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# **SLIC**

# **SIMULATION-BASED LIQUID**

# **INJECTION CONTROL**

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***Kuang-Ting Hsiao***

**UD-CCM • 1 July 2003**

## Report Documentation Page

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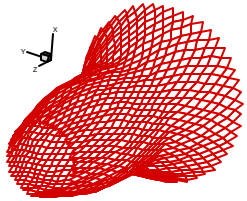
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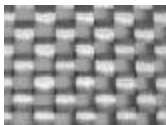
# Simulation-based Liquid Injection Control: Philosophy



**Mesh**

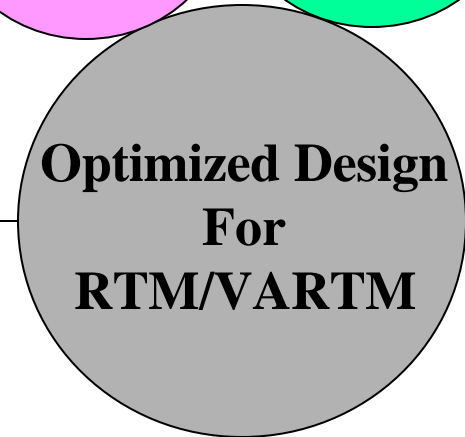
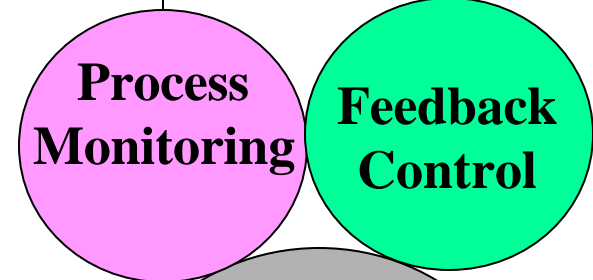
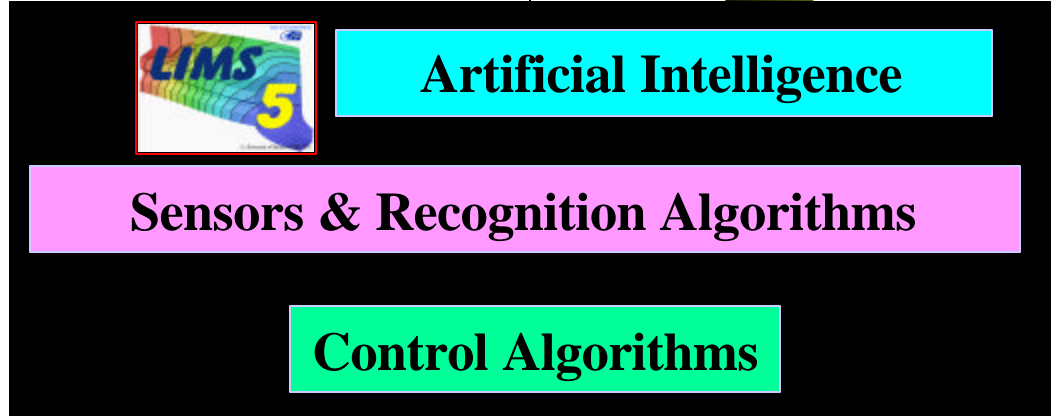
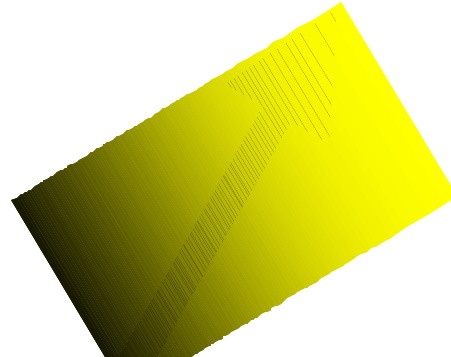
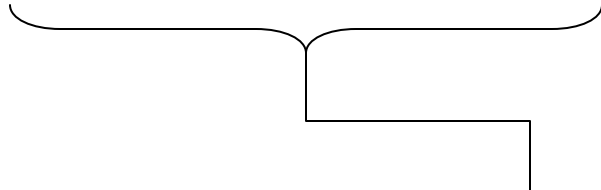


