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# Process optimization for high-temperature aerospace applications

Rogelio Ceceña, Research engineer in aerospace manufacturing  
Benjamin Boniface, R&D manager NIMITECH (Lauak Group)  
Gilles Dusserre, Associate Professor, IMT Mines Albi-Institu Clément Ader

## Abstract

Nowadays, the aircraft parts that are installed in zones subjected to temperatures between 200°C and 400°C are almost entirely metallic. Alloys based on aluminium, titanium and steel dominate these zones while composites are a no-go for this temperature range. This is due to the limitation in operating temperatures of conventional thermosets as well as the lack of economic viability of ceramic-matrix composites at temperatures below 400°C. Simulation of a known process, combined with innovative materials, might overcome the rule and increase the percentage of composites used in the "warm" zones of aircraft.

Supported by the Aerospace Valley French competitiveness cluster, the TACT research programme was launched to address the 200- 400°C gap. Led by Nimitech Innovation, this programme brings together several academic and industrial partners such as Airbus, Institut Clément Ader, ESI Group, Liebherr Aerospace and Tomoadour. The main goal is to develop a family of cyanate ester matrix composites capable of operating in the warm zones near the engines, but also to reduce the weight of the targeted aircraft parts by 30% and the production costs by 20%. One of TACT's sub-projects aims at

simulating the complete manufacturing chain of an Airbus A320 part. The plenum is a pressurized chamber mounted on the air conditioning system of the aircraft. This component, which is currently made of two GFRP parts bolted together (Figure 1), requires thermal stability at a continuous operating temperature of more than 210°C.

Since 2011, Nimitech Innovation has partnered with Liebherr Aerospace to develop a new GFRP design built as a single part (Figure 2). The conceptual design cuts down the weight by 30% and includes the use of a cyanate ester resin capable of withstanding the high temperatures encountered in service. However, using this resin presents certain challenges such

as the high level of process automation and control required compared to traditional epoxy systems.

The well-known Resin Transfer Moulding (RTM) process matched the challenge and Nimitech gained expertise in the process/material selection through the fabrication of several technology demonstrators. However, if the concept was to remain competitive with the baseline design, further work was needed to design an automated preform stamping process and to fine-tune the manufacturing parameters in such a way that part quality and fabrication costs are optimized.

This is where the PAM-Composites solution for virtual composite manufacturing from ESI Group came in handy.



Fig. 1: Current design of the plenum, courtesy of Liebherr Aerospace



Fig. 2: Conceptual design of the plenum, courtesy of Nimitech Innovation

The PAM-FORM module can simulate the automated dry preforming process and export the results to the PAM-RTM module, where the resin injection parameters are managed. The idea is to virtually test different manufacturing configurations and key parameters in order to optimize them without using the conventional trial and error approach of physical testing.

The simulation of the complete RTM process chain is a complex multi-physical problem that requires a significant amount of characterization and material behaviour modelling. This work was carried out at the Institut Clément Ader research lab (UMR CNRS5312), at the IMT Mines Albi site. The general workflow of the RTM simulation is shown in Figure 3.

### Characterization and modelling

In this study, a fabric model was developed to simulate the dry fabric draping process in PAM-FORM. The most important material data are the main deformation modes of the fabric: in-plane shear, in-plane extension and out-of-plane bending.

The characterization experiments for these deformation modes were conducted both physically and numerically. Other influential parameters are the frictional interactions between plies and between the plies and the forming tools. These interactions were also characterized and new analytical models for fabrics with binder were developed. The experimental basic forming operations and the simulations were compared to validate the material model with a 15% estimated error. By doing so, the level of confidence in the ability of the simulations to predict fibre orientation, shear angle and prevent defects was increased.

Similarly, the pre-heating, injection and curing simulations in PAM-RTM require inputs such as the rheological characteristics of the fabric/resin mixture, particularly the fabric permeability and the resin viscosity. In addition, a good knowledge of the parameters that define the resin's thermo-kinetic behaviour is paramount for an accurate curing simulation, with the curing kinetics, the specific heat and

the thermal conductivity being the most significant properties.

### Results

An automated preforming process using mechanical stamping was designed in PAM-FORM (Figure 4). By examining a variety of tooling configurations that would otherwise be too expensive to test physically, the preform was produced using the least possible number of forming operations, thus optimizing cycle time, minimizing costs and maximizing quality. Due to the complexity of the plenum's geometry, the minimum number of sub-preforms required was set at four.

