Research Directions in Simulation Moldflow

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Class summary

This class will review new functionality in Simulation Moldflow Insight software and discuss current research directions in the development of Simulation Moldflow software.

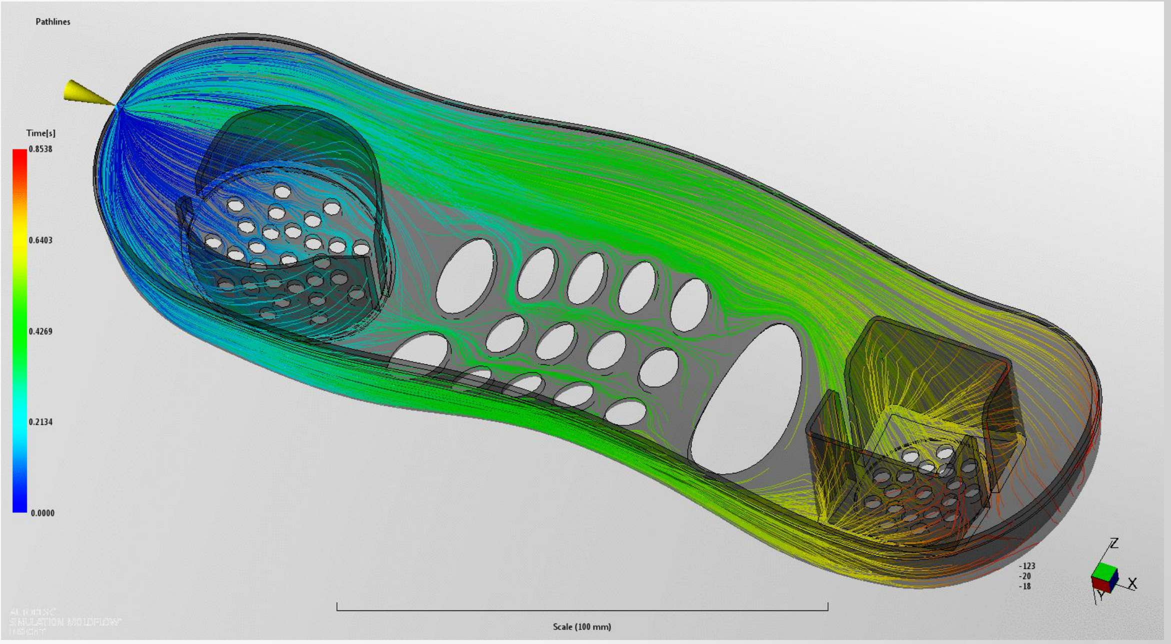
Key learning objectives

At the end of this class, you will be able to:

- Examining the polymer particle history during injection
- Understand how to model non-standard viscosity behavior
- Anticipate the new functionality in the Moldflow Insight Beta
- Choose the right technology for performing microcellular foaming simulation

Agenda

- 2015 Scandium Technology Preview
- Moldflow Insight 2016 Beta
- Some API Tools
- Long Term Research Collaborations



Disclaimer

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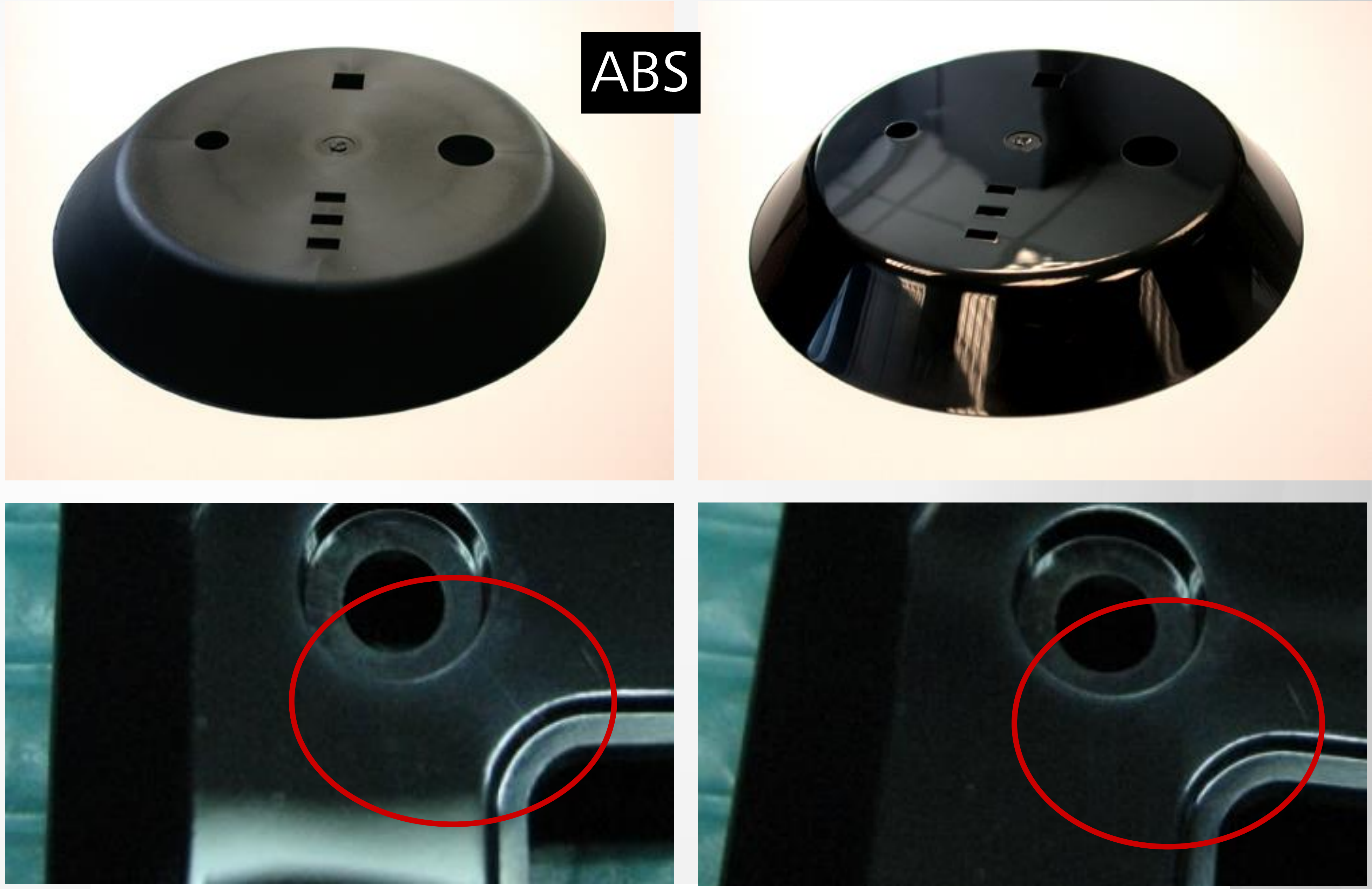
The Company assumes no obligation to update these forward-looking statements to reflect events that occur or circumstances that exist or change after the date on which they were made.

Rapid Temperature Cycling

(RTC ®) / RHCM® / Variotherm ®

- **Heat Mold for Filling**
  - Eliminate visible weld-lines
  - Increase flow length
  - High (uniform) gloss finish
  - Eliminate Gate Marks (Cold slugs)
  - Typically only the cavity side is heated
- Heat by: Steam, Water, Electrical or Induction
- **Cool Mold during Packing**
  - Reduce cycle time

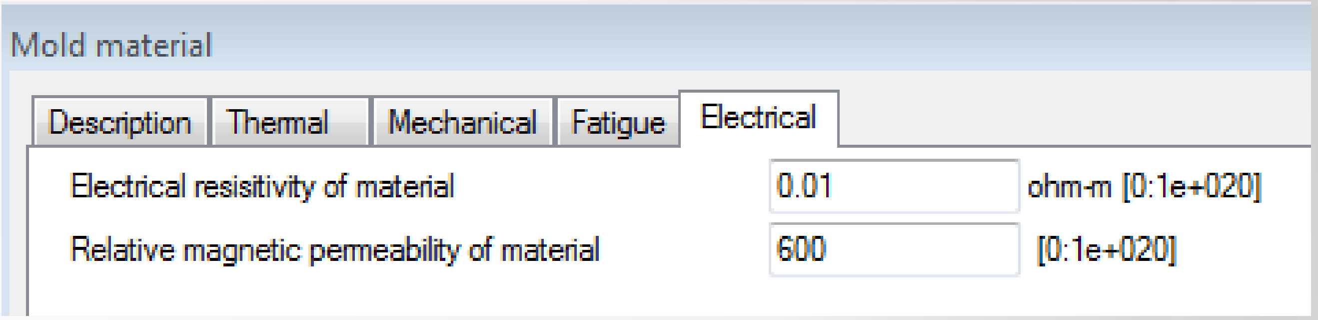
Conventional Molding | With RTC

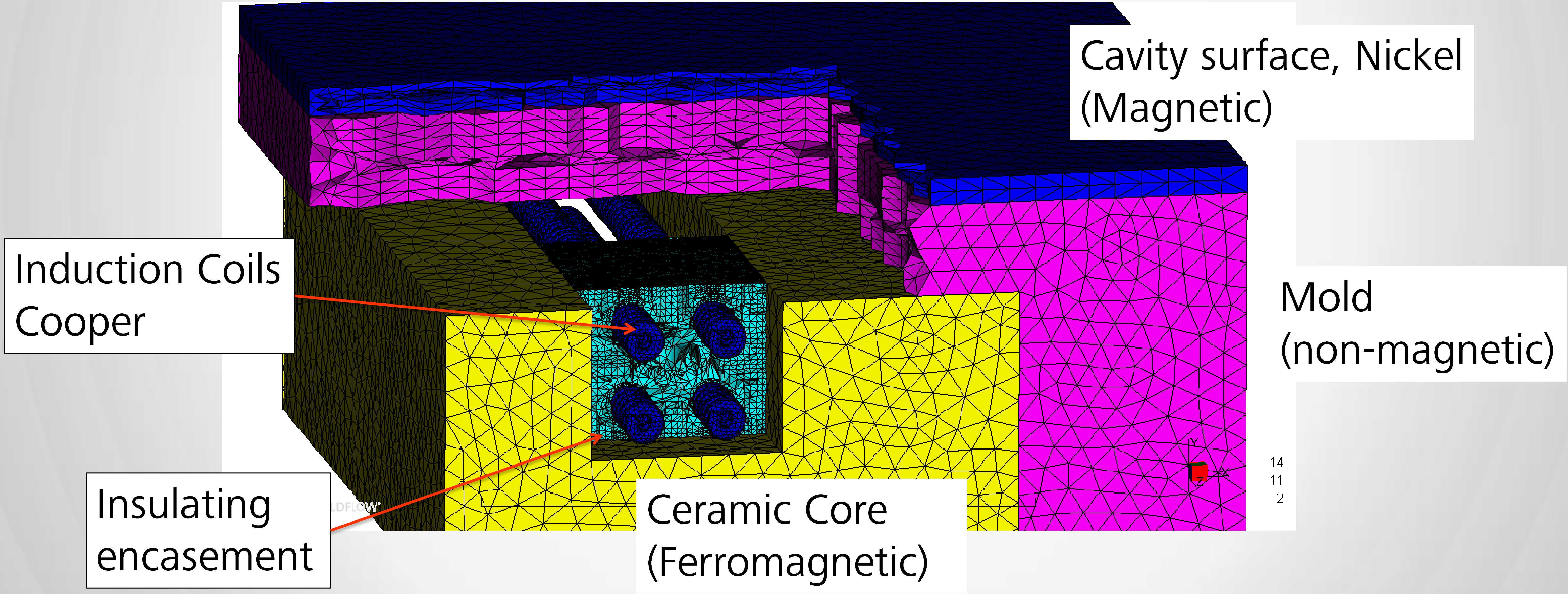


Images courtesy of GasInjection World Wide

Induction Heating for Cool (FEM)

- Modeling mold components

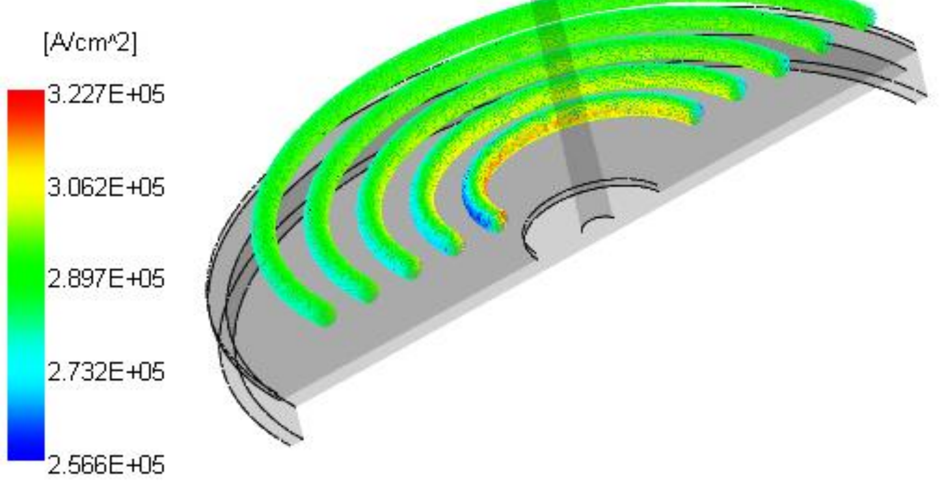


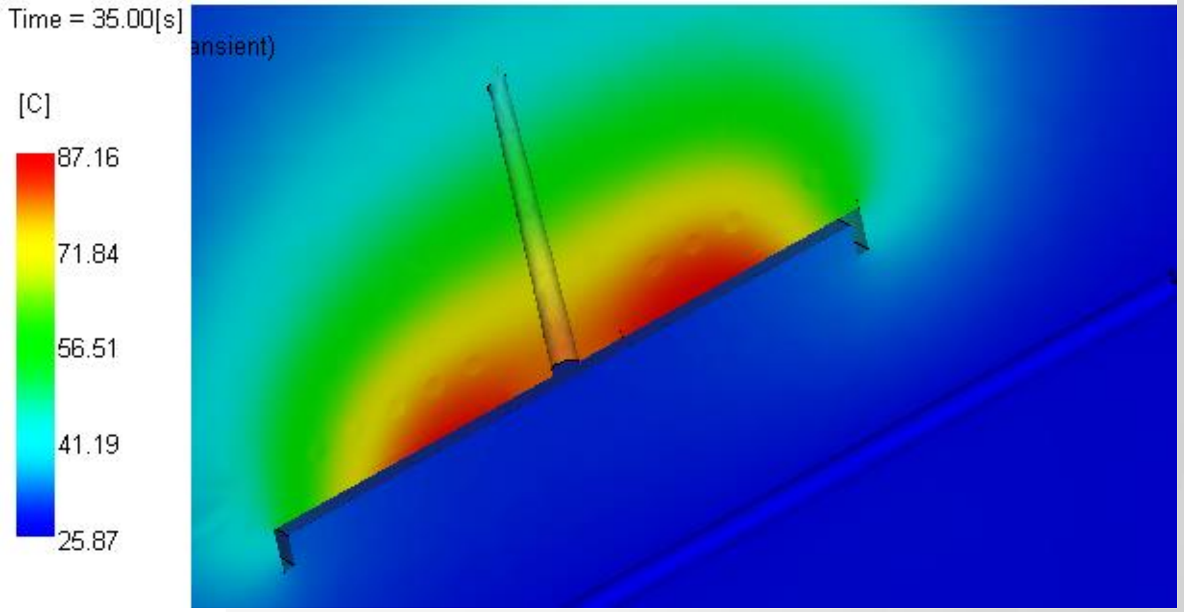


Induction Heating for Cool (FEM)

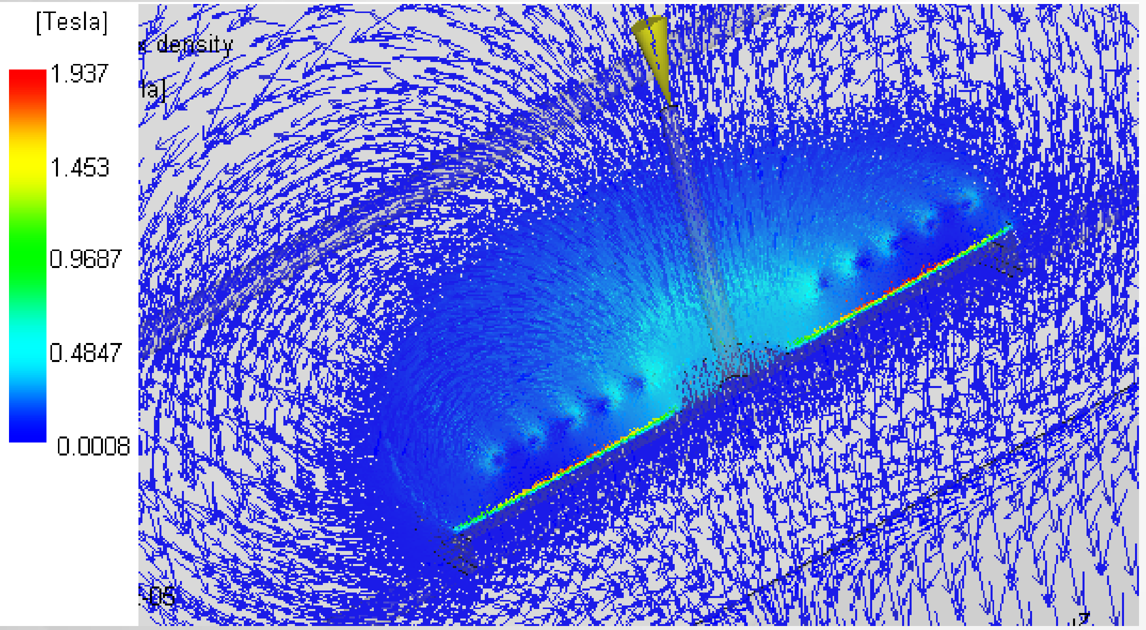
- Specify electric current and timing
  - Calculate current density
- Calculate Magnetic field and flux
- Calculate Joule Heating

Current Density

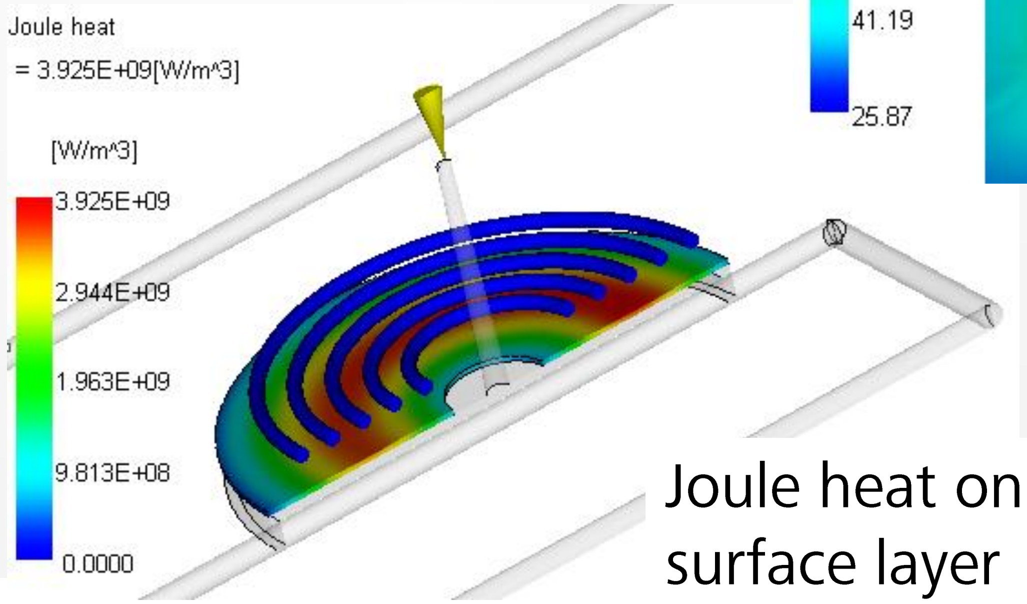




Mold Temperature



Magnetic Flux



Joule heat on surface layer

Microcellular Foaming - Current (ASMI2015)

