23RD INTERNATIONAL CONFERENCE ON COMPOSITE MATERIALS

ICCM23, BELFAST (IRELAND)

POLYTECHNIQUE MONTRÉAL
UNIVERSITÉ D'INGÉNIERIE

AN IN-SITU PRESSURE EVALUATION TOOL FOR 3D WOVEN COMPOSITES MANUFACTURED BY RESIN TRANSFER MOLDING

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Lm2 Laboratory of multiscale mechanics
Laboratoire de mécanique multi-échelles

LAVA Laboratoire d'analyse vibratoire et acoustique

crepec centre de recherche en plasturgie et composites

NSERC CRSNG

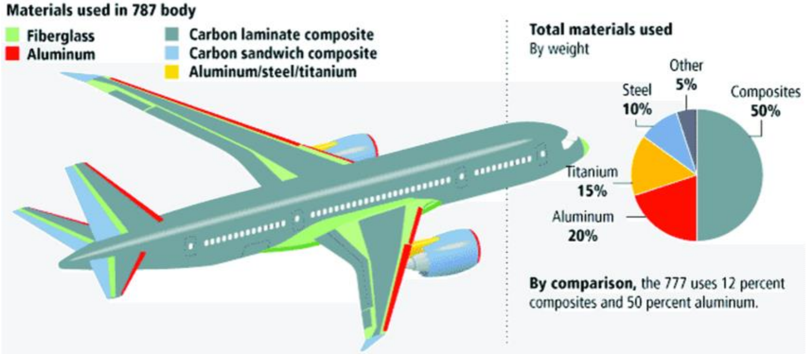
SAFRAN

OUTLINE

- Context & goal of the study
- Brief state of the art on in-situ pressure measurement in composite manufacturing
- Development of the measuring technology
- Application in RTM
- Conclusion and potential applications

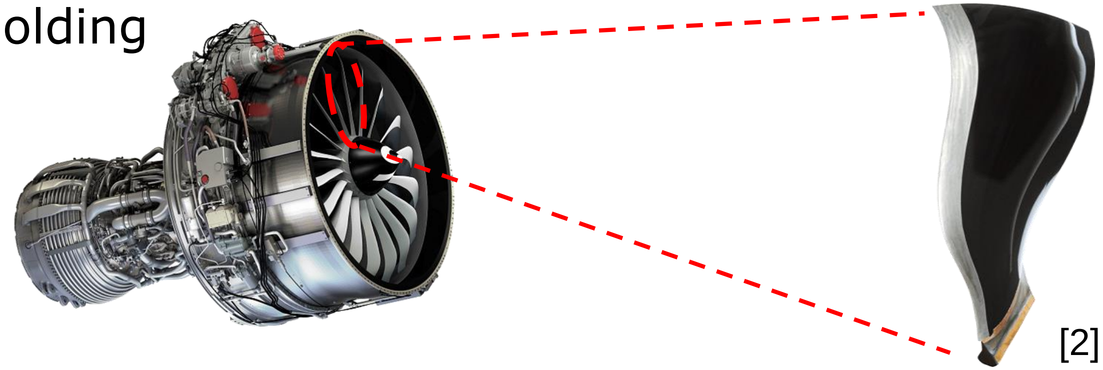
CONTEXT & GOAL OF THE STUDY

- Important use of CFRP in aeronautics (mass, mechanical properties)



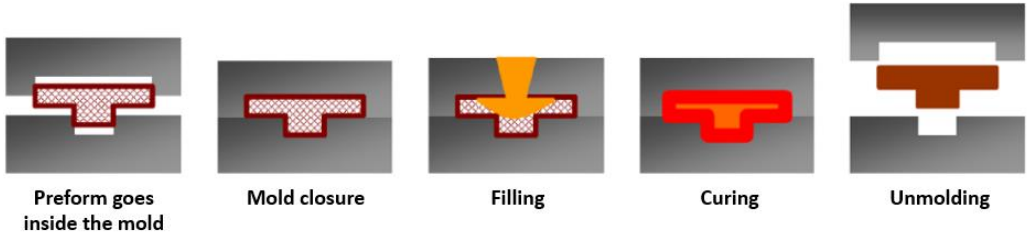
[1]

- Safran’s LEAP engine → fan blades made of 3D-woven CFRP manufactured by Resin Transfer Molding



[2]

RTM manufacturing steps



- However, very strict conditions for a part to be certified for flying: need to ensure material quality at a very high level in terms of embedded foreign objects, porosities, etc.

- Porosity formation and removal → complex phenomenon

CONTEXT & GOAL OF THE STUDY

- Porosity formation and removal in LCM processes → studied for a while in the literature:

- Different origins for porosity:
  - Air, solvents & other chemical species trapped in bulk resin
  - Mechanical entrapment during preform impregnation (micro/macro pores)
  - Volatile Organic Compounds porosities created during curing → **studied here**

- Strong link between VOC porosity removal and consolidation pressure [3]
  - → BUT experiments performed at a small scale & on pure resin → might differ on a real composite part
    - → Impact of the preform (weaving pattern & size) on the pressure transmission phenomenon?
      - → Influence on the final pressure distribution map & resulting porosity?