The stamping results were then exported to PAM-RTM, where the fibre orientations and the fabric shearing were taken into account to simulate Nimitech's cyanate ester injection process. Subsequently, injection-induced defects such as dry spots or macro-voids were eliminated, as well as premature resin curing.

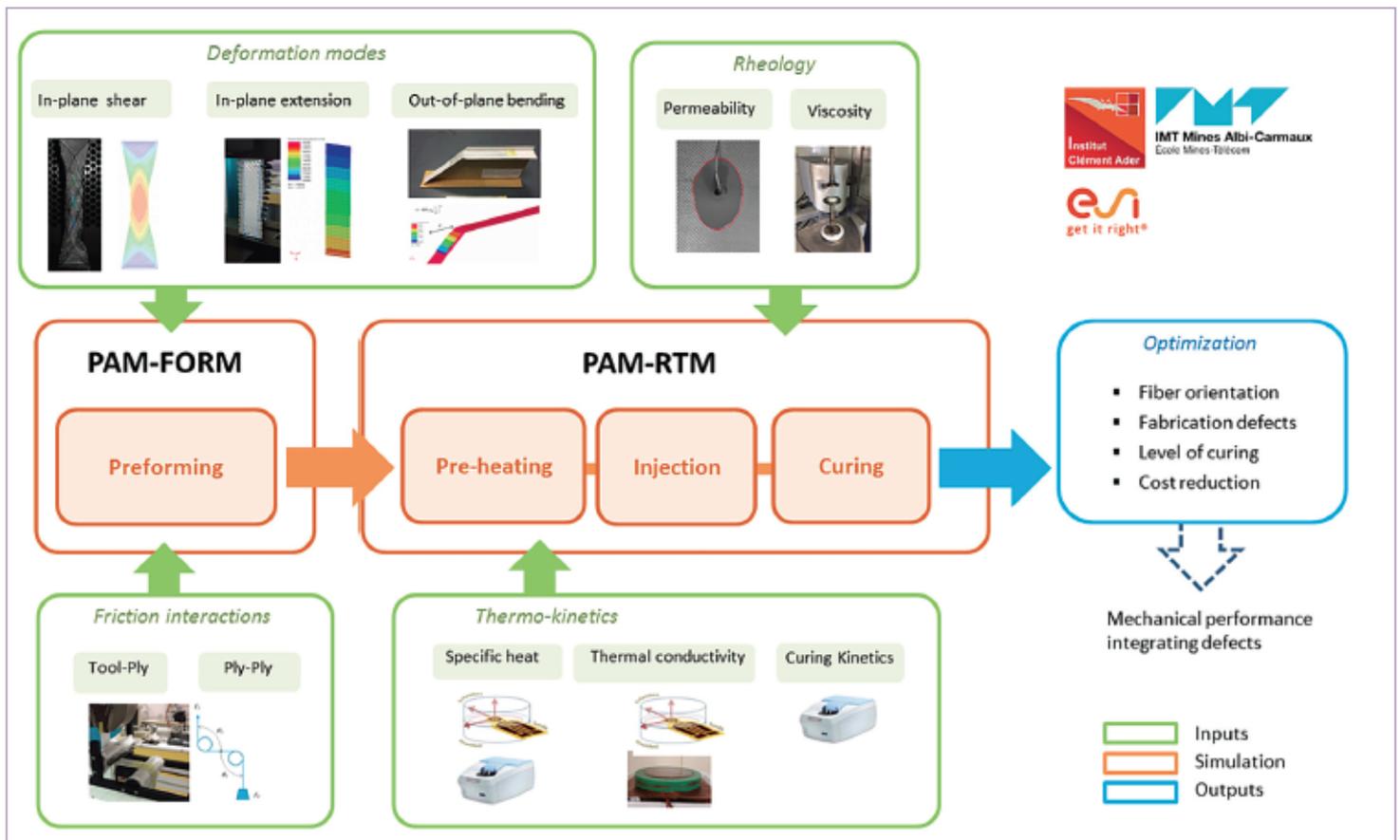


Fig. 3: Workflow of the process simulation conducted with ESI PAM-Composites

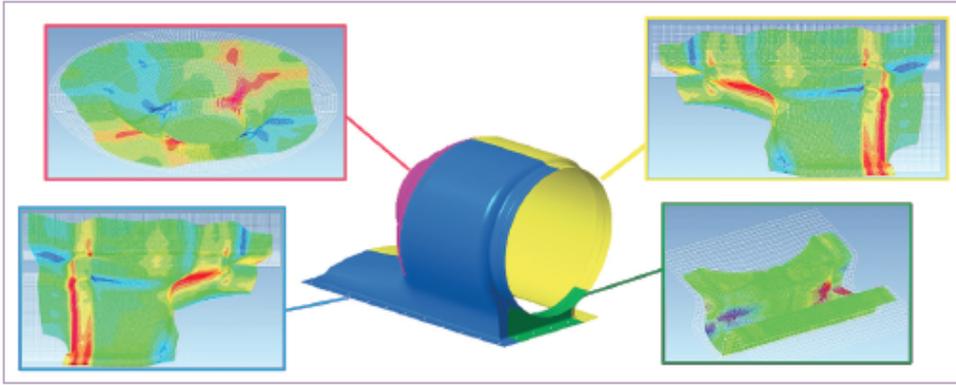


Fig. 4: PAM-FORM simulation: shearing distribution in the sub-preforms during stamping

The temperature differences between the inner and outer moulds were evaluated by modelling the thermal exchanges of the plenum with the moulds during the pre-heating and injection simulations (Figure 5a).

This piece of information is essential for the subsequent curing simulation.

Consequently, the curing cycle time was reduced by 36% as compared to the plenums previously built by Nimitex as technology demonstrators.

### Conclusions

The simulations performed with the ESI PAM-Composites software programme provided guidelines for a reliable au-