- Viscosity is modified by:
  - Gas in solution, c
  - Bubble volume, ϕ

$$\eta = \eta_r (1-\phi)^{V_1} \exp(V_2 c + V_3 c^2)$$

- Bubble growth:
  - Completes filling
  - Maintains packing pressure

$$\frac{\partial \rho}{\partial t} + \nabla \bullet \rho \vec{\upsilon} = 0$$

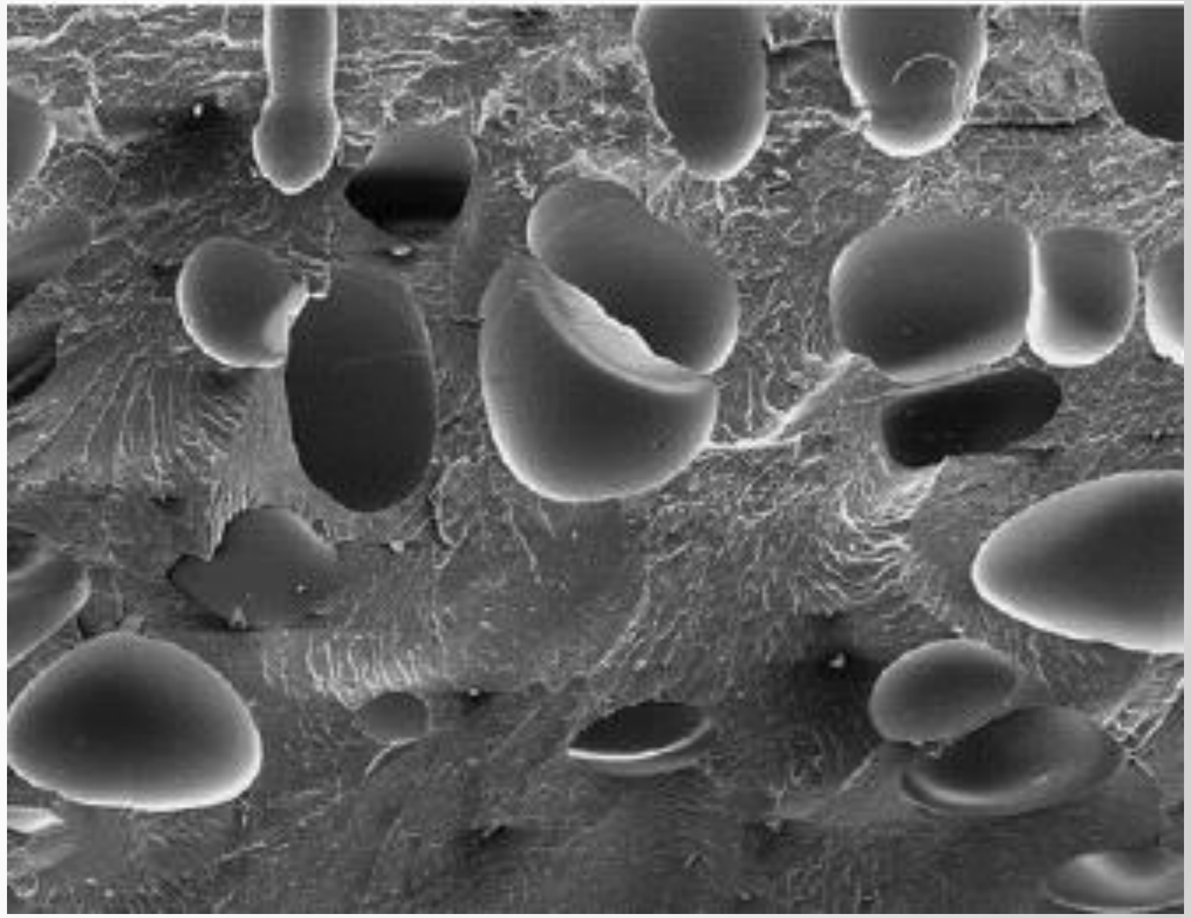
$$\rho = \rho_r (1-\phi)$$

- Other material properties also modified by ϕ
- Available in Midplane and Dual-domain
- Cell density is a user input
  - Modify according to process and material parameters based on previous molding trials

Microcellular Foaming - New Developments

- Nucleation model depends on:
  - Gas properties
  - Polymer properties
  - Local temperature and pressure

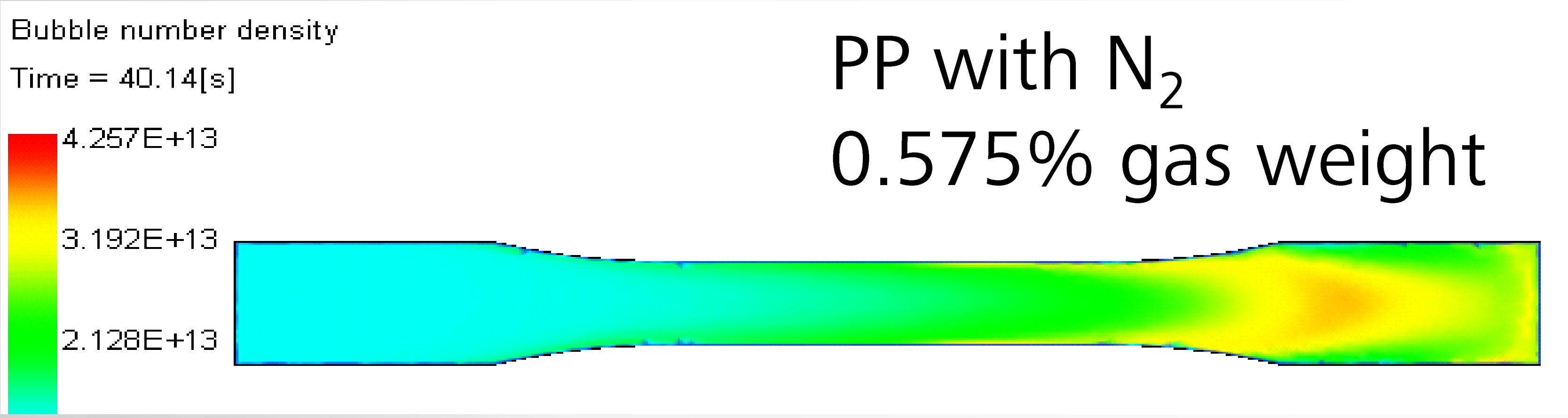
$$J = F_1 N \left[\frac{2\sigma}{\pi m}\right]^{\frac{1}{2}} exp\left[\frac{-16F_2\pi\sigma^3}{3kT[P_v - P_l]^2}\right]$$

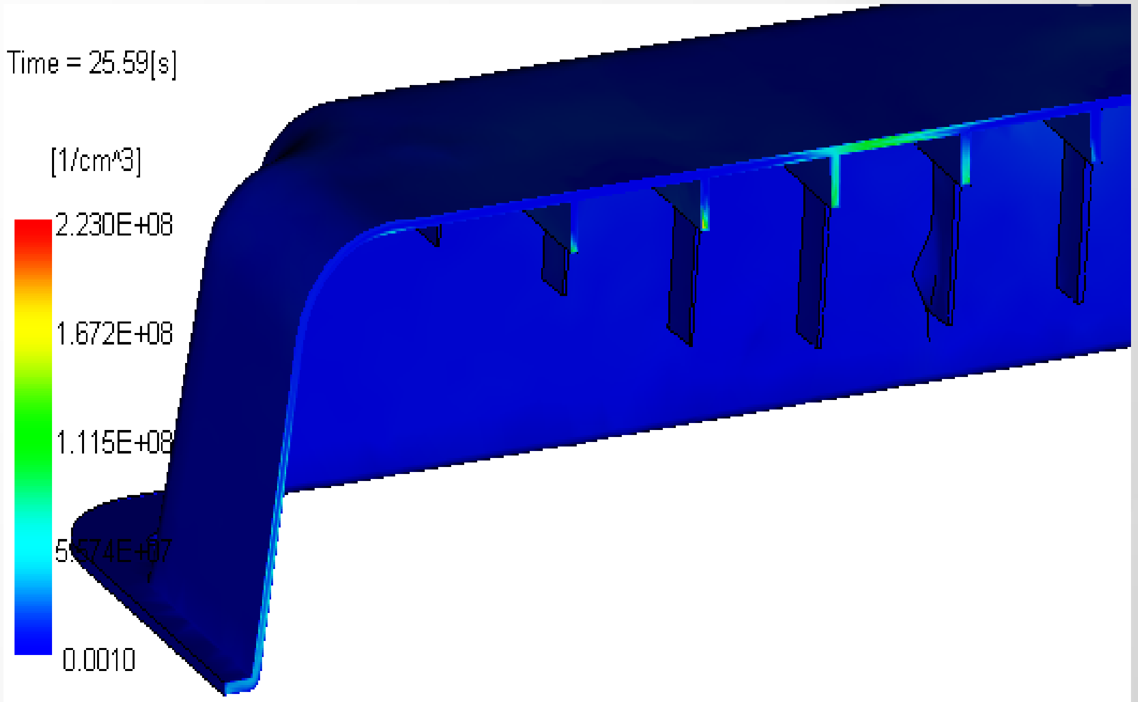


K. Taki, Chemical Eng. Sci. 63 (2008) 3643-3653
K. Taki, J. of Cellular Plastics 39 (2003) 155-169

Microcellular Foaming - New Developments

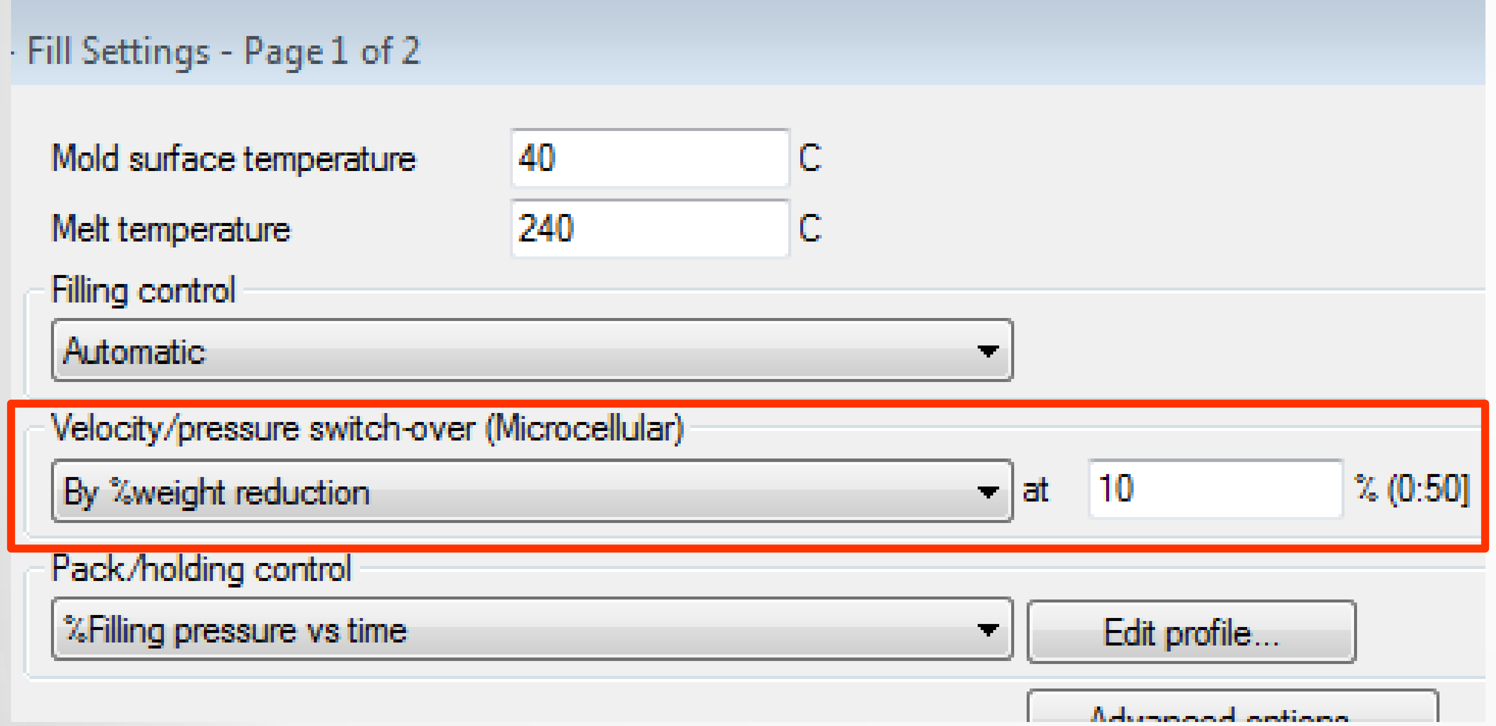
- Nucleation model results is non-uniform nucleation prediction
  - Depends on local pressure and temperature history



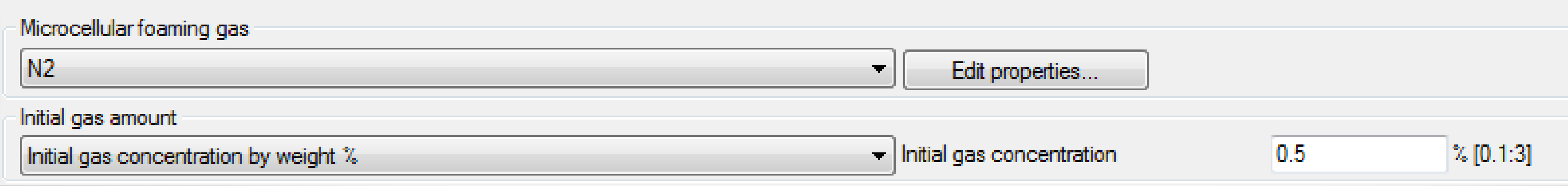


Microcellular Foaming - New Developments

- Extend Microcellular foaming simulation to 3D
- %weight reduction target in process setup

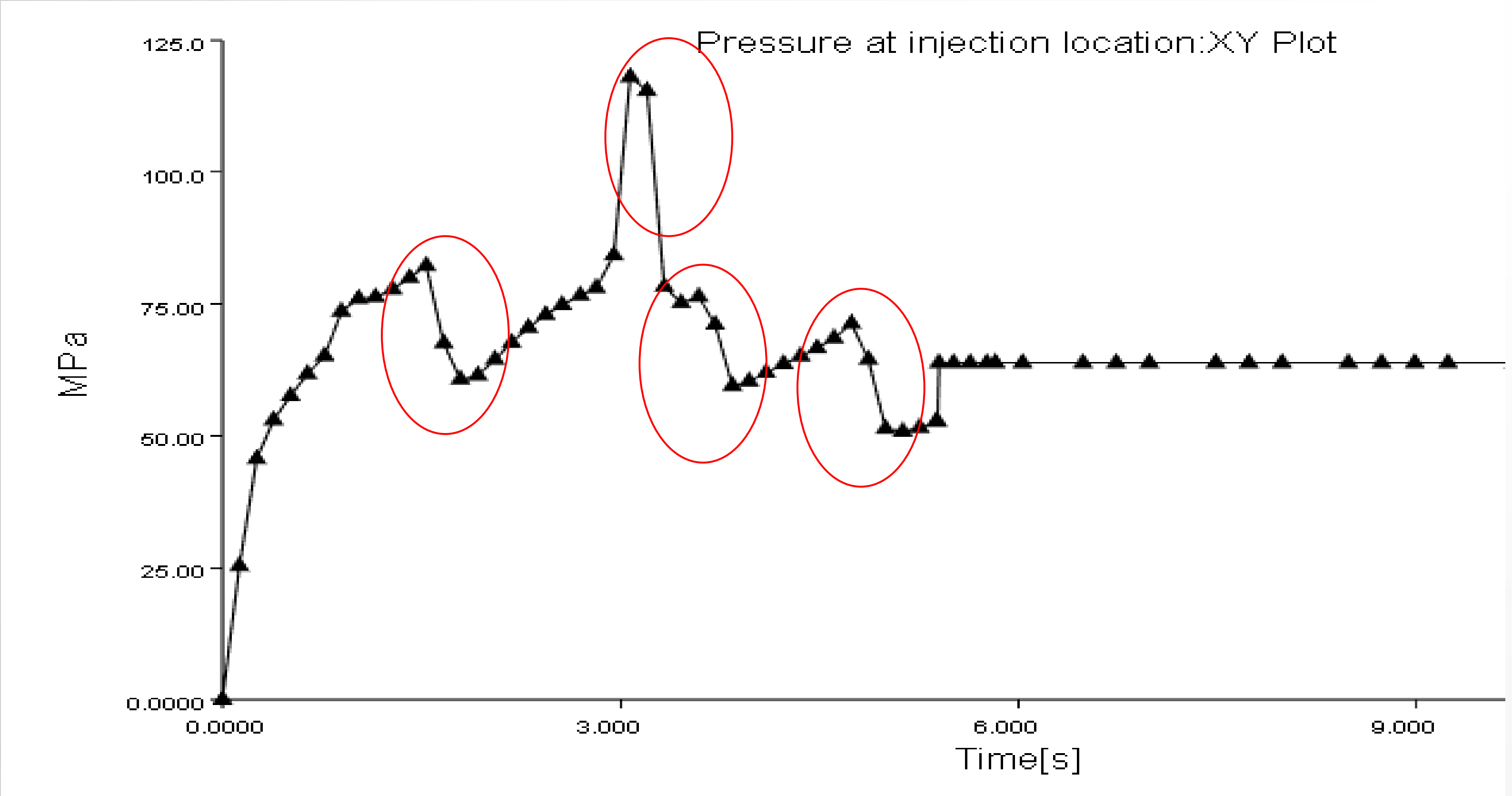


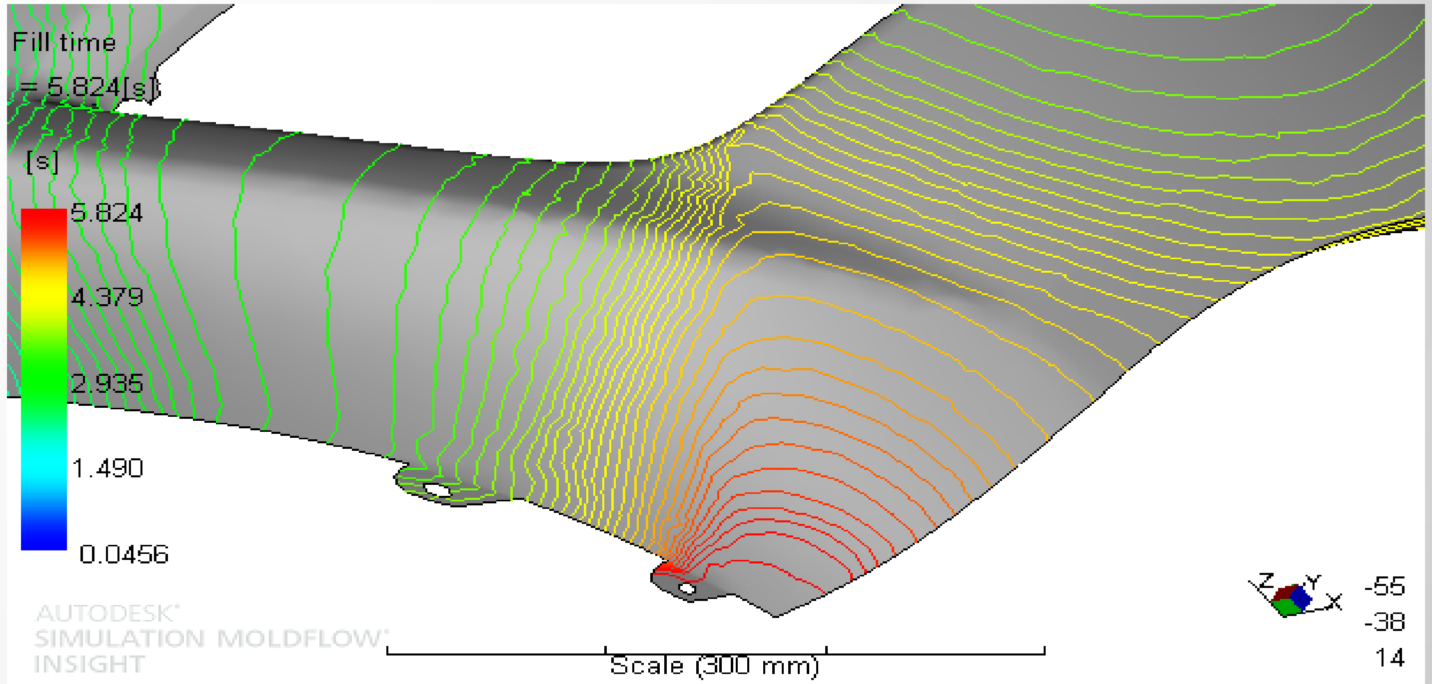
- Usability: Gas selection & concentration in process settings



