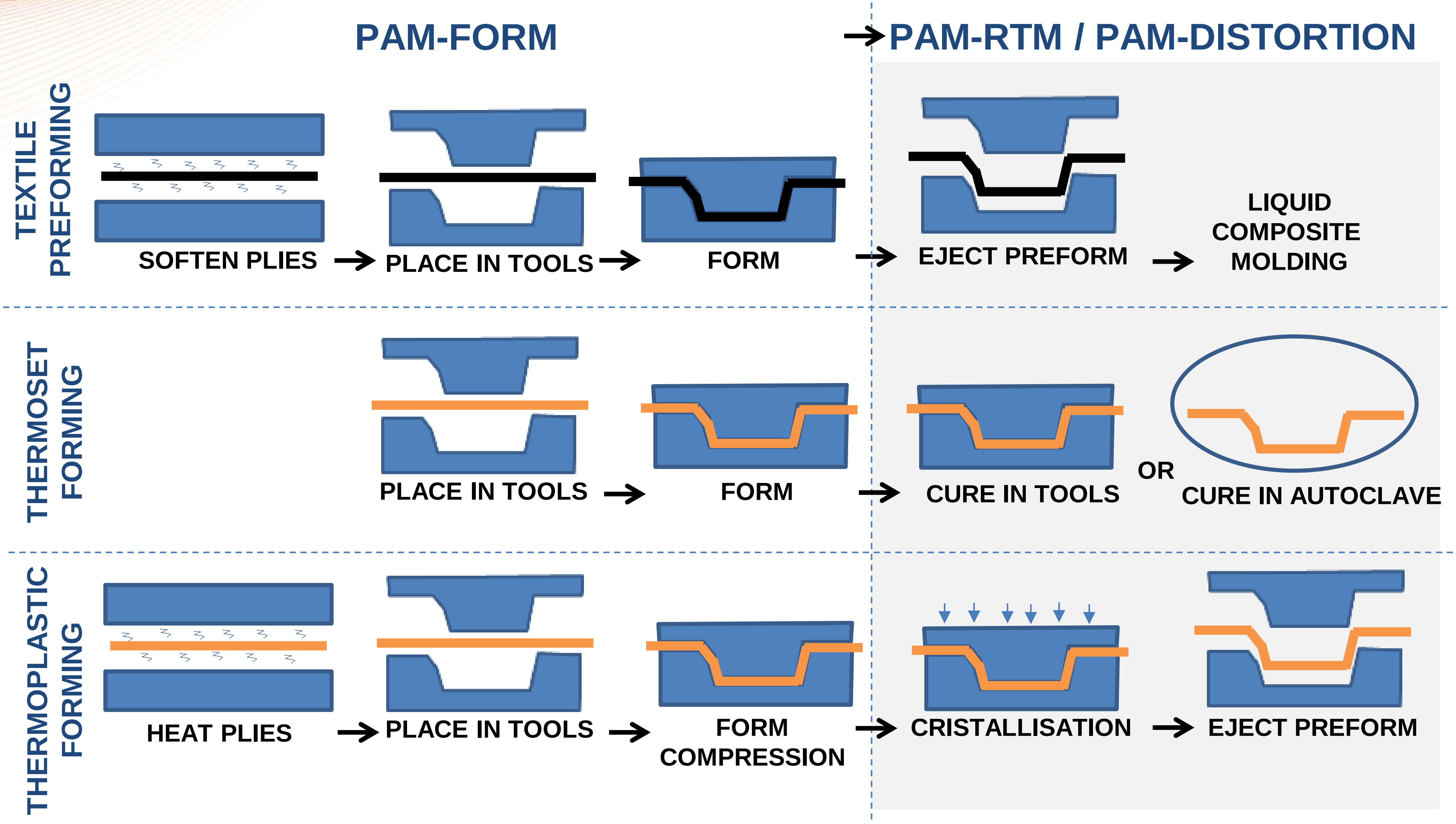
Courtesy: AAR, Cranfield University, EADS/M, ENISE

CONTENT

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

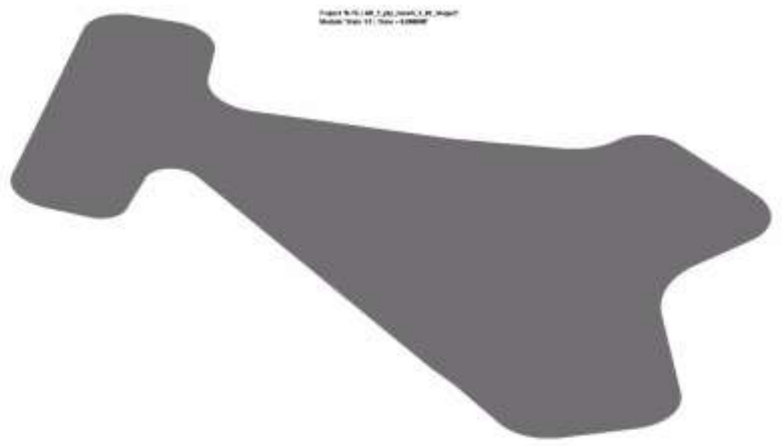
PAM-FORM 2G

Process Schematic



PAM-FORM 2G simulation
What for?

- **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

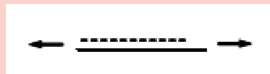
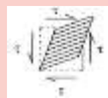
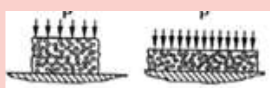
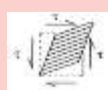


Automotive B-Pillar

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

PAM-FORM 2G simulation

Material data requirements

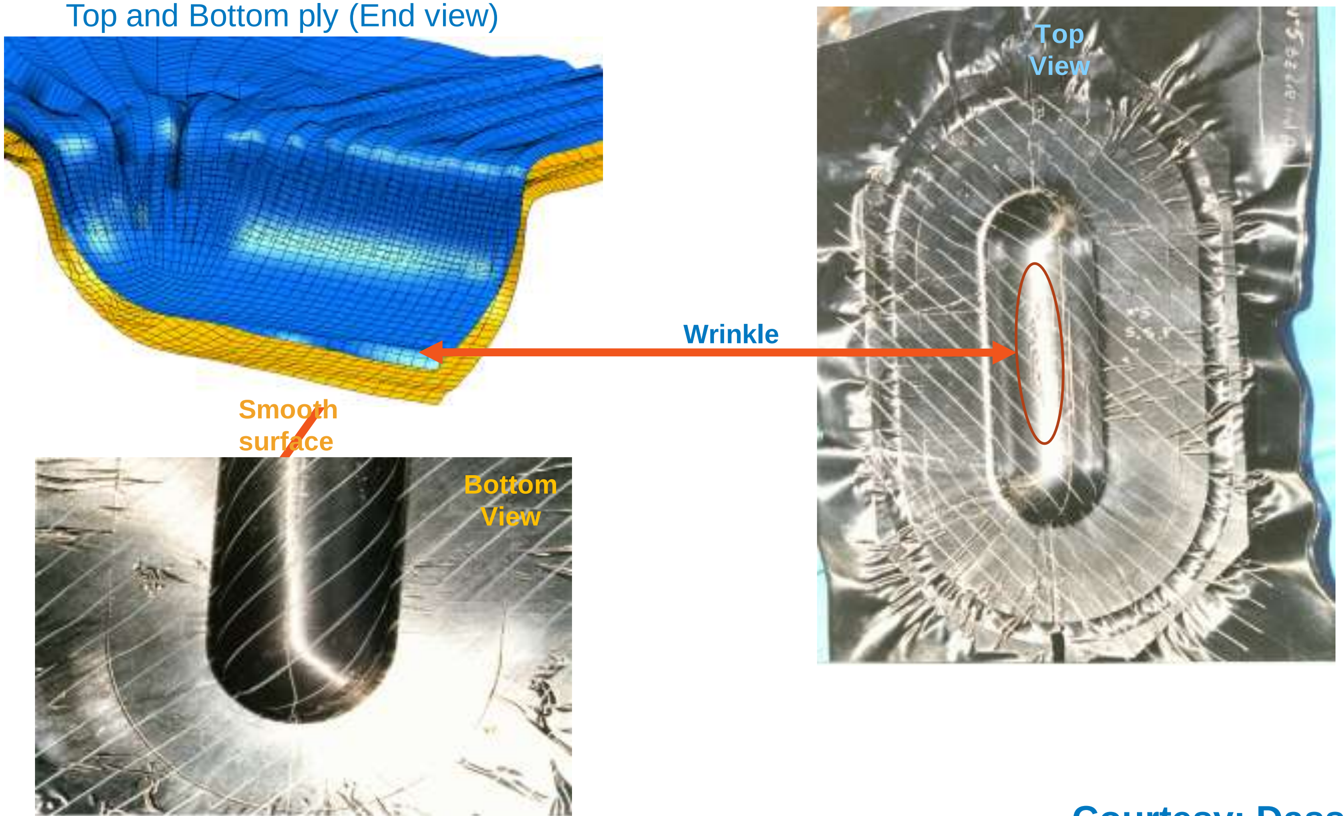
DEFORMATION MODE	REPRESENTATION	SIMULATION INPUT	COMMENTS
Fiber extension		Young's modulus (E1, E2)	To be done for both fiber directions
Fiber buckling		Young's modulus = f(strain) (E1, E2)	To be done for both fiber directions
In-plane shear		Force/Displacement (G)	To be done for positive and negative 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)

