



SMARTMolding UPDATE

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Report Documentation Page

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Outline



- **Review of new VARTM process variations**
 - ◆ **Channel-Assisted Resin Transfer Molding (CARTM)**
 - ◆ **Interlaminar Flow Media**
 - ✧ Verdant Polybeam™
- **New Features of SMARTMolding Software Suite**
 - ◆ **Design Tool**
 - ✧ Incorporated commercially available Distribution Media into Database
 - ◆ **Intelligent Process Control System**
 - ✧ Added Intranet connectivity
 - ✧ Automated Vacuum Debulking
 - ✧ On-line Work Instructions
 - ✧ Virtual Checklist of all Processing Steps
 - ✧ Sensor Test
 - ◆ **New Data Review Graphical User Interface**
 - ✧ Allows on-line reporting on all recorded data over Intranet
 - ✧ Export to Excel, Printing Capability

Outline

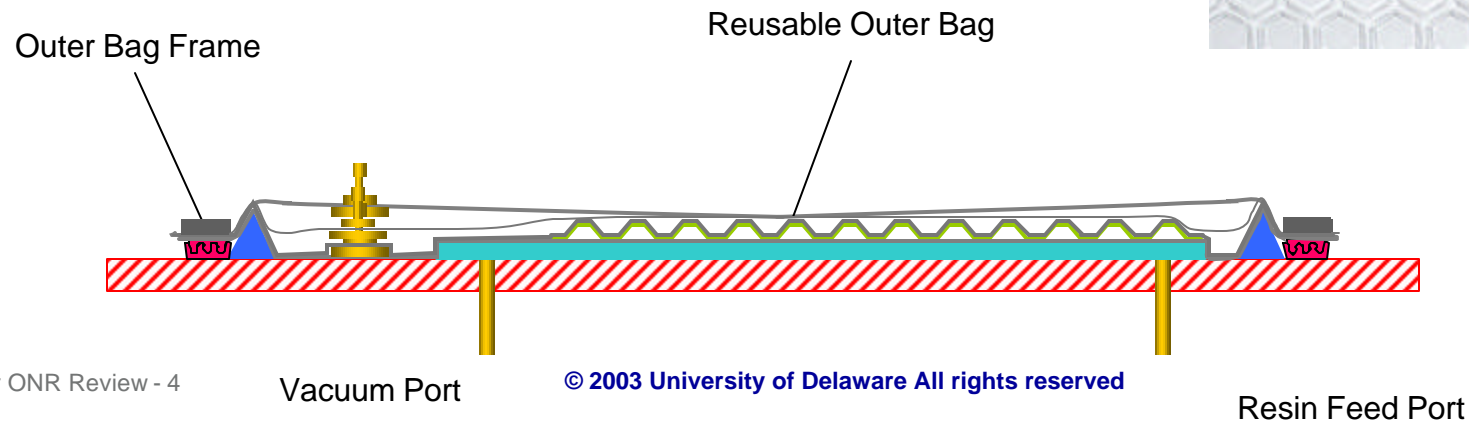


- **New Features of SMARTMolding Software Suite**
 - ◆ **Recipe Definition GUI (In Progress)**
 - ✧ Complete Process Flow Description (Recipe) is automated
 - ✧ Checks on Database and Process Consistency
 - ◆ **Automated Statistical Analysis Tool (In Progress)**
 - ✧ Detects Outliers
 - ✧ Ranking of Important Process Variables
- **New Features of SMARTMolding Hardware Suite**
 - ◆ **Wireless Tool-Mounted Sensors (In Progress)**
 - ◆ **Tool-Mounted Time-Domain Reflectometry**
- **Technology Transfer**
 - ◆ **Important Conference Participation**
 - ✧ SMARTMolding Demonstration at SAMPE '03 Long Beach, CA
 - ✧ Invited Lecture "Intelligent Process Control For Automated VARTM Processing" Composite Fabricator Association (CFA) Liquid Molding Conference in Dayton, OH
 - ◆ **In Progress of Updating Beta-Sites with new Software Components**
 - ✧ NSWC Caderock has been updated
 - ◆ **Strong Interest in SMARTMolding from several Companies**
 - ✧ Boating
 - ✧ Wind Energy

The CARTM Process I



- Channel-Assisted Resin Transfer Molding Process
- Patented and Commercially Licensed
- Similar attributes compared to FASTRAC, but flow media and completed double bagging systems are commercially available