**Resin Viscosity**

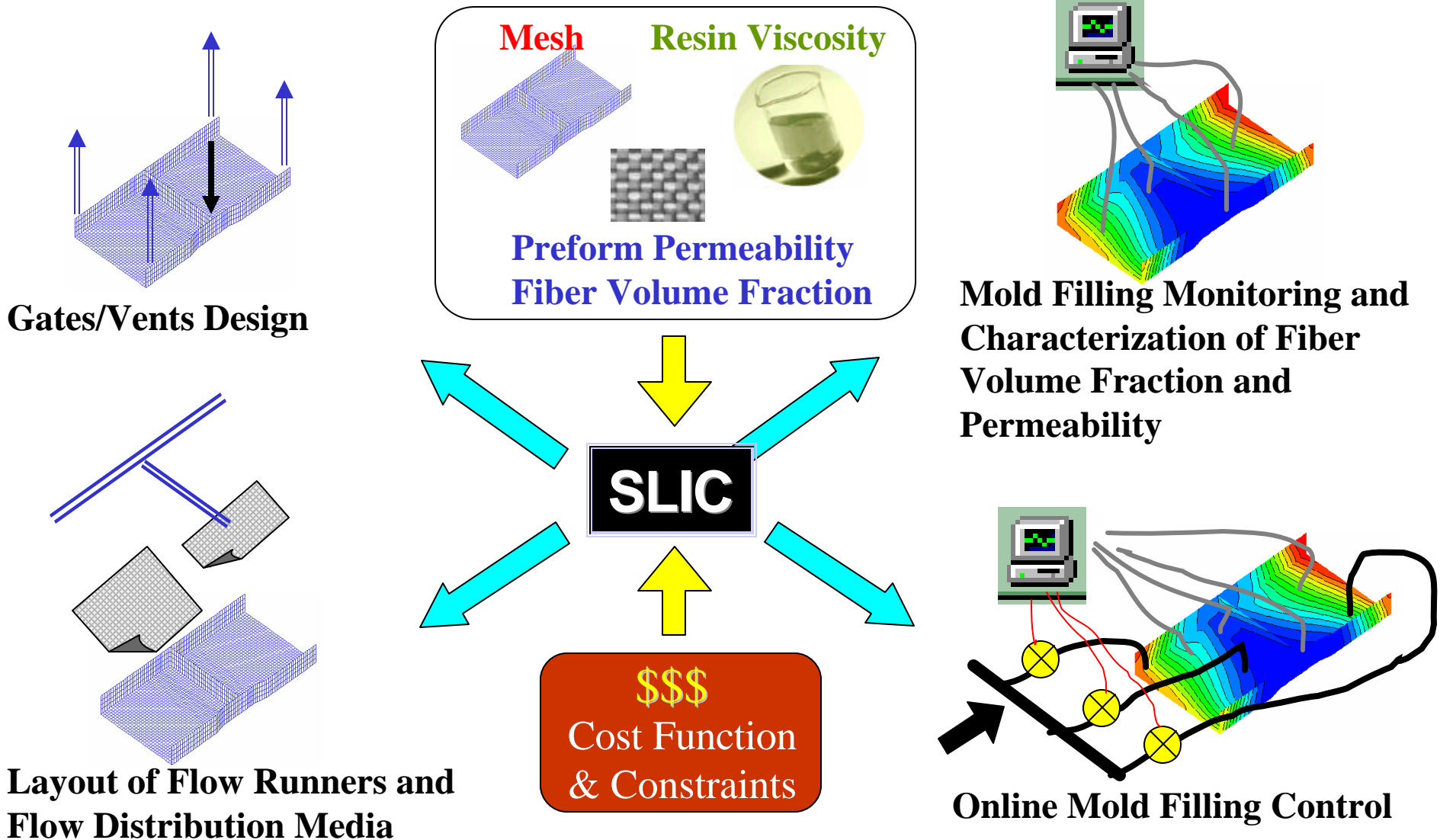


**SLIC**

**Preform Permeability  
Fiber Volume Fraction**



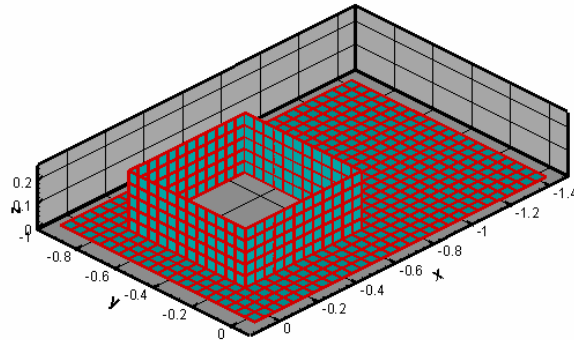
# Features of SLIC



# Case 1: Optimize Gate & Vent Locations



## Input



Length=1.50m  
Width=1.00m  
Height=0.20m

Thickness = 0.01m  
 $K_{xx} = K_{yy} = 1E-10 \text{ m}^2$   
 $V_f=0.5$

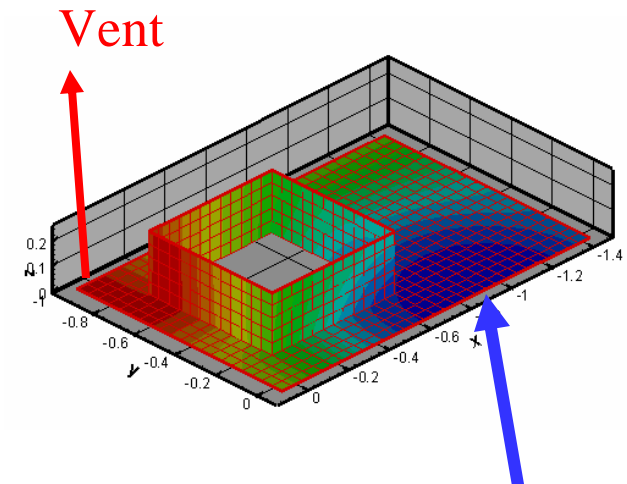
Resin Viscosity = 0.12 Pa-sec = 120 cps

Injection Pressure =  $3.03E+5 \text{ Pa}$   
Vent Pressure =  $1.01E+5 \text{ Pa}$

## Cost Function

**SLIC**

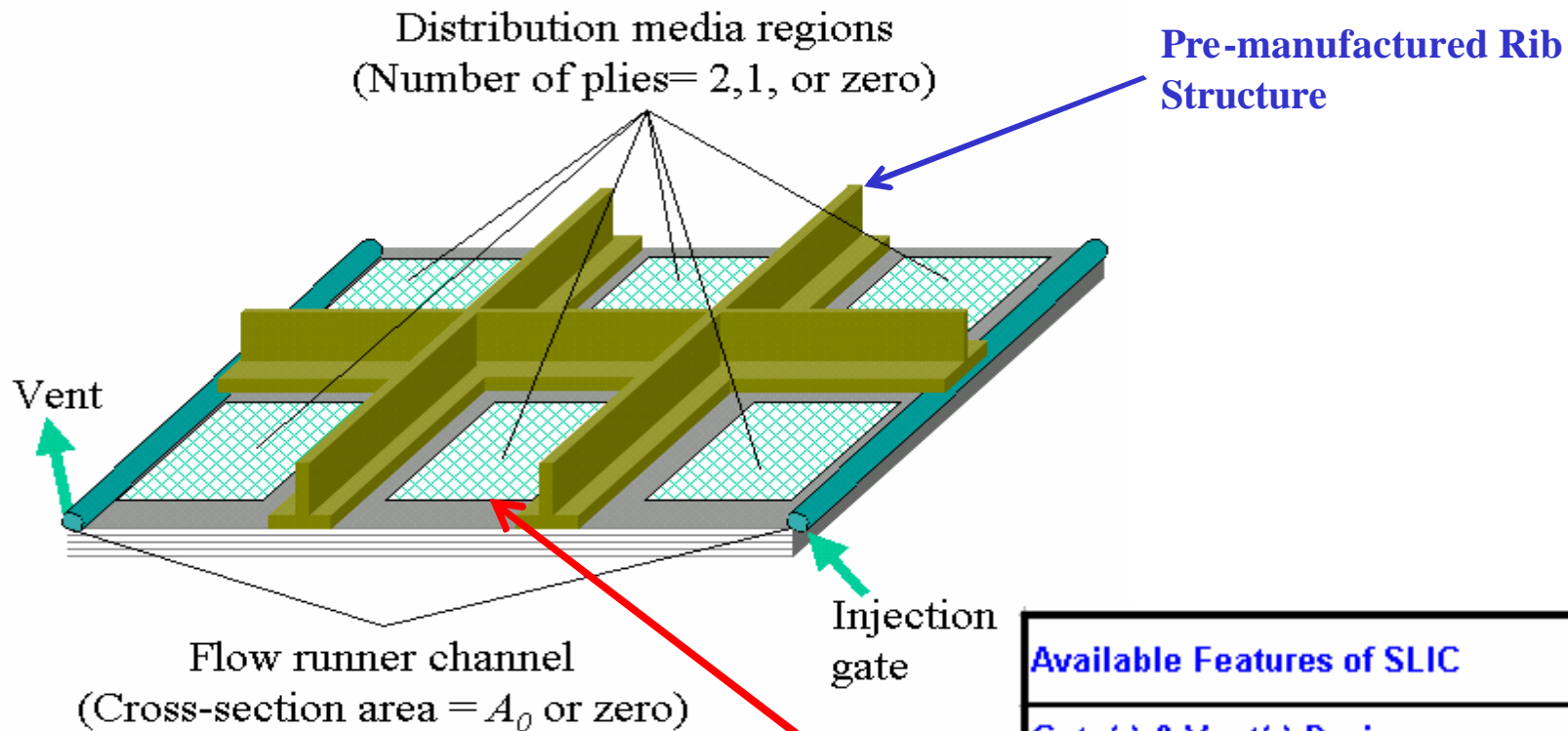
## Optimized Mold Filling



Injection Gate

Available Features of SLIC	Features Used
Gate(s) & Vent(s) Design	x
Flow Distribution Network Design	
Mold Filling Monitoring & Online Characterization of Permeability/Volume Fraction	
Online Mold Filling Flow Control	