Cascading valve gates

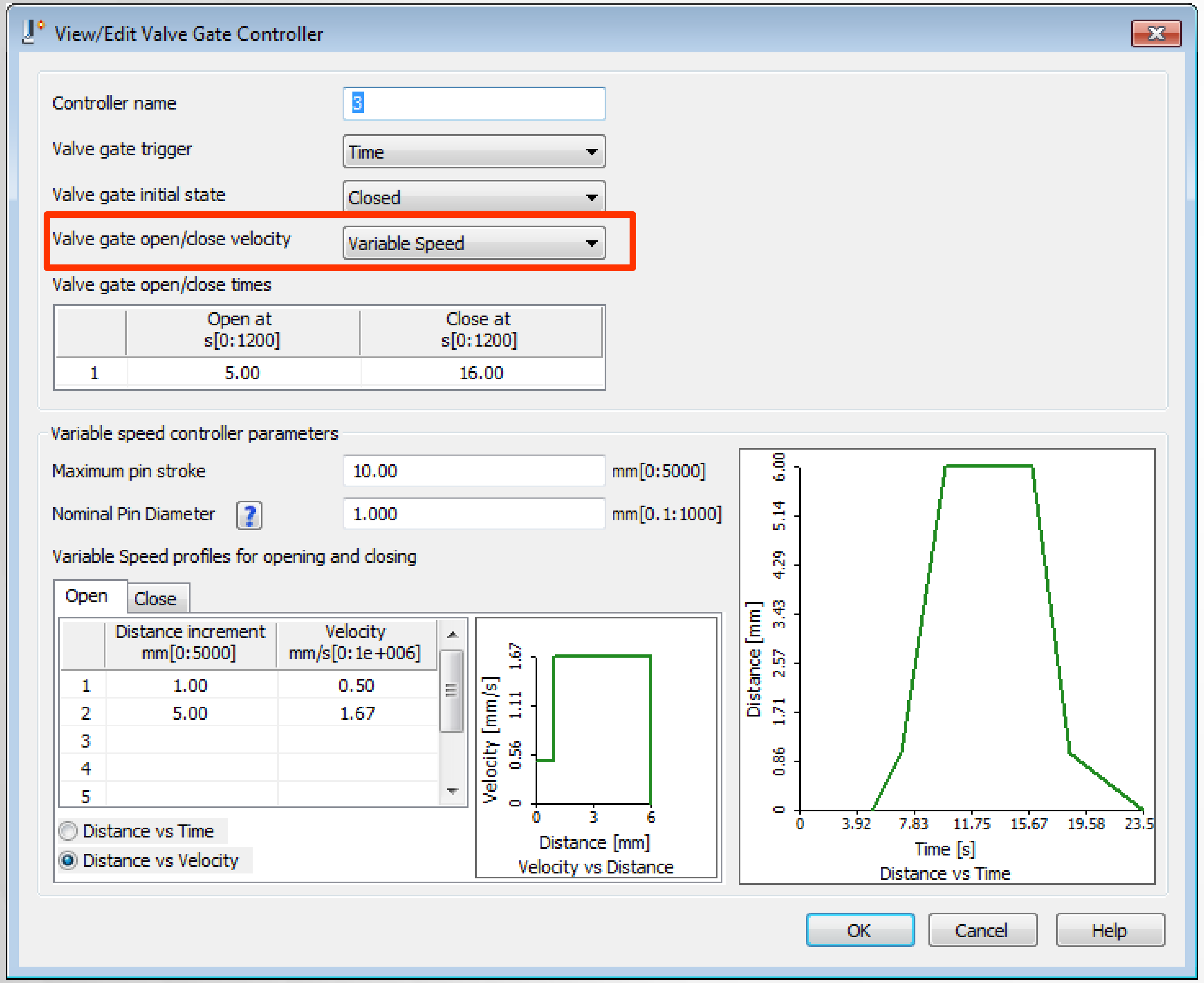
- Injection pressure dips abruptly
- Flow front has periods of sharp acceleration
  - Visible flow marks
- Solution is to open valve gates gradually

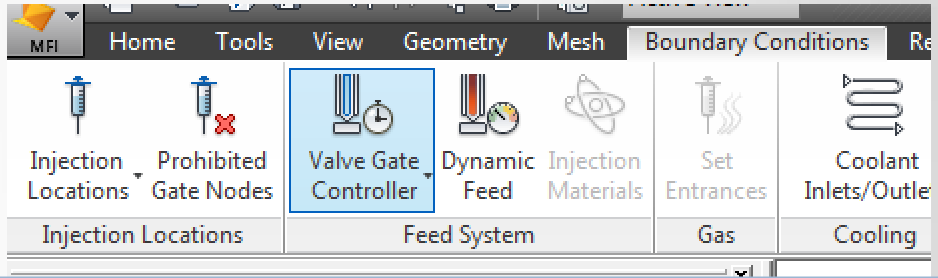


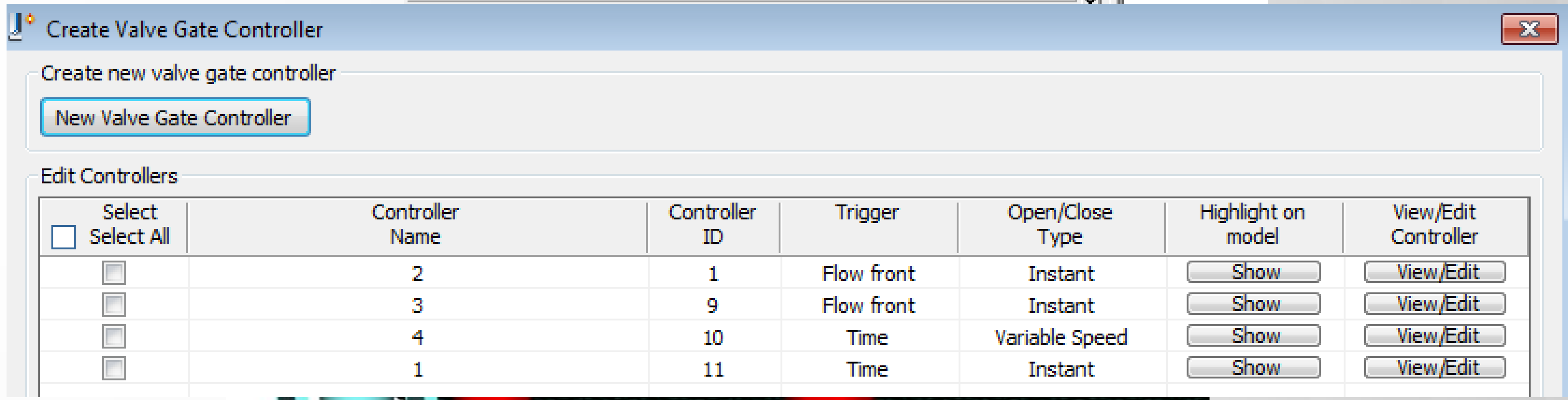


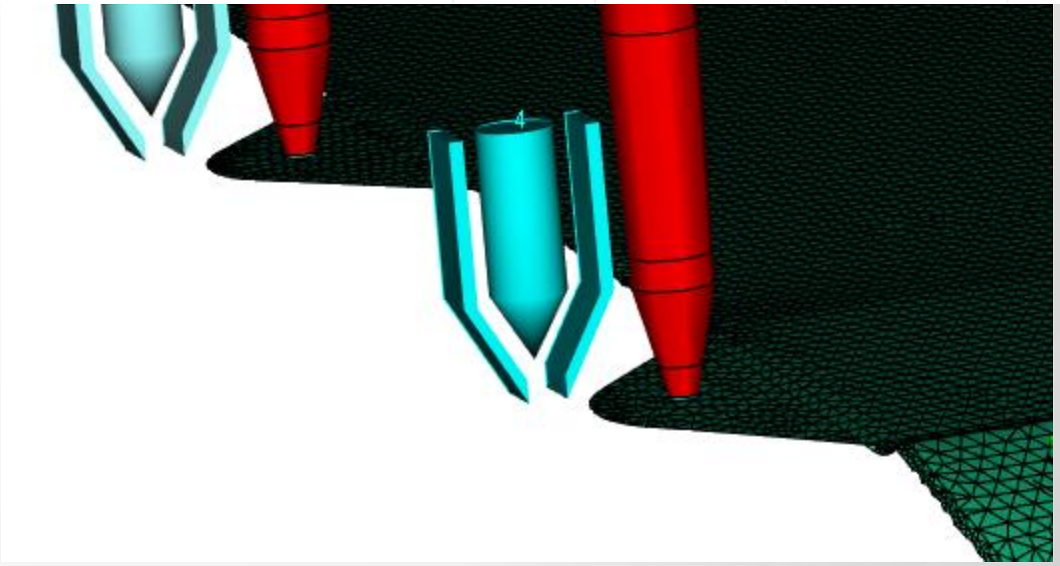
Velocity controlled valve gate settings

- Select whether a valve gate has abrupt or variable speed
  - Specify by either time or velocity



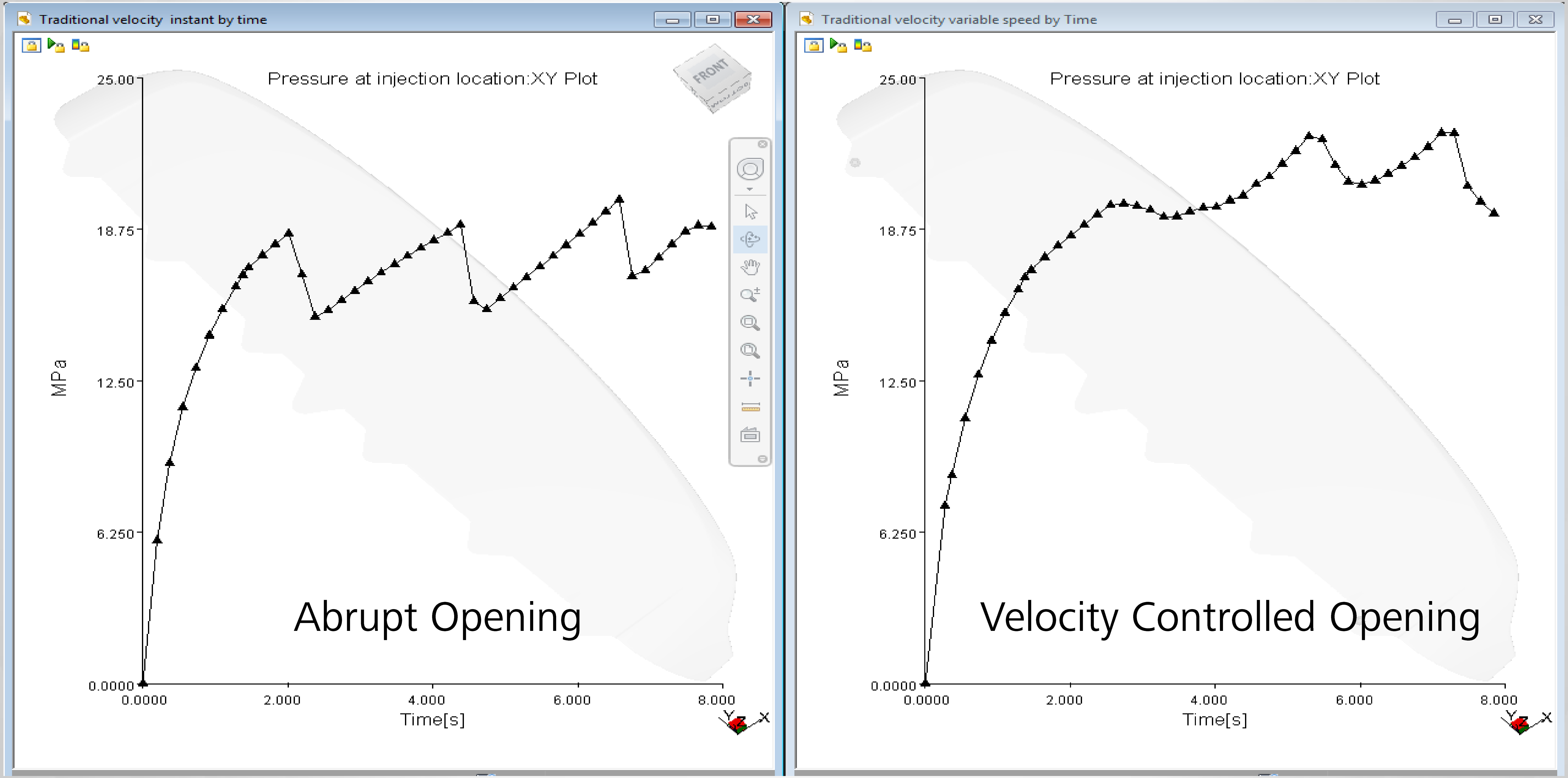




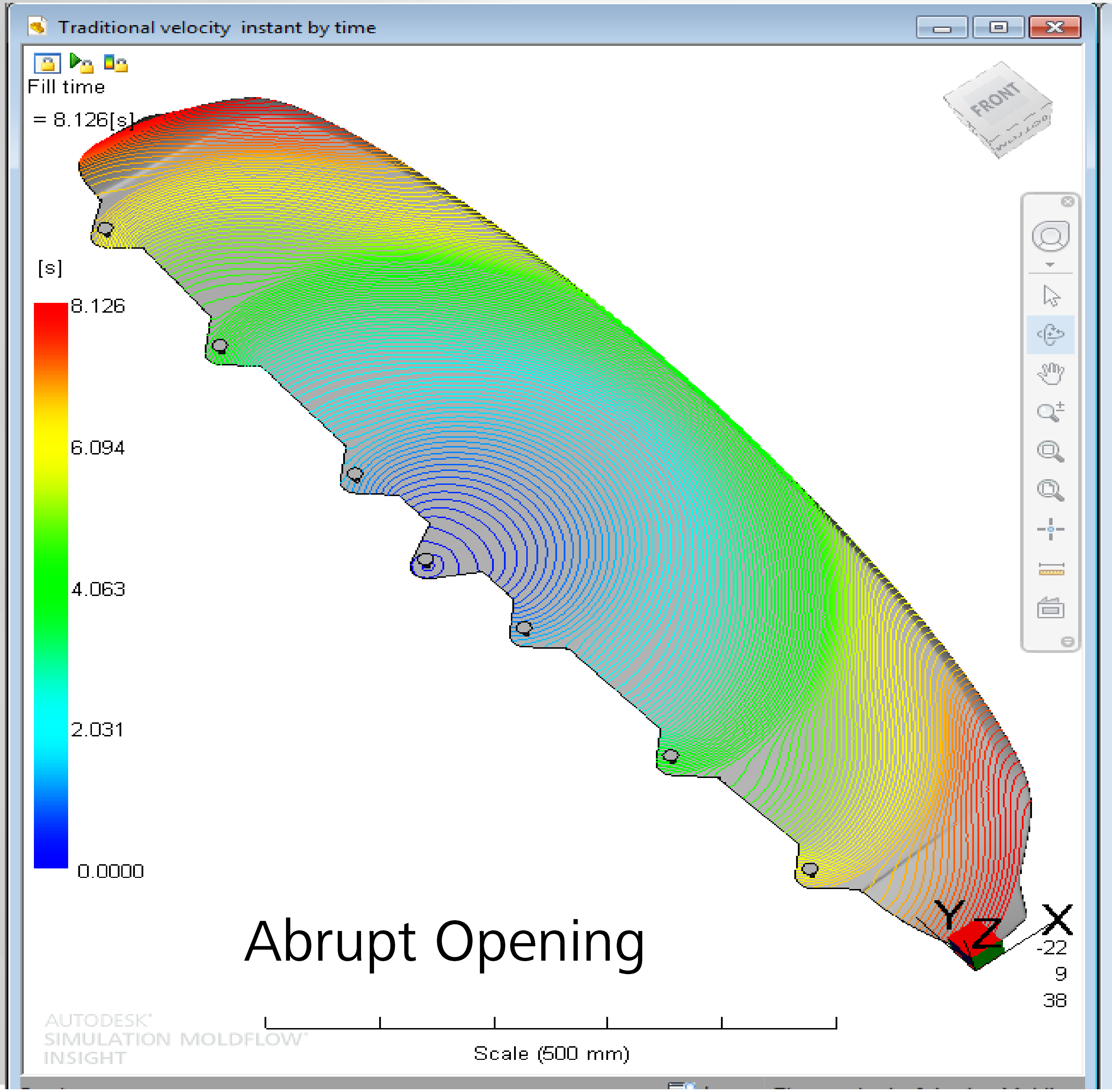


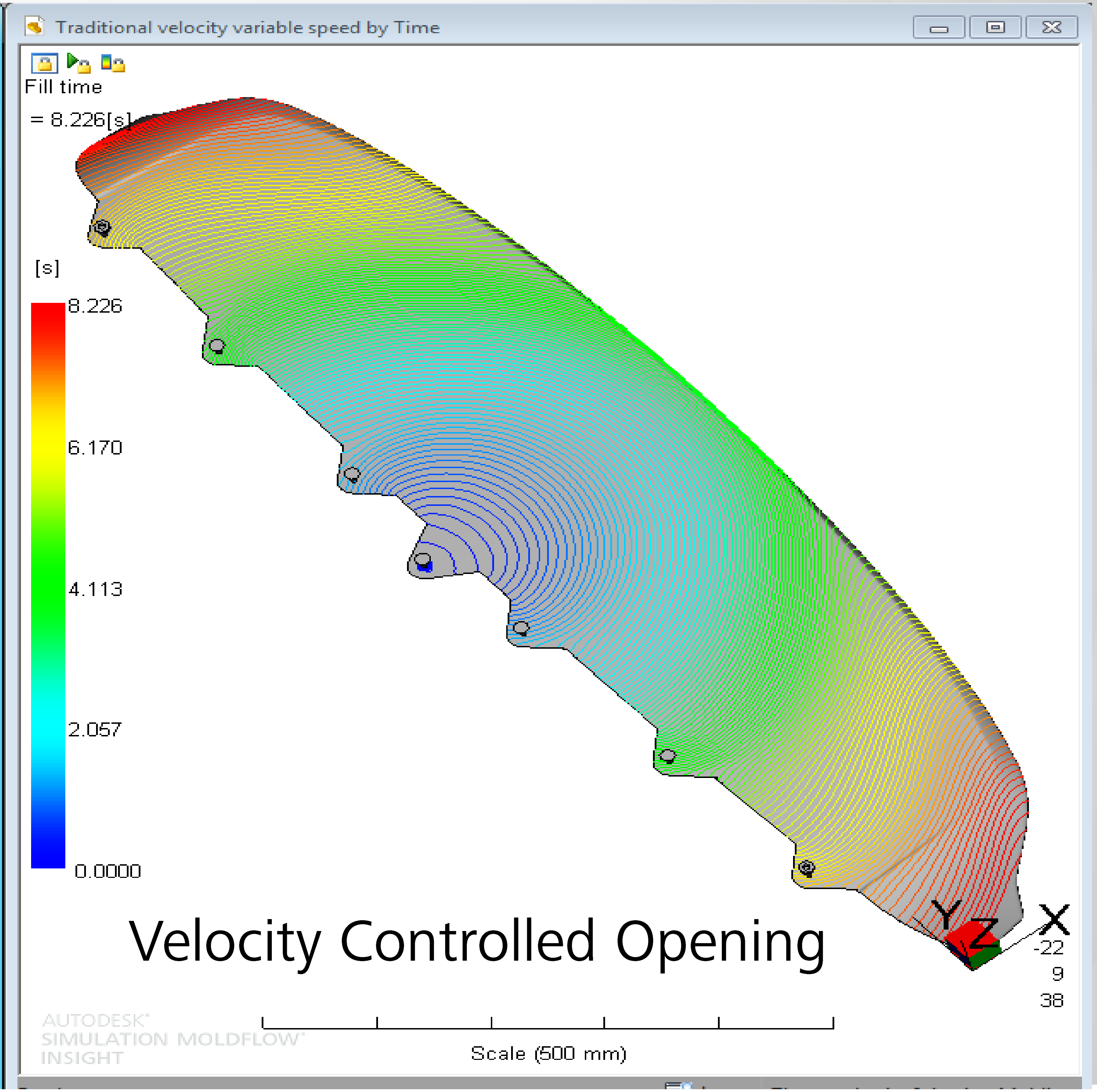
(Midplane and Dual-Domain only)