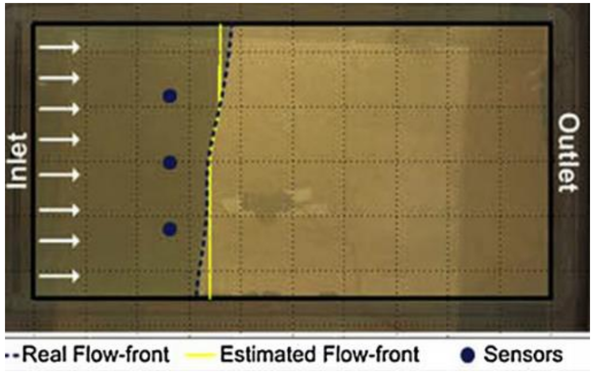
→ Goal of the work: study the pressure transmission phenomenon **within** a 3D-woven composite part, and link it with its residual porosity

→ Need of a device to measure pressure **anywhere** in the part!

STATE OF THE ART ON IN-SITU PRESSURE MEASUREMENT

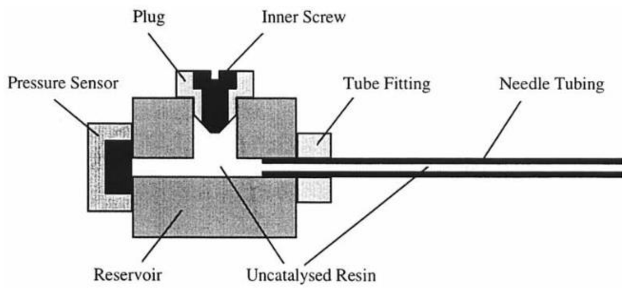
- Various existing technologies for Polymer-Matrix Composites manufacturing:

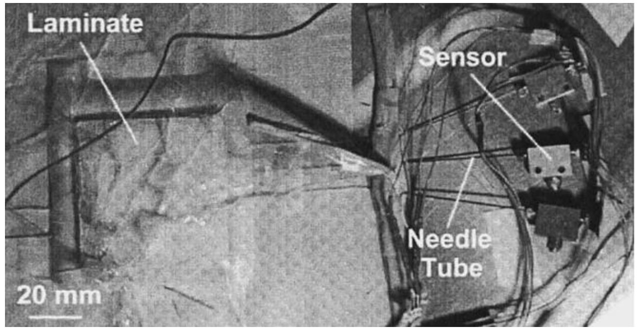
Cavity piezoelectric pressure sensors [4]



- ➢ Process: RTM
- ➢ Sensor position / part: **external**

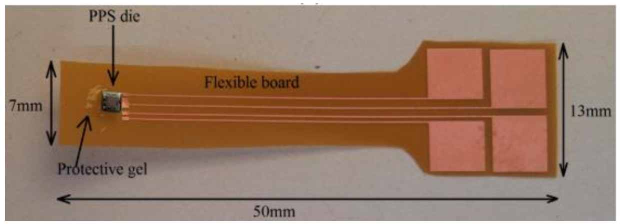
Pressure needles [5]

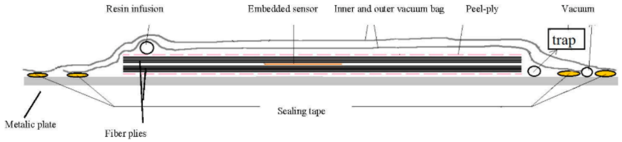




- ➢ Process: Autoclave
- ➢ Sensor position / part: **in-situ**

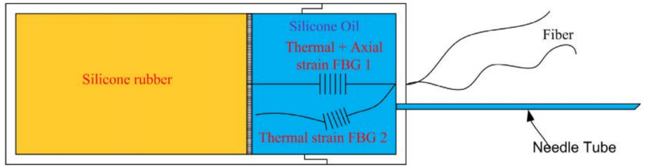
Piezoresistive sensors [6]

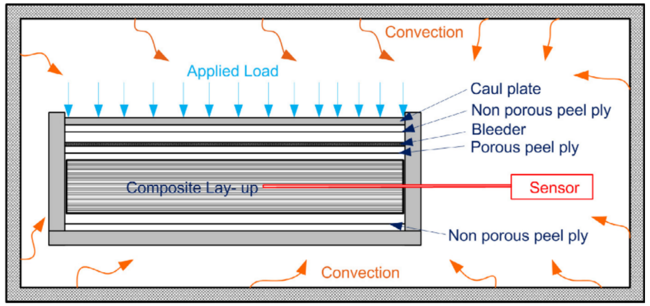




- ➢ Process: Liquid Resin Infusion
- ➢ Sensor position / part: **in-situ**

Optical Fiber sensors [7]





- ➢ Process: Thermal compaction
- ➢ Sensor position / part: **in-situ**

→ No commercially available technique to measure in-situ pressure in RTM…

→ Need to develop a dedicated solution! → **Needle Probe Pressure Sensor (NPPS)**

DEVELOPMENT OF THE NPPS TECHNOLOGY

- Main goal : measure pressure anywhere in the part during RTM manufacturing steps

1/ REQUIREMENTS TO BE MET:

- Temperature
- Pressure

RTM recipe

- Electrical insulation (carbon fibers)
- Resistance to chemical products (epoxy resin)
- Signal resolution (equivalent to mold transducers)
- Dimensions (as small as possible)
- Re-usable
- “Plug & play”, “user friendly”

Intermediate solution:

Conventional diaphragm pressure sensor with an added extension

NPPS

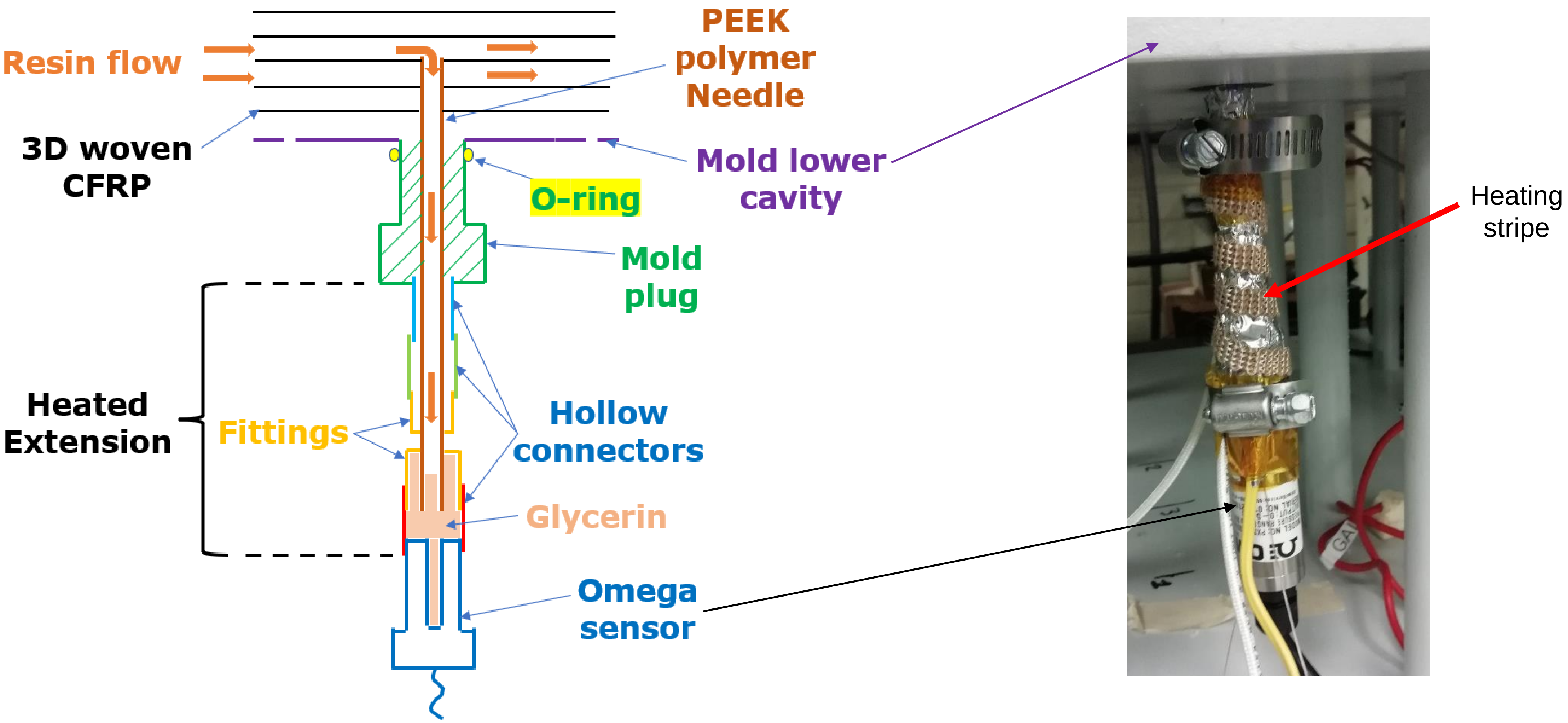
Extension to be designed!

PX309 300A5V
Omega Engineering:
Steel diaphragm
bonded to strain gage

[8]

DEVELOPMENT OF THE NPPS TECHNOLOGY

2/ DESIGN OF THE SOLUTION: GLOBAL EXPLANATION



Resin flow

PEEK polymer Needle

3D woven CFRP

Mold lower cavity

O-ring

Mold plug

Heated Extension

Fittings

Hollow connectors

Glycerin

Omega sensor

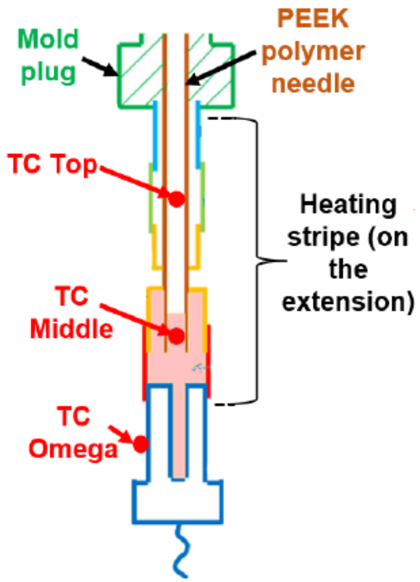
Heating stripe

DEVELOPMENT OF THE NPPS TECHNOLOGY

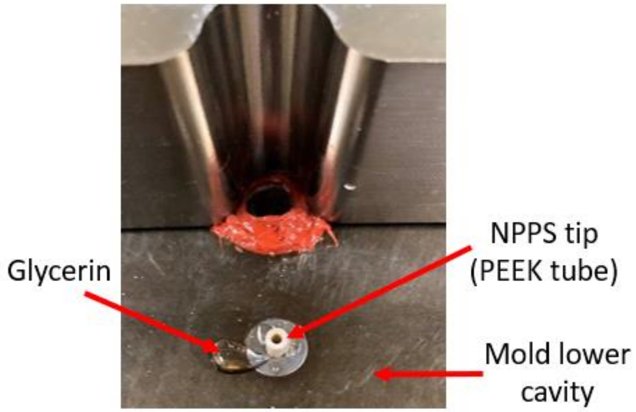
2/ DESIGN OF THE SOLUTION: CHALLENGES TO OVERTAKE