# Case 2: A VARTM/Co-Cure Case Study

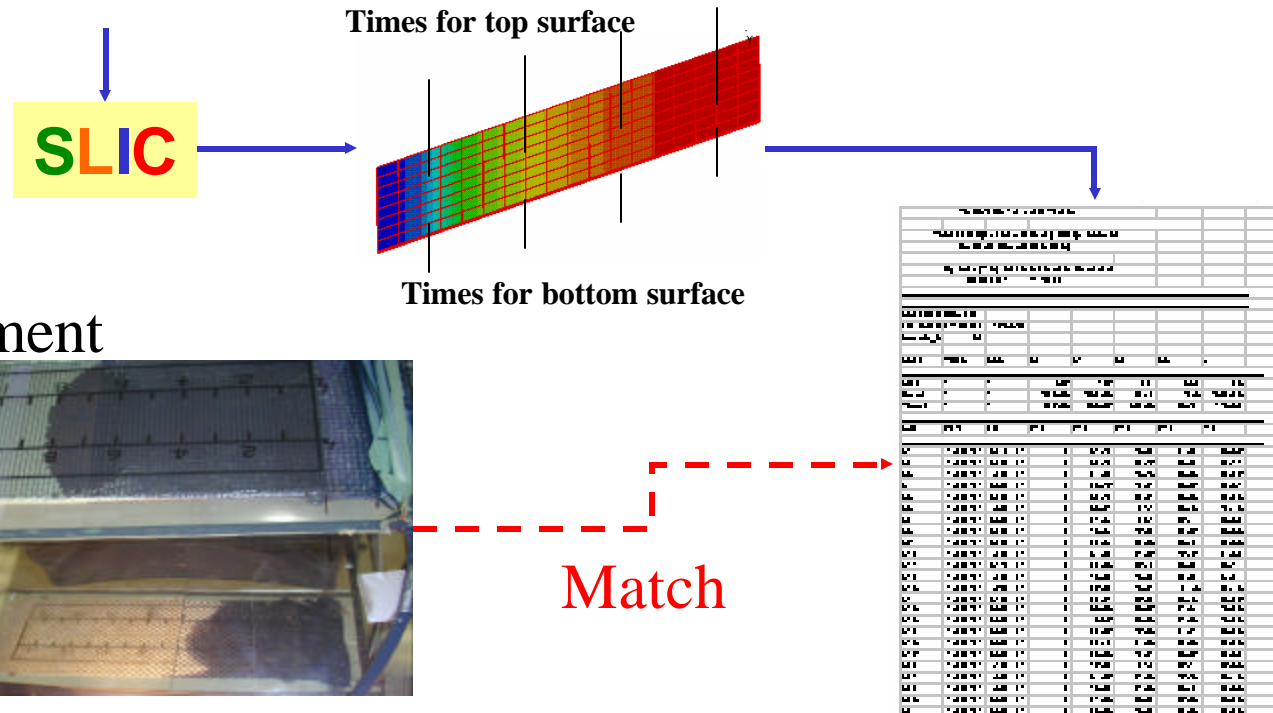
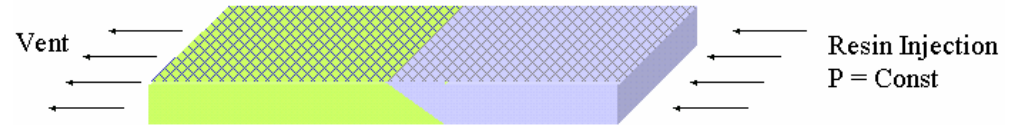


Available Features of SLIC	Features Used
Gate(s) & Vent(s) Design	
Flow Distribution Network Design	x
Mold Filling Monitoring & Online Characterization of Permeability/Volume Fraction	x
Online Mold Filling Flow Control	

# Distribution Layer Permeability Measurement with SLIC (Case 2)

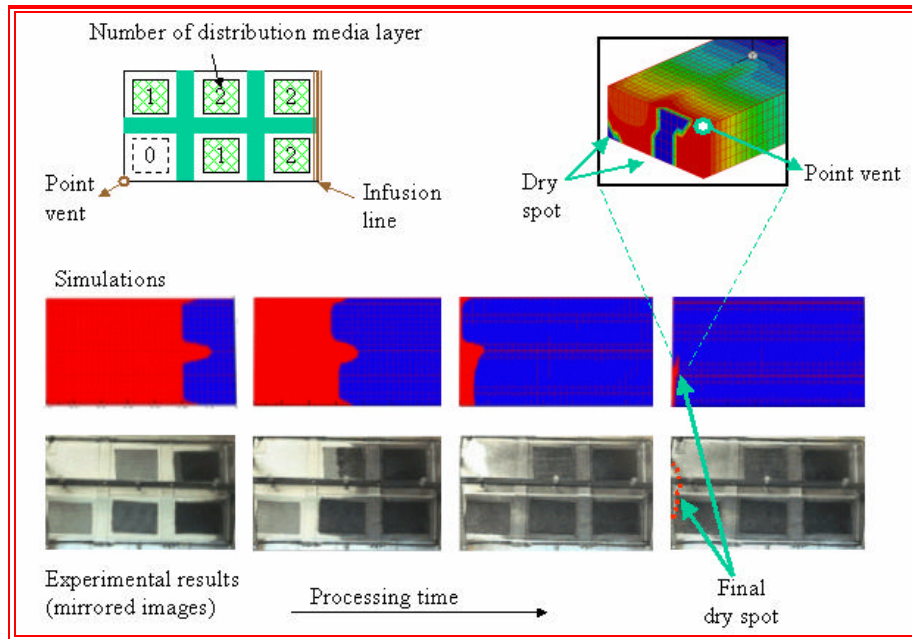


Permeability ratio of the distribution layer and the preform is assumed as 5, 10, 15,...,150.

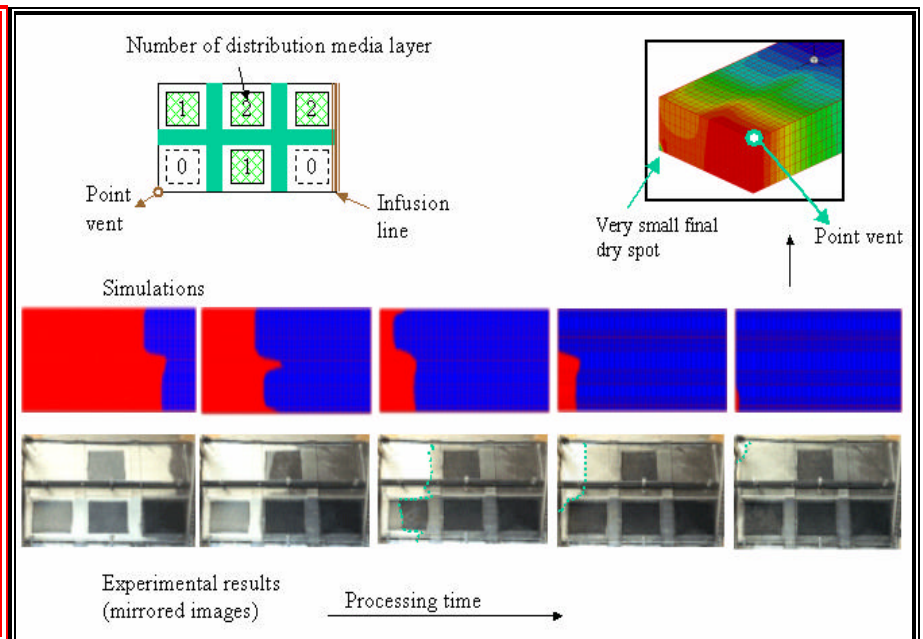


12 Experiments were conducted, the permeability ratio was obtained as 20-40.

# Intuitive (Trial-And-Error) Design vs. SLIC's Design (Case 2)



Final (fourth) intuitive design



SLIC's design

	Dry spot content	Fill time	Number of experiments
Trial-and-error intuitive design	0.851%	10.87 min	4
GA/simulation-based design (SLIC)	0.034%	13.05 min	1

