VARTM Variability and Substantiation

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May 19th, 2010

A Center of Excellence
AMTAS
Advanced Materials in Transport Aircraft Structures

University of Delaware
Center for Composite Materials
INTERNATIONALLY RECOGNIZED EXCELLENCE

CECAM
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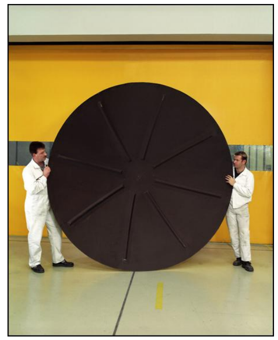
The Joint Advanced Materials and Structures Center of Excellence

FAA Sponsored Project Information

- Principal Investigators & Researchers
  - Dirk Heider (PI)
  - John W. Gillespie, Jr. (Co-PI)
- FAA Technical Monitor
  - Curtis Davies
  - David Westlund
- Industry Participation
  - Gore (Munich, Germany)
    - Provided membrane materials, access to instrumentation and technical input
  - Donaldson Membranes (Warminster, PA)
    - Provided membrane materials
  - Hexcel (Seguin, Texas)
    - Provided resin and fabric material and technical input
  - Cytec (Anaheim, CA)
    - Provided resin and fabric material and technical input
  - EADS (Germany)
    - Provided technical and financial input
  - Boeing (Philadelphia, PA)
    - Provided technical input

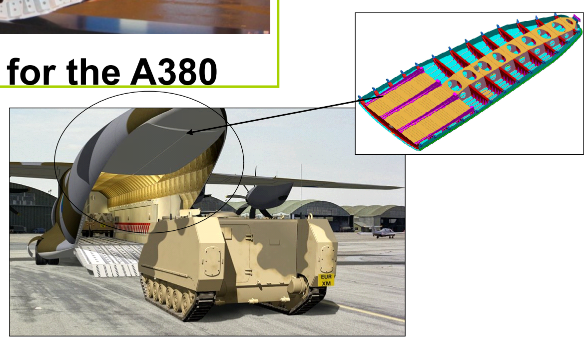
AEROSPACE VARTM'D COMPONENTS

Flap tracks for the A380

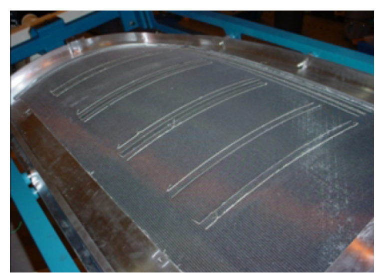


Pressure Dome

CH-47 Chinook Forward Pylon



A400M CFC Cargo Door

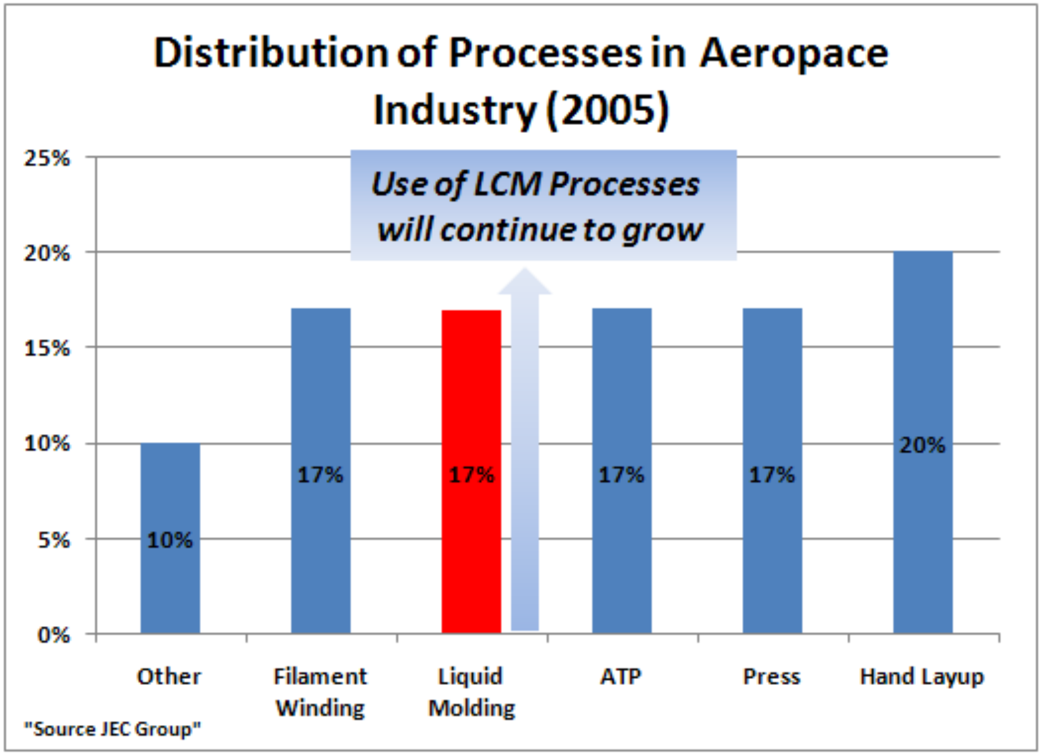


C-17 Main Landing Gear Door

Other BOEING Components
- LAIRCOM panels
- Leading edge 787
- Rear Bulkhead 787

MOTIVATION

- VARTM process:
  - Main advantages: low cost, high fiber volume fraction, large scale parts
  - Still some limitations
    - Limited fundamental understanding of process
    - High variability
      - From part to part
      - In the same part
  - Automation is still limited
  - Certification for new aerospace applications