Velocity Controlled Valve gate - Pressure



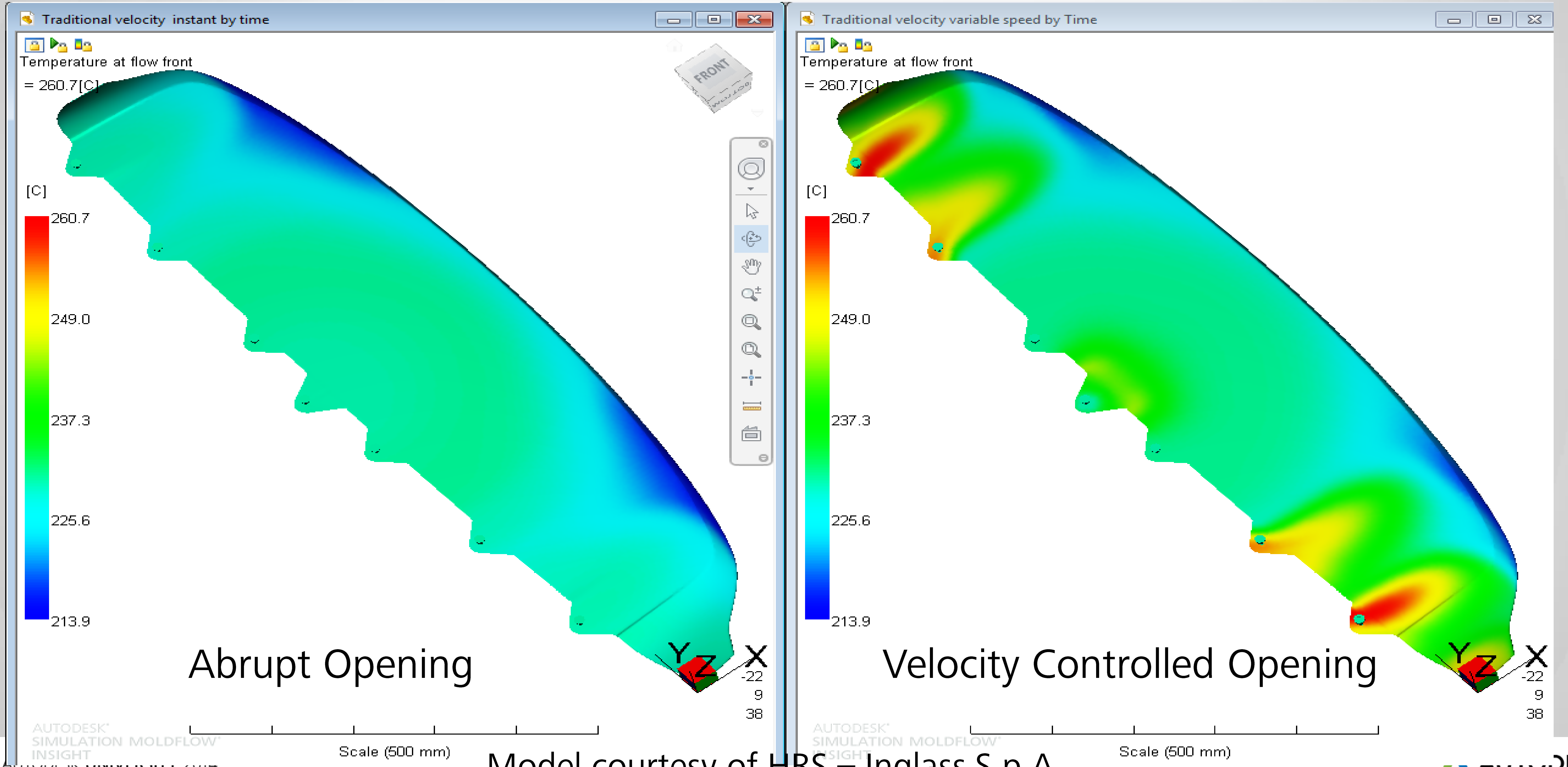
Velocity Controlled Valve gate – Fill Pattern





Model courtesy of HRS – Inglass S.p.A

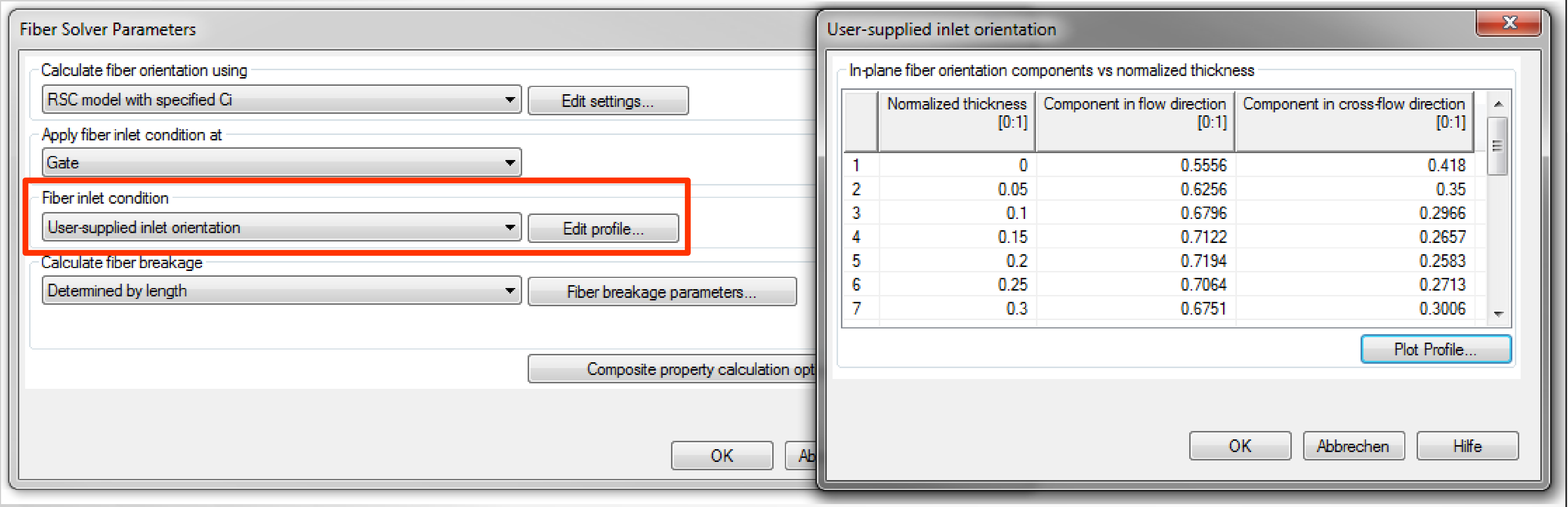
Velocity Controlled Valve gate – Flow Front Temperature

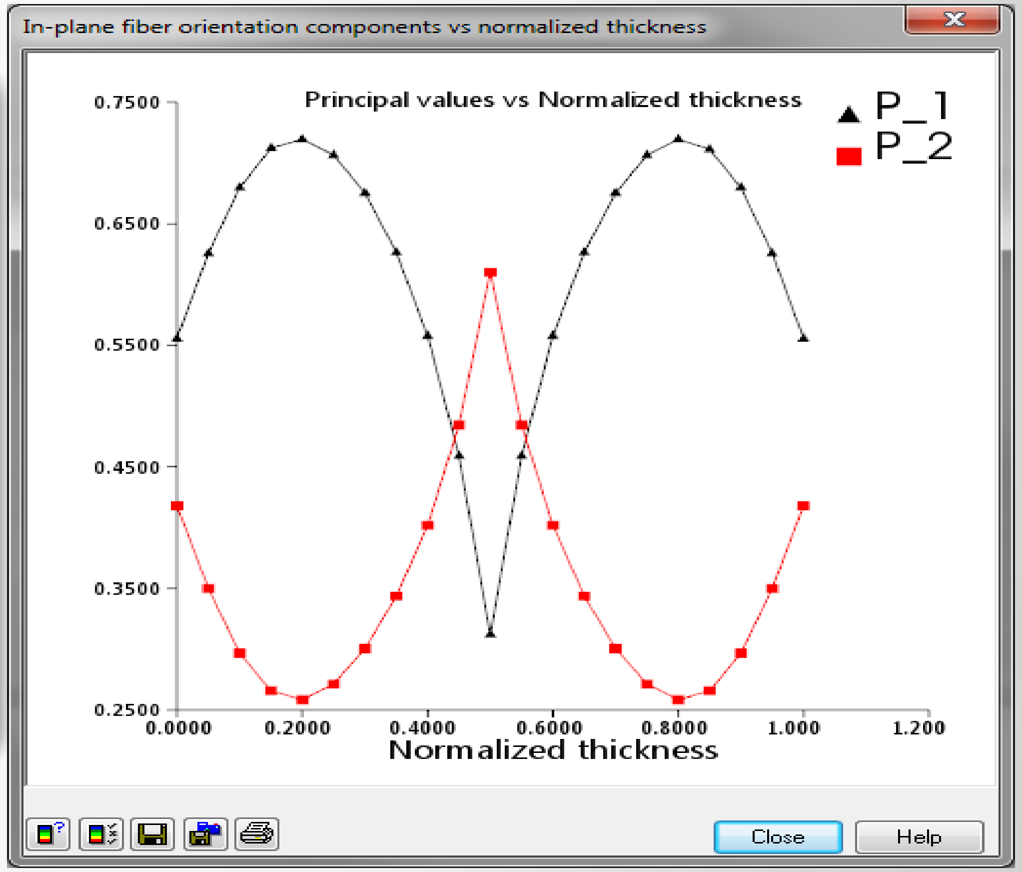


Model courtesy of HRS – Inglass S.p.A

3D Fiber – New Inlet Option

- Add specified inlet orientation
  - Already previously available for Midplane/DD

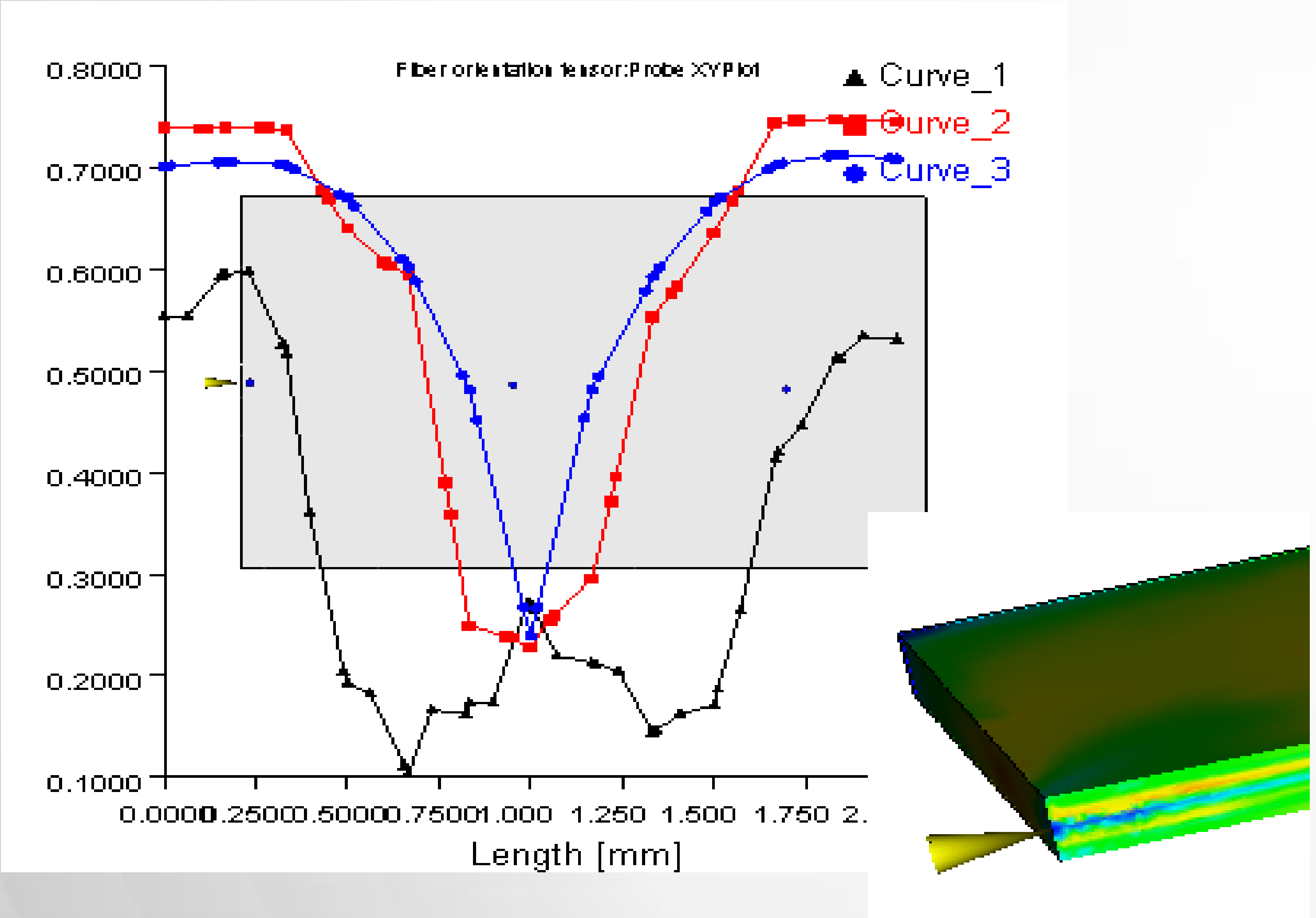




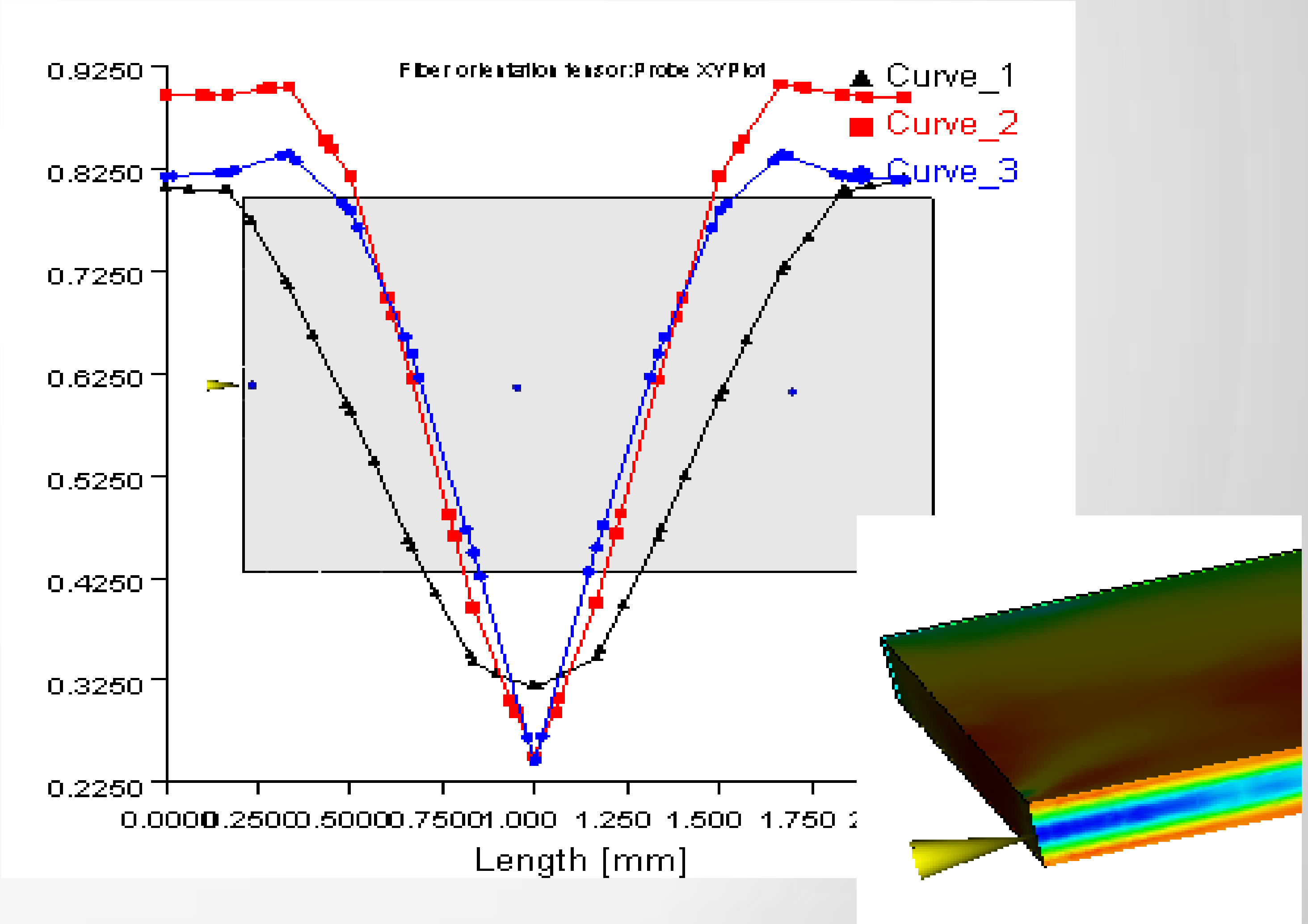
3D Fiber Improvements

- Preserving the inlet fiber orientation profile
  - Black line ("Curve_1") is immediately inside inlet