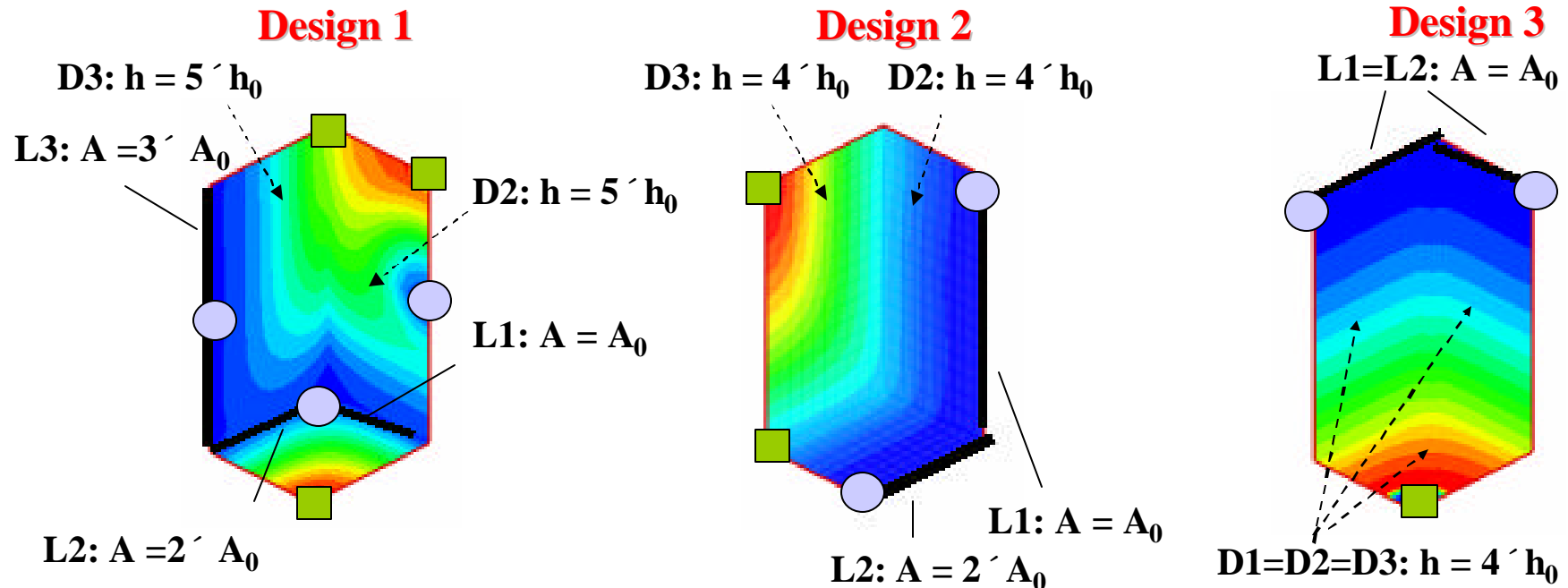
# Case 3: A VARTM Case Study



○ Gate  
 ■ Vent

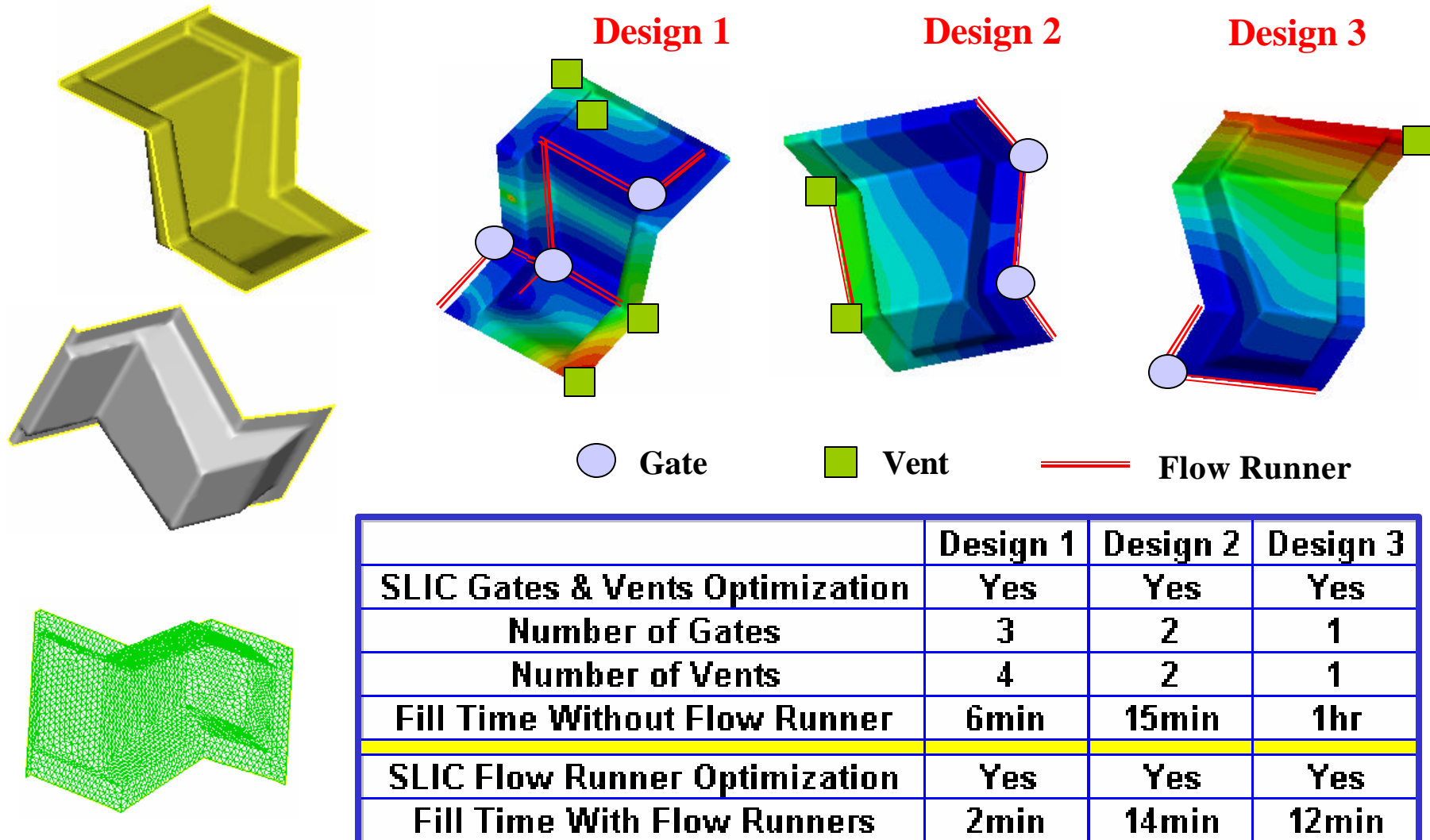
D: Distribution Media  
 L: Flow Runner

$h_0$ : Thickness of 1-ply distribution media  
 $A_0$ : Cross-section Area of reference Flow Runner