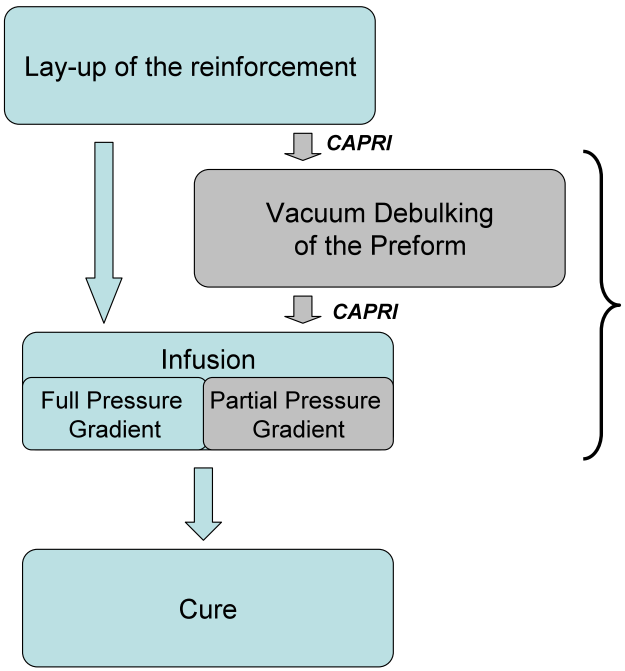
APPROACH

- Establish the fundamental understanding of the various VARTM processes
  - Modeling the full VARTM process to understanding process physics including
    - Pre-Infusion (Compaction Behavior)
    - Infusion
      - Flow model is fully developed for SCRIMP, VAP, and CAPRI process
      - Effect of dual-scale flow behavior has to be further studied to better understand micro-void formation
    - Post-Infusion
      - Resin Bleeding
  - Evaluate other process recommendations
- Optimize membrane material (VAP)
  - Understand membrane mechanisms
  - Recommend material improvements
- Establish an elevated temperature VARTM workcell for toughened epoxies

VARTM Process Variations

1. Seemans Resin Infusion Molding Process (SCRIMP)
   - Use of Distribution Media
   - Patent held by TPI Inc.
2. Vacuum-Assisted Processing (VAP)
   - Use of an additional membrane
   - Patents held by EADS
   - Reduces Void Content, Improves Process robustness
3. Controlled Atmospheric Resin Infusion Process (CAPRI)
   - Reduced pressure differential
   - Patent held by the Boeing Co.
   - Reduces thickness gradient, improves fiber volume fraction variation

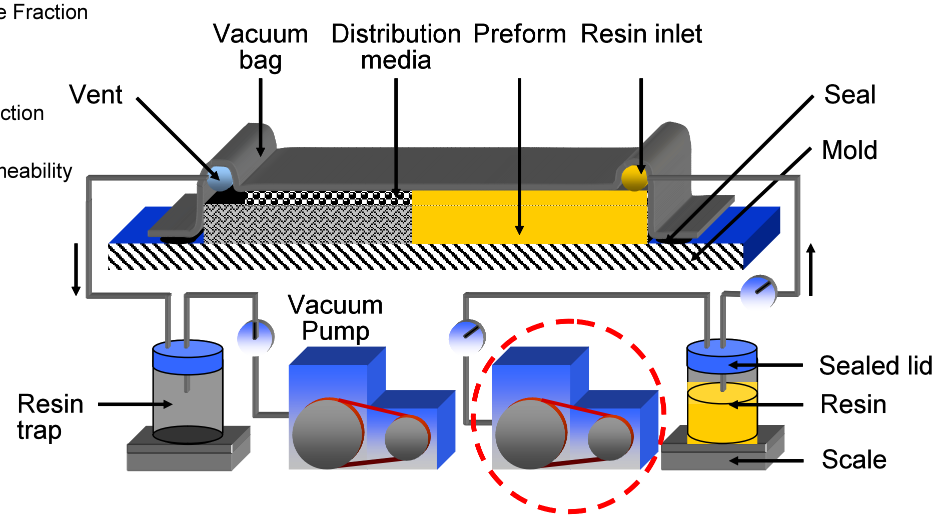
Process Variations: The CAPRI Process



- Controlled Atmospheric Pressure Resin Infusion
- Adds vacuum debulking and reduce pressure differential to setup

<u>Advantages</u>
- Increased Fiber Volume Fraction
- Reduced Gradients
  - Pressure
  - Thickness
  - Fiber Volume Fraction

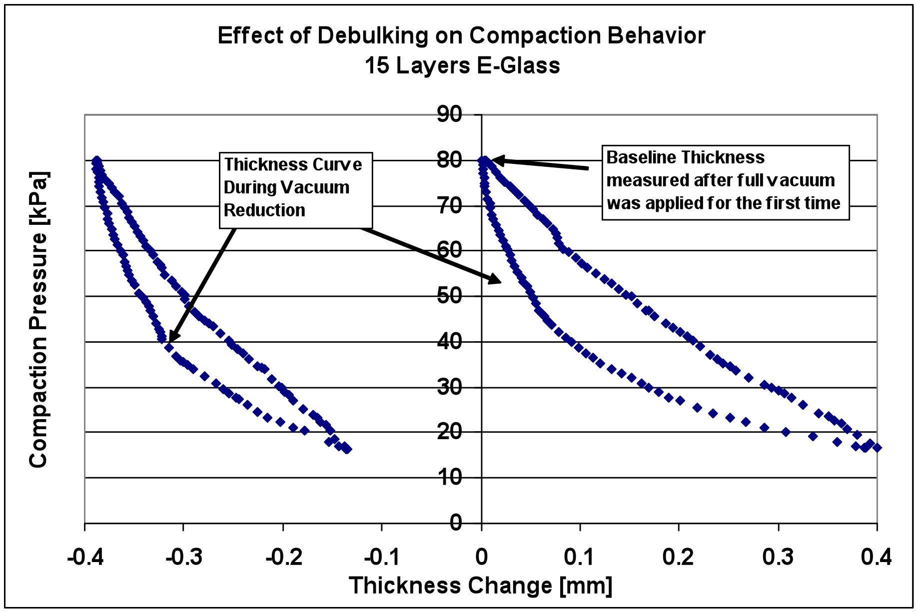
<u>Disadvantages</u>
- Decrease in fabric permeability
- Increase in flow times
- Increase in lead length