The CARTM Process II



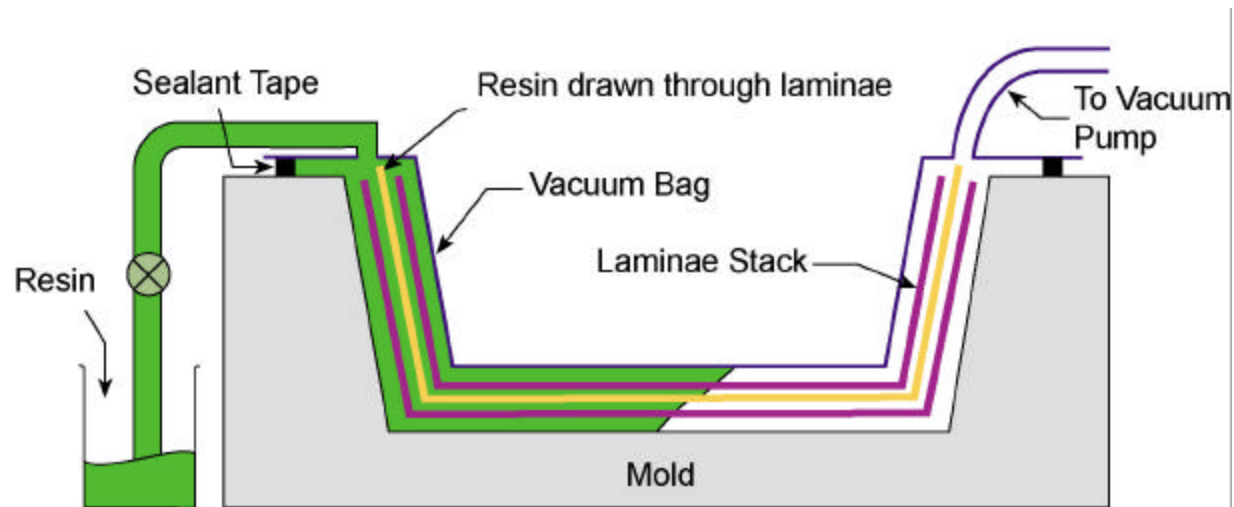
- **System can be modeled as a typical VARTM process with distribution media**
 - ◆ **Permeability is a function of CARTM media (channel pattern) and differential vacuum pressure**
 - ◆ **Opportunity to optimize surface flow for complex structures by designing the CARTM layer (off-line control)**
 - ◆ **On-line flow control possible by adjusting differential vacuum pressure**
 - ◆ Zones
 - ◆ Vacuum gradient
 - ◆ Delay Lines

- **Establishment of a CARTM workcell at UD-CCM in July with help of “Why not Composites”**

Interlaminar Flow Medium



- Resin introduced through the preform via an integrated inter-laminar distribution media
- Peel ply not necessary
- Thick preforms can be divided in multiple laminates

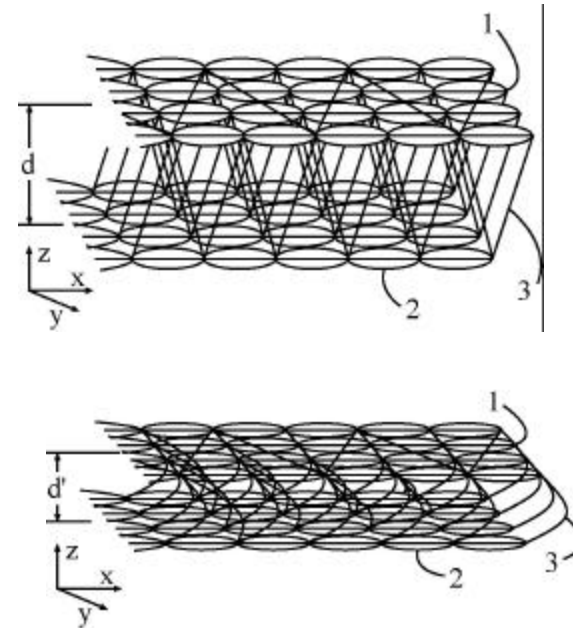
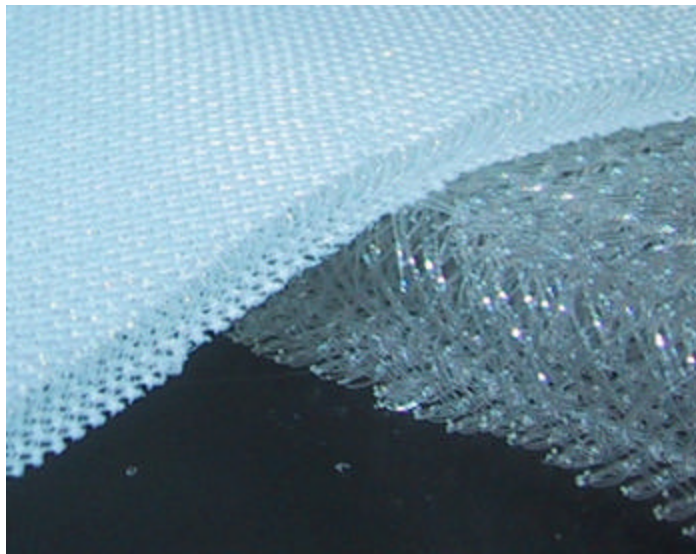


Courtesy of

Polybeam Flow Media™



- Patented Polybeam technology increases permeability during infusion due to spring-back and reduces porosity after infusion due to unique compaction behavior

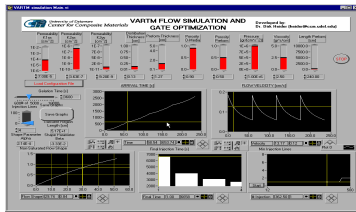


- Talks initiated with Verdant to evaluate compaction behavior and mechanical performance
 - ◆ Bonding to cored structure
 - ◆ Inter--laminar shear