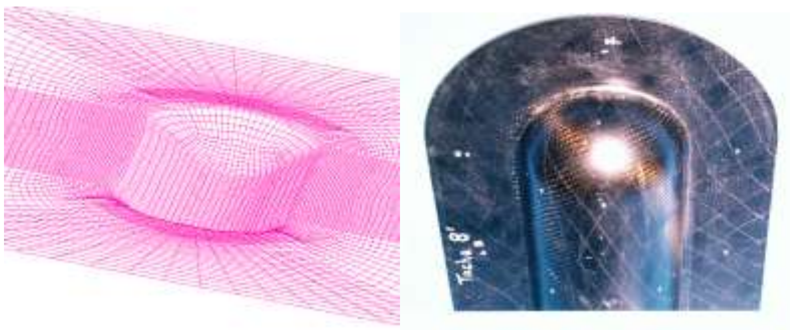


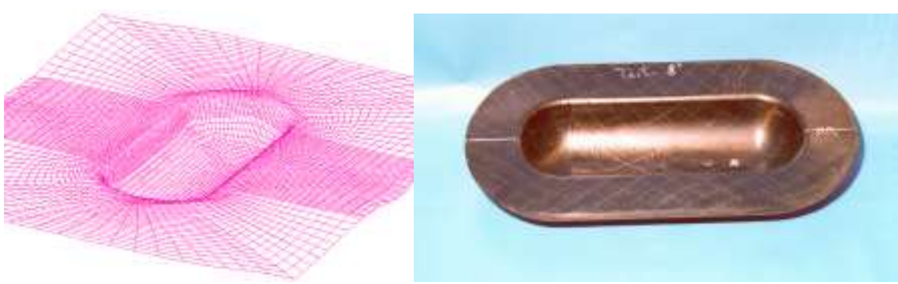
Courtesy: Dassault Aviation

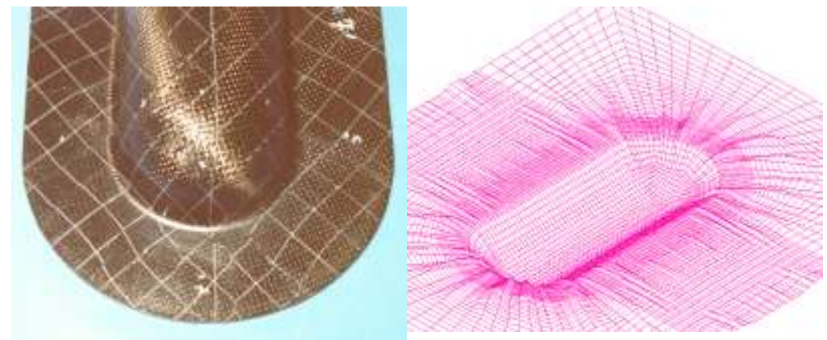
PAM-FORM 2G simulation

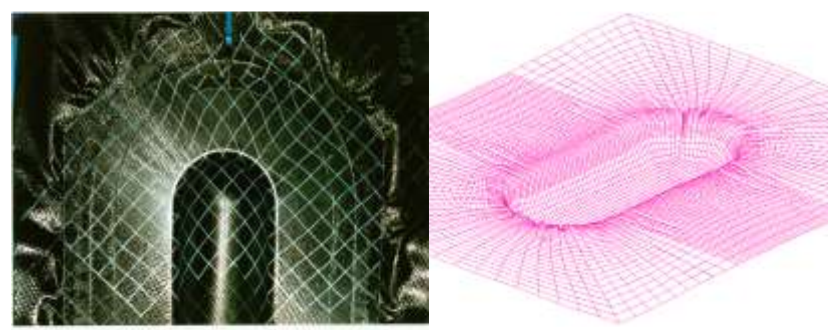
Example 2: Process definition

- Woven fabrics thermoforming: impact of punch velocity









PUNCH VELOCITY= 5.mm/s

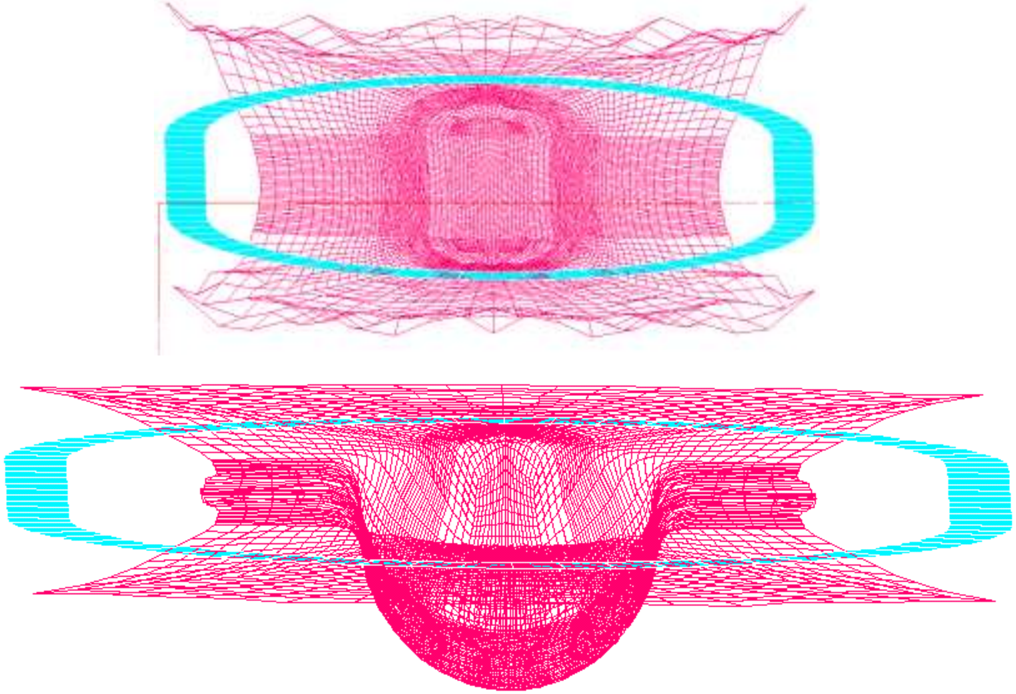
PUNCH VELOCITY=40.mm/s

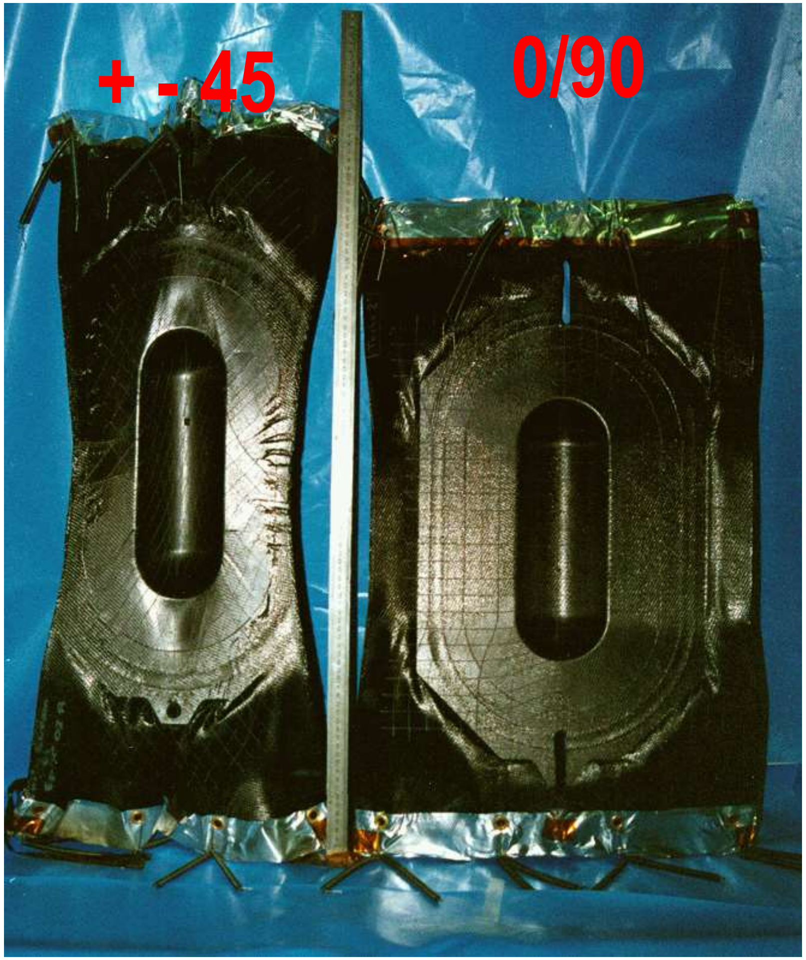
PEI-CETEX; 8 plies

Courtesy: Dassault Aviation

PAM-FORM 2G simulation
Example 3: Material definition

- Clamping system definition
- Laminate definition

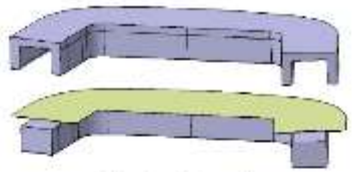




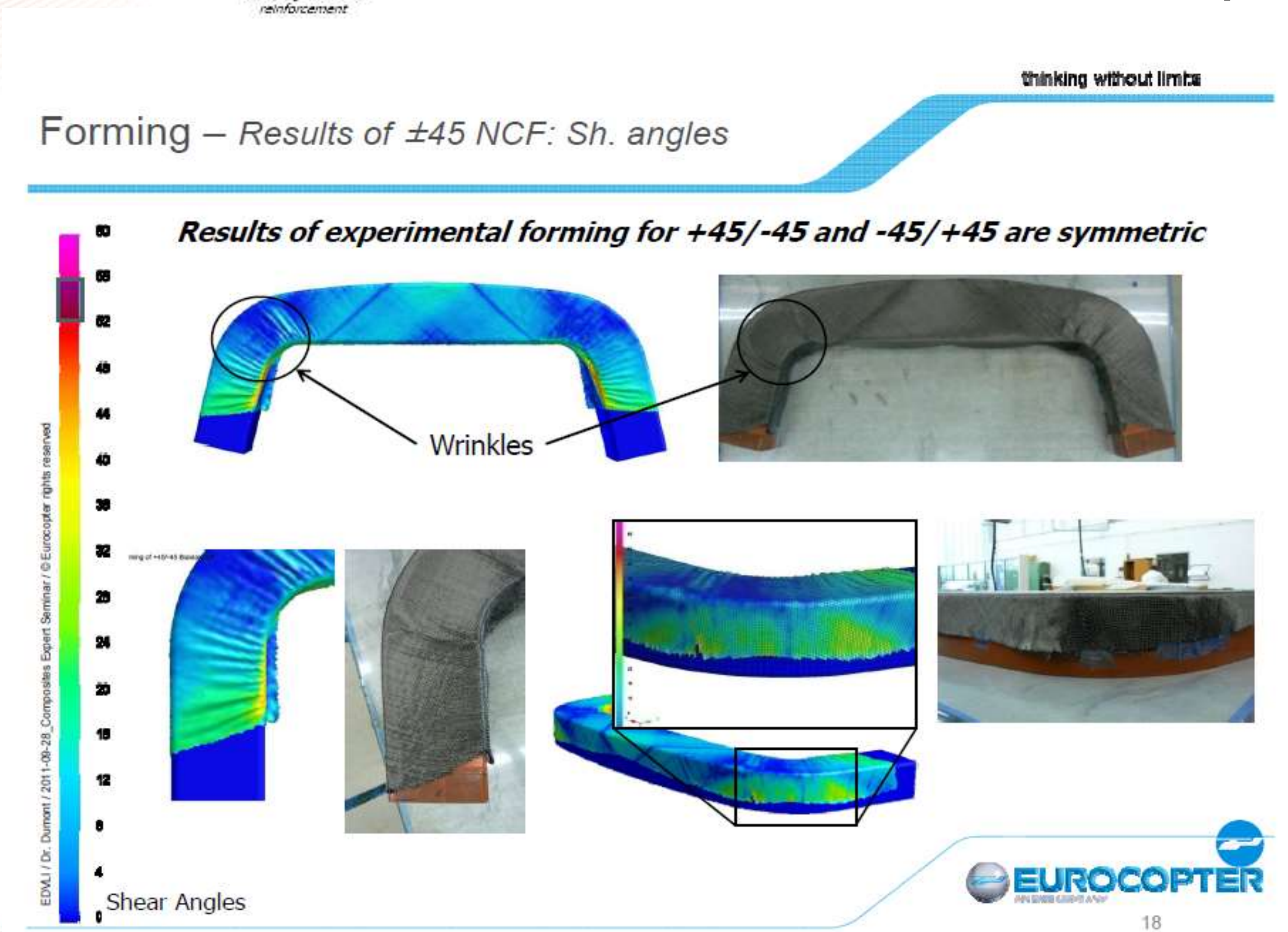