ASMI 2015



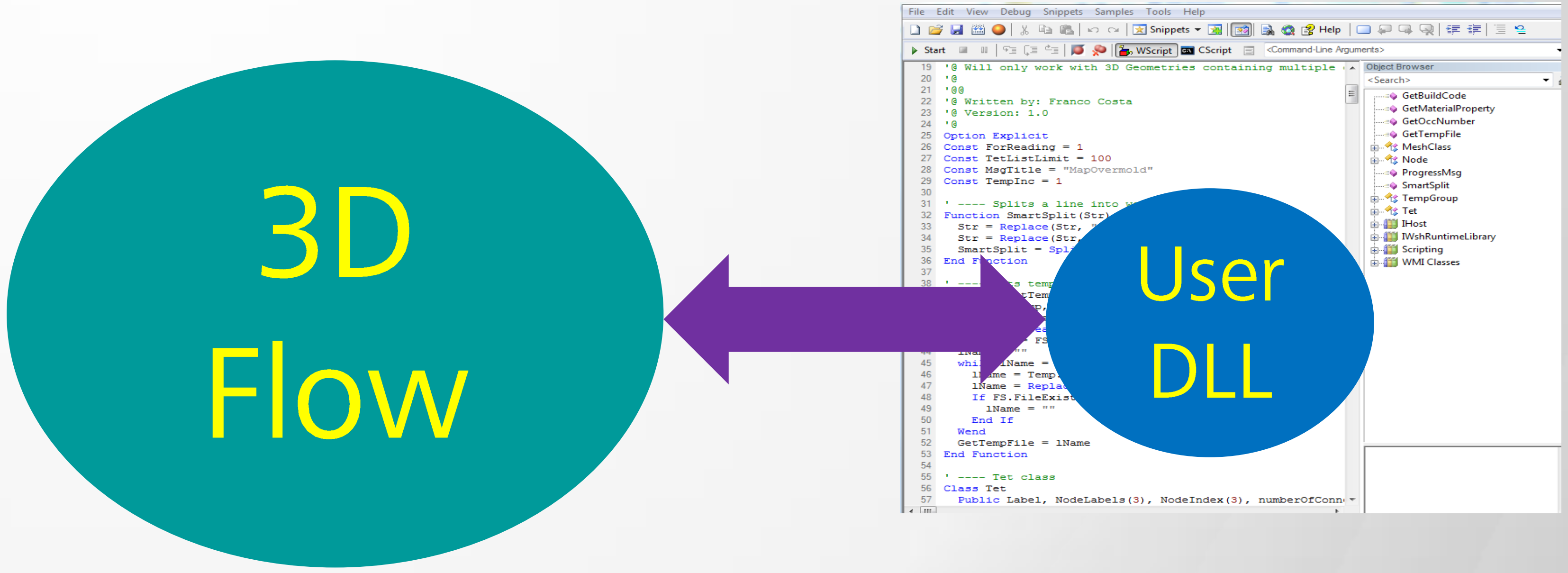
Development version



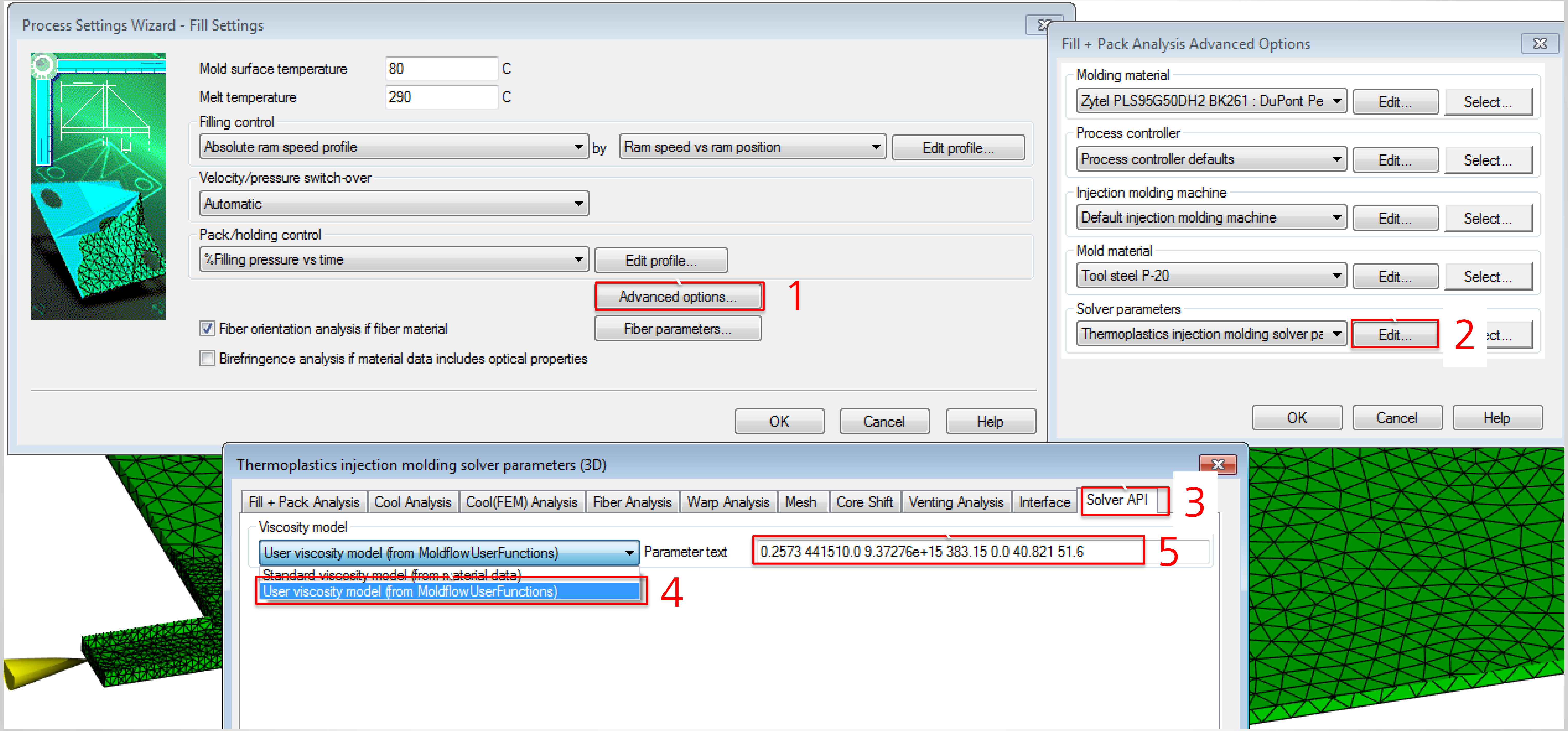
Using a finer mesh around gate

3D Flow Solver API

- Allow user routines for selected properties and calculations
  - Easier research collaborations
  - User-coded routines in a DLL (VS2012 recommended)
    - Example Template provided
  - First implementation is for a user viscosity routine
  - Others to follow:
    - Fiber Orientation ?
    - PVT ?
    - Curing ?
    - ?



Selecting the User Viscosity Function



Cross-WLF Viscosity with Pressure Dependence

$$\eta = \frac{\eta_0}{1+\left(\frac{\eta_0 \dot{\gamma}}{\tau^*}\right)^{1-n}}$$

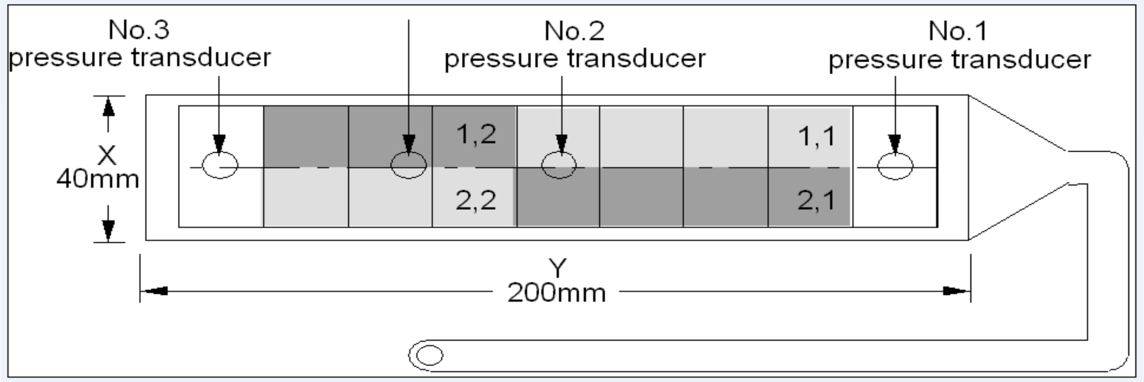
$$\eta_0 = D_1 \exp\left[\frac{-A_1\left(T-T^*\right)}{A_2+\left(T-T^*\right)}\right]$$

η: Viscosity (Pa.s)
$\dot{\gamma}$: shear rate (1/s)
T: Temperature
$T^* = D_2 + D_3 * P$
P: Pressure (Pa)
$A_2 = \tilde{A}_2 + D_3 * P$
D_3 is the pressure dependence term

Barus Model: $\eta_0(T,P) = \eta_0(T)e^{\beta P}$,

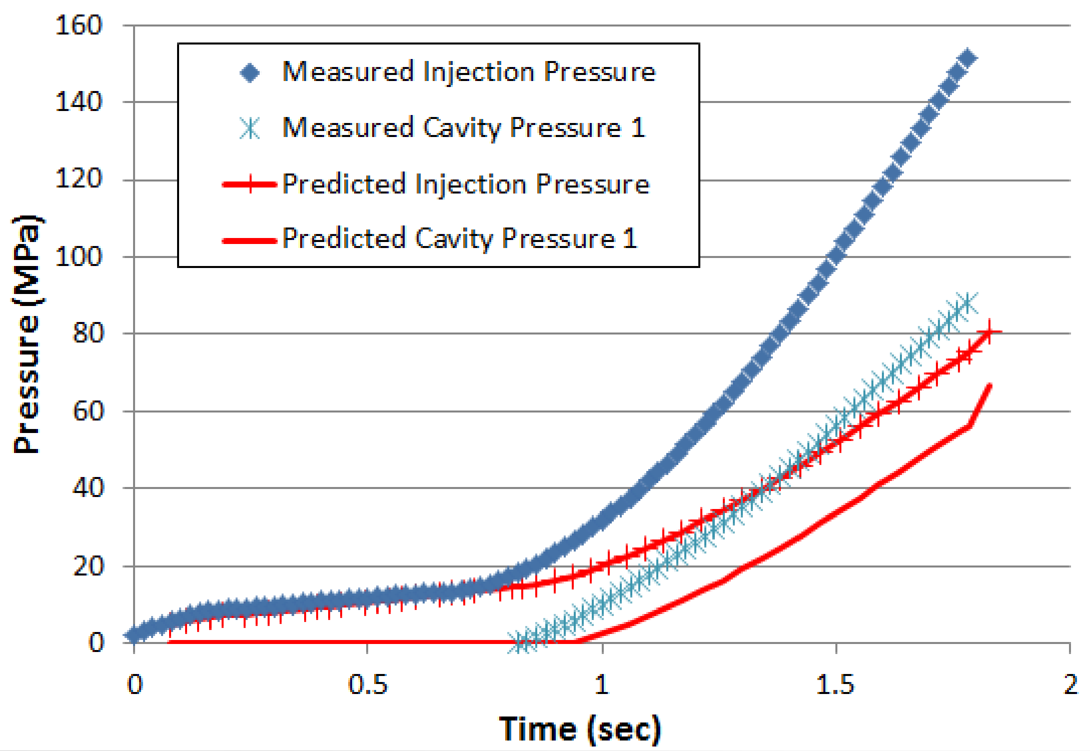
Quadratic Exponent Model: $\eta_0(T,P) = \eta_0(T)e^{\beta P+\kappa P^2}$

Evaluate Pressure Dependent Visc using Solver API

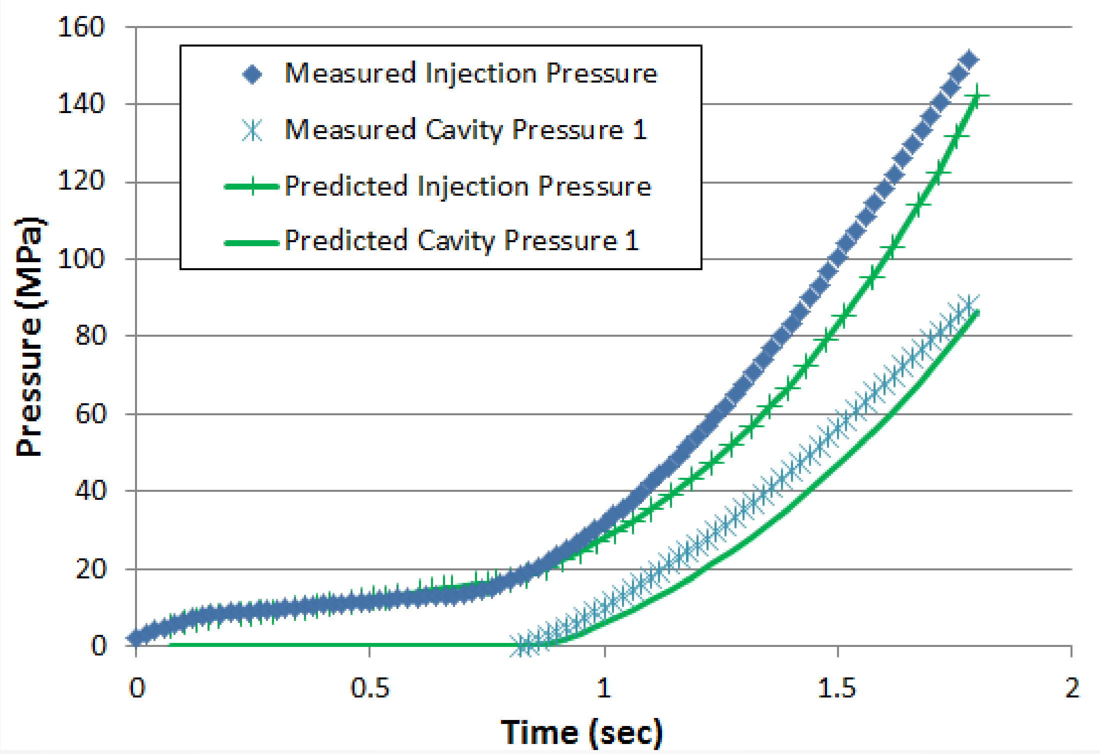


Unfilled PC Material

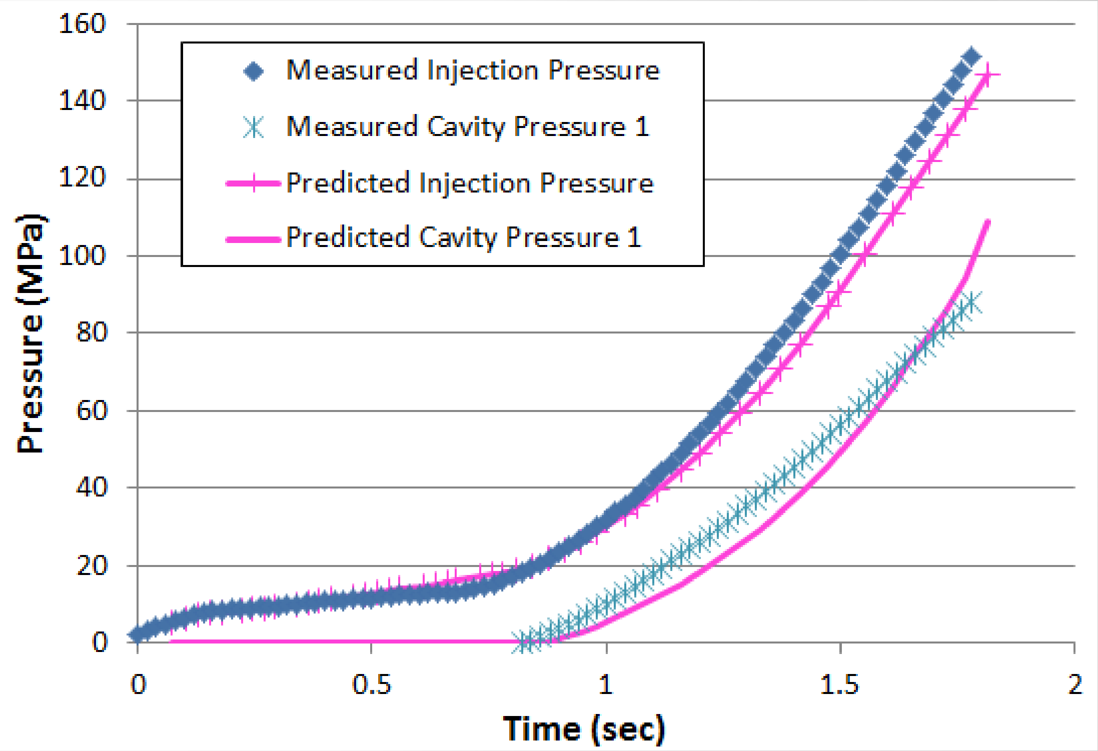
$$\eta_0(T,P)=\eta_0(T)e^{\beta P+\kappa P^2}$$



No Pressure Dependence



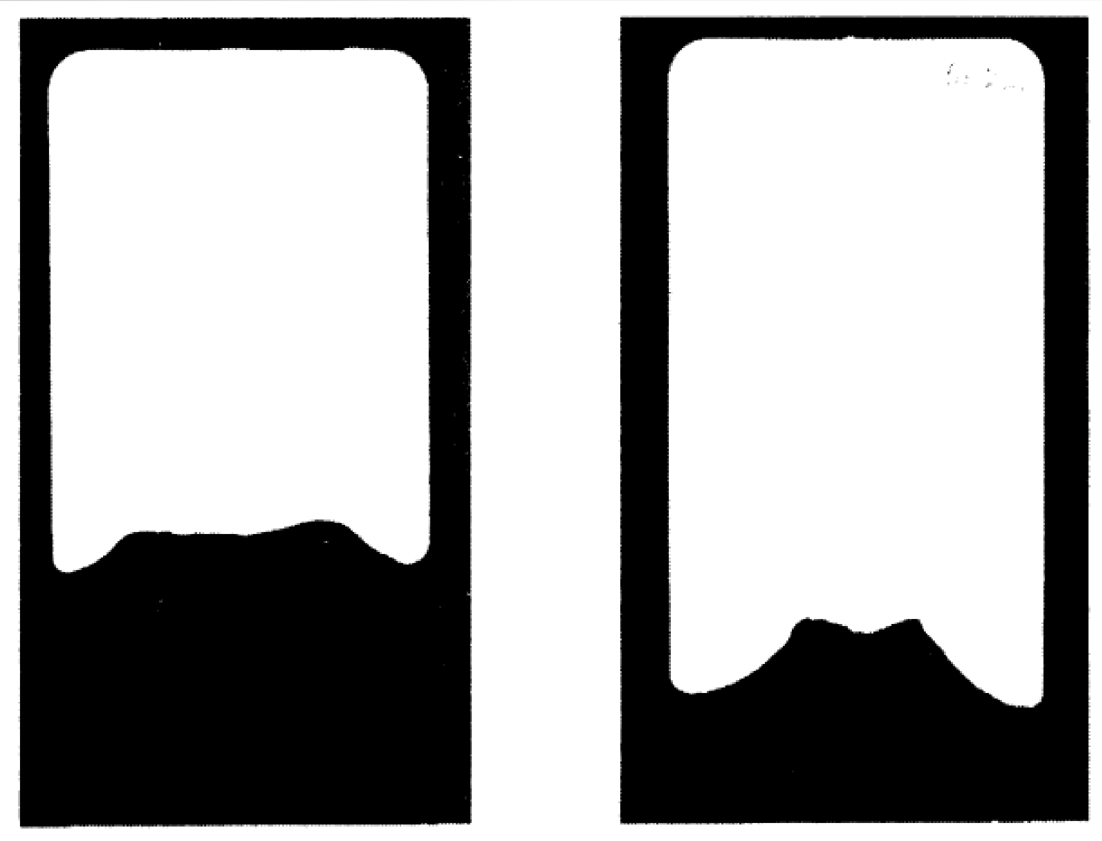
Barus (Standard)