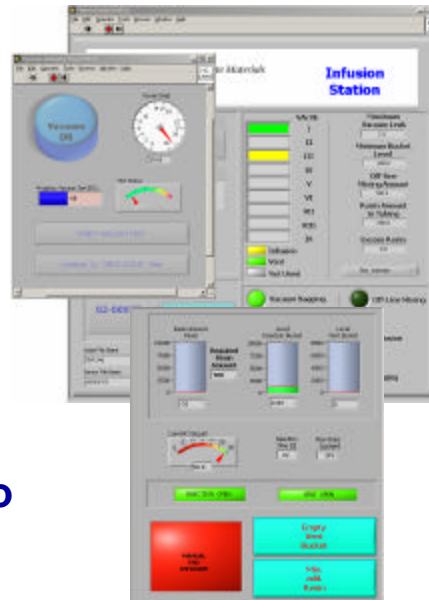
SMARTMolding Software Suite



Design Tool



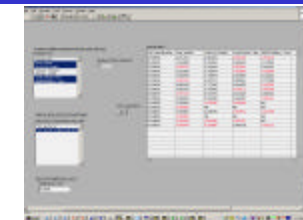
IPC System



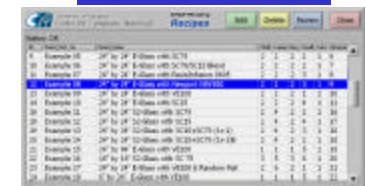
Data Review



Statistical Package



Recipe GUI



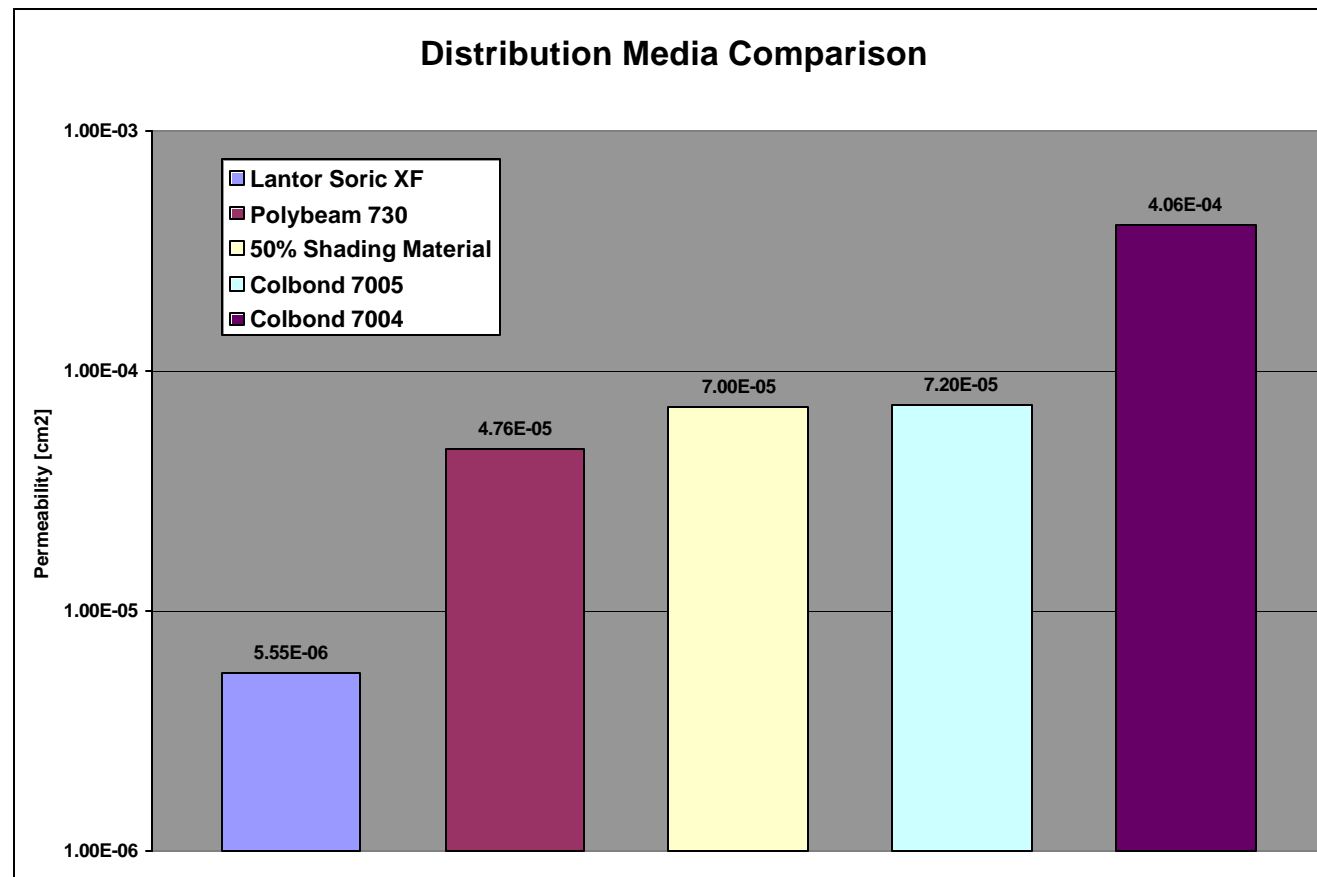
- Simple Interface, Limited to simple geometries
- Predicts Flow Times, Lead Length
- Optimizes # of Seq. Injection Lines
- Database with Material Properties

- Automates the VARTM Process
- Records the processing steps
- Reporting of collected data
- Enables statistical analysis
- Guidance Software to define process recipe

Added Permeability Data to Database of Commercially Available Distribution Media



Data Courtesy of Gaetan Denis



- Database includes now 5 Distribution Media (4 more in progress)
- Design tool chooses DM based on lead length and flow times

Recipe Definition GUI



➤ Supports Definition of

◆ Process Set Points

- ◆ Vacuum Leak Level
- ◆ Resin Volume
- ◆ Debulking
 - ◆ Cycles
 - ◆ Vacuum Level and Cycle Time
- ◆ Infusion Setup
 - ◆ Sensors
 - ◆ Valves
 - ◆ Sequential Injection Script
- ◆ Dwell Time and Dwell Vacuum level