Courtesy: Dassault Aviation

PAM-FORM 2G simulation

Example 4: Shearing prediction on preform



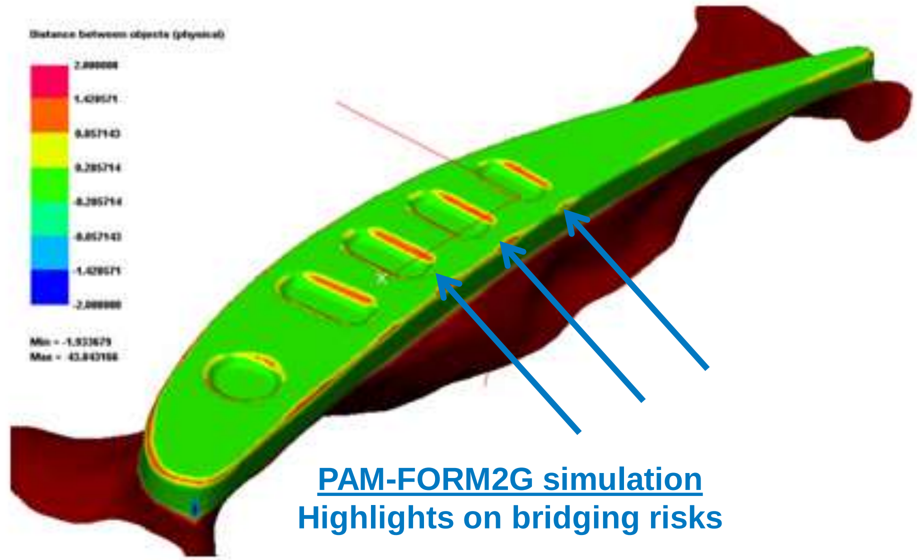
Stamping tools and reinforcement



PAM-FORM 2G simulation

Example 5: Bridging prediction

- Fabric / 6 plies / PPS Matrix



Courtesy: Delft University of Technology

CONTENT

- 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

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PAM-RTM 2013

Product presentation

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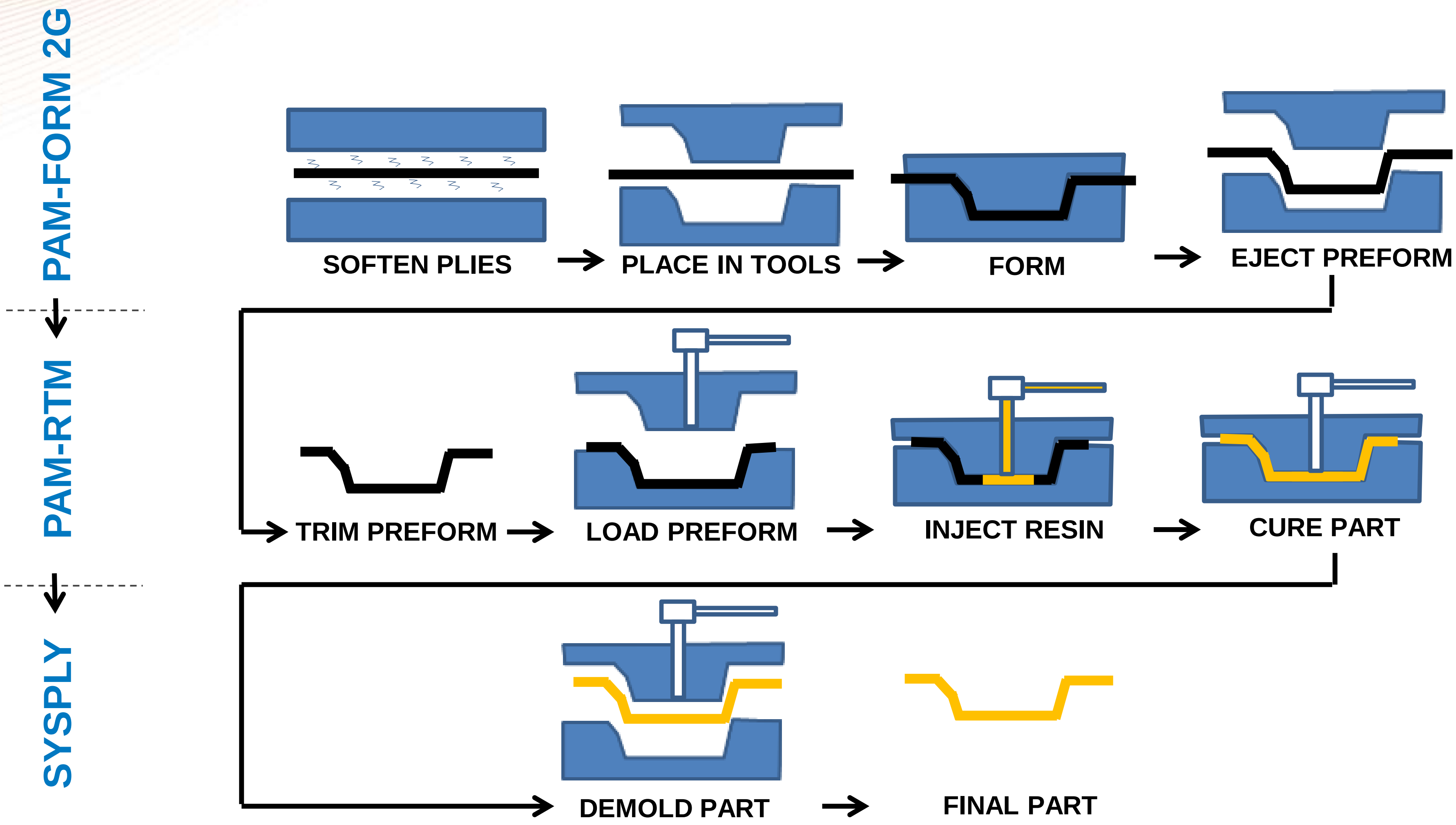
Liquid Composites Molding

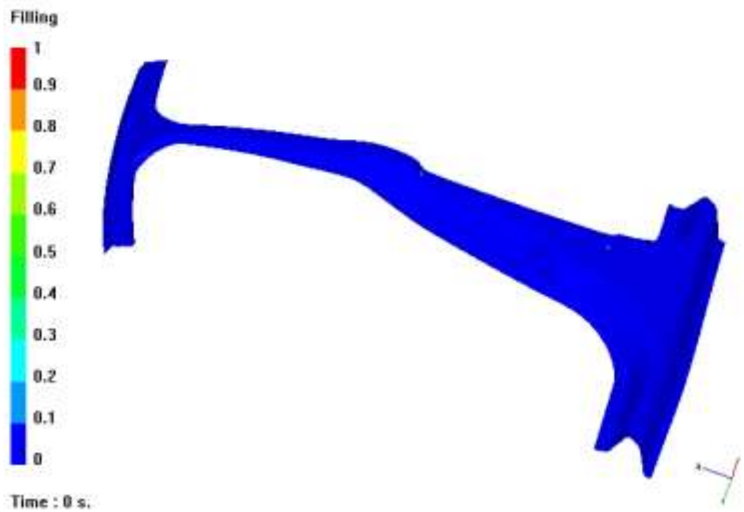
Process Schematic



Liquid Composite Molding simulation
To do what and how?