- Ensure resin/glycerin interface creation
  - → Good pressure information transmission
- Adjust glycerin quantity
  - → No leakage, needle fully filled with glycerin
- Optimize NPPS tip embedding steps
  - → Avoid needle clogging

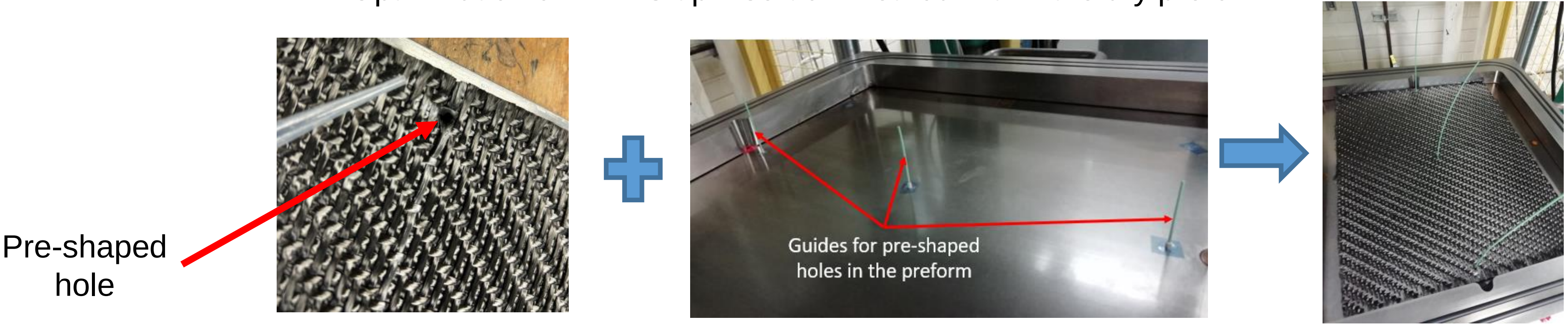
Thermal mapping of NPPS heated extension