◆ Material Selection

- ◆ Materials and Material Sequence during Lay-up
- ◆ Resin
- ◆ Bagging
- ◆ Mold

➤ Validates complete definition of recipe

➤ Review Recipe Definition

The screenshot displays the SMARTHolding Recipes interface. At the top, there are buttons for 'Edit', 'Delete', 'Review', and 'Close'. Below this is a table of existing recipes:

ID	Panel Part No	Panel Name	Mold	Layup	Req.	Dwell	Cure	Infusion
9	Example 05	24" by 24" E-Glass with SC79	2	2	2	2	1	6
10	Example 06	24" by 24" E-Glass with SC79/SC15 Blend	2	2	2	2	1	7
11	Example 07	24" by 24" E-Glass with ResinInfusion 0605	2	2	2	3	1	8
12	Example 08	24" by 24" E-Glass with Newport NBV850	2	2	2	3	1	9
13	Example 09	24" by 24" E-Glass with VE100	2	2	2	1	1	10
14	Example 10	24" by 24" E-Glass with SC15	2	2	2	4	1	11
16	Example 11	24" by 24" S2-Glass with SC79	2	4	2	2	1	16
18	Example 12	24" by 24" S2-Glass with SC15	2	4	2	4	1	17

Below the table is a 'New Recipe' dialog box with the following fields:

- ID: 10
- Panel Part No: Example 10
- Panel Name: 24" by 24" E-Glass with SC15
- Mold Class ID: 2
- Layup ID: 2
- Bag Class ID: 2
- Dwell ID: 4
- Cure ID: 11
- Infusion ID: 11

At the bottom, there is another table showing the current database:

ID	Panel Part No	Panel Name	Mold	Layup	Req.	Dwell	Cure	Infusion
11	Example 07	24" by 24" E-Glass with ResinInfusion 0605	2	2	2	3	1	8
12	Example 08	24" by 24" E-Glass with Newport NBV850	2	2	2	3	1	9
13	Example 09	24" by 24" E-Glass with VE100	2	2	2	1	1	10
14	Example 10	24" by 24" E-Glass with SC15	2	2	2	4	1	11
16	Example 11	24" by 24" S2-Glass with SC79	2	4	2	2	1	16
18	Example 12	24" by 24" S2-Glass with SC15	2	4	2	4	1	17
19	Example 13	24" by 24" S2-Glass with SC15+SC79 (1+1)	2	4	2	3	1	18
20	Example 14	24" by 24" S2-Glass with SC15+SC79 (1+1)B	2	4	2	2	1	18

New IPC Graphical User Interface Features 1/2

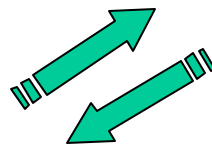
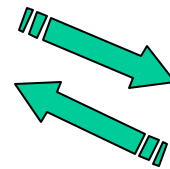
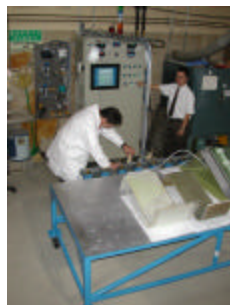


Intranet connectivity

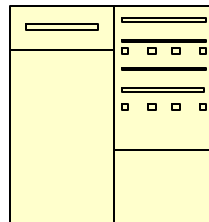
IPC 1



IPC 2

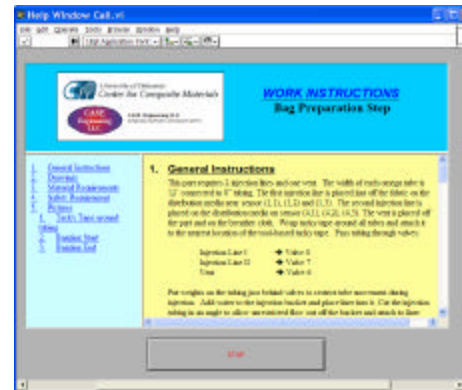


Server



- Automatic Backups
- Multiple IPC's can be connected

On-Line Work Instructions



- MSDS
- Pictures
- AutoCAD drawings
- Video

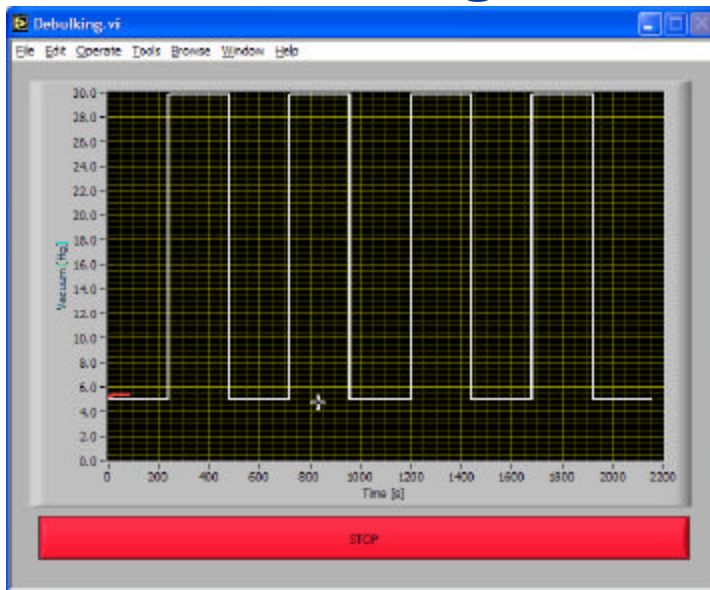
Virtual Checklist of all Processing Steps