- **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

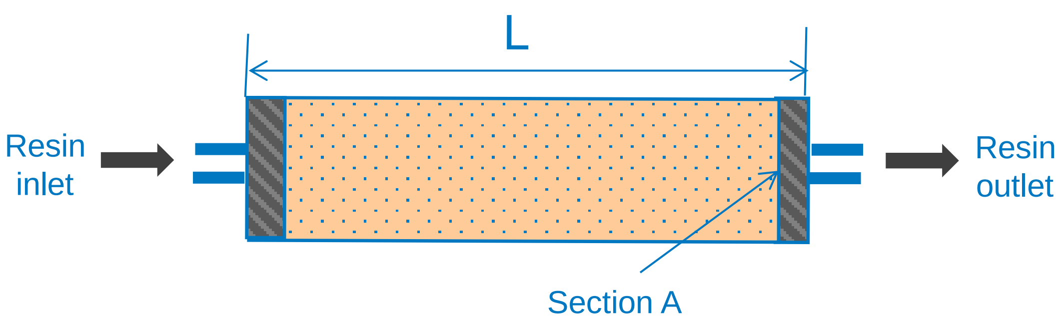
Liquid Composite Molding simulation

PAM-RTM flow model

- **Resin flow in a porous medium using**

DARCY'S LAW

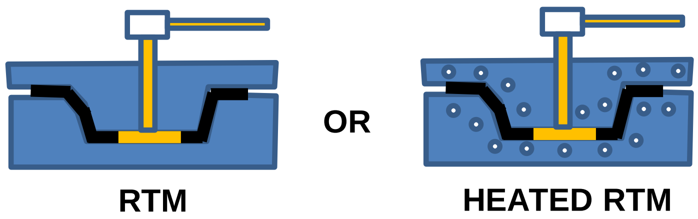
$$q = \frac{Q}{A} = \frac{K}{\mu} \cdot \frac{\Delta p}{L}$$

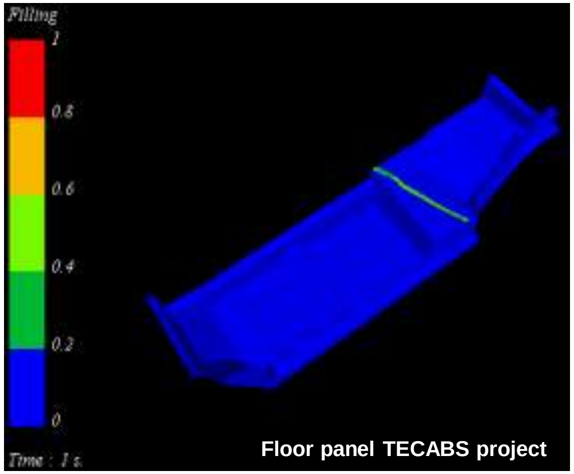


Liquid Composites Molding

Process variants with PAM-RTM

- **RTM**: Resin Transfer Molding



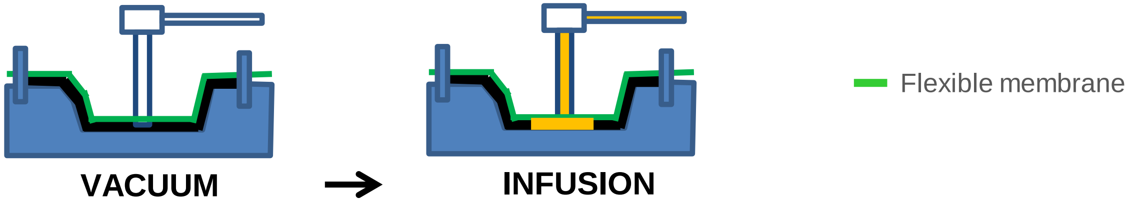


- Material data for simulation

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

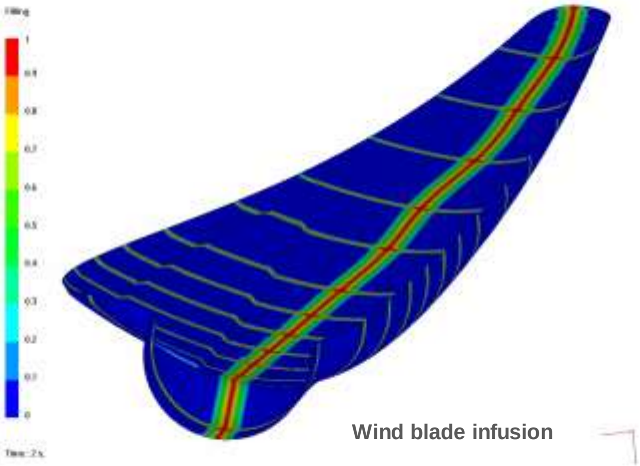
Liquid Composites Molding
Process variants with PAM-RTM

- **VARI**: Vacuum Assisted Resin Infusion



- Material data for simulation (added data)

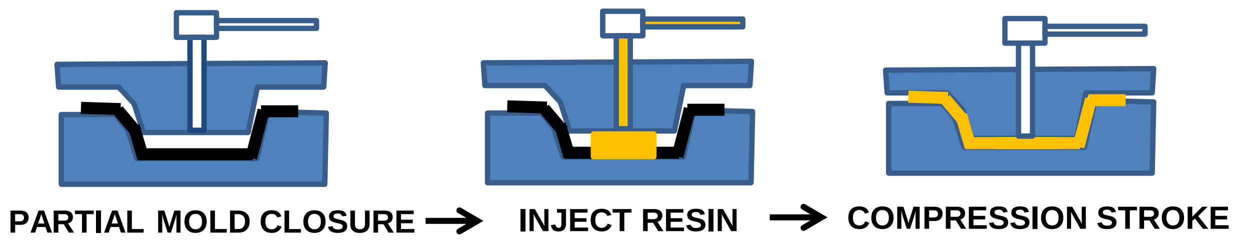
	VARI *(added data)*
Reinforcement	**Permeability tensor (K1,K2,K3)** *f(fiber content)* **Compressibility curve** *Pressure of compaction=f(fibre content)*



Liquid Composites Molding

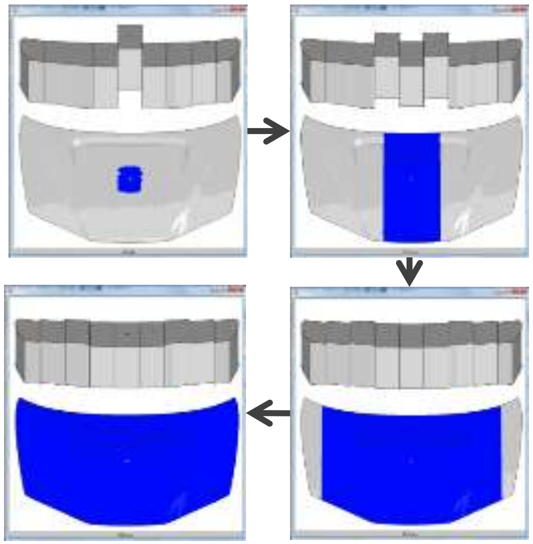
Process variants with PAM-RTM

- **CRTM**: Compression Resin Transfer Molding



- Material data for simulation

	CRTM
Reinforcement	**Permeability tensor (K1,K2,K3)** *f(fiber content)*



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

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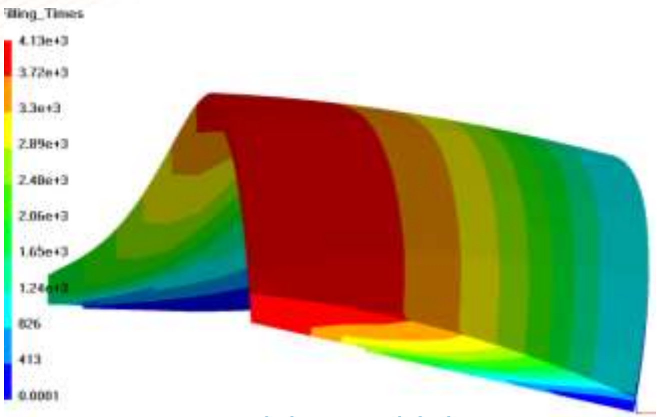
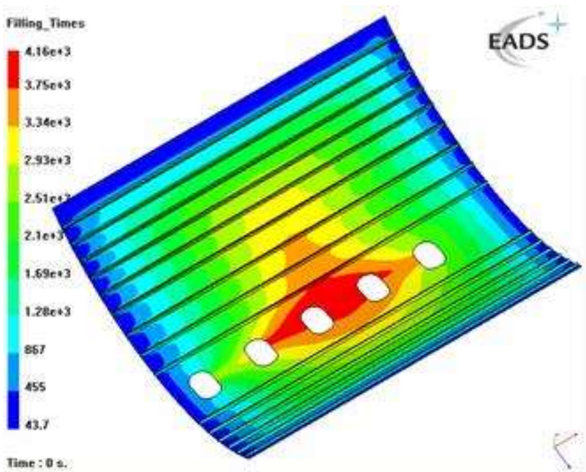
PAM-RTM simulation