Optimization of pressure transfer fluid quantity



Optimization of NPPS tip insertion method within the dry preform

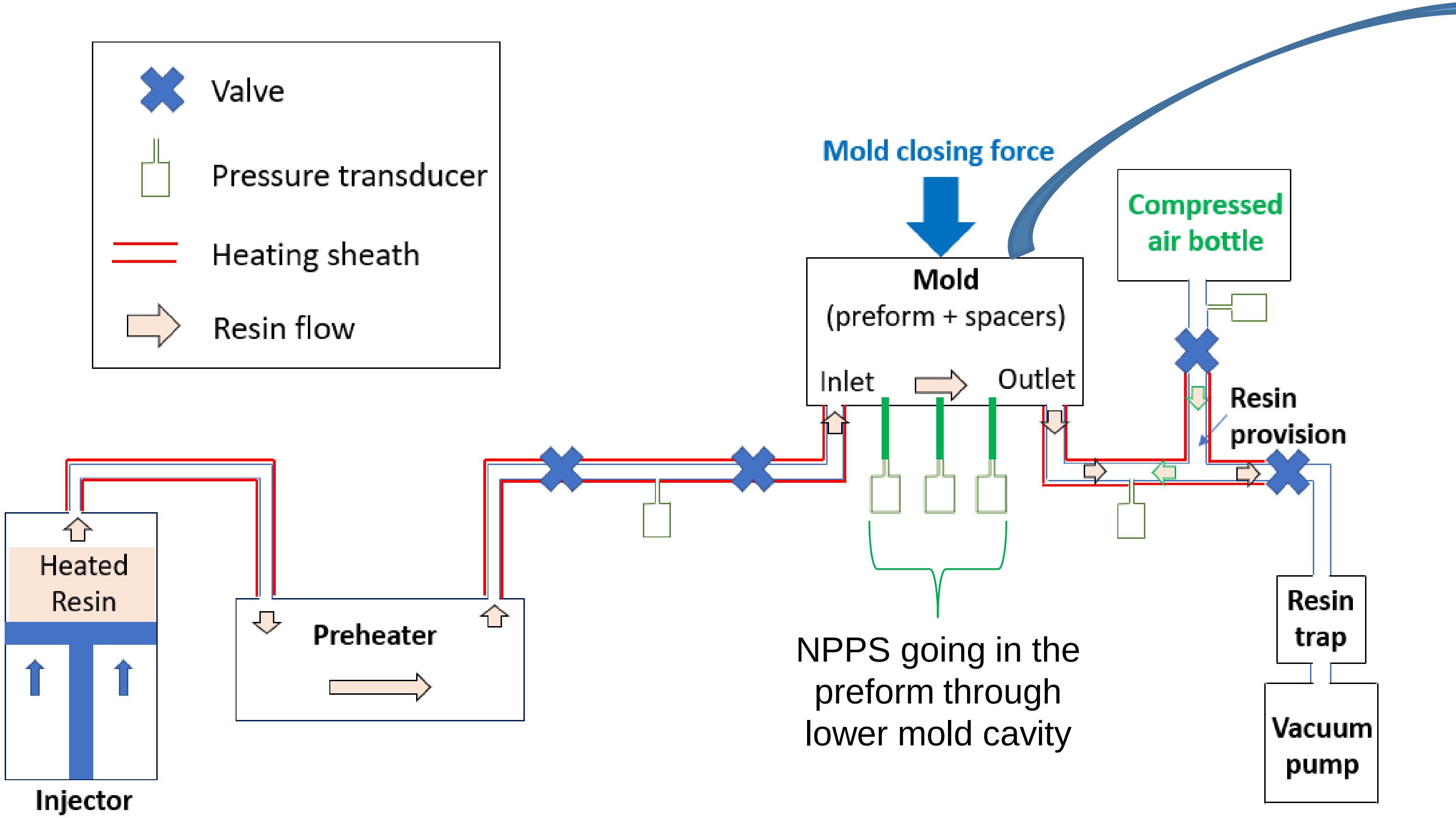


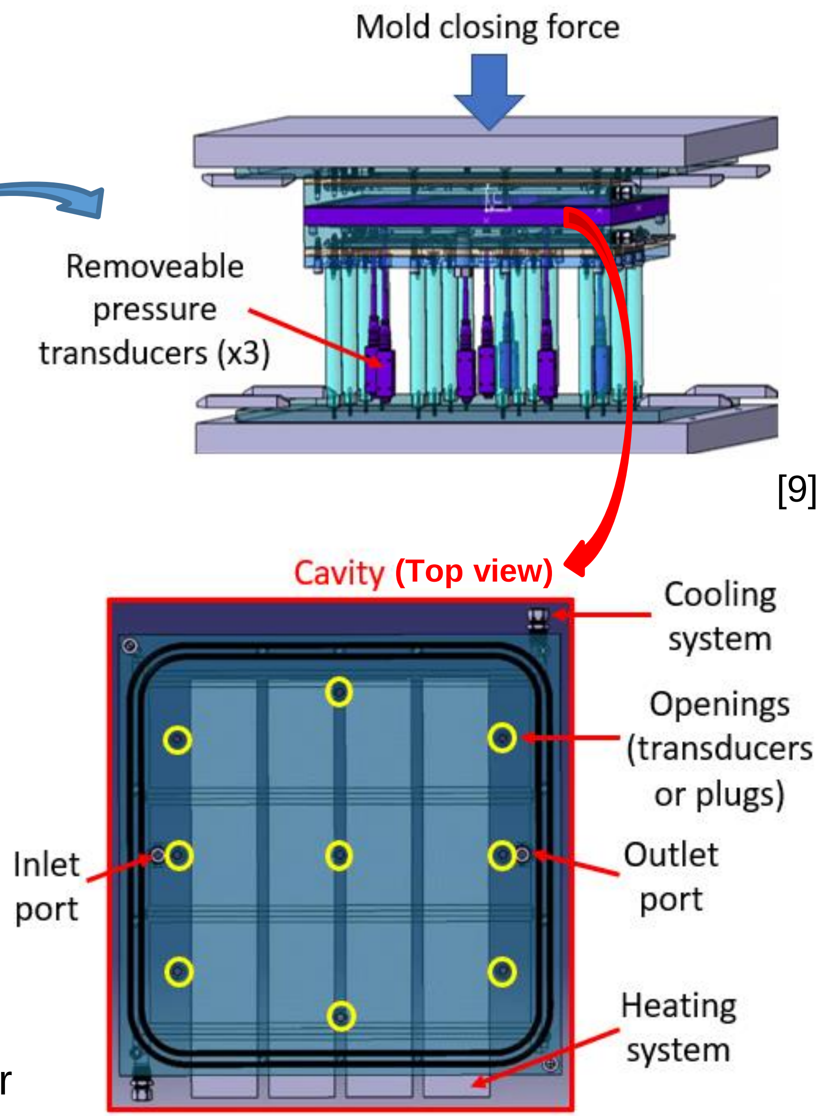
APPLICATION IN RTM

1/ PRESENTATION OF THE MANUFACTURING SETUP:

→ RTM injection line built at EPM

→ Mold from Ruiz Aerospace Manufacturing (Laval, QC)





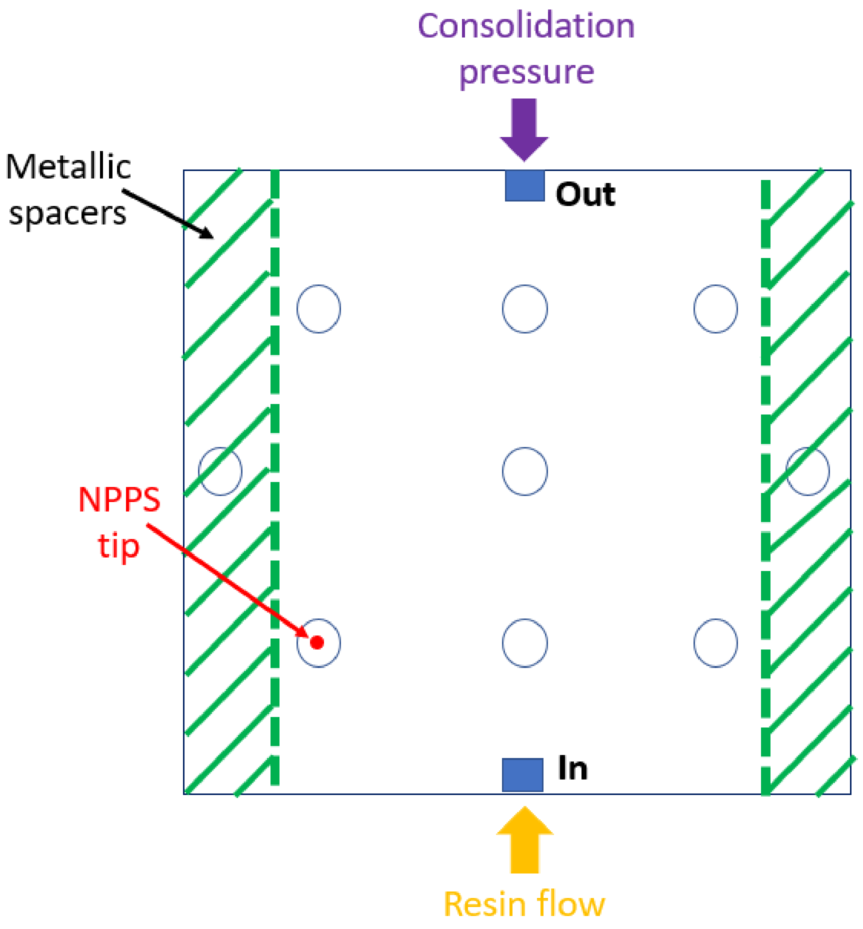
→ Dedicated thermal mapping to characterize the right thermal cycle for the mold