New IPC Graphical User Interface Features 2/2

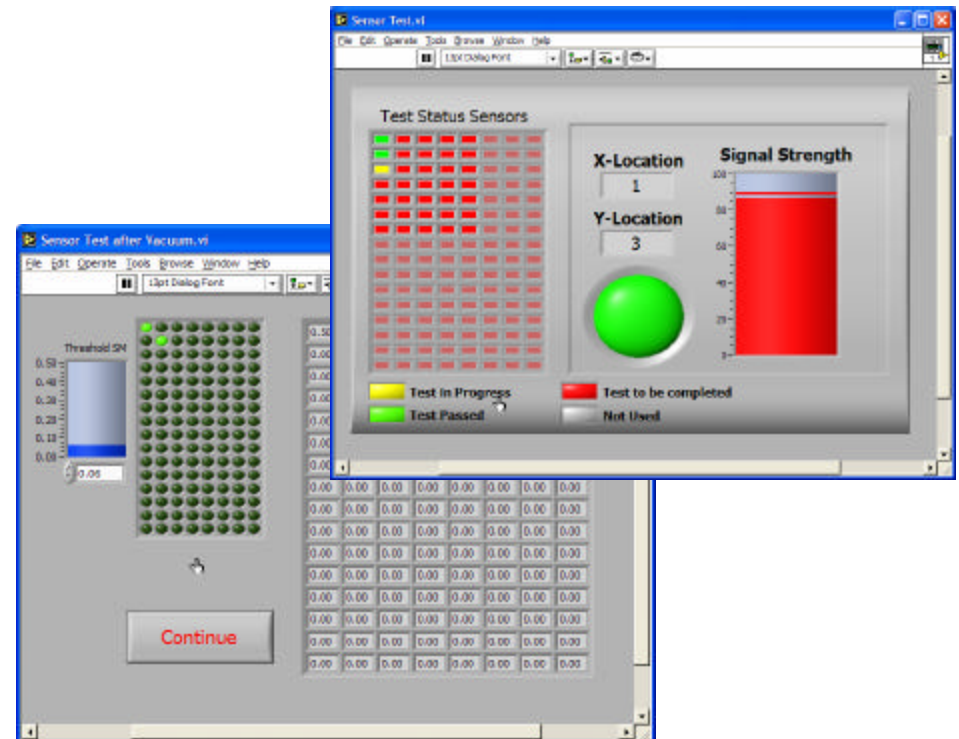


Automated Vacuum Debulking



- Automatic Debulking
- Improves repeatability and reduces preform thickness prior to infusion

Sensor Test GUI

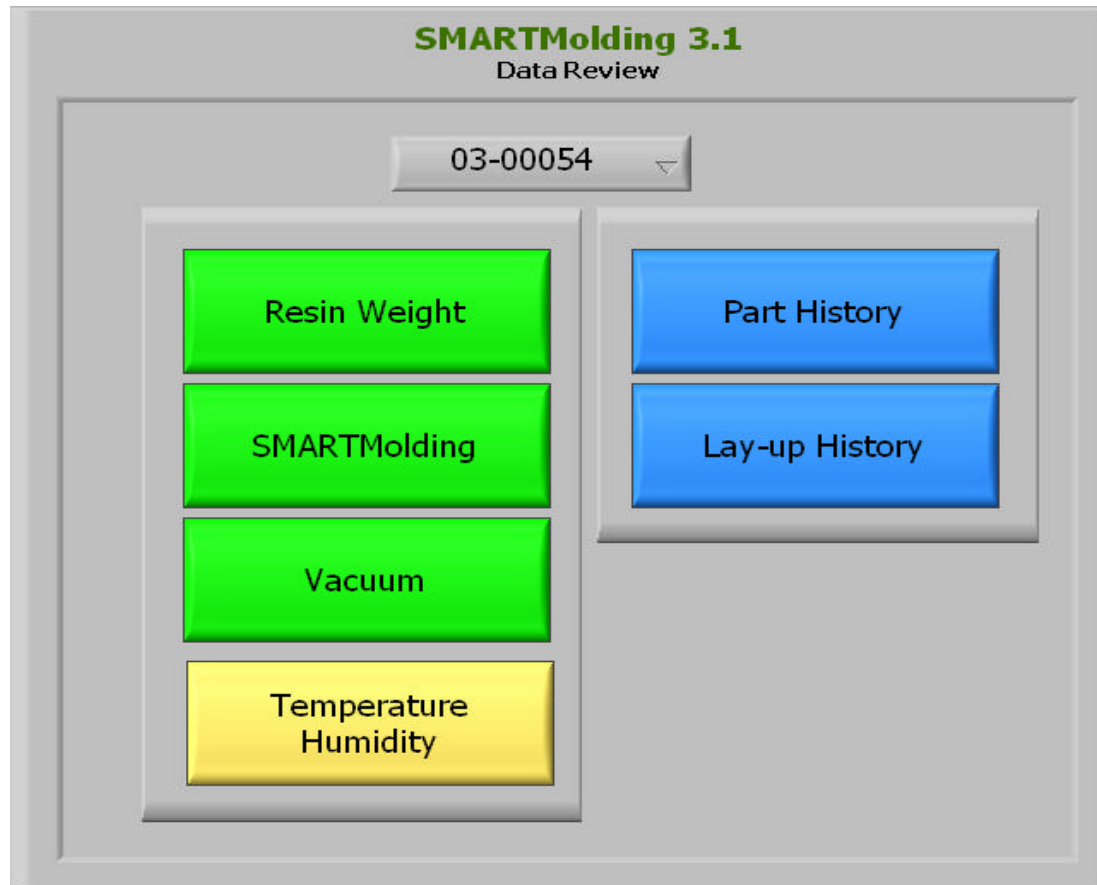


- Ensures sensor functionality
- Adjust resin arrival threshold for different resin systems