	Design 1	Design 2	Design 3
SLIC Gates/Vents Optimization	Yes	No	No
SLIC Flow Distribution Network Optimization	Yes	Yes	No
Fill Time	28min	1hr 08min	1hr 38 min
Number of Empty Nodes/Number of Nodes	0/948	0/948	4/948

# Case 4: Steps on a Boat Deck (VARTM with Flow Runners)



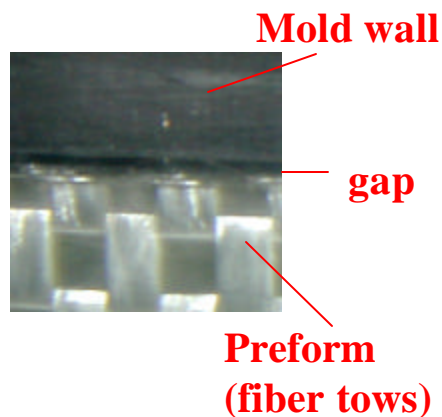
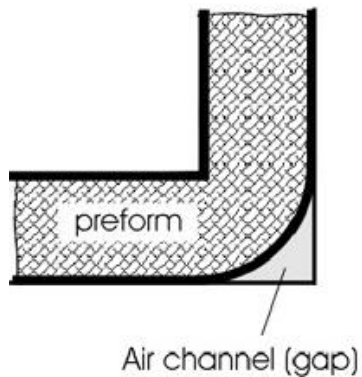
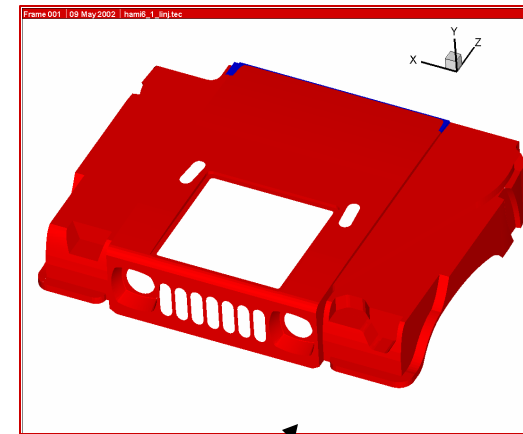
# Permeability Variation in Process



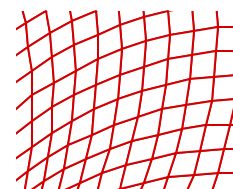
- ✓ • Injection Pressure/Port
- ✓ • Vent Pressure/Port
- ✓ • Resin Viscosity
- ? • Fiber Volume Fraction
- ? • Permeability of the the Preform

Characterization Challenges !