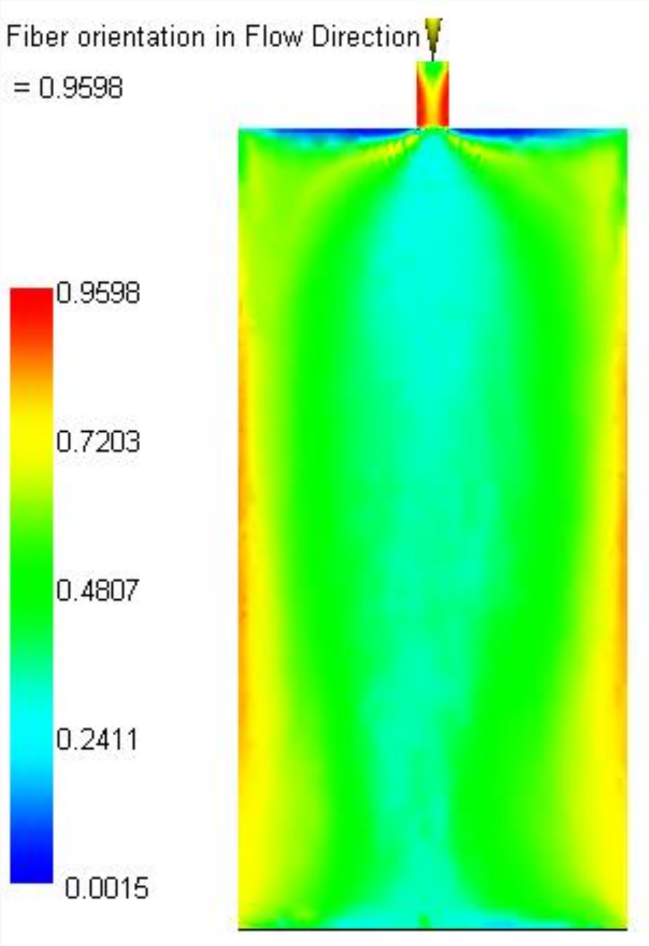
Quadratic Exponent

Dependence of Viscosity on Fiber Orientation

50%wt fiber filled PA



FOD on mid-surface



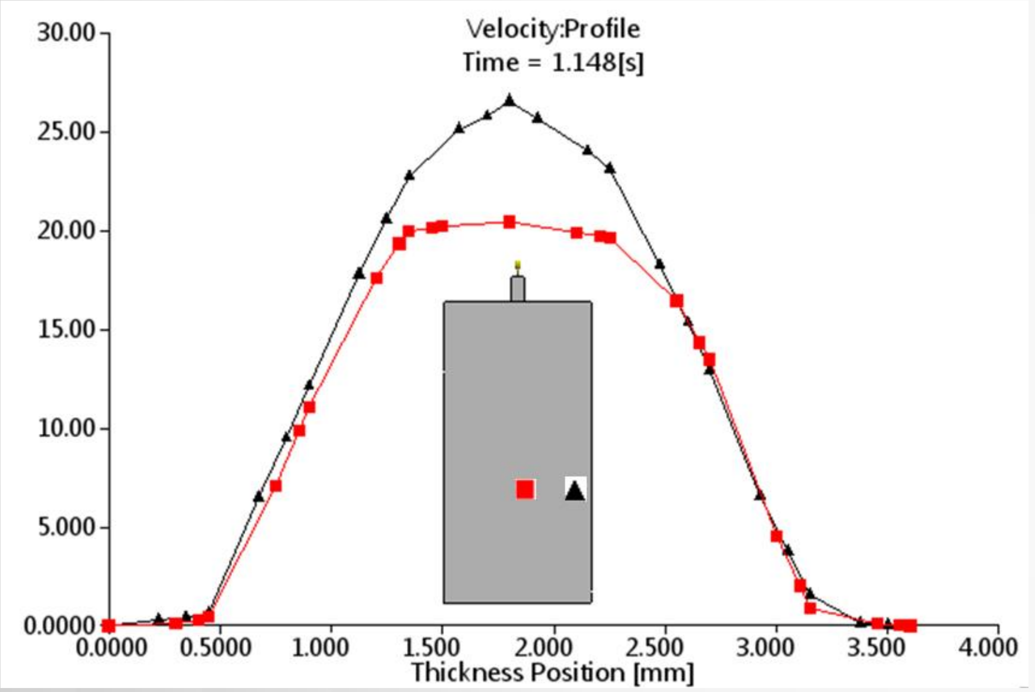
$$\eta(A_{ff}) = \Psi\,\eta \qquad when\ A_{ff} < A_{crit}$$
$$\eta(A_{ff}) = \eta \qquad when\ A_{ff} \geq A_{crit}$$

$$A_{crit} = 0.6$$
$$\Psi = 5$$

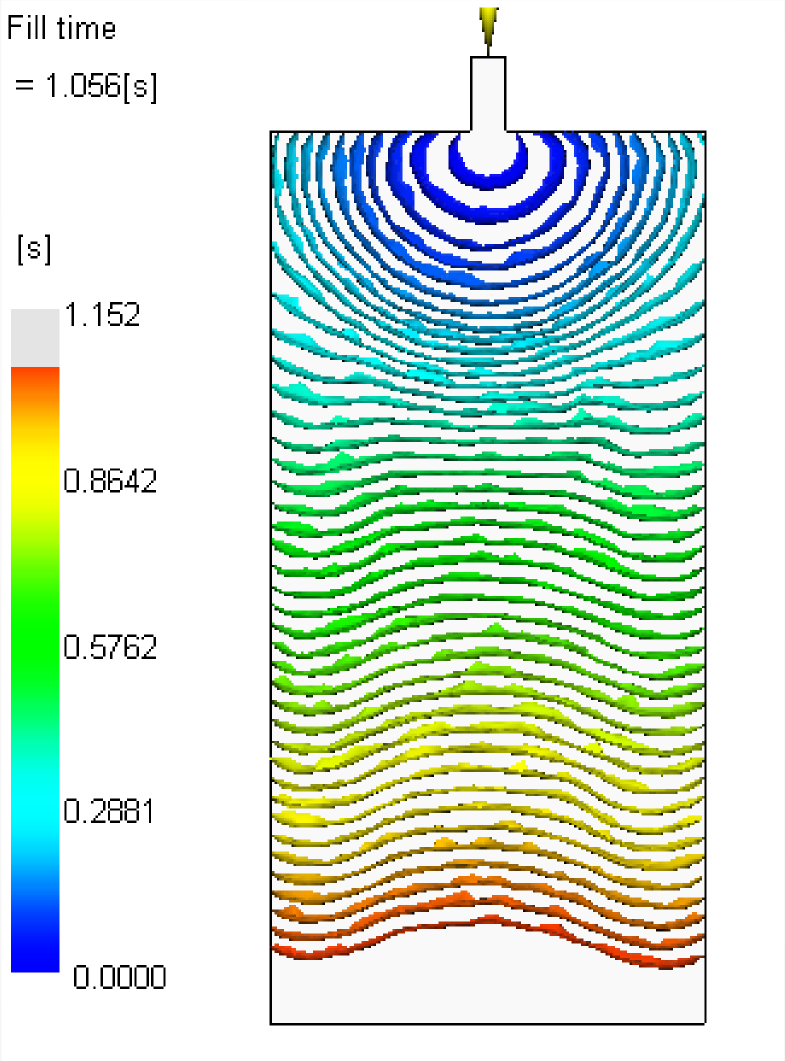
M. Akay and D. Barkley, *Plastics, Rubber & Composites Processing and Applications*, **20**, 137 (1993)

Dependence of Viscosity on Fiber Orientation

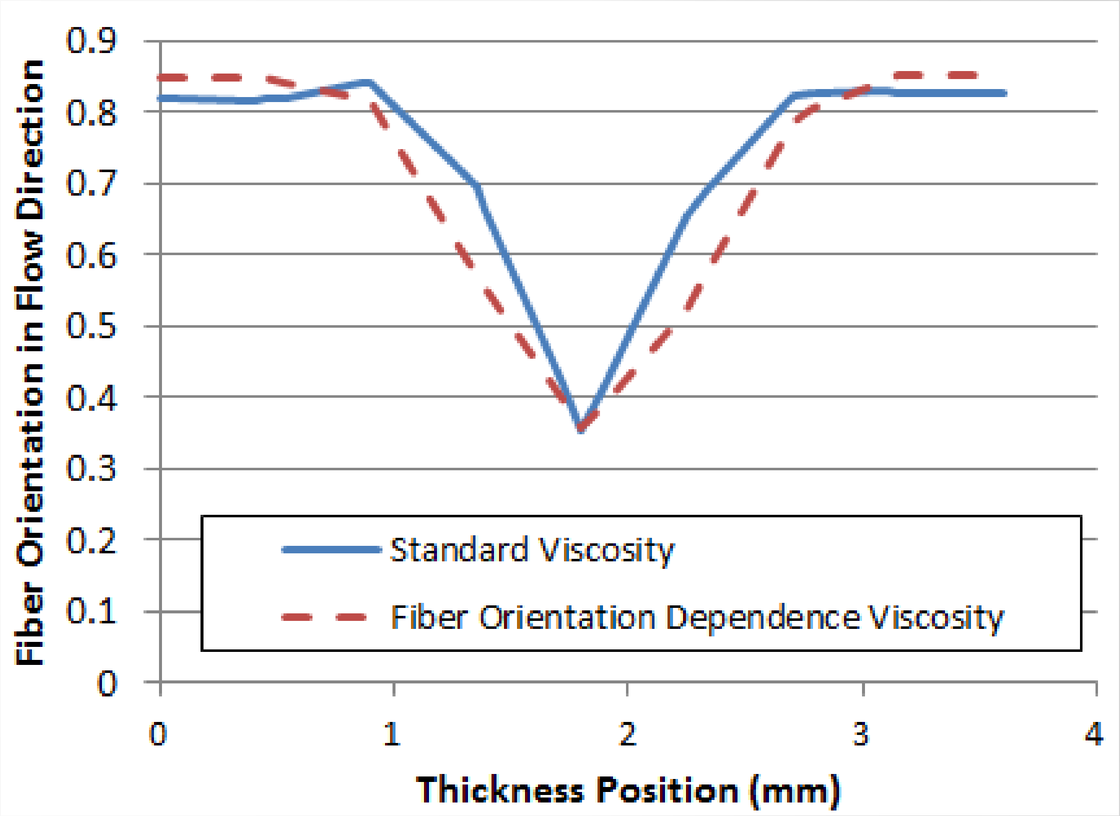
Velocity Profile



Fill Contours



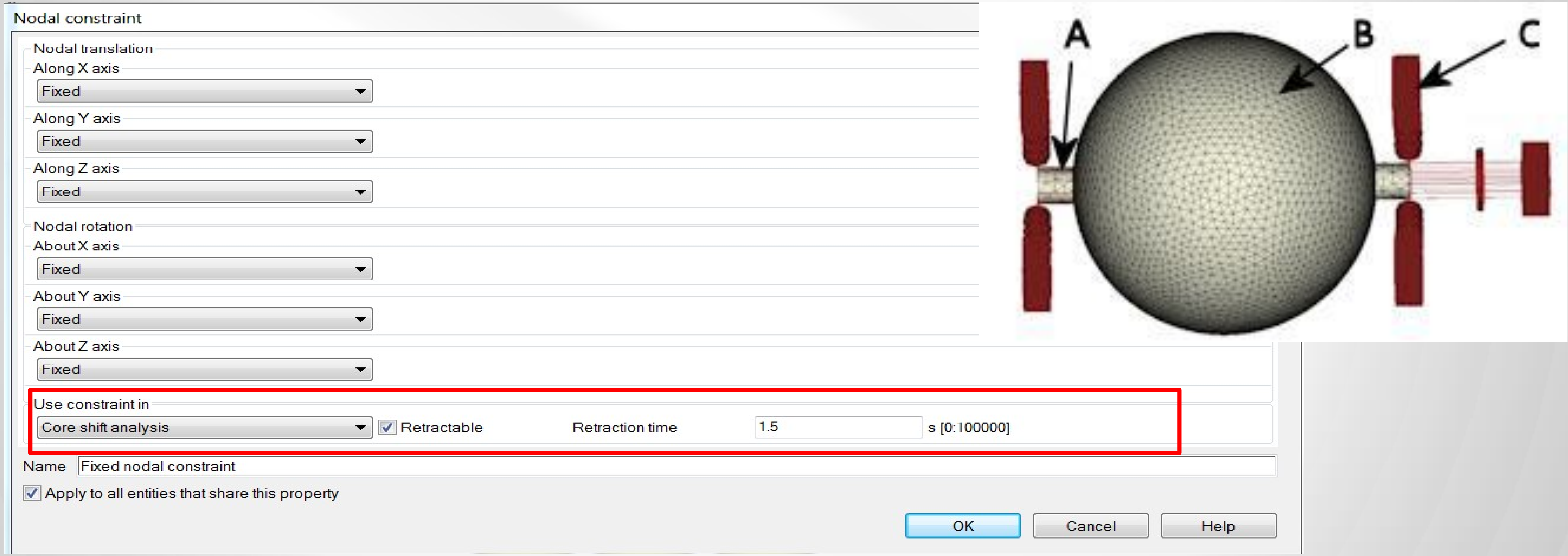
Fiber Orientation Profile



Retractable Core pins

Tech Preview Only

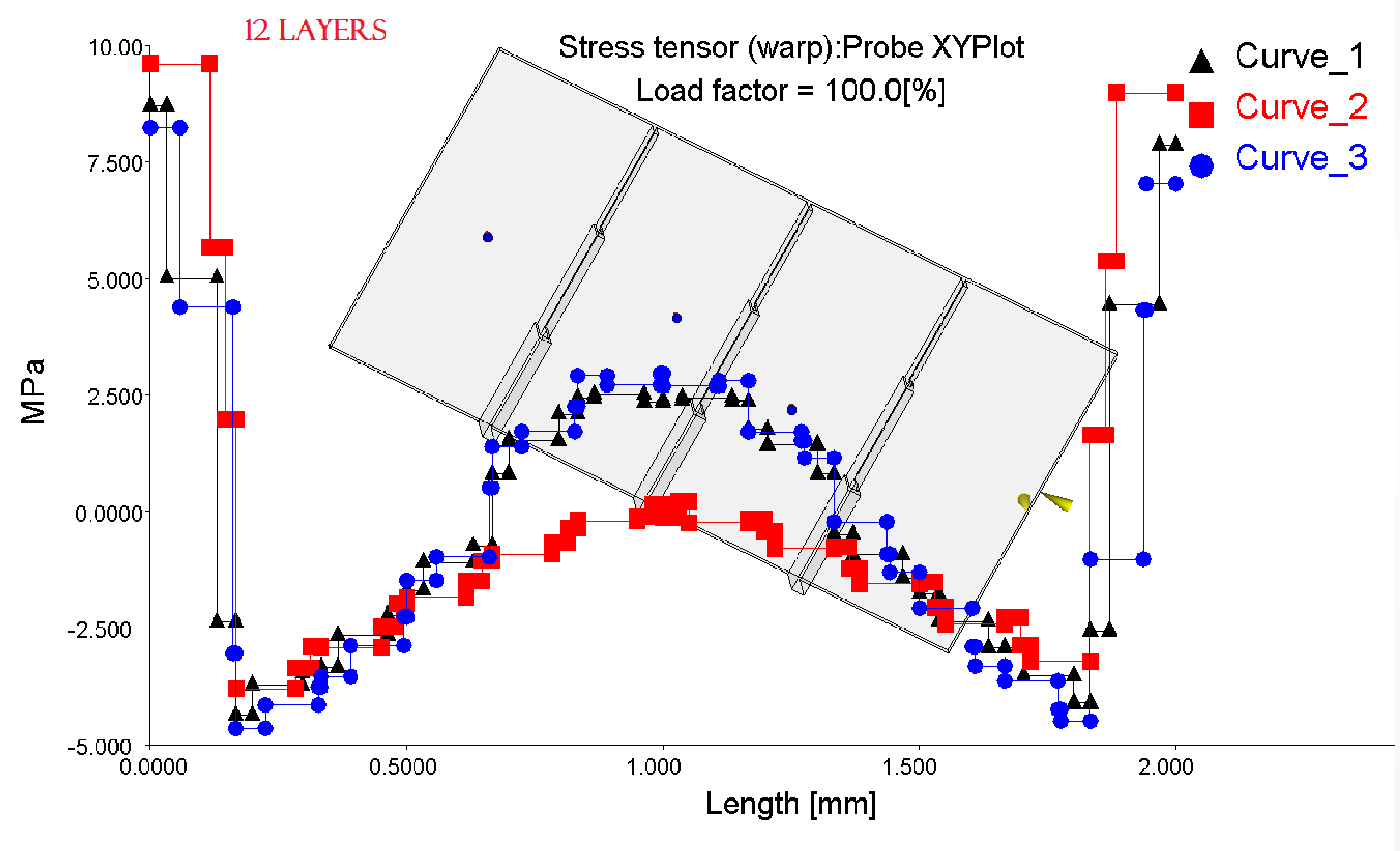
- Supports part insert until pin is retracted



3D Residual Stress: Post-warp

Tech Preview Only

Phase 1: Assume full mold constraint



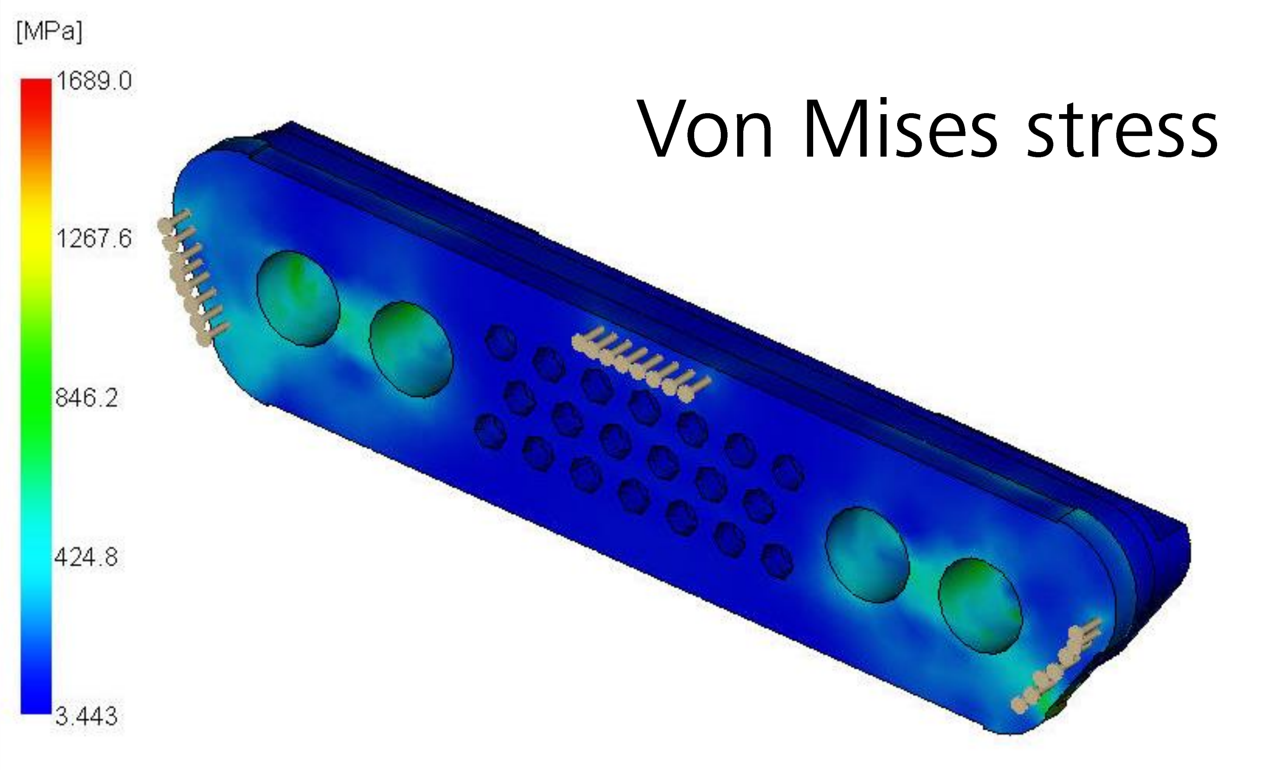
Next Phases: Stress evolution

- Detachment from mold (before ejection)
- Consider viscoelastic stress relaxation

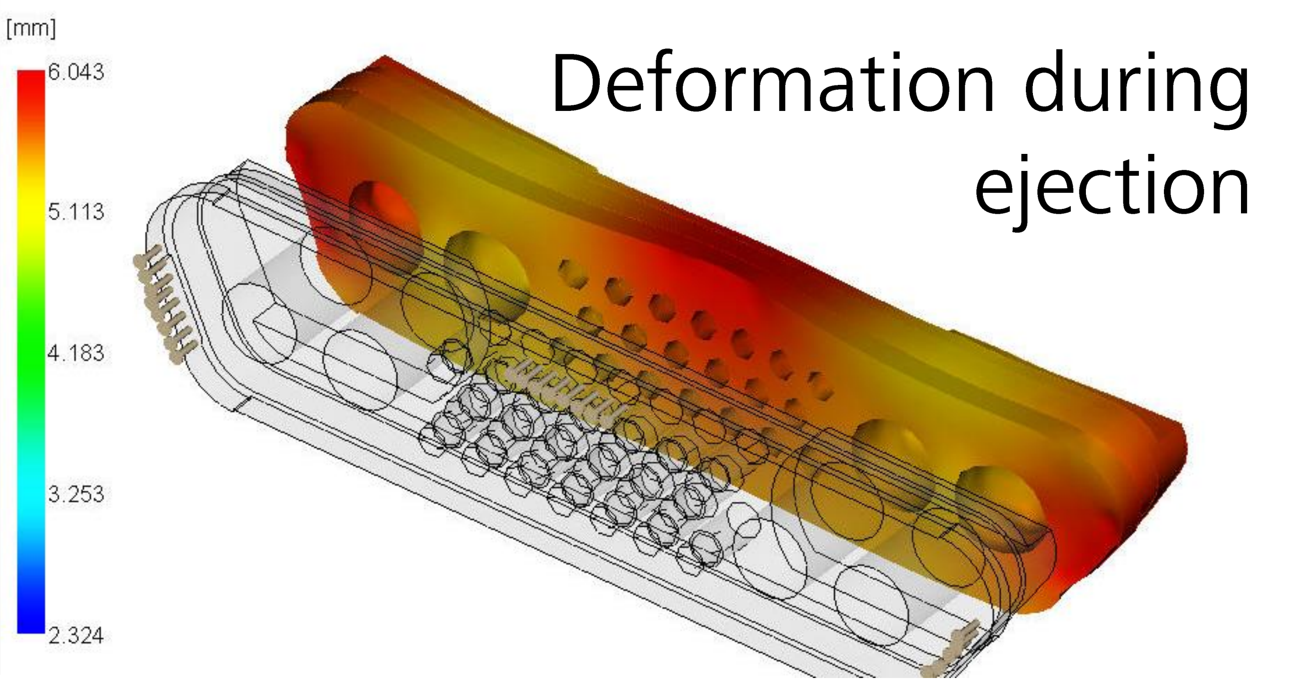
Ejection Force Calculation with Autodesk Mechanical Simulation