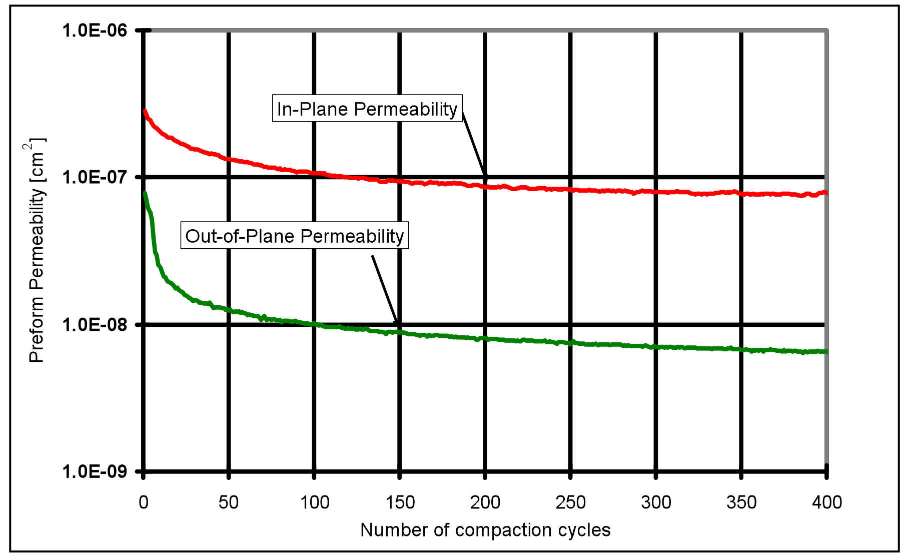


<u>CAPRI Patent held by Boeing</u>

Woods, J., Modin, A. E., Hawkins, R. D., Hanks, D. J., "Controlled Atmospheric Pressure Infusion Process", International Patent WO 03/101708 A1.

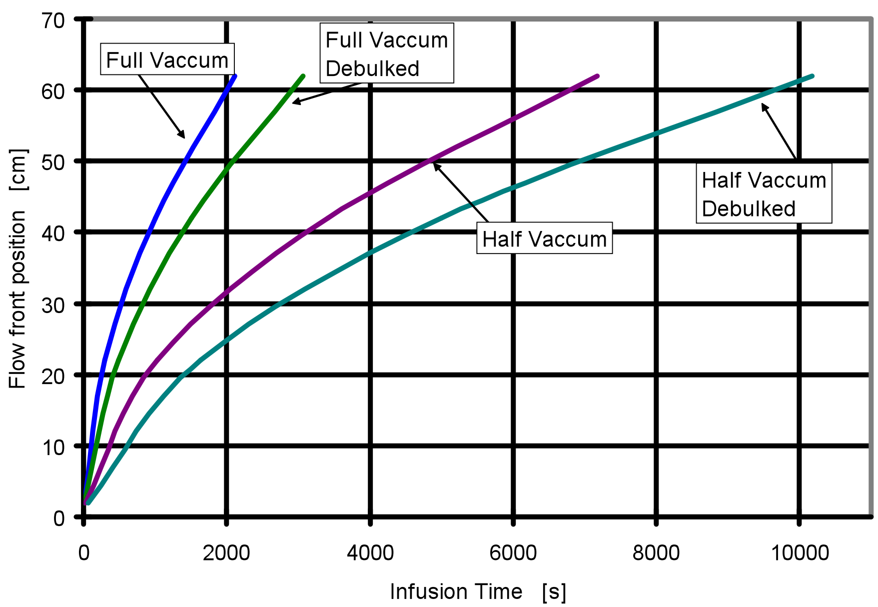
Effect of Debulking on Thickness and Permeability

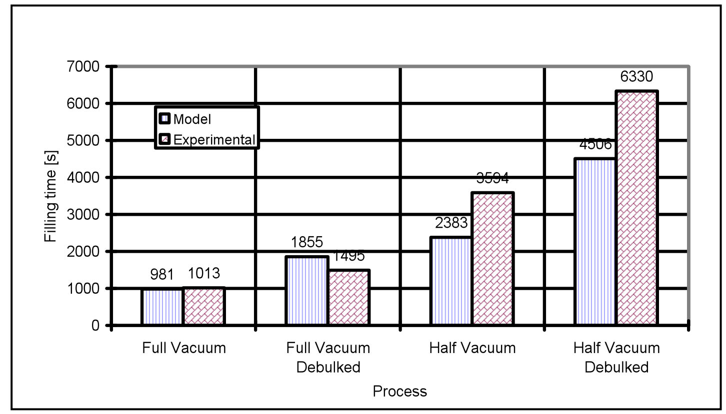


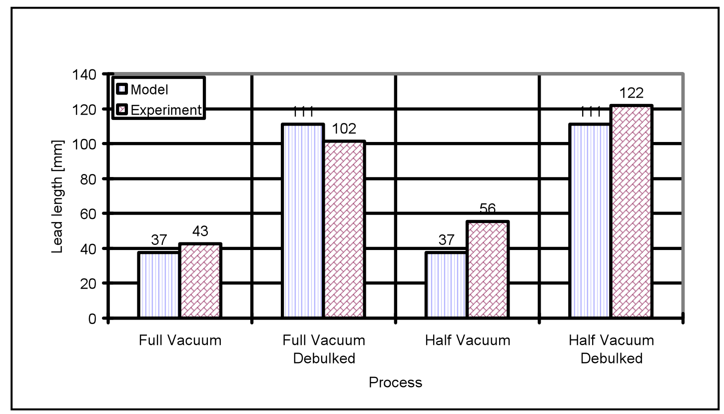


- The thickness and spring-back behavior is greatly reduced during debulking
  - Increases Fv
  - Reduces thickness gradient
  - Decreases permeability