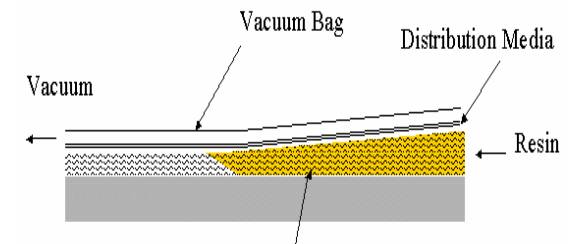
LIMS



Deformed fabric Draping over a tool surface

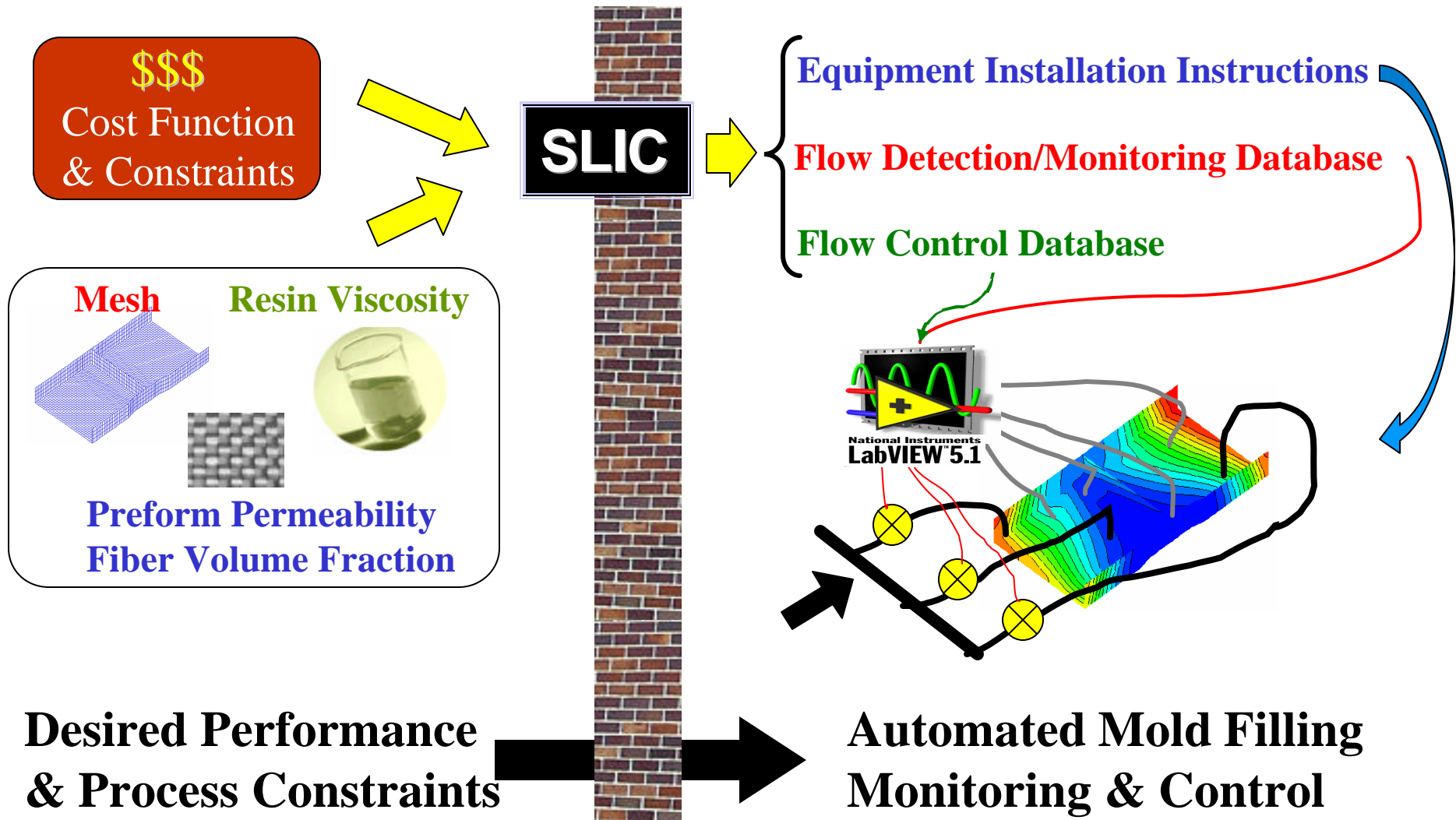


$K$  and  $V_f$  change

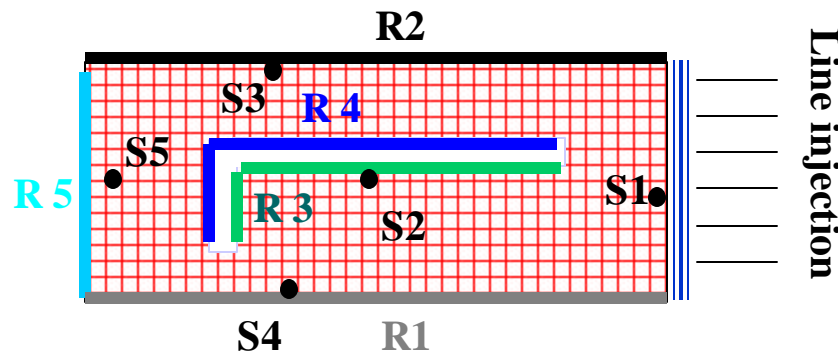


$K$  and  $V_f$  Change due to the Compaction Variation in VARTM

# Streamlined Flow Monitoring & Control - From Design To Automation

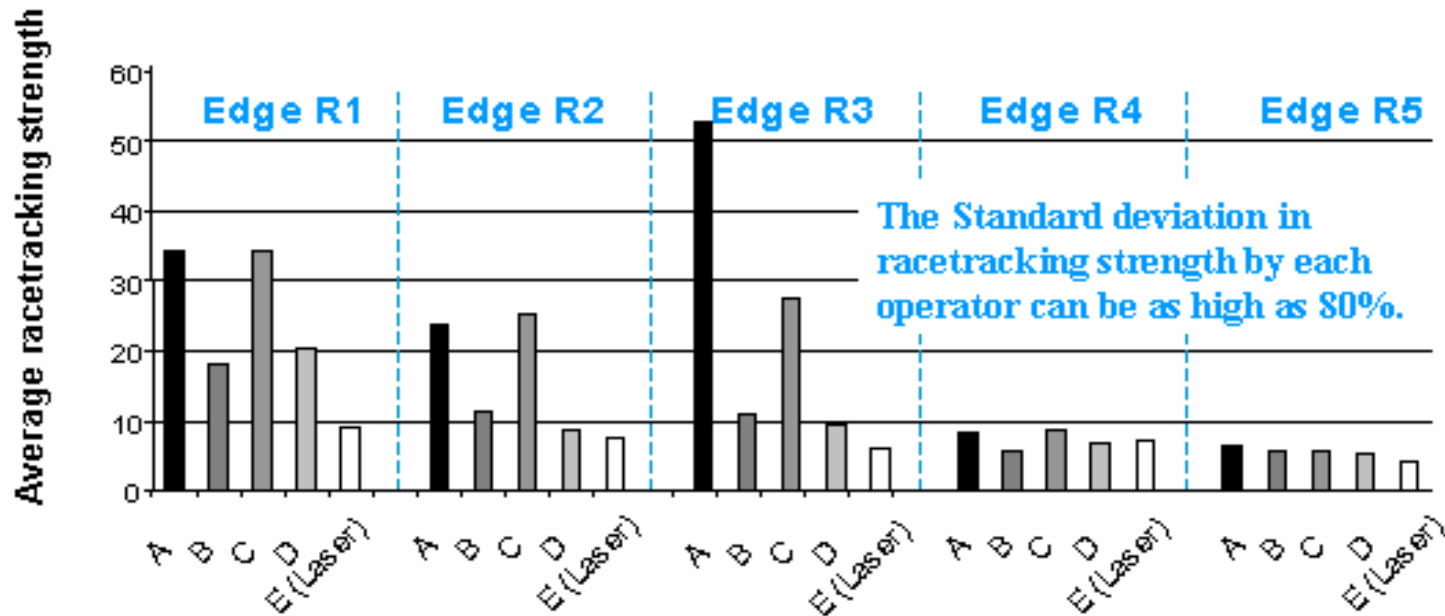


# Case 5: Using SLIC to Characterize the Racetracking (Edge Effect)

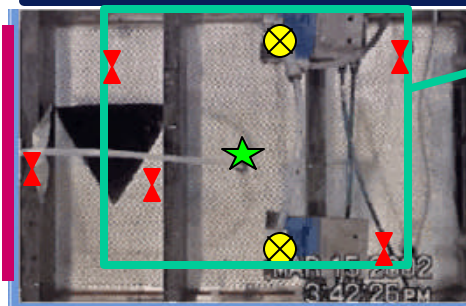


Available Features of SLIC	Features Used
Gate(s) & Vent(s) Design	
Flow Distribution Network Design	
Mold Filling Monitoring & Online Characterization of Permeability/Volume Fraction	x
Online Mold Filling Flow Control	

Five different operators A, B, C, D and E run 10 experiments each. A, B, C and D cut the fabrics by hands, E used a laser cutter.

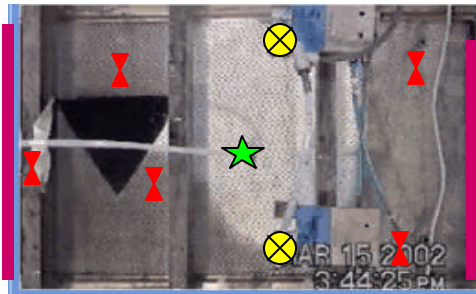


# Case 6: Online Flow Monitoring & Control with SLIC



Tekscan™ Sensor Area (Pressure Grid Film)

Available Features of SLIC	Features Used
Gate(s) & Vent(s) Design	
Flow Distribution Network Design	
Mold Filling Monitoring & Online Characterization of Permeability/Volume Fraction	x
Online Mold Filling Flow Control	x



Experimental resin arrival times  $t_0, t_1, t_2, t_3, t_4$  are all collected

Disturbance Mode 29 is selected from the Database

Implement the customized control action for Mode 29

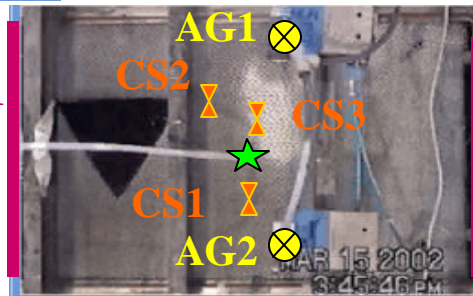
Initial injection gate (IG) with flow runner

Fixed vent

Auxiliary gate (AG)

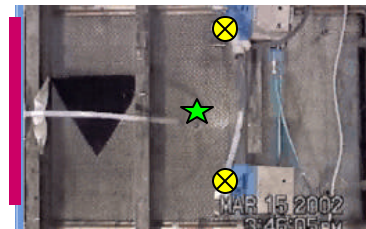
Disturbance detection sensor (DS)

Control action trigger sensor (CS)



Control action Mode 29 is taking place.