Tech Preview Only

- Consider:
  - Friction of part sliding on core
  - Residual stress / pressure in the part
  - Temperatures of the part
  - Ejector position and direction
  - Ejector speed profile

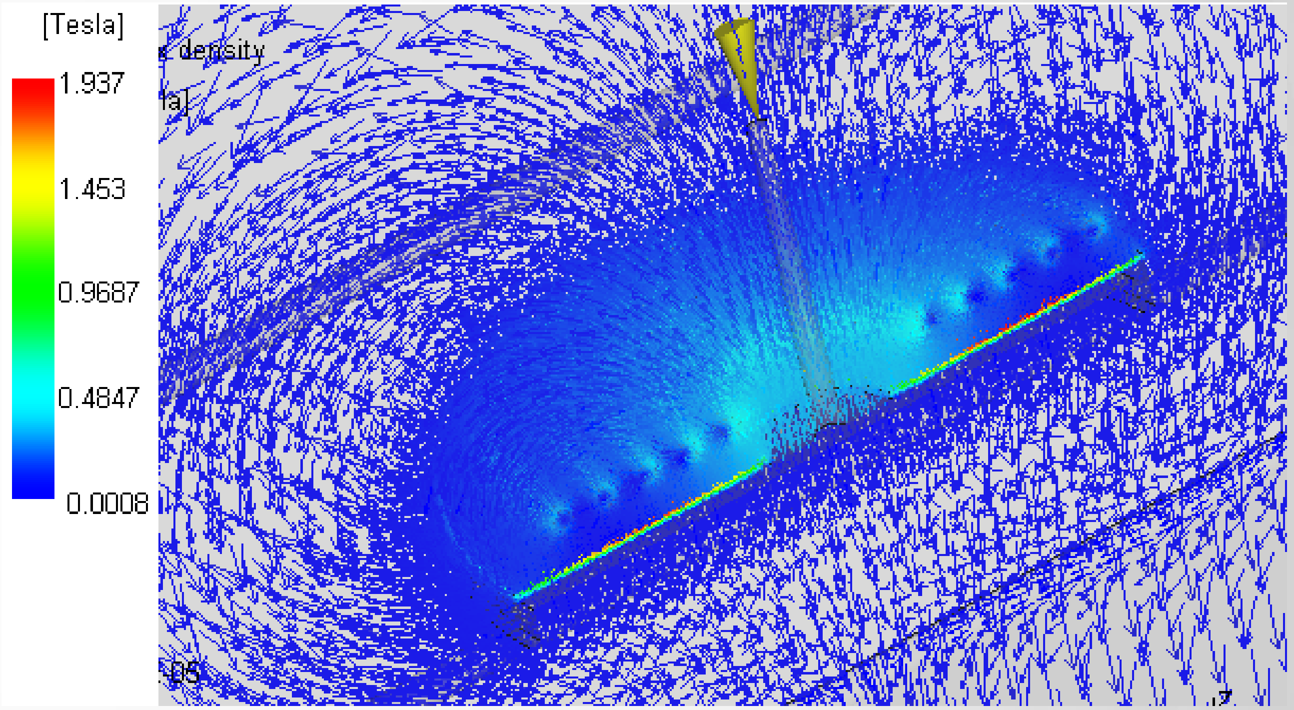


- Predict:
  - Deformation of plastic part during ejection
  - Force required to eject



Summary

- 2015 Scandium Technology Preview
  - Induction Heating
  - Microcellular Foaming
  - Controlled Valve Gate Opening
  - 3D Fiber Inlet
  - Solver API (Viscosity)
  - Retractable Core Pins
  - 3D Residual Stress
  - Ejection Force



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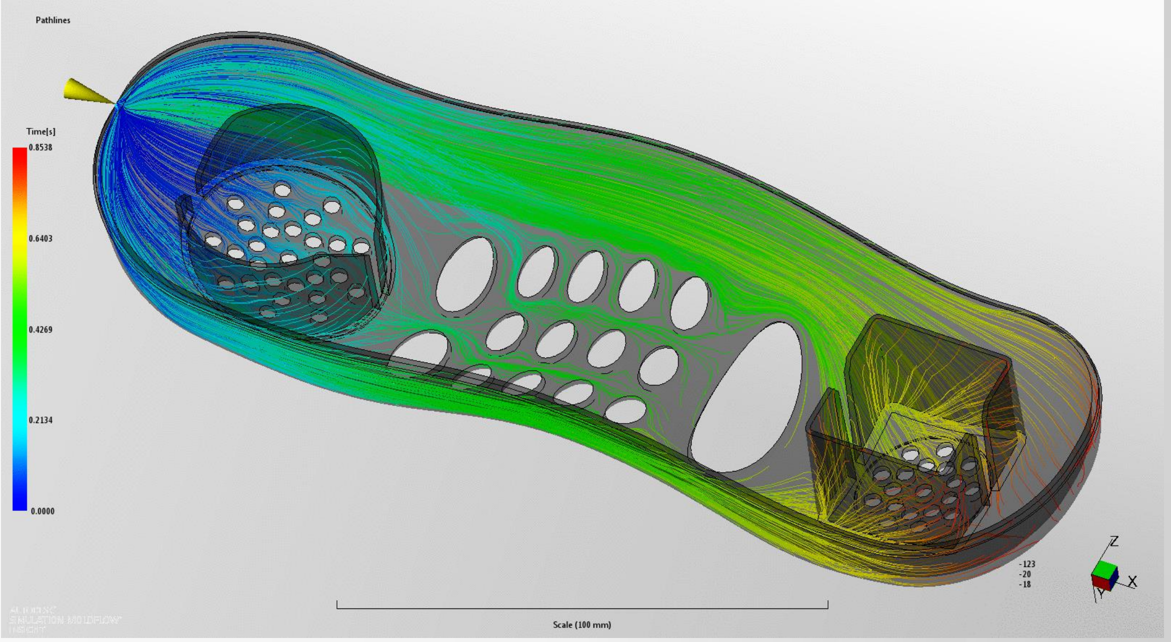
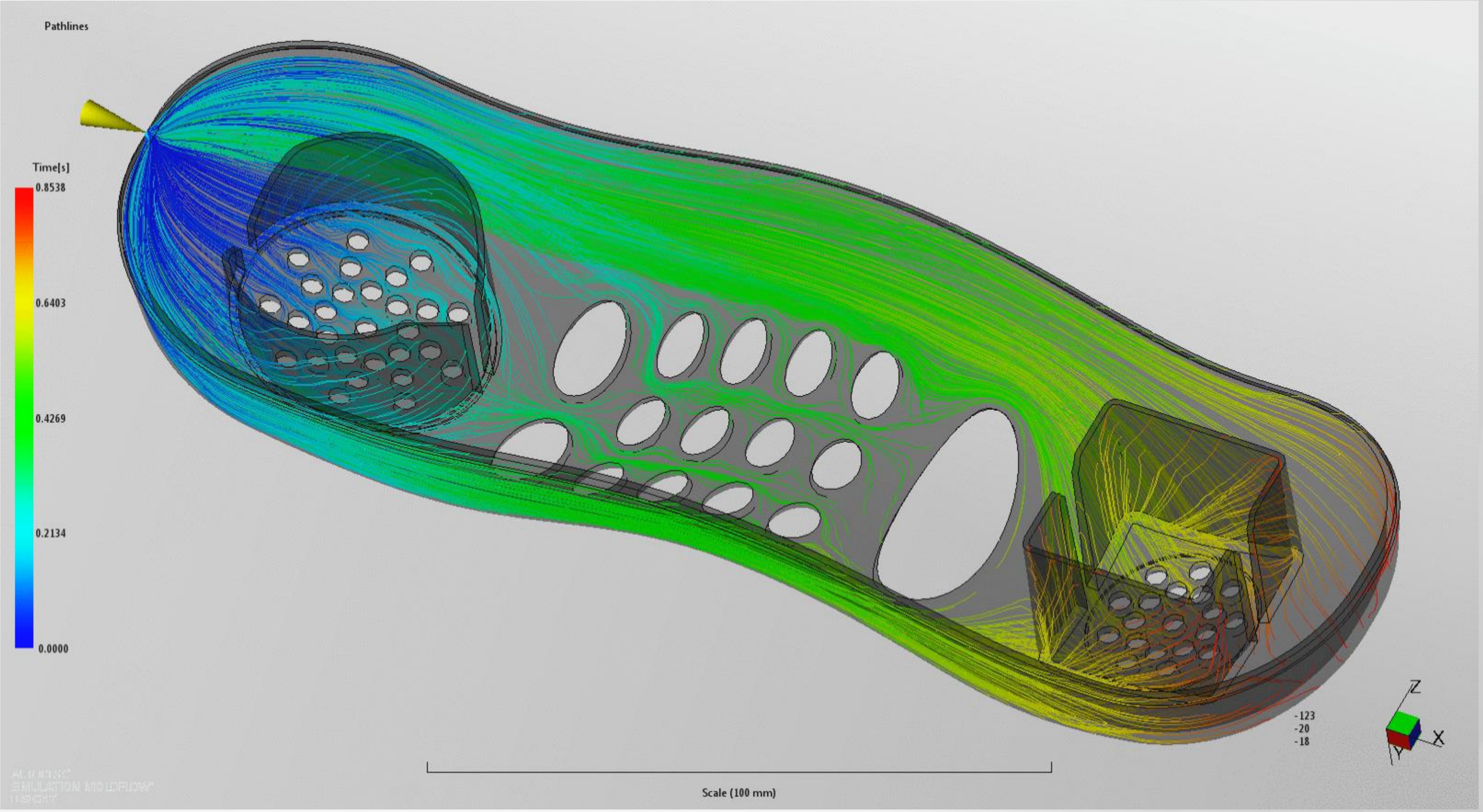


Pathlines

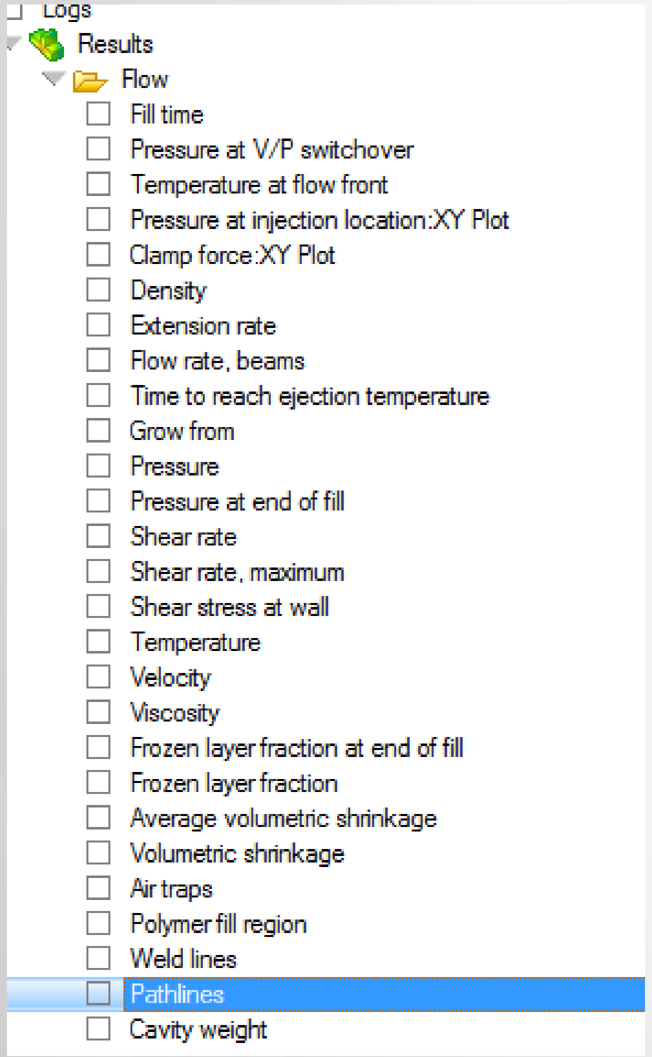
Track the flow path of polymer

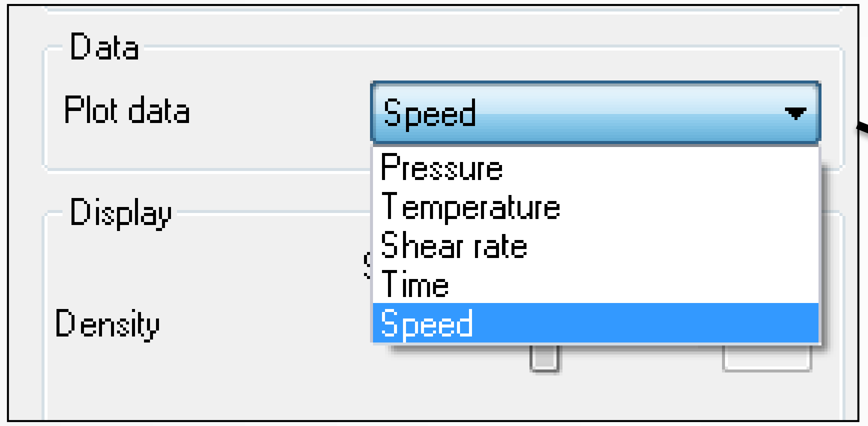
- Overlay with
  - Time
  - Temperature
  - Pressure
  - Speed
  - Shear Rate