→ Creation of an entire manufacturing procedure linked to the setup

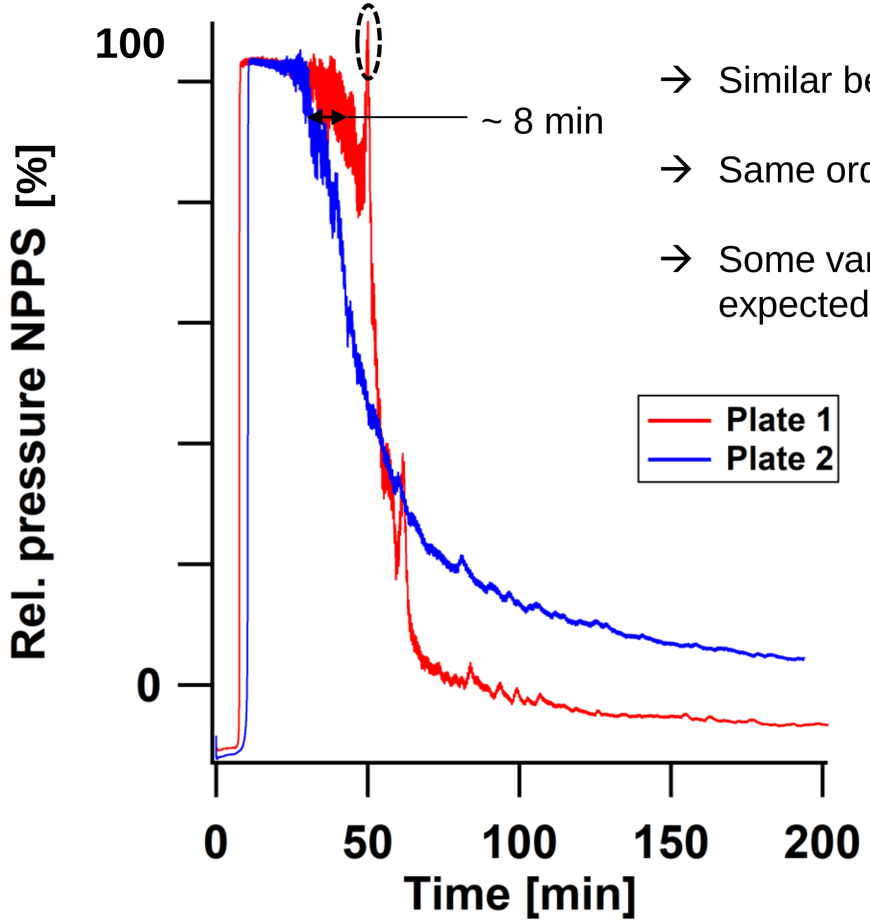
APPLICATION IN RTM

2/ REPEATABILITY OF THE NPPS PRESSURE SIGNALS:

Top view of the mold cavity



Evolution of NPPS signals from the application of consolidation pressure



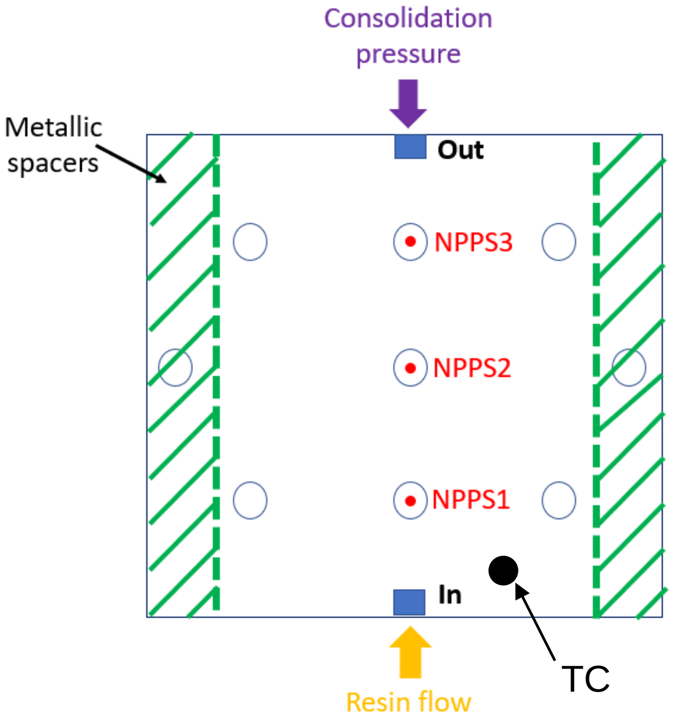
- → Similar behavior ✓
- → Same order of magnitude
- → Some variability to be expected (complex process)