Data Review Graphical User Interface



DEMONSTRATION



Repeatability Analyses of the VARTM Process



- **PhD student is establishing theoretical and experimental understanding of VARTM repeatability → see presentation of Amoroux**
- **Boeing Corporation is supporting the VARTM repeatability project**
 - ◆ **Information will be provided from the AST Wing and CAI program**
 - ◆ **POC Boeing: Scott Holmes**
V-22 Affordability
Integrated Defense Systems, PHL

Statistical Analysis Package



Objective

- ◆ Flag outliers based on process parameter values and reduce number of post-inspections
- ◆ Rank parameters based on their repeatability
- ◆ Identify parameters that relate to quality of part
- ◆ Detect quality based on parameter values

Approach

- ◆ Iterative statistical detection scheme for outliers
- ◆ Repeatability measure to rank parameters,

Data Analysis: Fiber Weight



➤ Discrete vs. Continuous

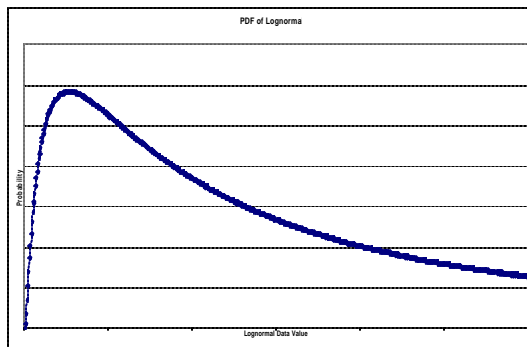
- ◆ Discrete parameters have one value per part, Ex. Fiber Weight
- ◆ Continuous parameters are time-dependent, Ex. Resin Weight Infused vs. Time

➤ Lognormal Distribution

- ◆ Assuming Lognormal distribution for process parameters (When RV X is lognormally distributed, then $\ln(X)$ is normally distributed.)

➤ Lognormal Validation

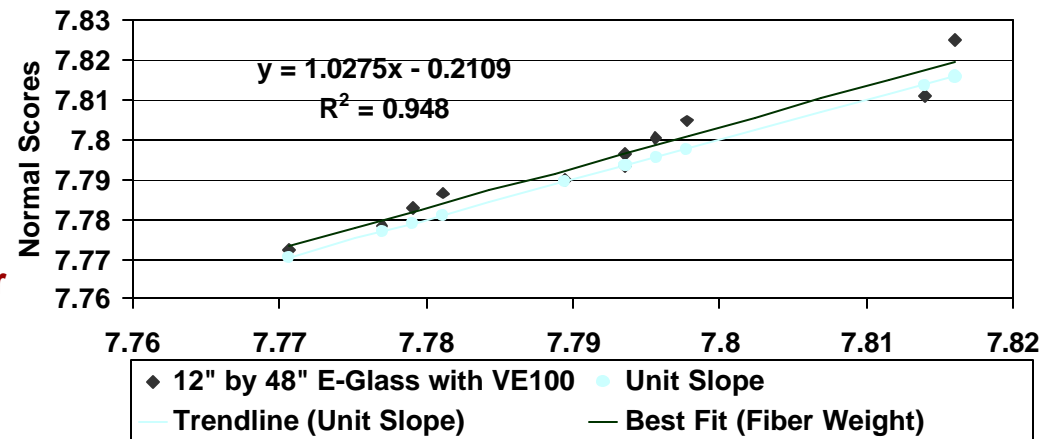
➤ Outlier Detection based on Probability Level



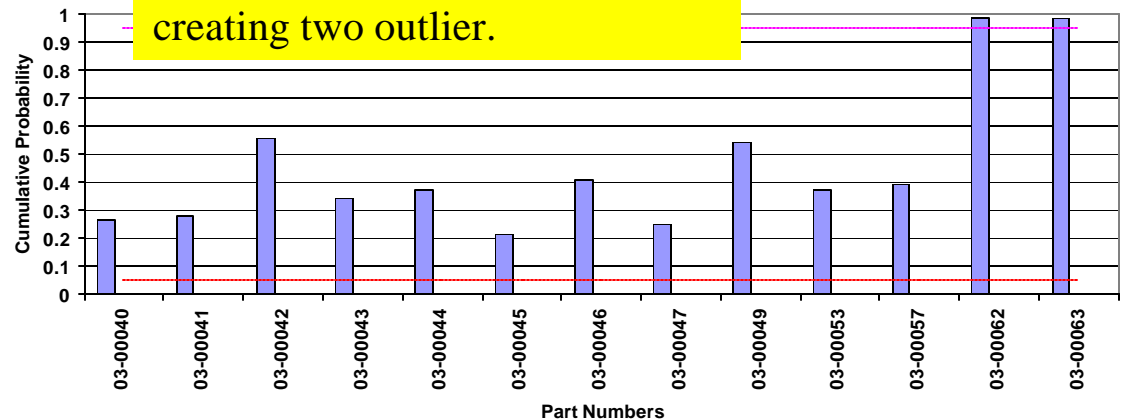
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Lognormal Distribution fits the Fiber Weight Data

Normal Scores vs. Sorted Data Values for Fiber Weight



Additional Layer was added to part 03-00062 and 03-00063 creating two outlier.