CAPRI Flow Behavior

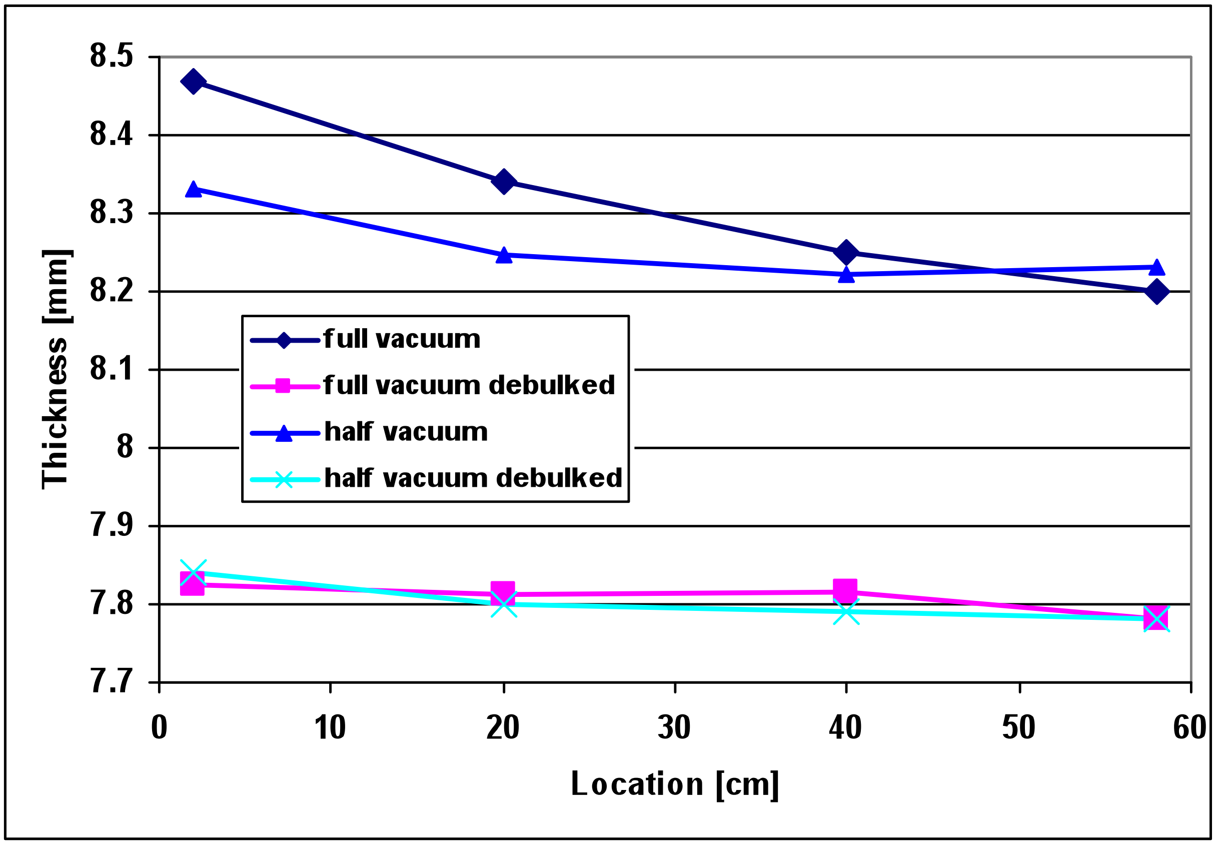






- Flow behavior changes due to reduced pressure gradient and decreased permeability
- 1-D analytical flow model has been developed and can predict lead length and fill time

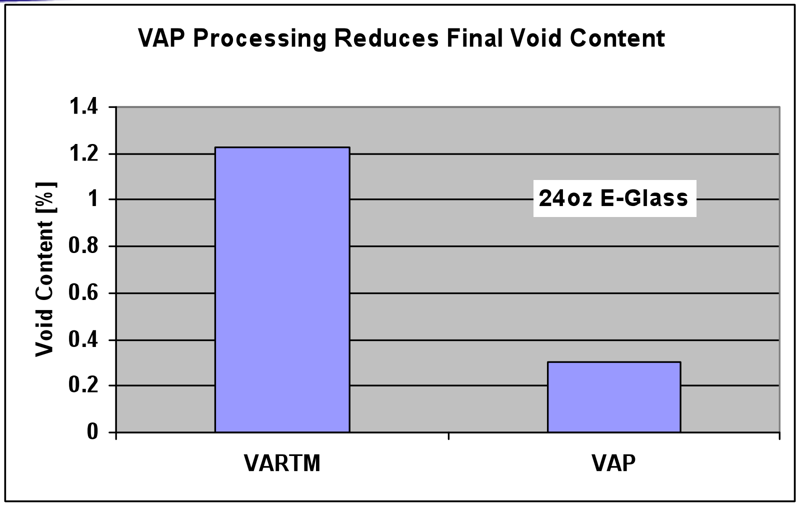
Thickness Behavior Comparison between CAPRI and SCRIMP

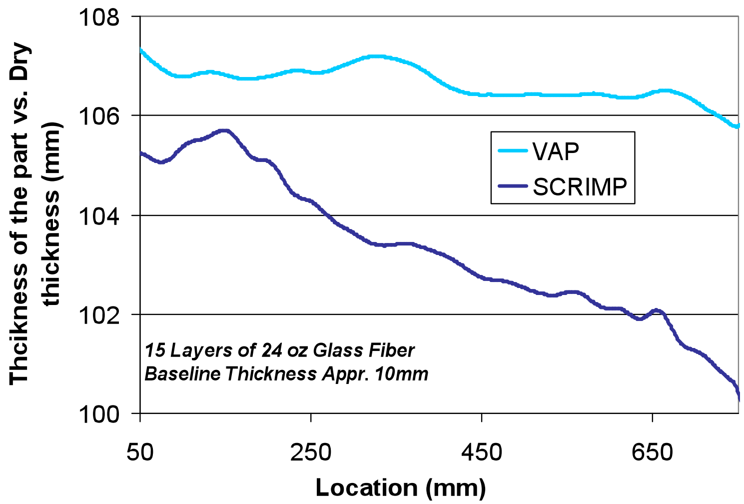


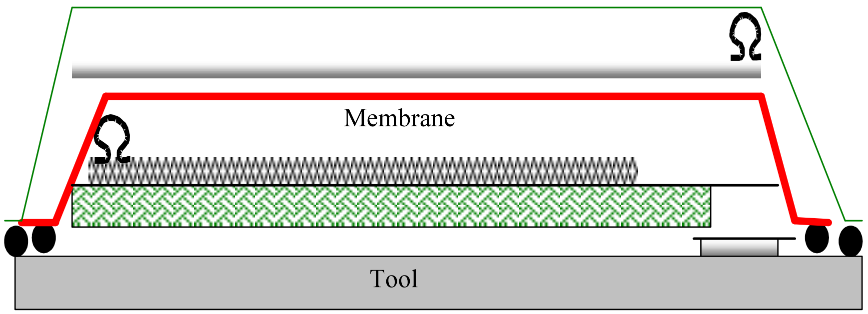
- Debulking can greatly increase final fiber volume fraction
- The thickness gradient is reduced when the CAPRI pressure is applied (insignificant for the debulked case)

MEMBRANE-BASED VARTM PROCESSING (VAP)

- Utilize membrane cover to allow continues degassing and uniform vacuum pressure during VARTM processing
  - Reduces void content
  - Improves uniformity (fiber volume fraction, thickness)
  - Eliminates dry-spots