APPLICATION IN RTM

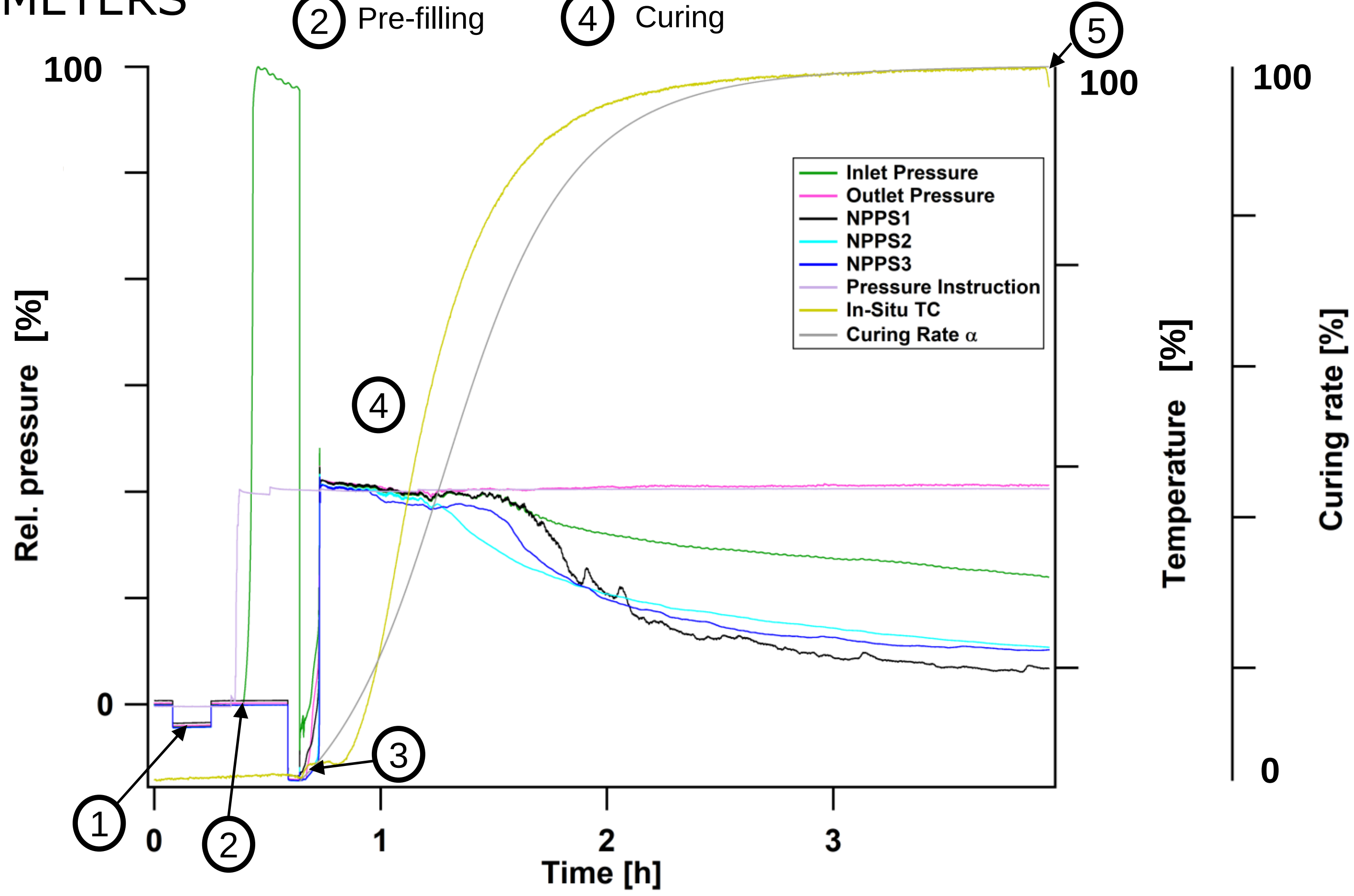
3/ USE OF NPPS TO STUDY KEY PARAMETERS

Porosity threshold

Specific pressure instruction not to obtain porous parts (specific to a configuration)