Post-Processing examples

- Filling time

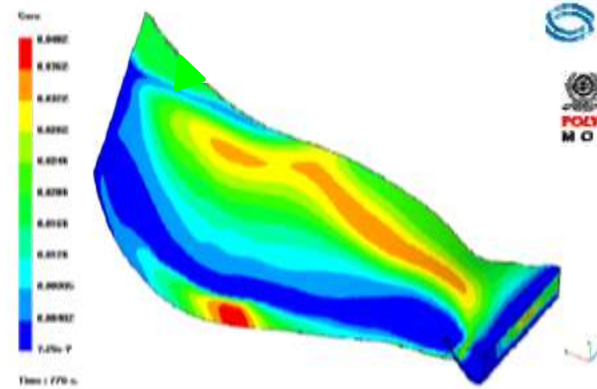


30 meters wind spar cap infusion



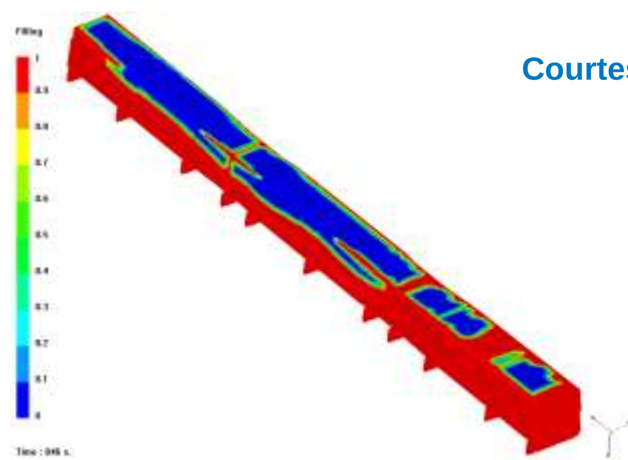
Fuselage panel infusion

- Curing time



Fan blade of an aircraft engine RTM

- Filling degree

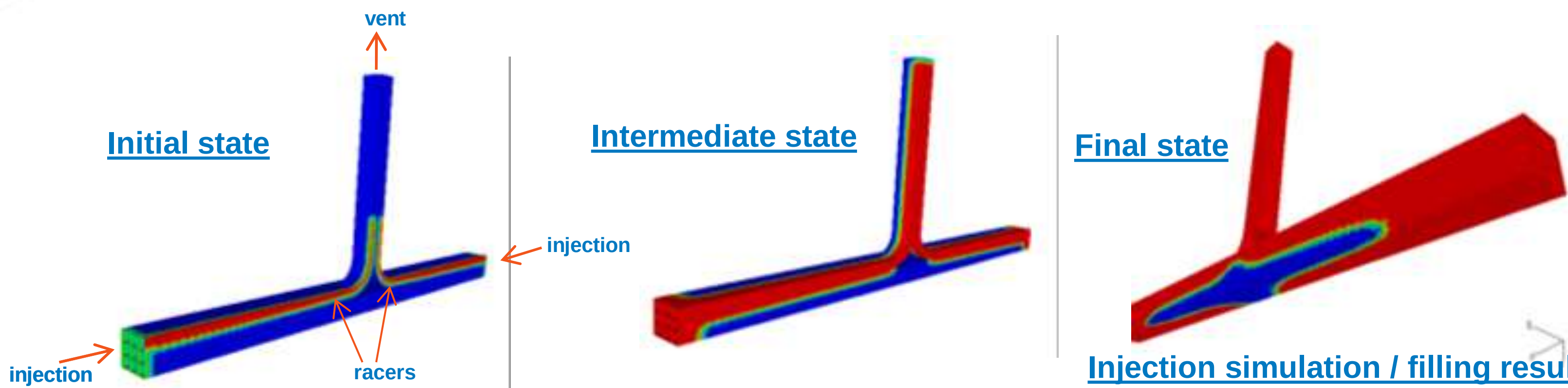


Courtesy: Airbus

PAM-RTM simulation

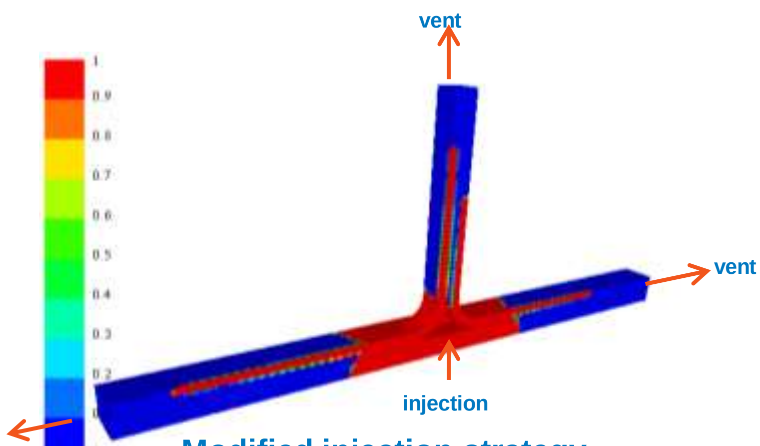
Post-Processing examples

- Dry spots



Injection simulation / filling result

Dry spot prediction with PAM-RTM



Modified injection strategy

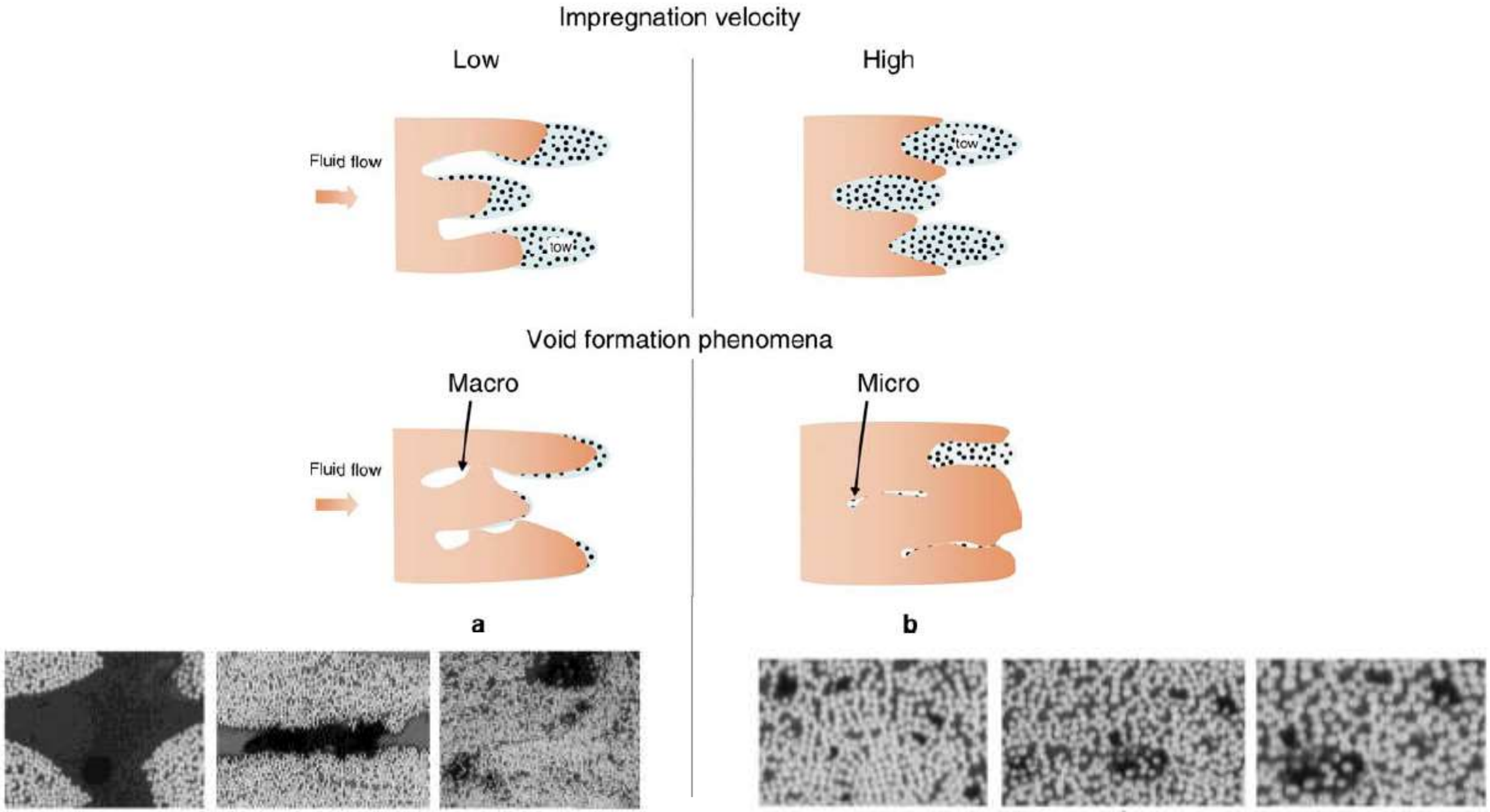
To avoid dry spots

Final part

Courtesy: Cranfield University