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Wireless Sensor Network

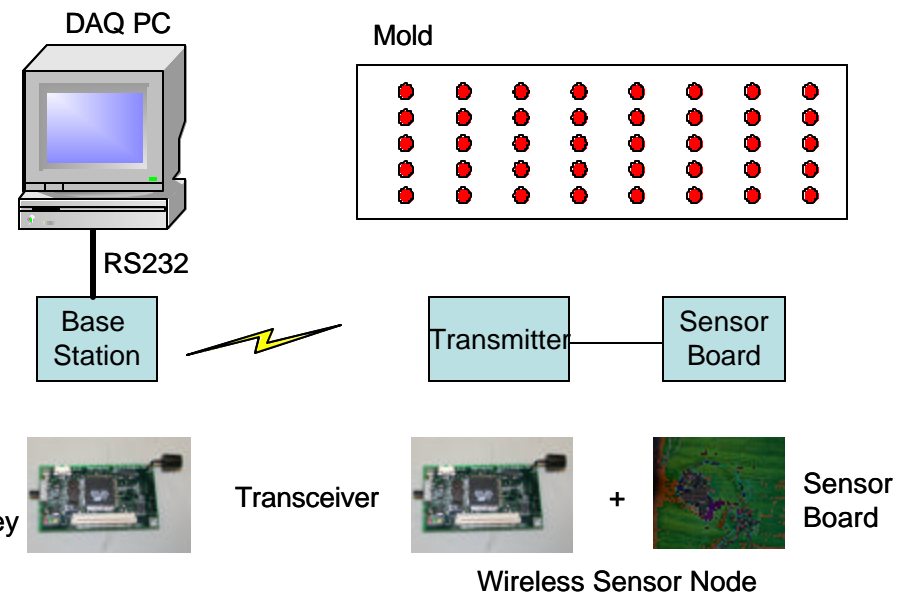


Objective:

- Reduce noise due to wiring
- Allow seamless switching of molds without connecting/disconnecting sensor cables

Approach:

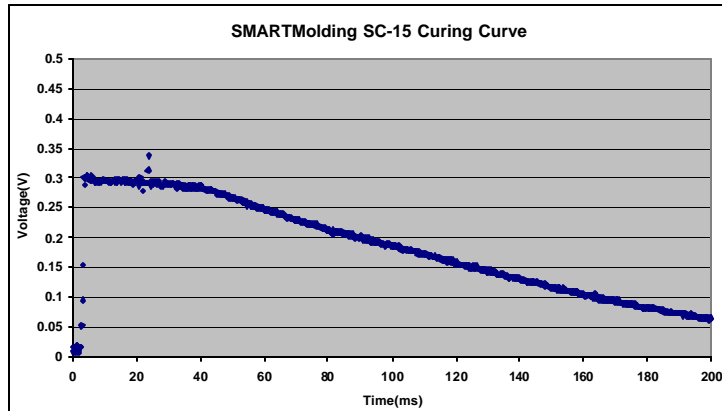
- Using existing wireless sensor network technology
- Develop custom DAQ to connect locally to transmitter
 - ◆ DC-based flow measurement
 - ◆ Other sensors such as temperature and humidity sensor
- Wireless sensor network technology replaces multiplexing technology
- Sensor signal quality is improved due to a reduction in cross-talking and cable noise
- Simple plug & play reduces the setup time. System can be reduced if mold is scrapped