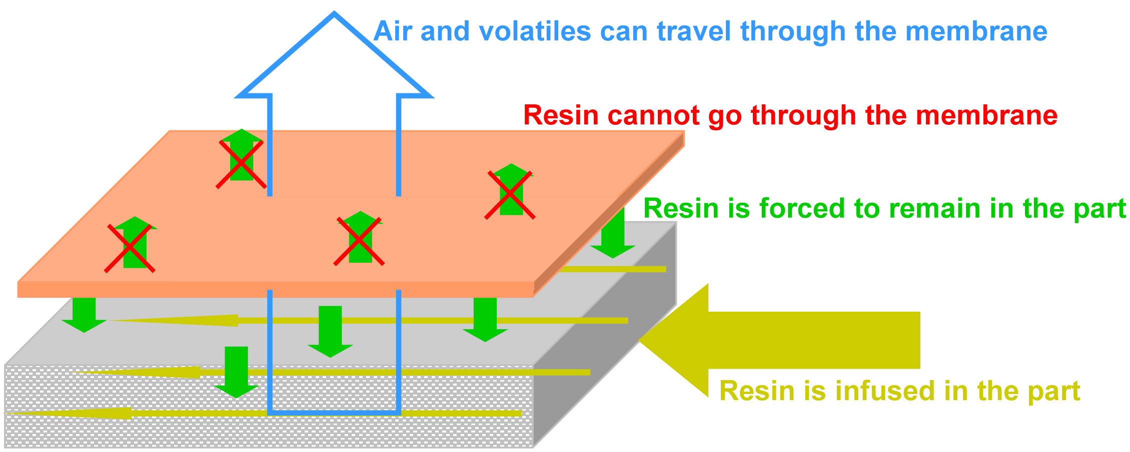


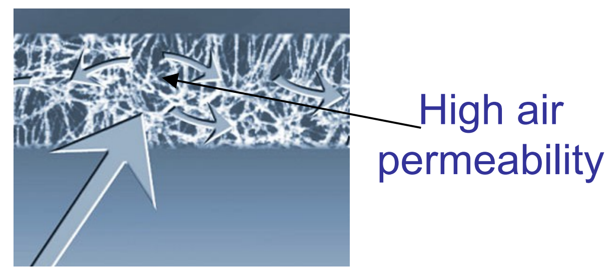




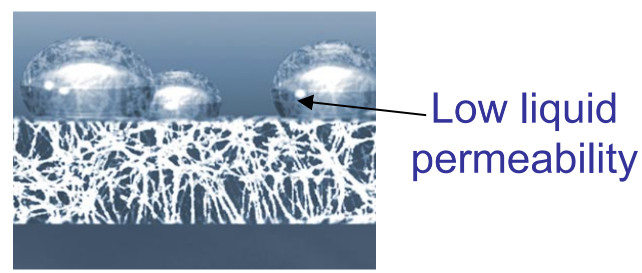
MAIN REQUIREMENTS OF THE MEMBRANE

- **Desirable Characteristics** for a membrane used in VARTM:
  - Gas permeable material
    - OR High air permeability through the thickness
  - Resin-proof material
    - OR Low liquid/resin permeability through the thickness
- **Compatibility with resin**
  - Compatible: The resin does not go through the membrane and is forced into the part
  - Incompatible: The resin penetrates the membrane



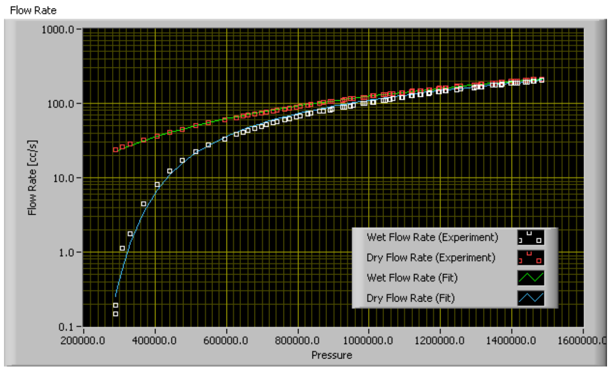


www.gore-tex.co.uk

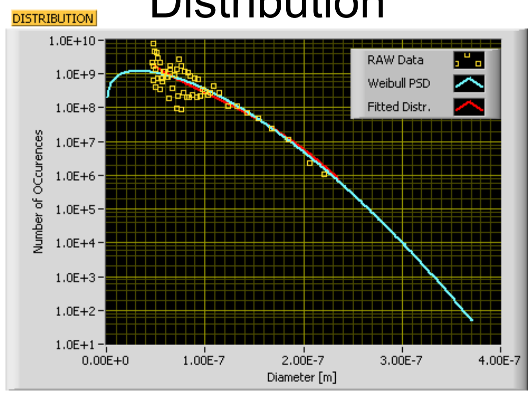


Statistical Analysis of Membrane

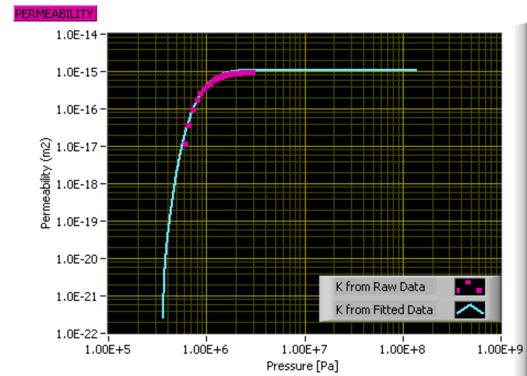
Fitted Porometer Data



Improved Pore Size Distribution

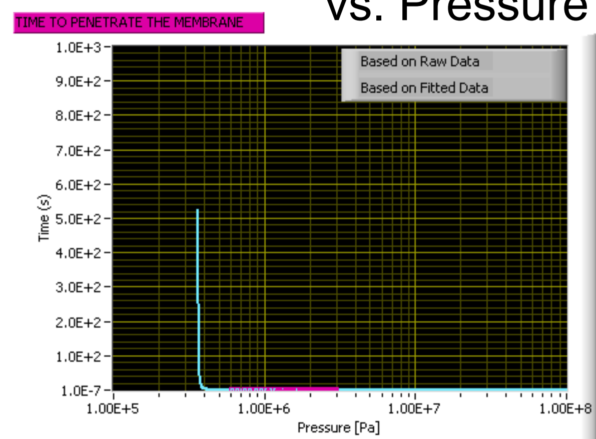


Permeability vs Pressure



- Analysis and model implementation can be used to predict membrane performance for a wide variety of resin choices and process approaches (includes higher pressure application such as autoclave)
- Can be used to used to optimize membrane behavior
  - Increase contact angle, surface tension
  - Decrease “tail” of pore size distribution
- Effect of stretching can be incorporated in model (TBD)