PAM-RTM simulation
Additional functionalities

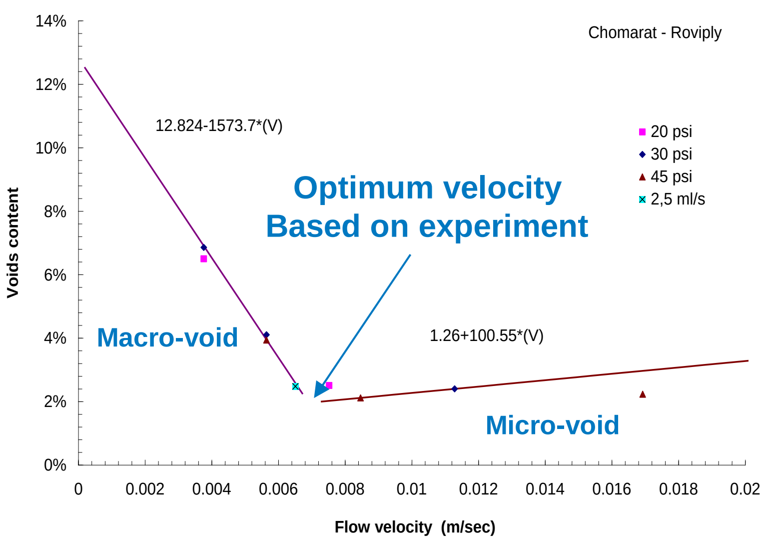
- Porosity prediction and reduction:
  - Principle: Critical impregnation velocity: $\max \left\| \vec{v}_{front} \right\| \leq \left\| \vec{v}_{crit} \right\|$



PAM-RTM simulation
Additional functionalities

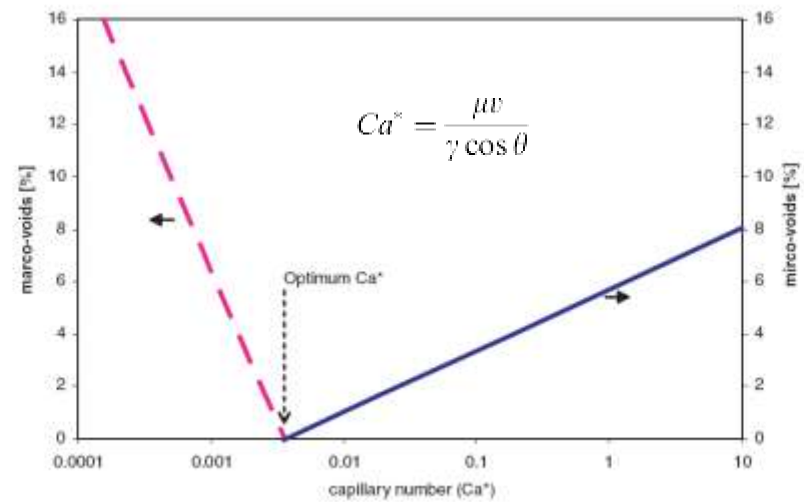
Porosity prediction and reduction:

- PAM-RTM input data:



[Experimental data]

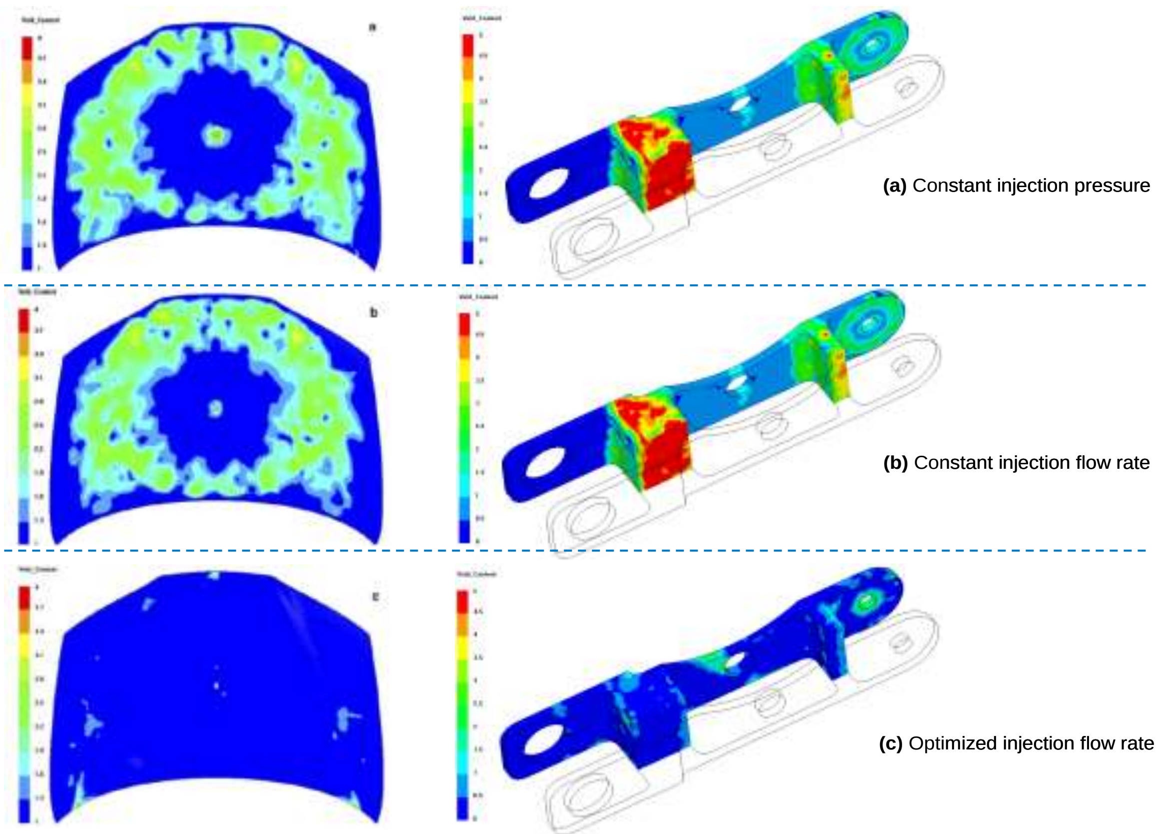
Ca= viscosity*velocity/surface tension/contact angle

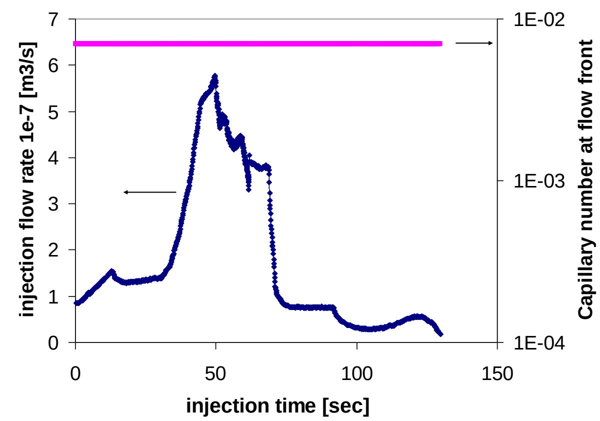


[PAM-RTM input curve]

Porosity prediction and reduction:

- PAM-RTM output: injection flow rate curve

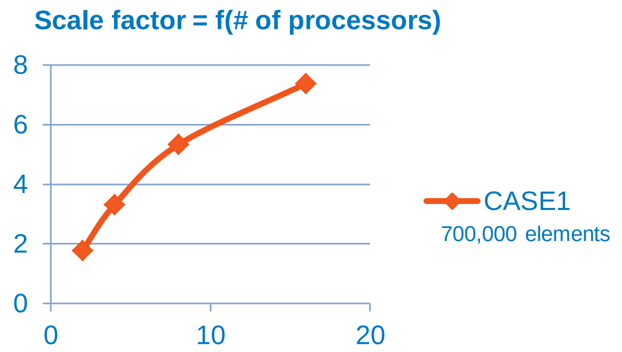




PAM-RTM simulation

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

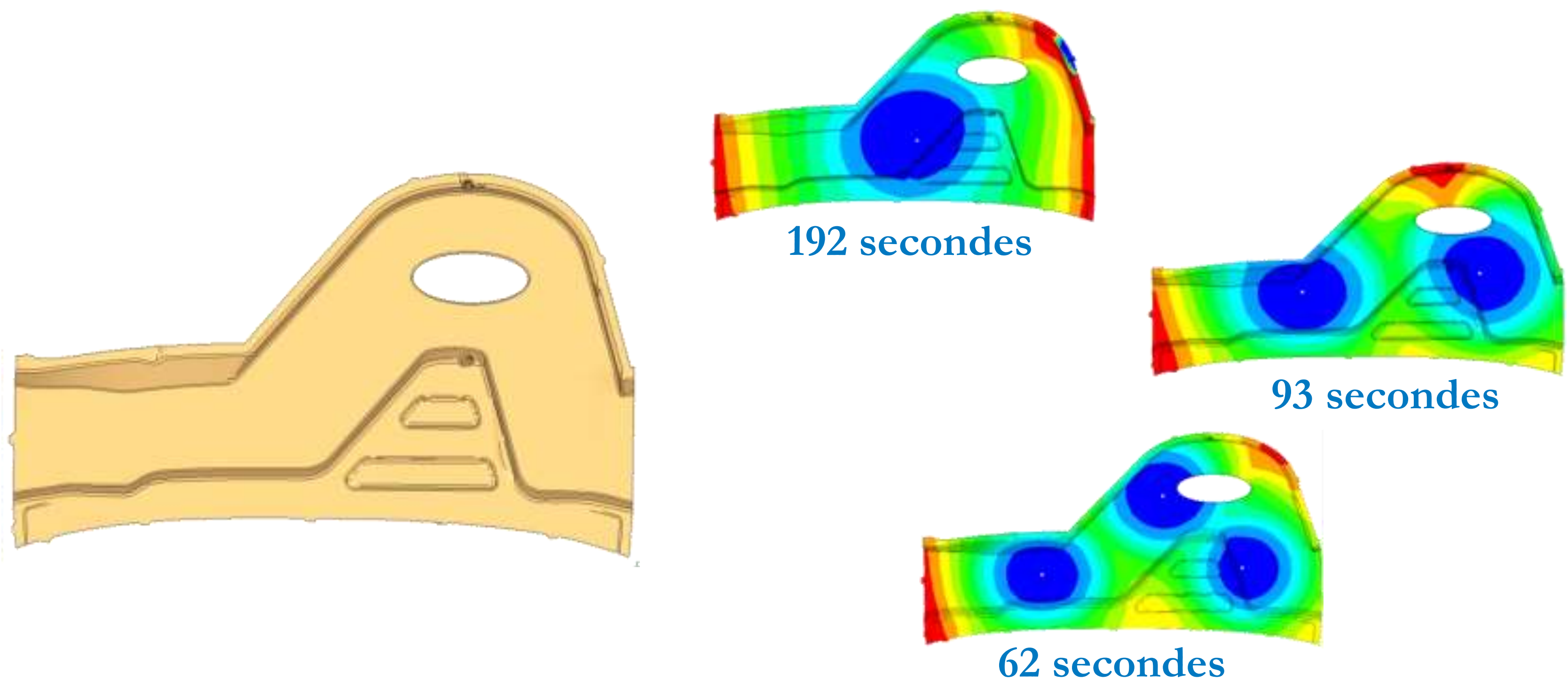


- Gravity effect on resin flow

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



What's new in 2013?

- 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

Liquid Composites Molding

PAM-RTM permeability database

- Based on Nottingham University data available on ESI customer portail: MyESI

PAM-RTM simulation

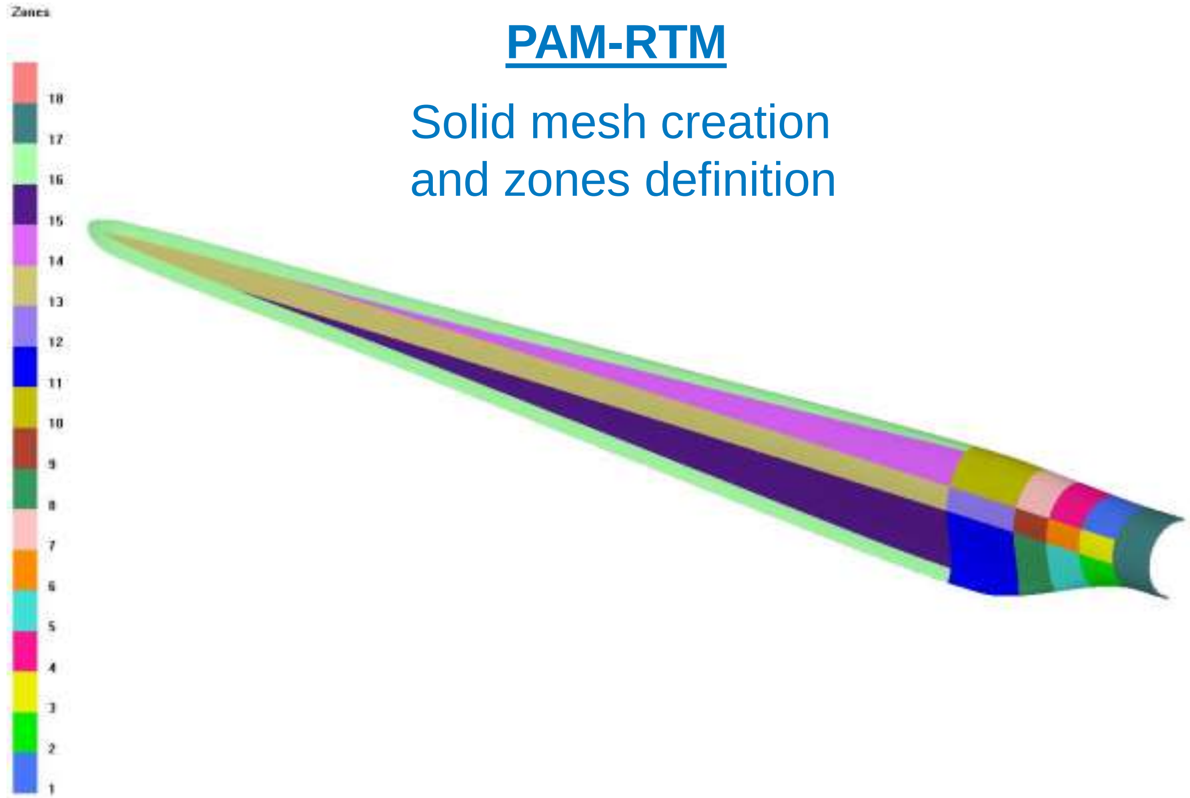
Workflow example (1/4)