Improved Signal to Noise Ratio 5:1

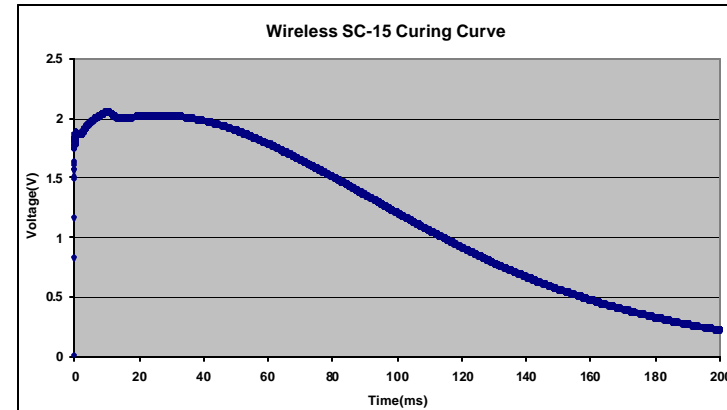


Existing SMARTMolding System

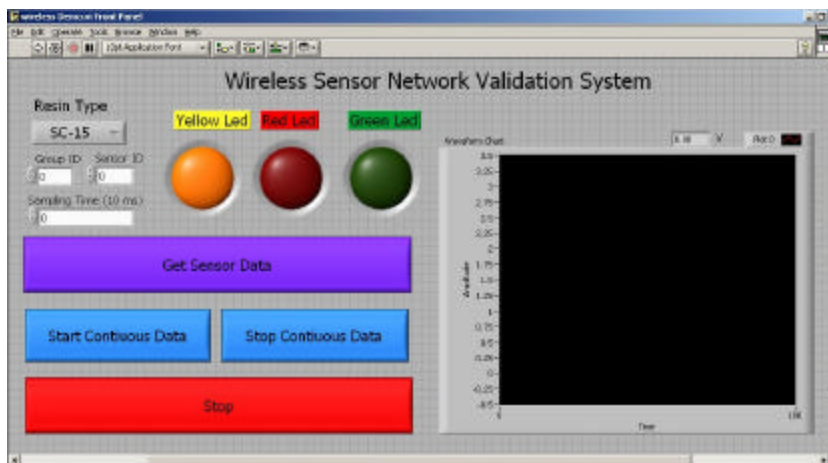


$$SNR=10*\log(0.3/0.01)=4.7db$$

Wireless Single Sensor



$$SNR=10*\log(2.02/0.01)=23.05 db$$



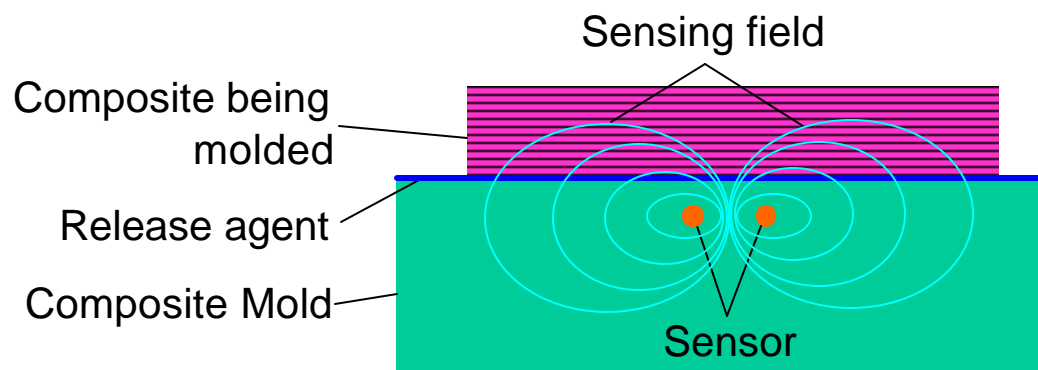
Demonstration!!!

Tool-Embedded TDR Sensing

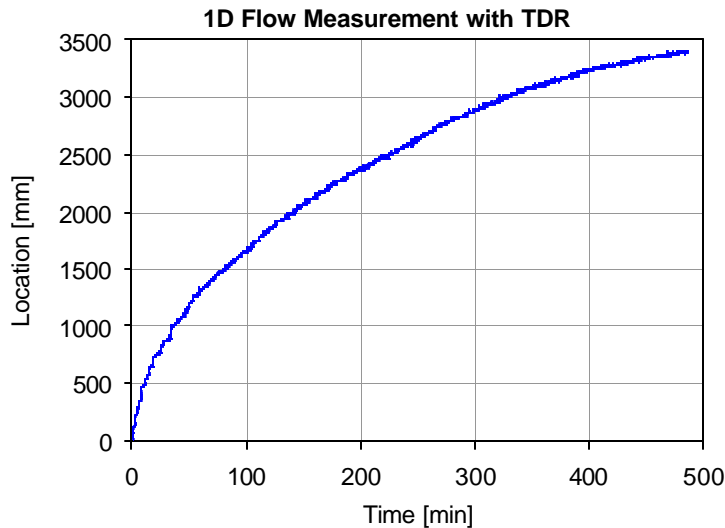


Technology benefits:

- ✓ Non-contact sensing;
- ✓ Sensing through release agent and gel coat;
- ✓ No post service required;
- ✓ Low cost manufacturing;
- ✓ Application for non-conductive polymer based tools with various curvatures.



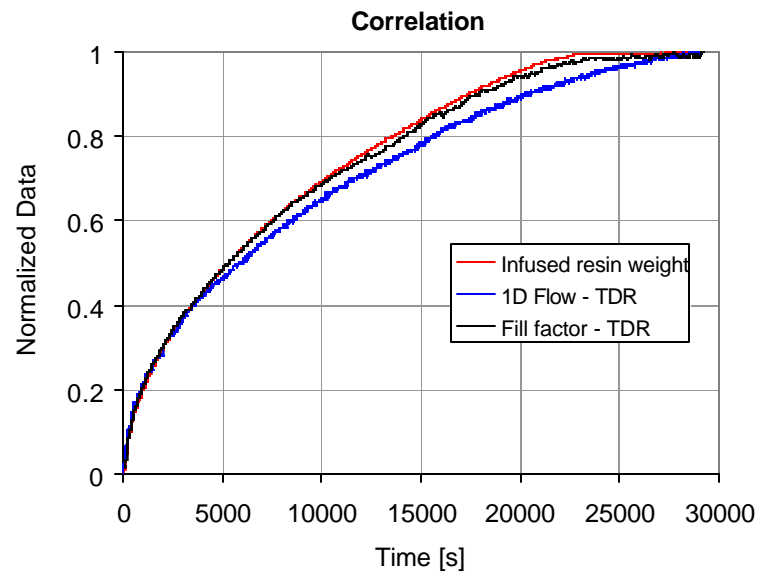
5m Tall Structure Infusion



- ✓ Tool embedded TDR sensing has been tested during vertical infusion;
- ✓ TDR sensor response fits infused resin weight data very well.

✓ 1D TDR Flow data shows flow progression after fill factor shows no response

✓ The resin cures in bucket faster and stops injection in the preform



Summary



- **New VARTM processes create opportunity for on-line control**
- **Additions to IPC software creates new capabilities (debulking) and adds to industrial requirements (work instructions, intranet capable)**
- **Major advances have been implemented to create user-friendly SMARTMolding environment**
 - ◆ **Recipe Definition**
 - ◆ **Data Review**
- **Data mining software components have been implemented to review automatically large amount of data collected and to detect processing outliers**
- **New sensor hardware shows promise for industrial environment**
 - ◆ **Reduced wire count**
 - ◆ **Tool-Mounted TDR allows monitoring through gel coat**