tomated stamping process that could cope with the high production rates of the Airbus A320 family. Additionally, the plenum curing cycle was optimized, reducing the fabrication lead time. Taking this in consideration, the study provides key information for decision-making and for cost-benefit analysis of the conceptual design. If this solution is retained, it could also be directly input into the industrialization phase.

More importantly, the high costs associated with physical testing were avoided. Even if the RTM process gains more inertia in aerospace, it remains a trial-and-error type of process. Many defects still appear in the first production runs because it is difficult to foresee what could go wrong by pure experience. Evidently, this approach is more expensive than virtual manufacturing tools.

Furthermore, the successful application of the redesigned cyanate ester RTM plenum might open the door for the migration of this technology into other warm zones of commercial aircraft. Future composite applications such as pylons, nacelles, electric engines, panels and many more would be possible where metallic parts remain unchallenged today. □

### Acknowledgements

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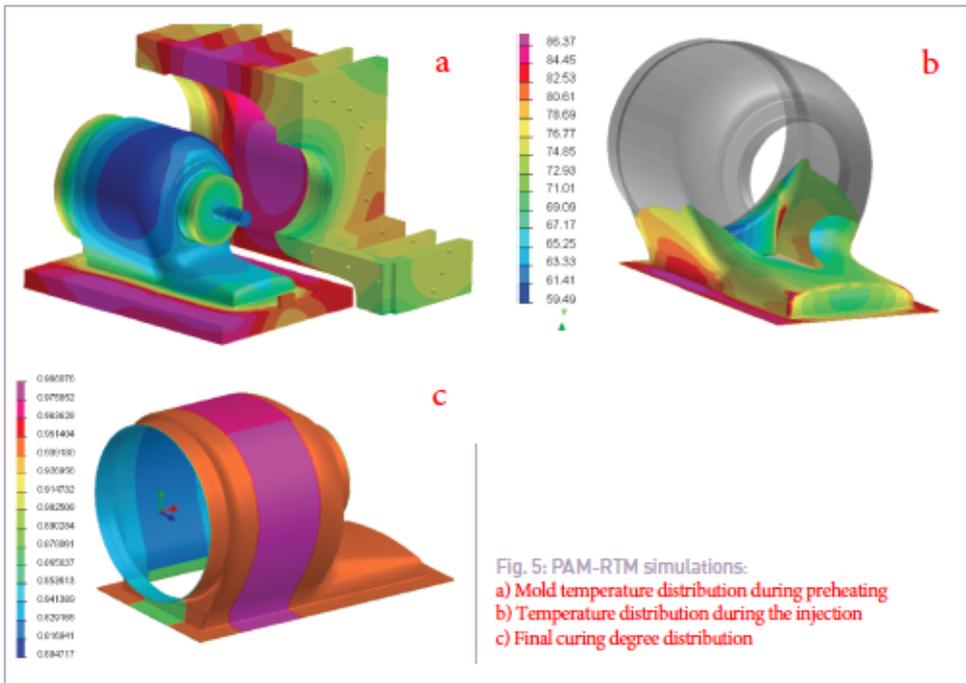


Fig. 5: PAM-RTM simulations:  
a) Mold temperature distribution during preheating  
b) Temperature distribution during the injection  
c) Final curing degree distribution