Ply lay-up

Fibers orientation

Material definition

Import



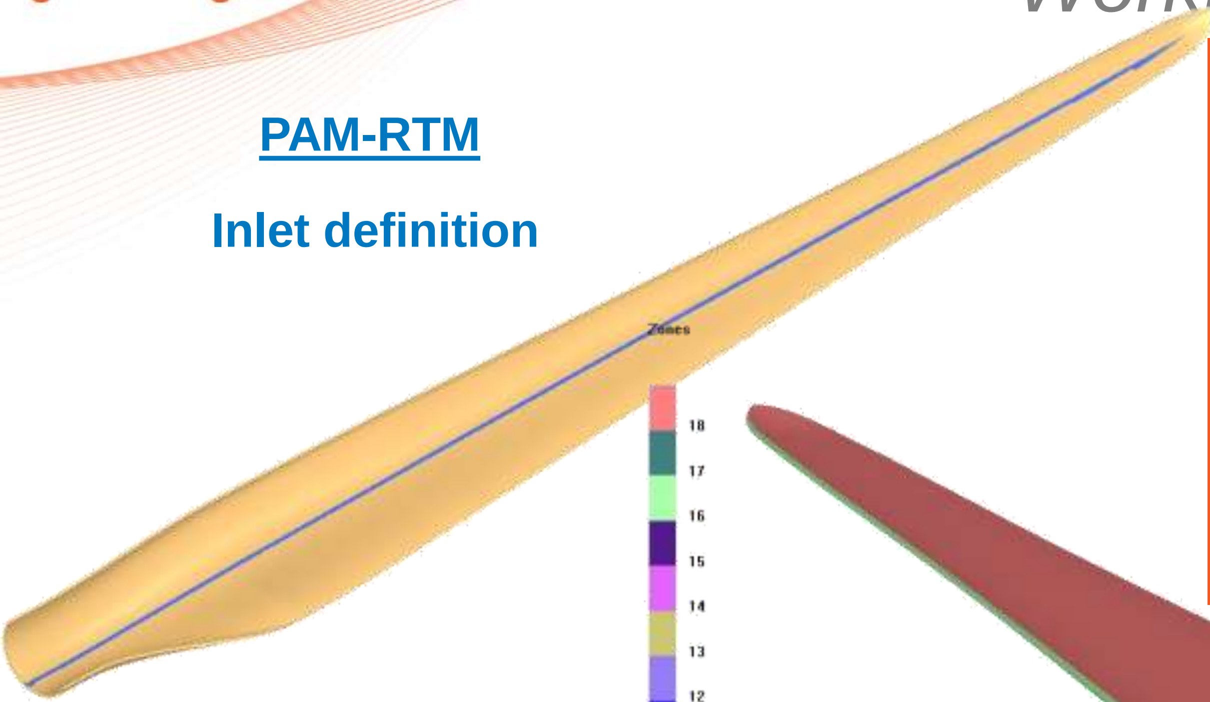
PAM-RTM

Solid mesh creation
and zones definition

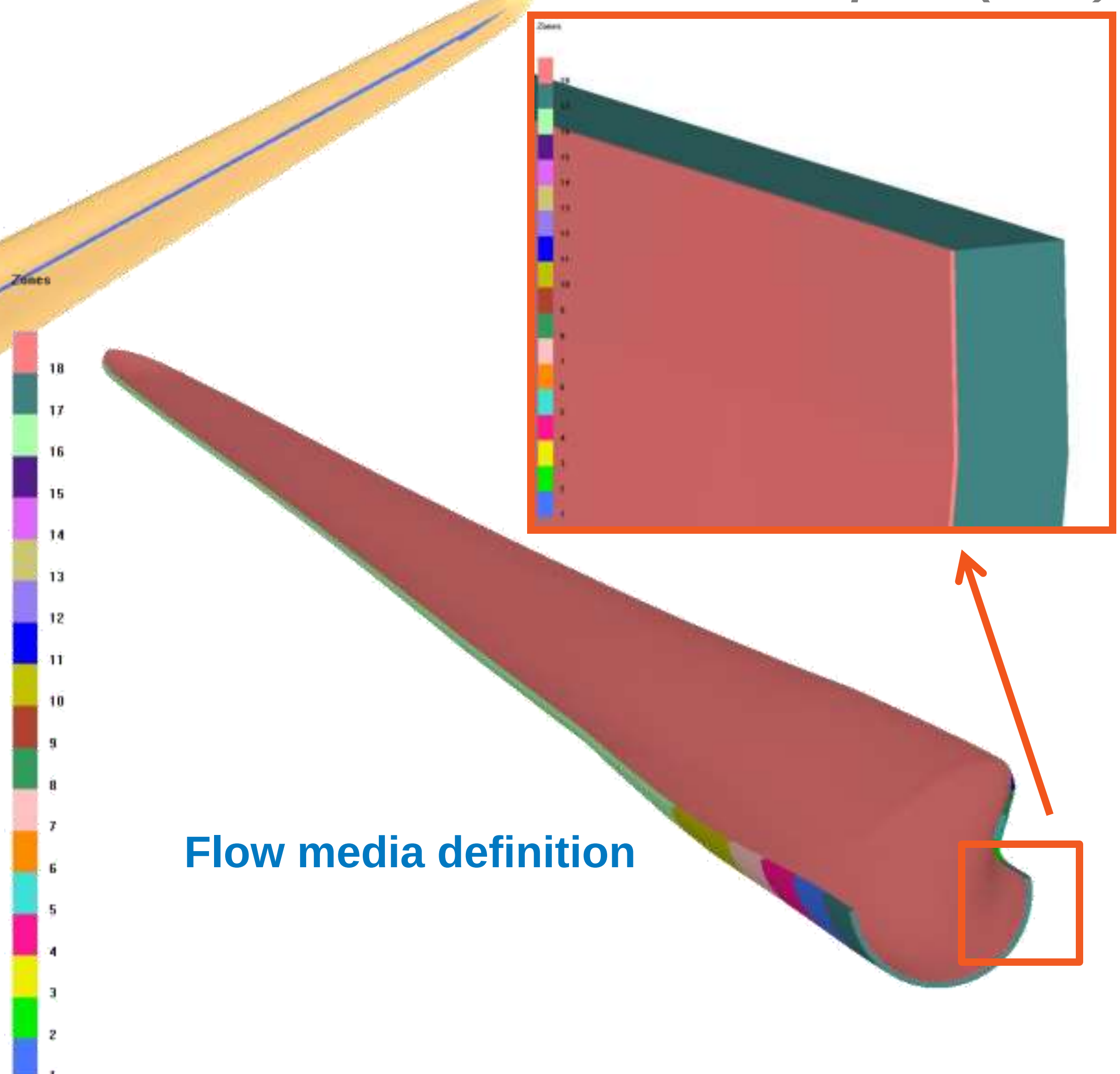
PAM-RTM simulation
Workflow example (2/4)

PAM-RTM

Inlet definition



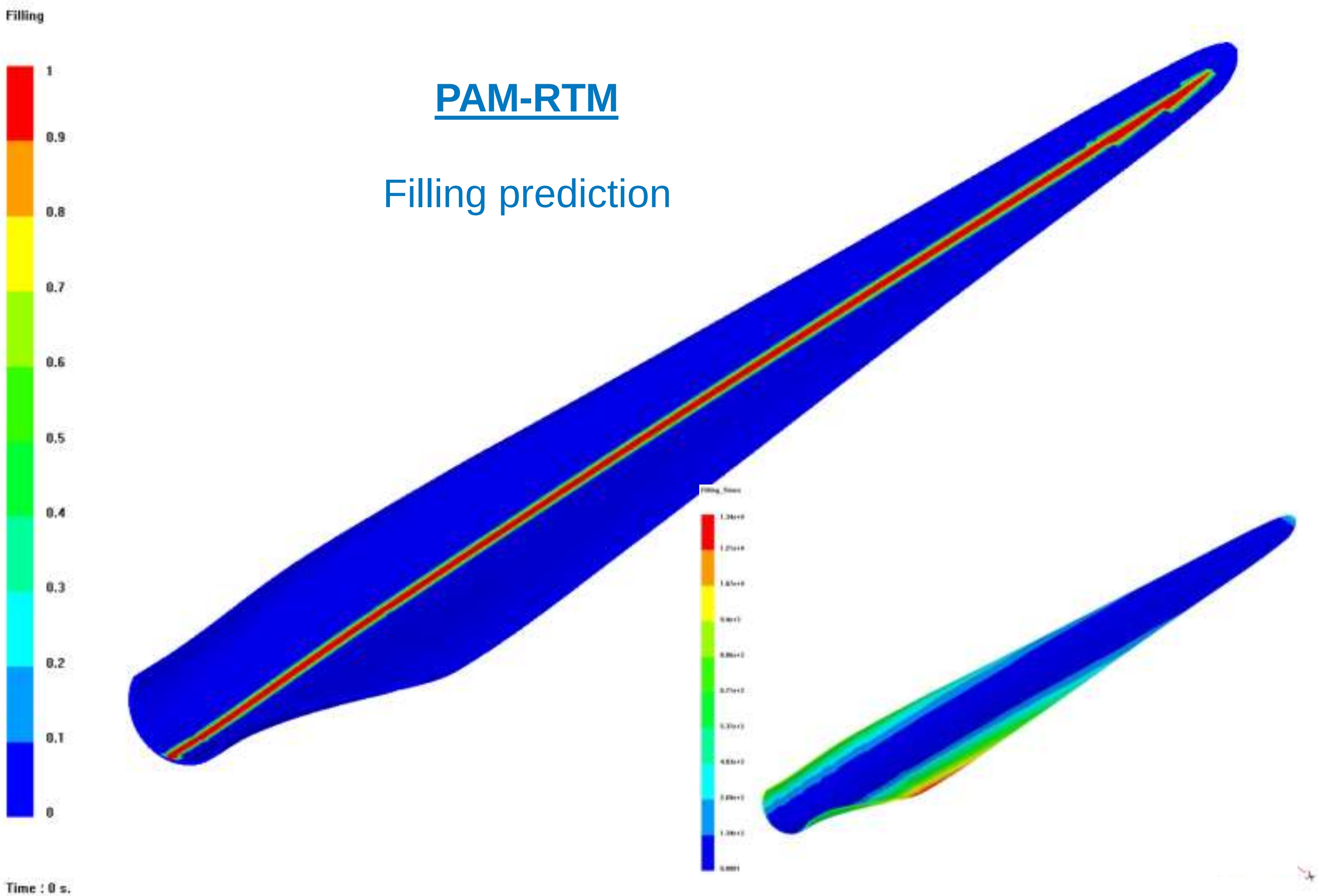
Flow media definition



PAM-RTM simulation
Workflow example (3/4)

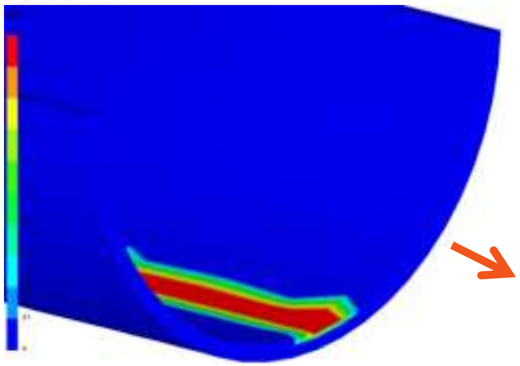
PAM-RTM

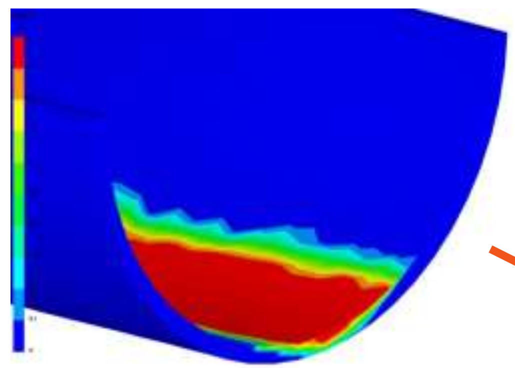
Filling prediction

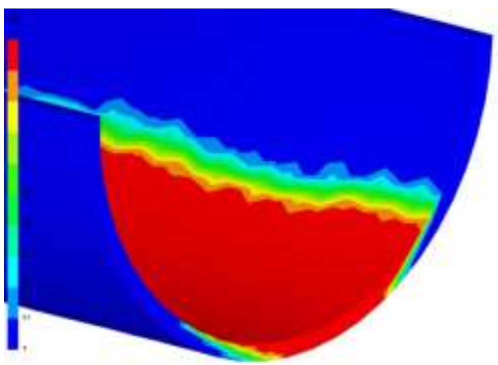


PAM-RTM simulation

Workflow example (4/4)

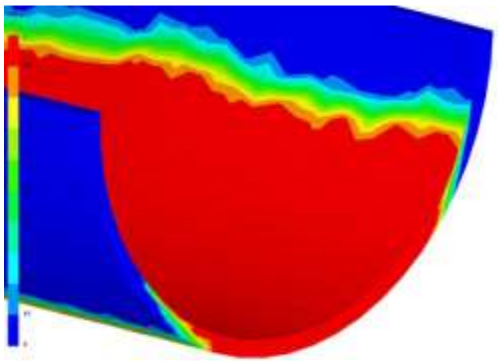


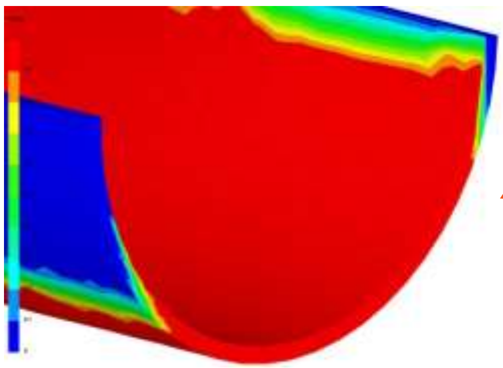




PAM-RTM

Zoom-in on flow media influence on resin flow front





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PAM-RTM
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…

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