- CS1 >>> Close IG2
- CS2 >>> Open AG1
- CS3 >>> Close IG1
- Vent Sensor >>> Close All Gates.



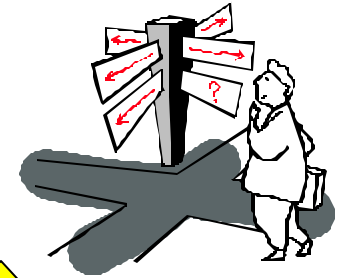
Successful injection



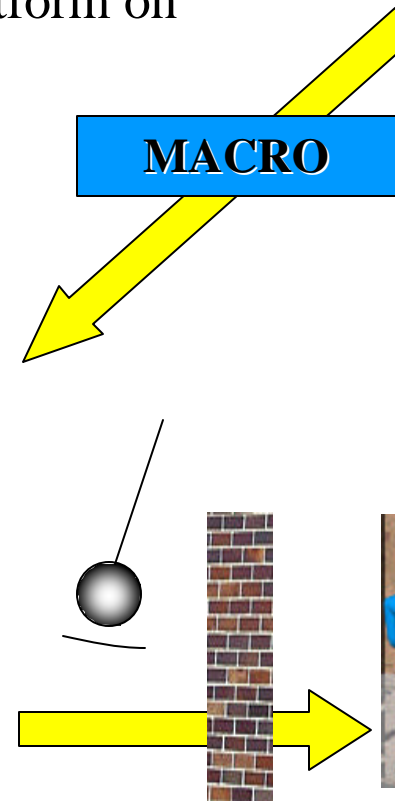
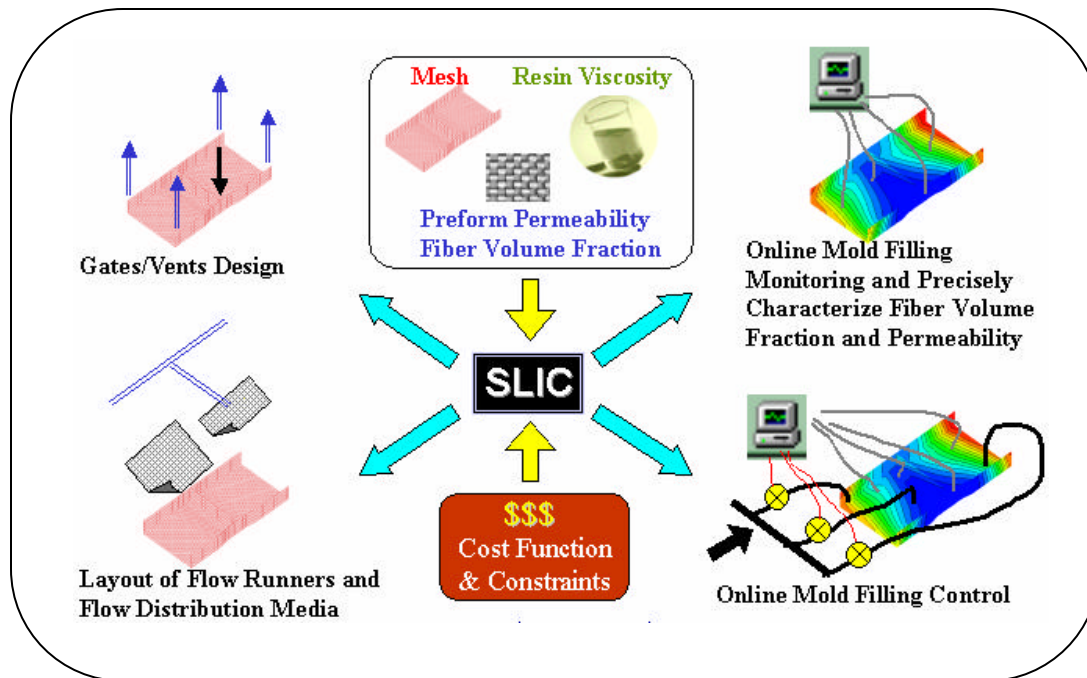
# Efforts Towards User-Friendly Software



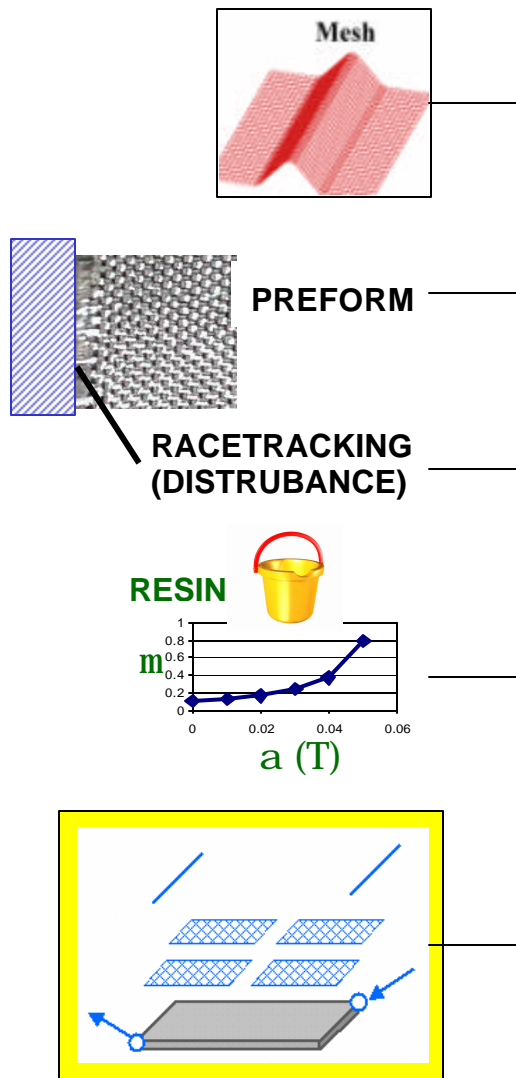
- Develop the MACRO feature which allows SLIC to be run by MACROS (either Defaulted or User Specified).
- Seamless interface with Automated RTM Platform on manufacturing floor.



Instruction 1  
 Instruction 2  
 Instruction 3  
 Instruction 4  
 Instruction 5  
 etc.



# Summary



## SLIC

### AUTOMATED DESIGN

- Selection of Initial Gate and Vent Locations
- Optimization of the Flow Distribution Network
- Online Flow Sensing/Permeability Characterization System Design
- Creation of Online Flow Control Solution

### Advantages of developing RTM/VARTM with SLIC

- Rapid design for RTM/VARTM.
- Less cost for process development.
- Reliable and comprehensive mold filling solution.
- Advanced flow monitoring/control technology provides the opportunity to elevate the part quality and reduce the cycle time.