Penetration Time vs. Pressure



Processing Steps for Modeling

Material Preparation
- Resin Mixing and Degassing
- Material Layup and Drying
- Preform Debulking
- Leak-Free Bagging and Tooling

↓

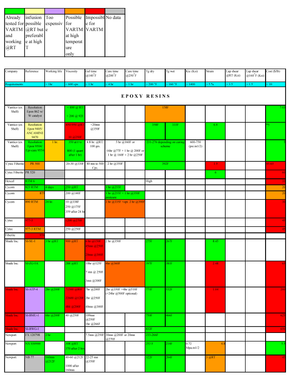
Infusion
- Optimum Infusion Setup
- Minimize thickness gradient
- Micro-Void Reduction
- Automation

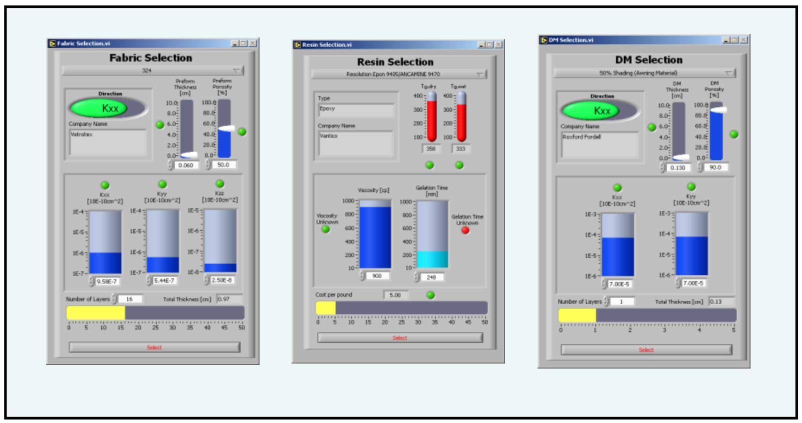
↓

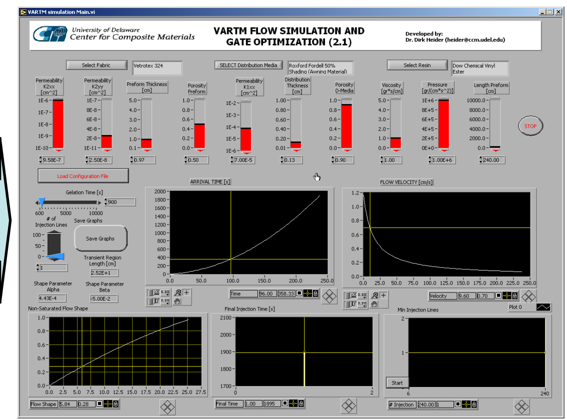
Post-Infusion
- Optimum Resin Bleeding
- Cure Control

- Models (analytical and FE) have been developed to capture the process physics of the various processing steps
- Degassing requirements and material drying has not been modeled yet but are empirically evaluated

DESIGN TOOL @ UD-CCM



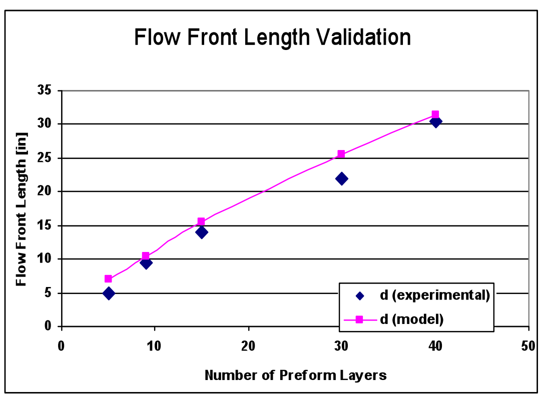


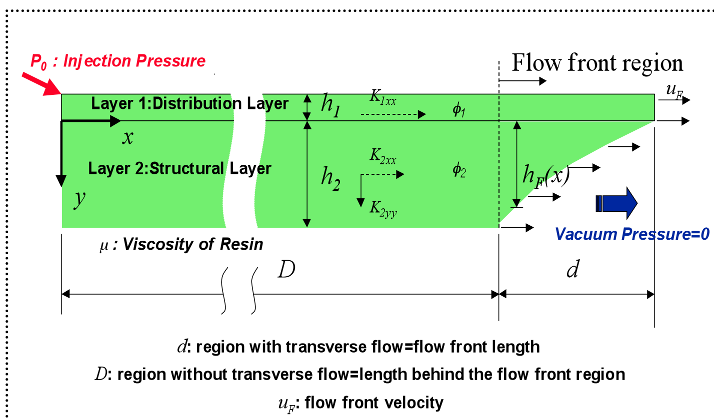


•Database

•Material Selection

•Design Interface

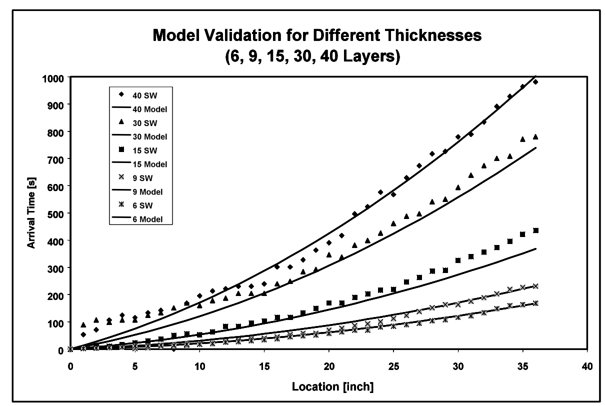




d: region with transverse flow=flow front length

D: region without transverse flow=length behind the flow front region

u_F: flow front velocity



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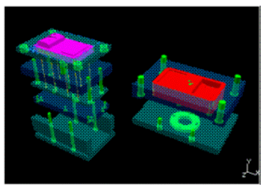
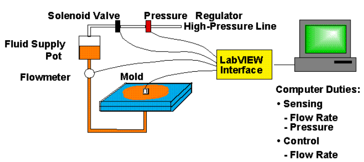
FE Element Simulation (LIMS)