① Leakage test
② Pre-filling
③ Filling
④ Curing
⑤ Cooling



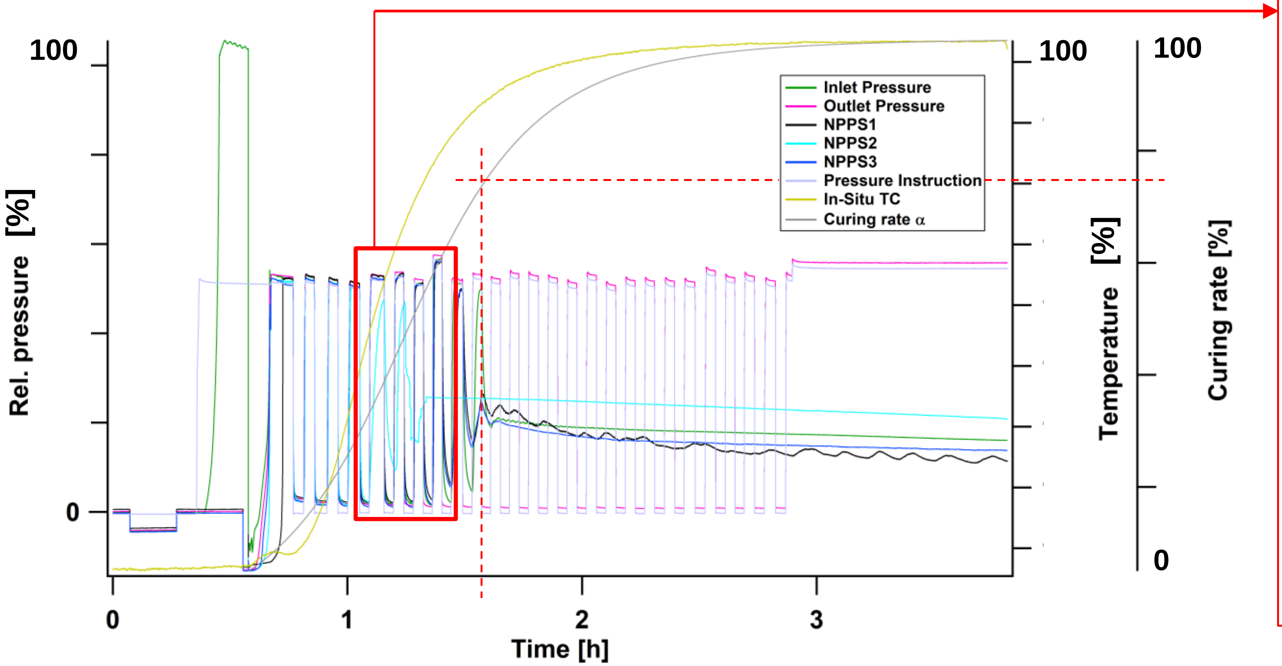
- Dedicated Design Of Experiments → Dichotomic study to narrow down an interval containing the threshold
- Iterative procedure with comparison of pressure curves and X Ray CT-scans of samples taken around NPPS tip areas
- When linked with curing irreversibility → Inner local pressure threshold to avoid pores → interesting data for numerical models

APPLICATION IN RTM

3/ USE OF NPPS TO STUDY KEY PARAMETERS

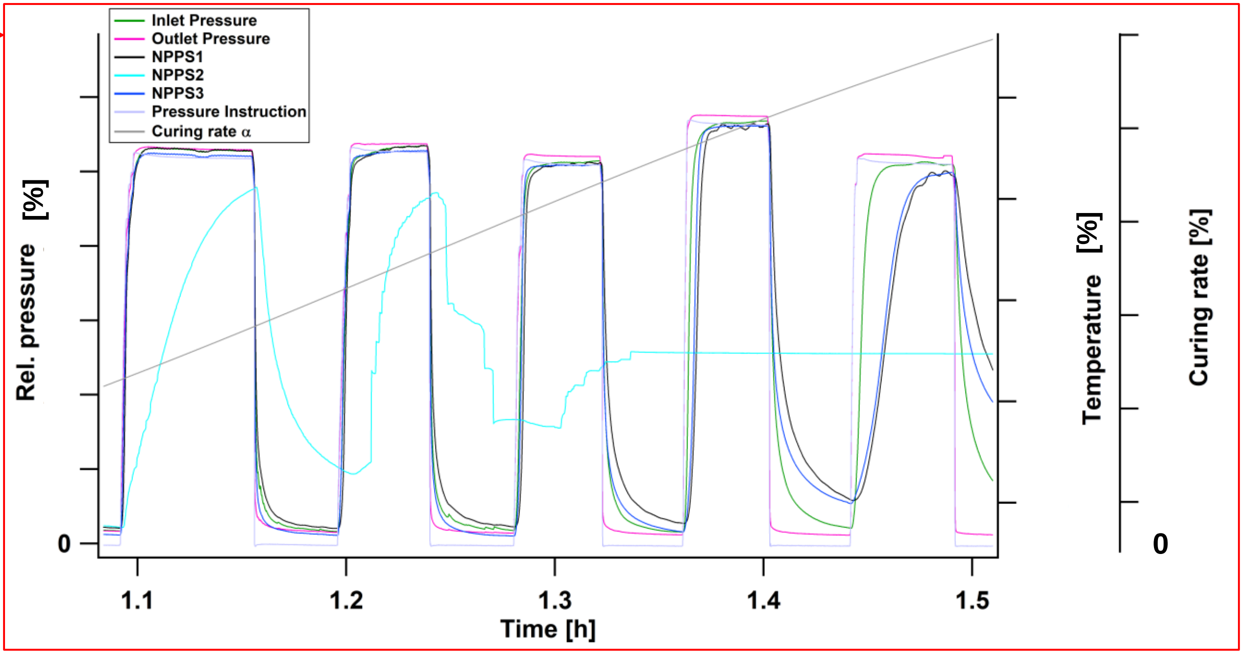
Curing Irreversibility

No more pressure transmission



Pressure transmission

From the compressed air system through the preform



→ Observation of the pressure transmission phenomenon, repeatable

→ Determination of the curing threshold when pressure transmission cannot be ensured anymore
  → Correlation with production values
  → to be linked with porosity threshold determined earlier

CONCLUSION AND FUTURE WORKS

- Optimization of conventional pressure sensor:
    - Ability to measure in-situ pressure during all steps of RTM process → allows to infer:
        - Pressure transmission
        - Curing irreversibility for pressure transmission
        - Pressure threshold to avoid porosity
    - Repeatable behavior of the technology
    - Needle easily replaceable within the NPPS extension
    - Versatility of the technique: could be used in infusion, autoclave, thermal compaction, Polyflex…
- Ongoing and future works
    - Improve NPPS technology (glycerin full retention within needle, optimal NPPS temperature)
    - Refine pressure threshold to avoid porosity within the part
    - Study other manufacturing configurations: Tvf, number of preform layers, size/shape of the part, preform weaving pattern, resin type, measurement direction, etc.…

      → better understanding of the physics & feeding numerical models (increase robustness)

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[9] www.ruizaero.com