# Future Work



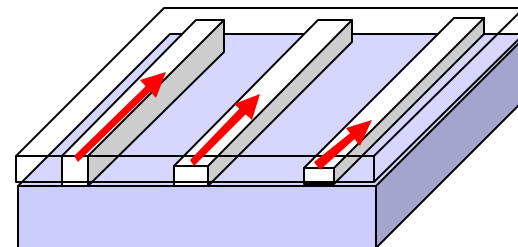
## Graphic User Interface (GUI)

### Documentation

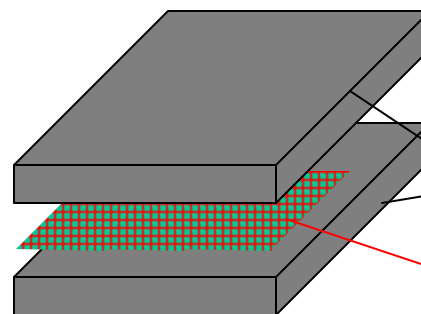
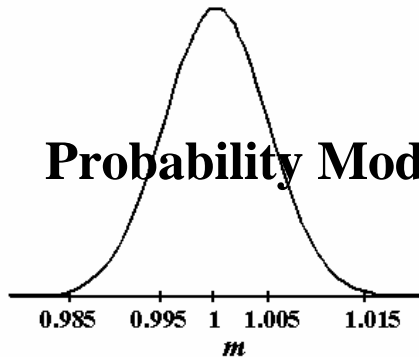
- User Manual
- Examples
- Tutorials

**SLIC**

**More Available Macros  
for Users to Choose from**



### Probability Model



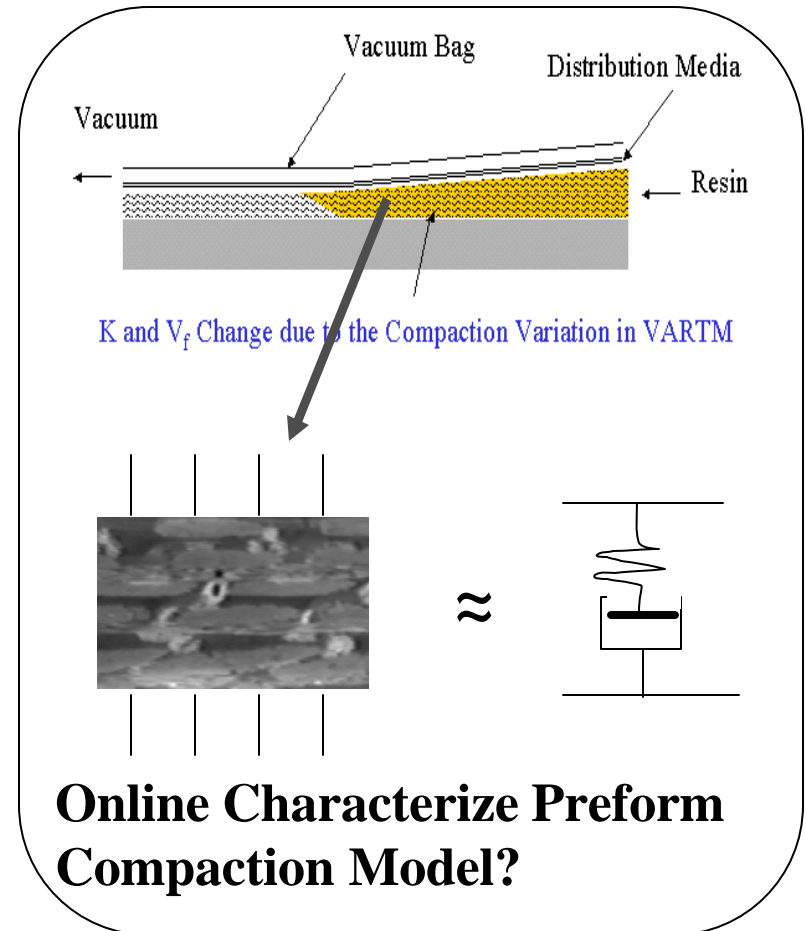
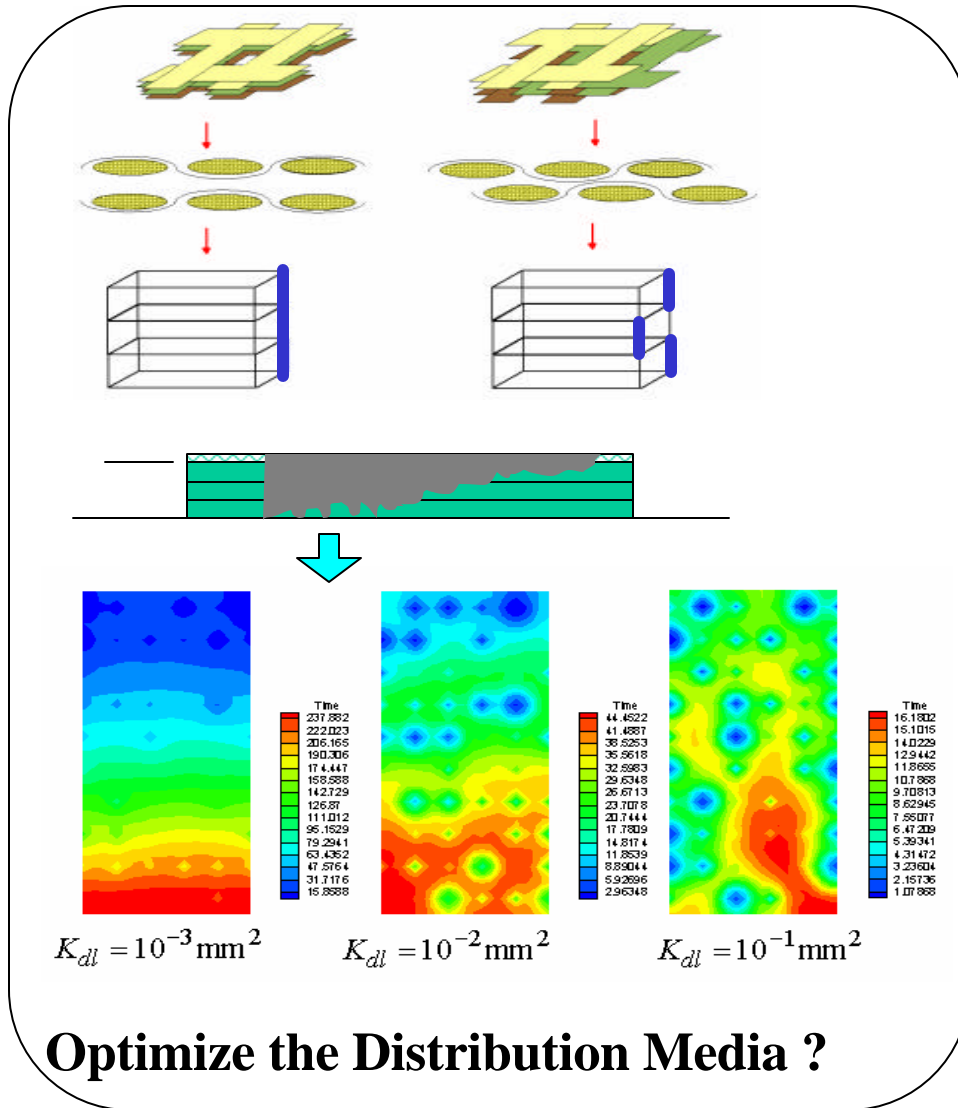
Preform

Distribution Media

**FASTRAC  
Flow Control in VARTM**

**RTM Light Optimization**

# Future Work



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# Acknowledgements

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