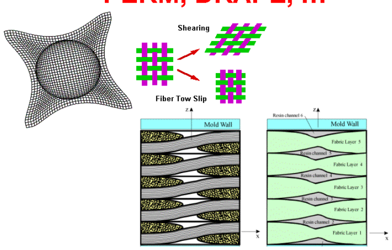
Part Design/Meshing
CAD Software



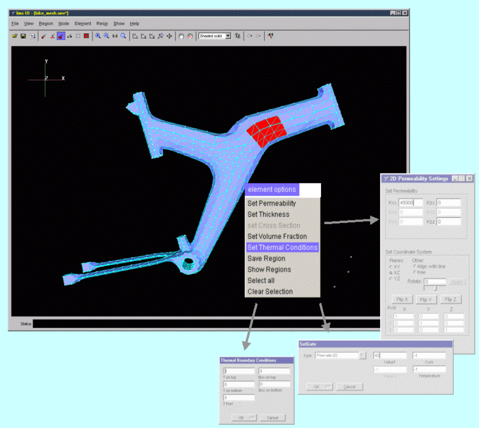
Permeability Measurement



Permeability and Preform Properties Computation
PERM, DRAPE, …



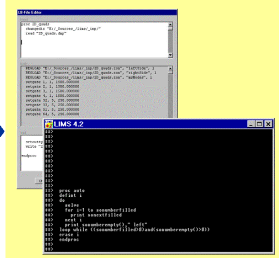
Preparing Data for Simulation
LIMS UI (User Interface)



- Converting Input Data
- Setting Material Properties
- Creating Gates and Vents
- Creating and Editing Control LBASICFiles

Running Simulation
LIMS or LIMSSLV

Directly From LIMS UI

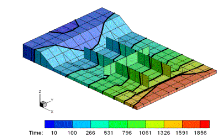


From Command Line

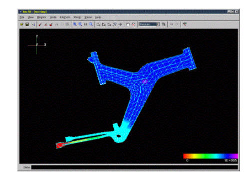
- Simulating Filling Procedure
- Executing Control Operations
- Writing Desired Output

Post-processing Results
LIMS UI, TECPLOT, …

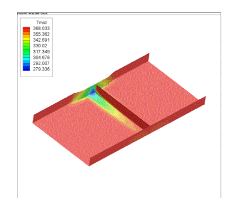
Flow Patterns



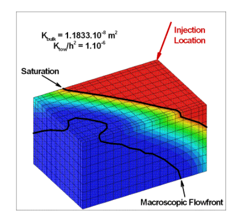
Pressure



Mid-plane Temperature



Saturation



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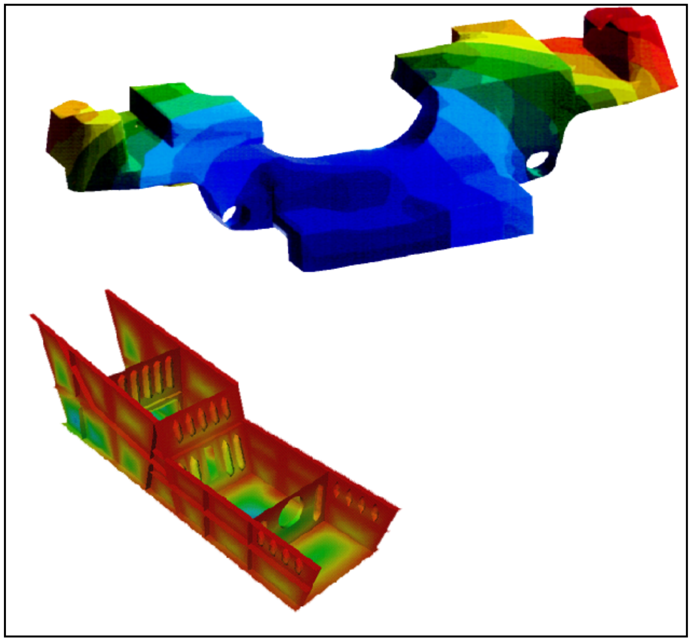
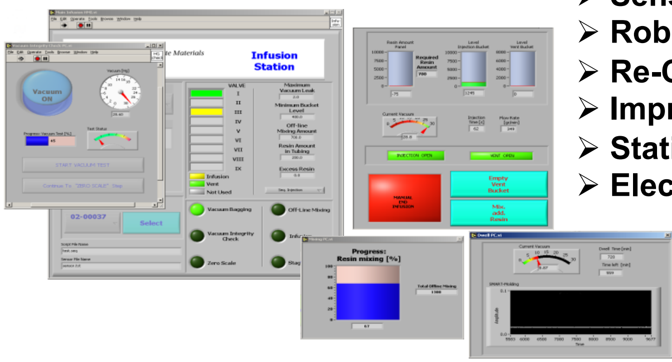
Complex Part Shapes

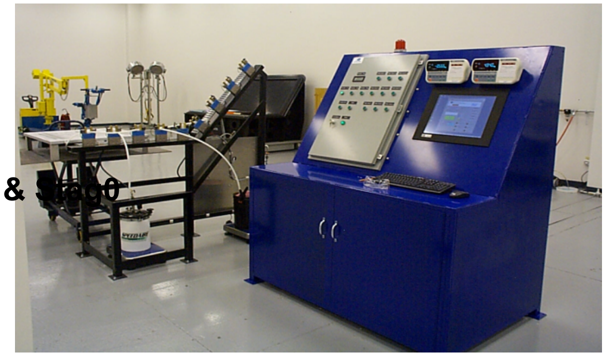
- **LIMS can handle complex 3D part geometry**
  - **Not only Shell like parts**
  - **T stiffeners, branching, inserts ...**
- **Any local variation of material properties is possible**
- **Combination of 1D and 2D elements may be used to add LCM-specific features to 2D or 3D mesh *without* numerical difficulties**
  - **Racetracking**
  - **Distribution Media**
  - **Dual-Scale Flow**

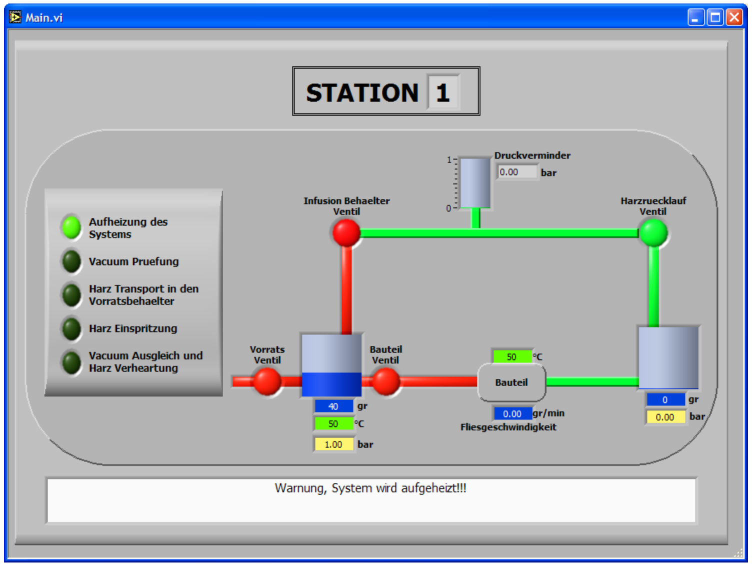


Aerospace VARTM Requires Elevated Temperature Processing



- Sensor Based Infusion Technology
- Robust System Construction
- Re-Configurable Infusion Schemes
- Improved Resin Mixing System
- Statistical Data Sampling During Infusion & Stage
- Electronic Work Instruction

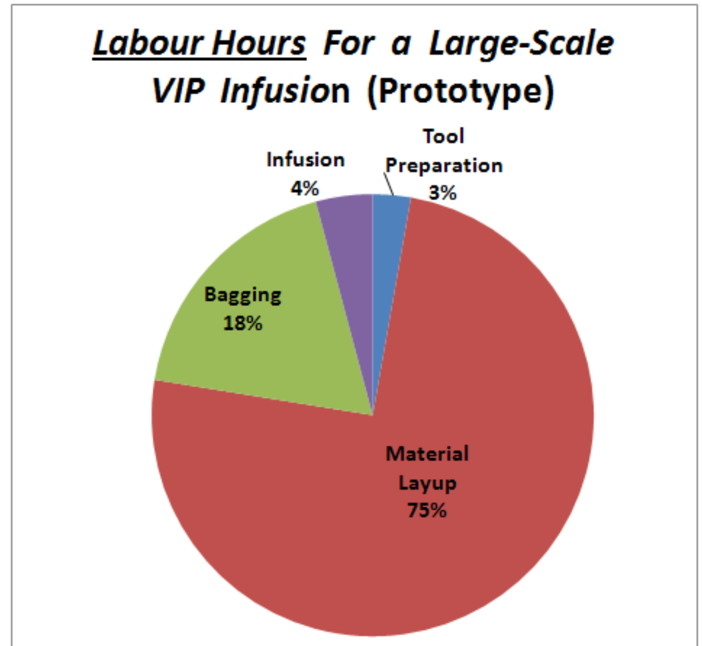




TRANSITIONED FOR R&D AND PRODUCTION AT DASAULT AVIATION (Paris, France)

Also available to other companies

Automated Layup: Key to Improved Repeatability



•Tool	<0.5hrs
•Layup:	>6hrs
•Bagging:	~2hrs
•Infusion:	~1hrPrep:

•*Material Layup is often the cycle time driver.*

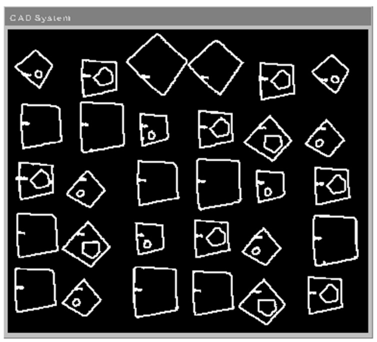
•*Automation is key for reduced cycle time and improved repeatability !!!*

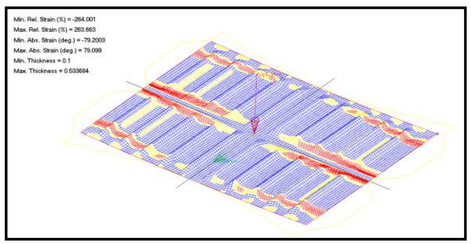
Material Handling Issues/ Opportunities

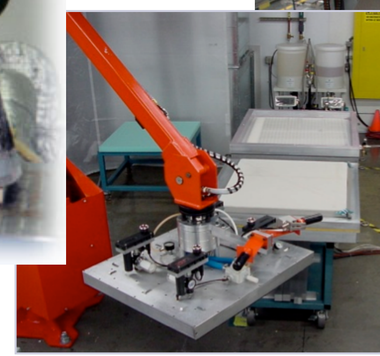
•Flat pattern generation, cutting

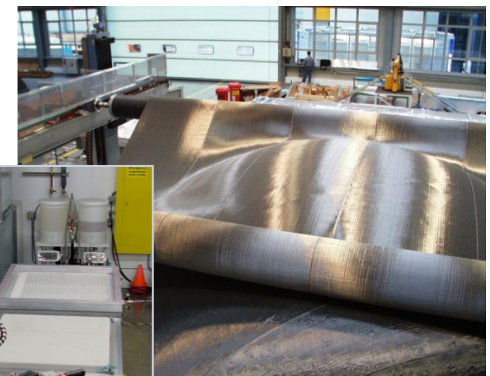
•and draping analysis

•Material Placement









•Photos courtesy of

- Flat pattern generation can be automated for complex geometries
  ➔ ensures correct draping and preform assembly
- Pattern can be cut net-shape on ply cutter
- Pattern can be directly projected on tool to improve placement accuracy

- Robotic placement improves
  - Repeatability
  - Reduces potential for defects
    - Pin holes
    - Missed layers
  - Cost reduction

•

A Look Forward

- Benefit to Aviation
  - Improved fundamental understanding of VARTM processing to evaluate benefits and disadvantages of various process variations
    - All processing steps are important including pre-infusion, infusion and post-infusion
  - Membrane processing shows promise to improve repeatability due to continuous surface venting
  - Reduce part-to-part variations / improve allowables
  - Automated VARTM will allow QA/QC of part production reducing costs and improve quality while maintaining traceability