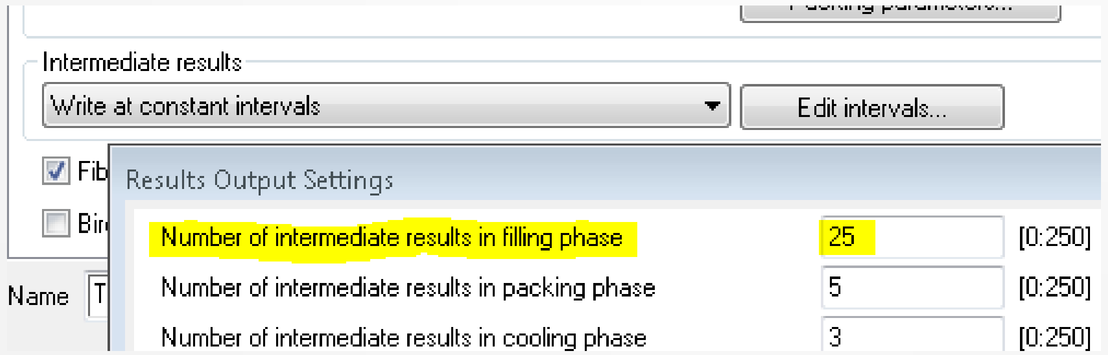


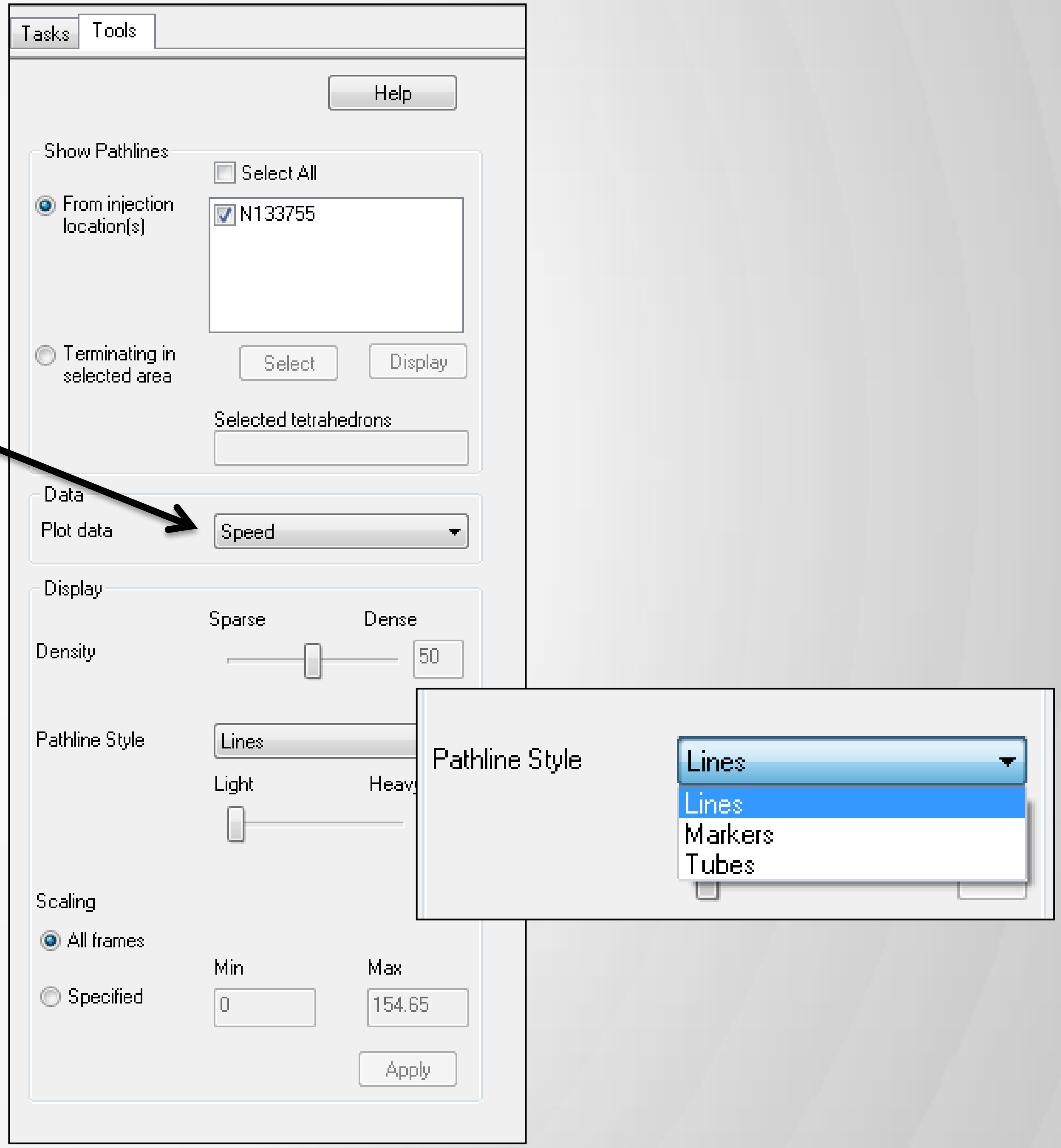
Pathlines: Where to find them

- Already in the default result list
- Old Studies: Rerun in 2016



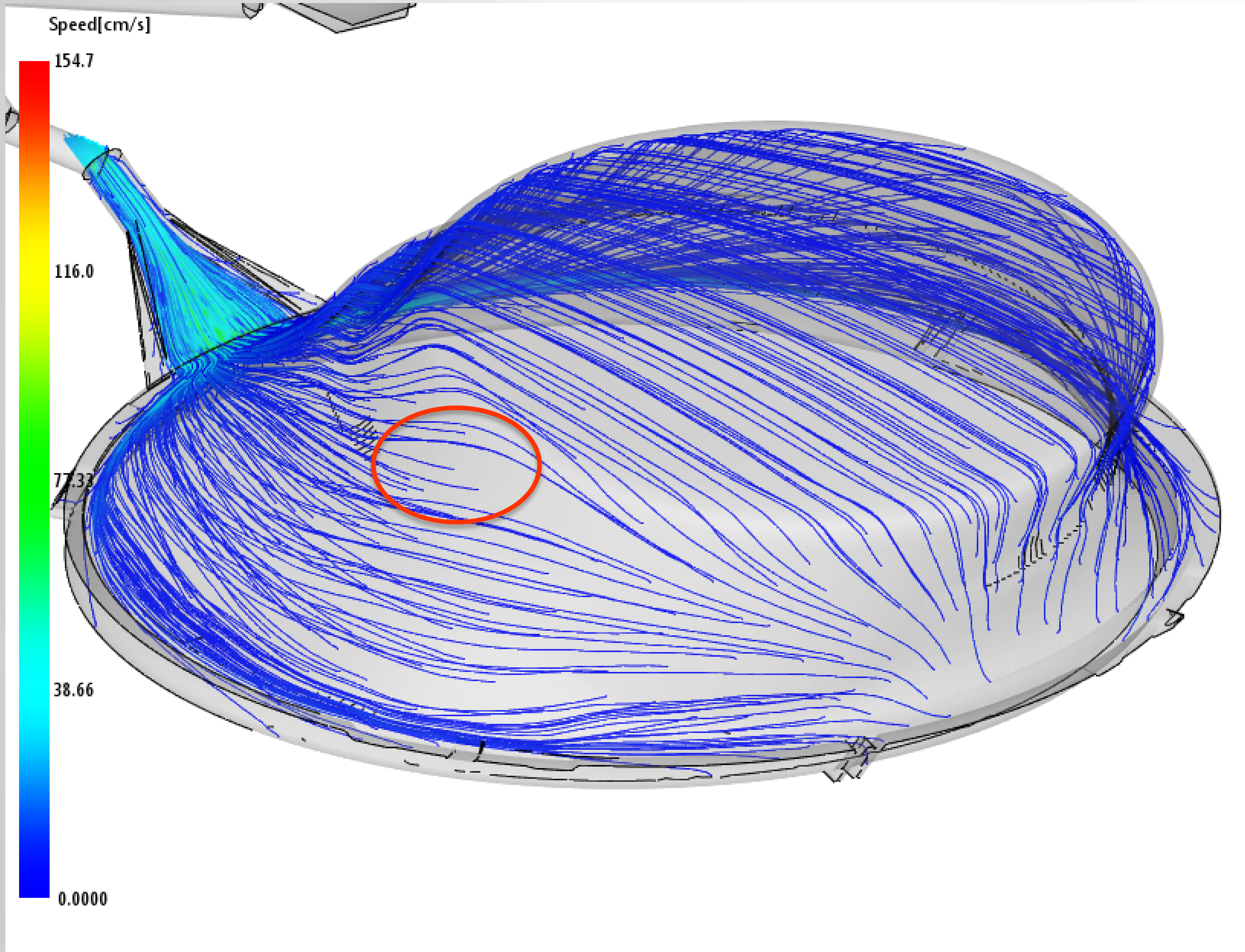


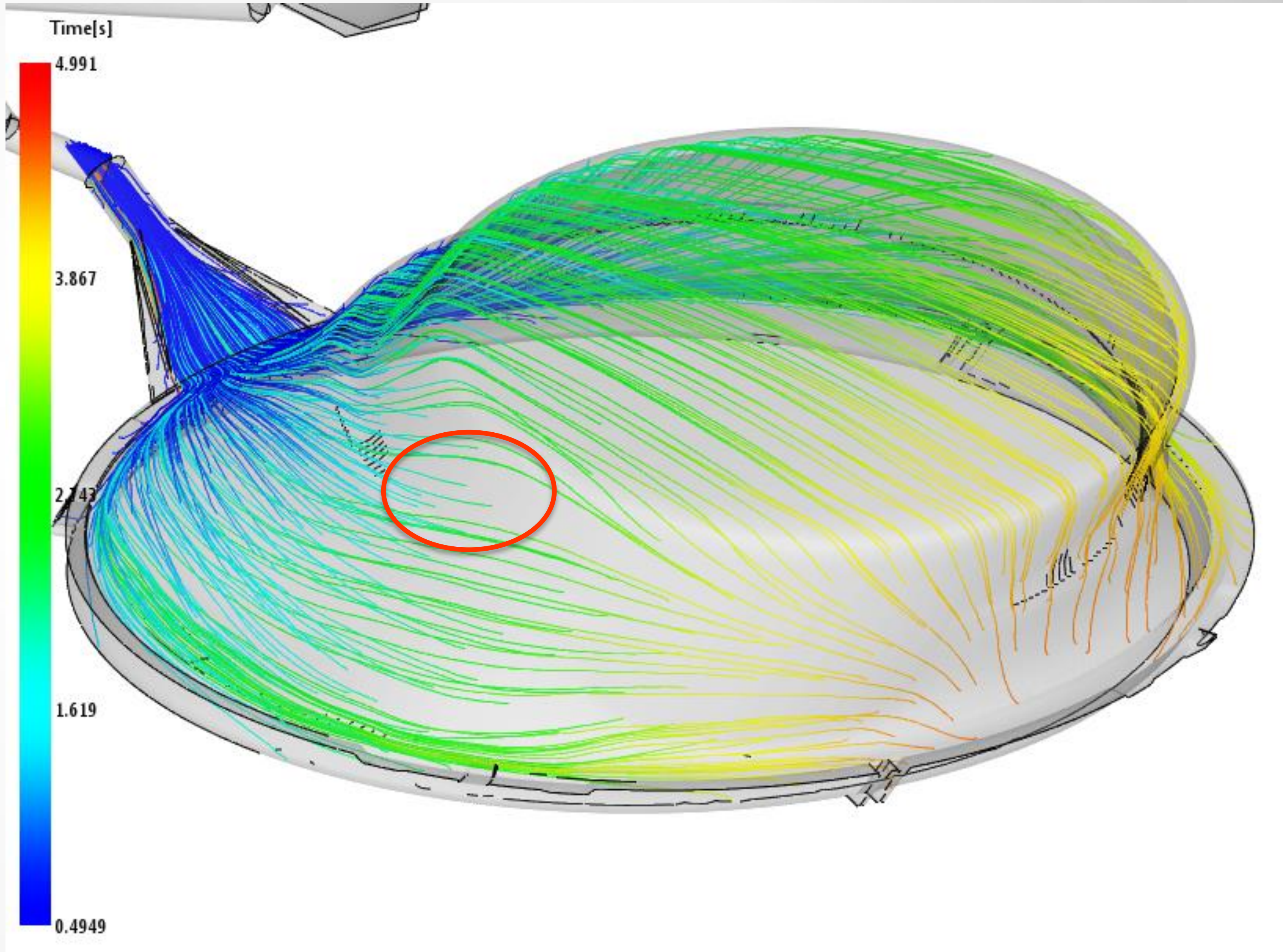




Pathlines: Speed & Time Results

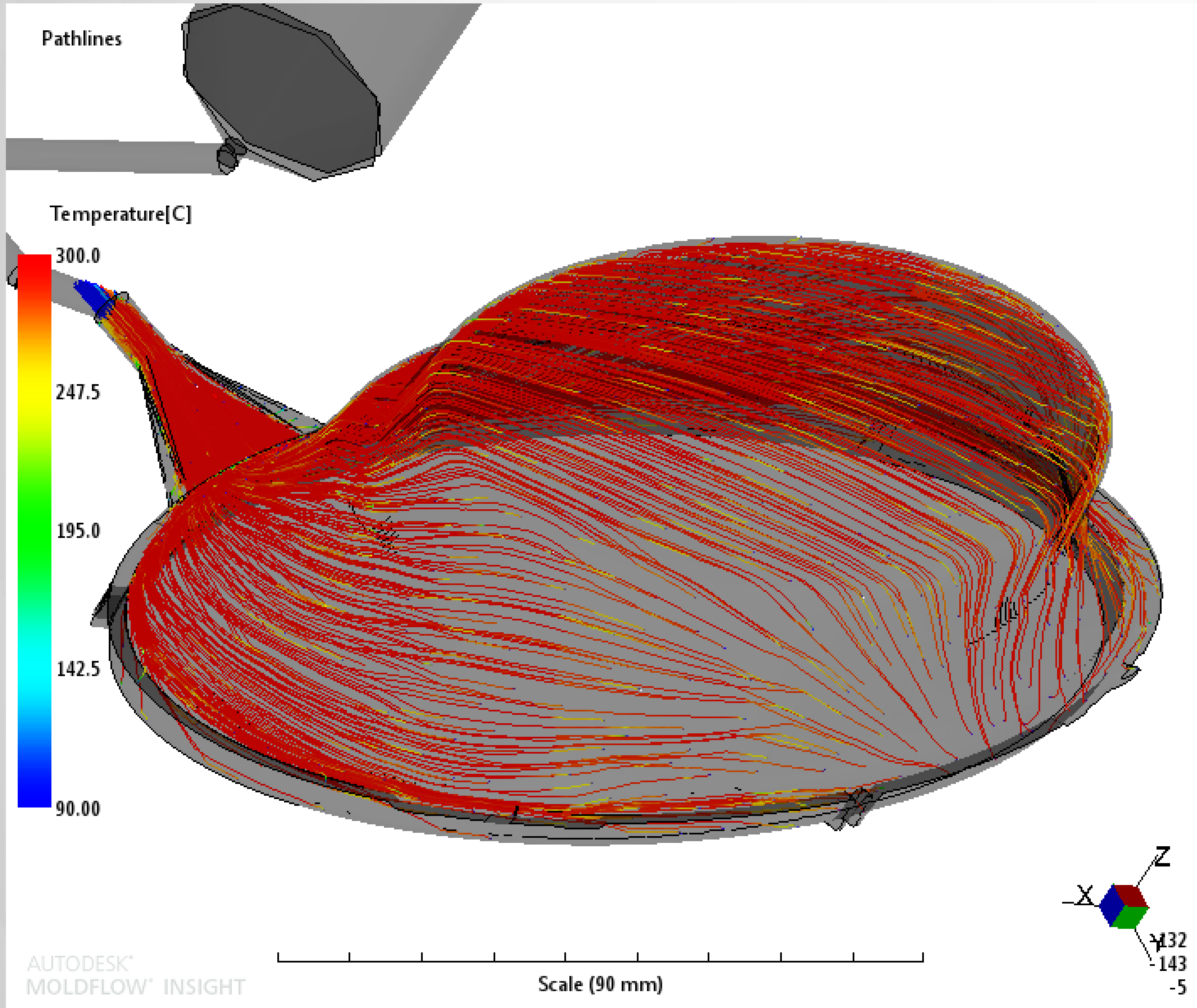
Notice: Not all paths reach the end of flow!



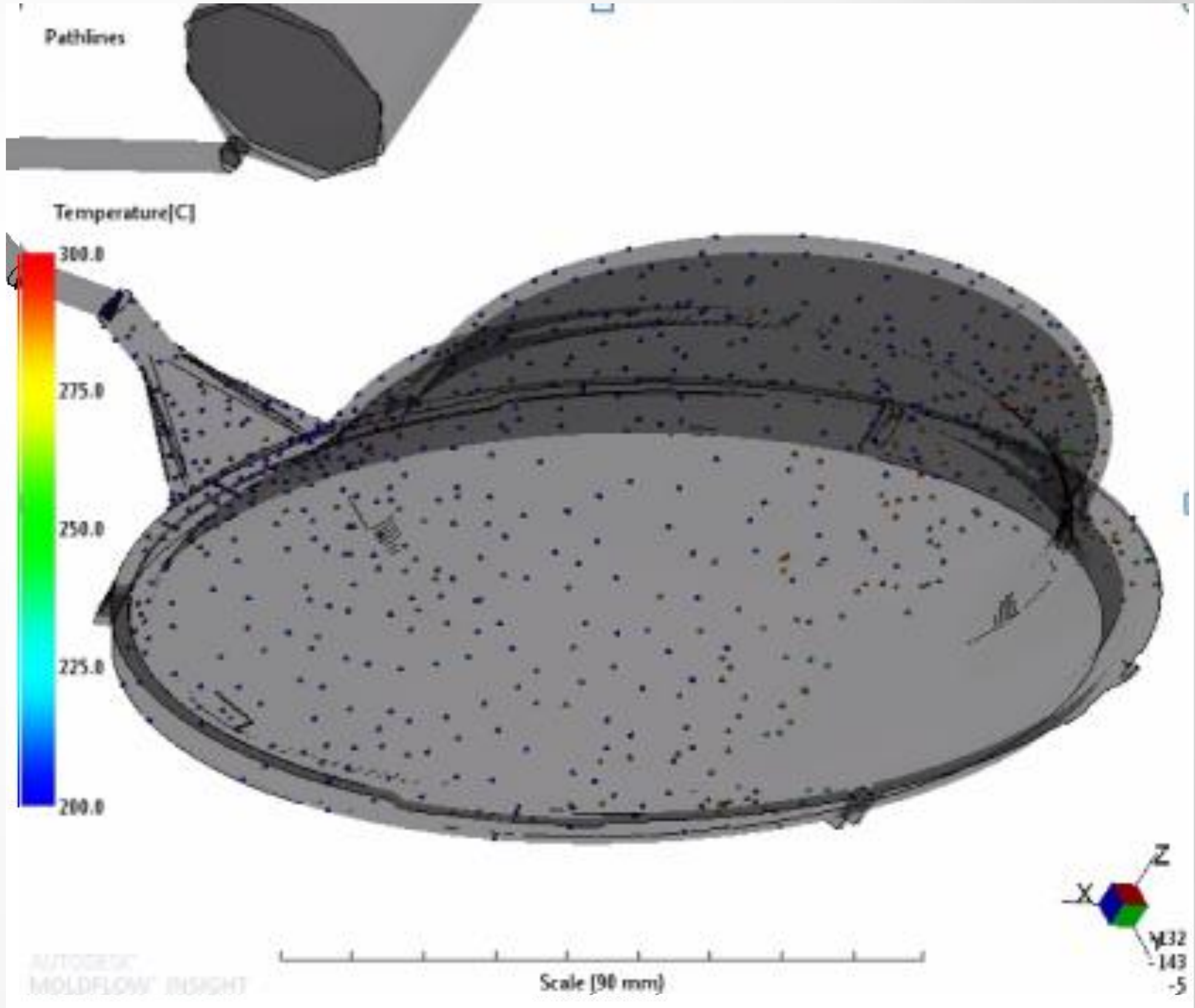


Pathlines: Temperature Result

Lines

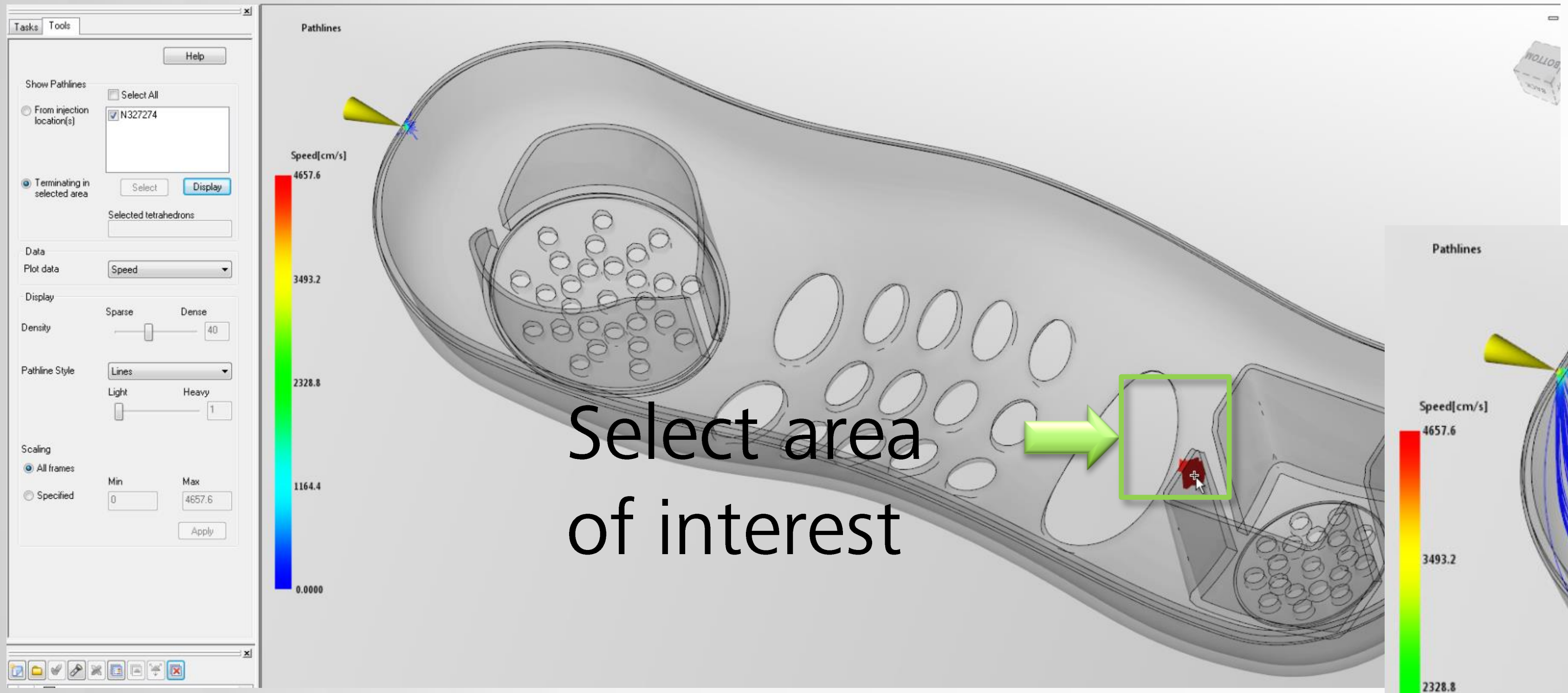


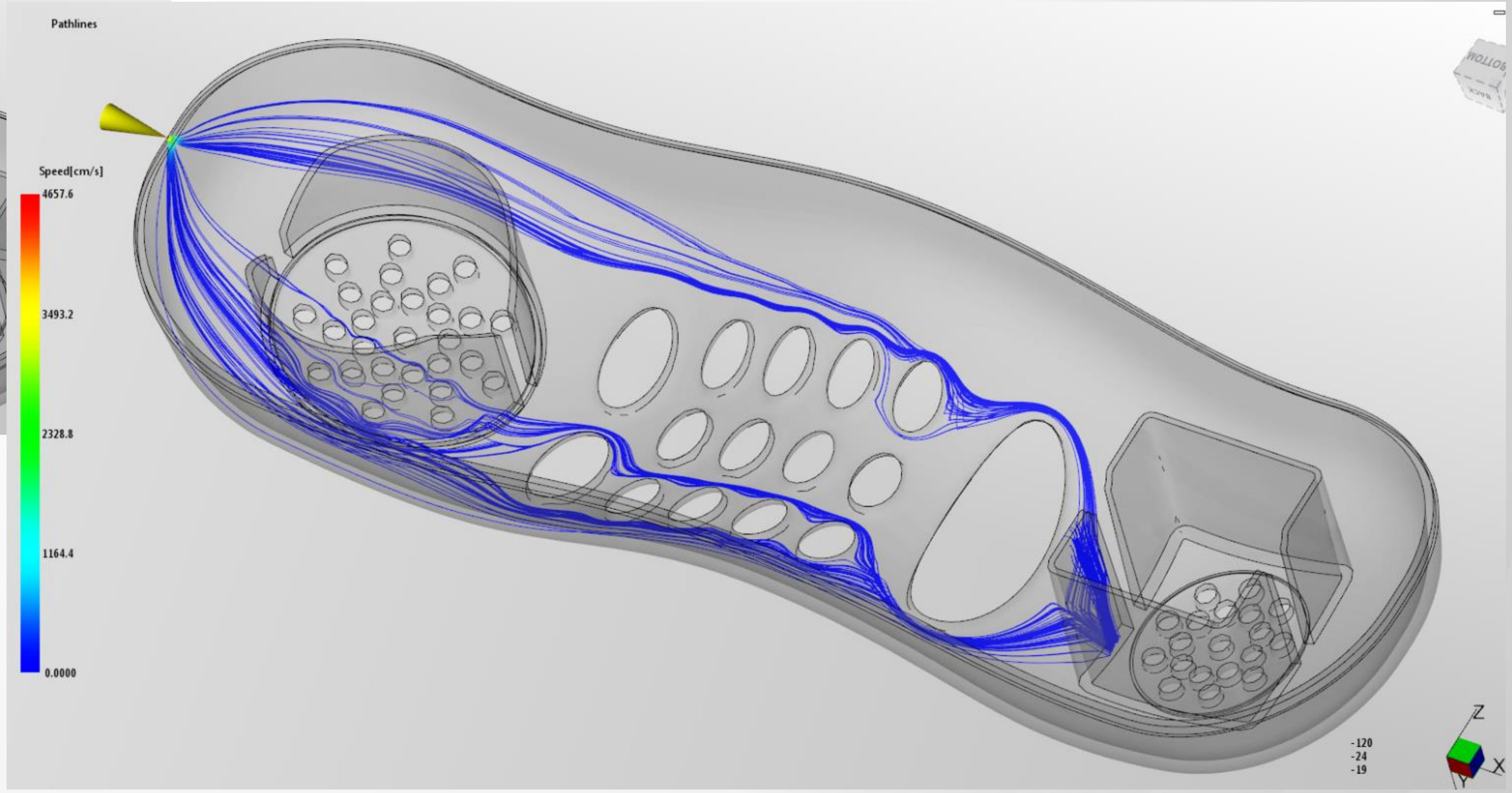
Markers



Pathlines: Examine paths terminating in a selected area

Choose to show only the path lines which terminate at a specified location





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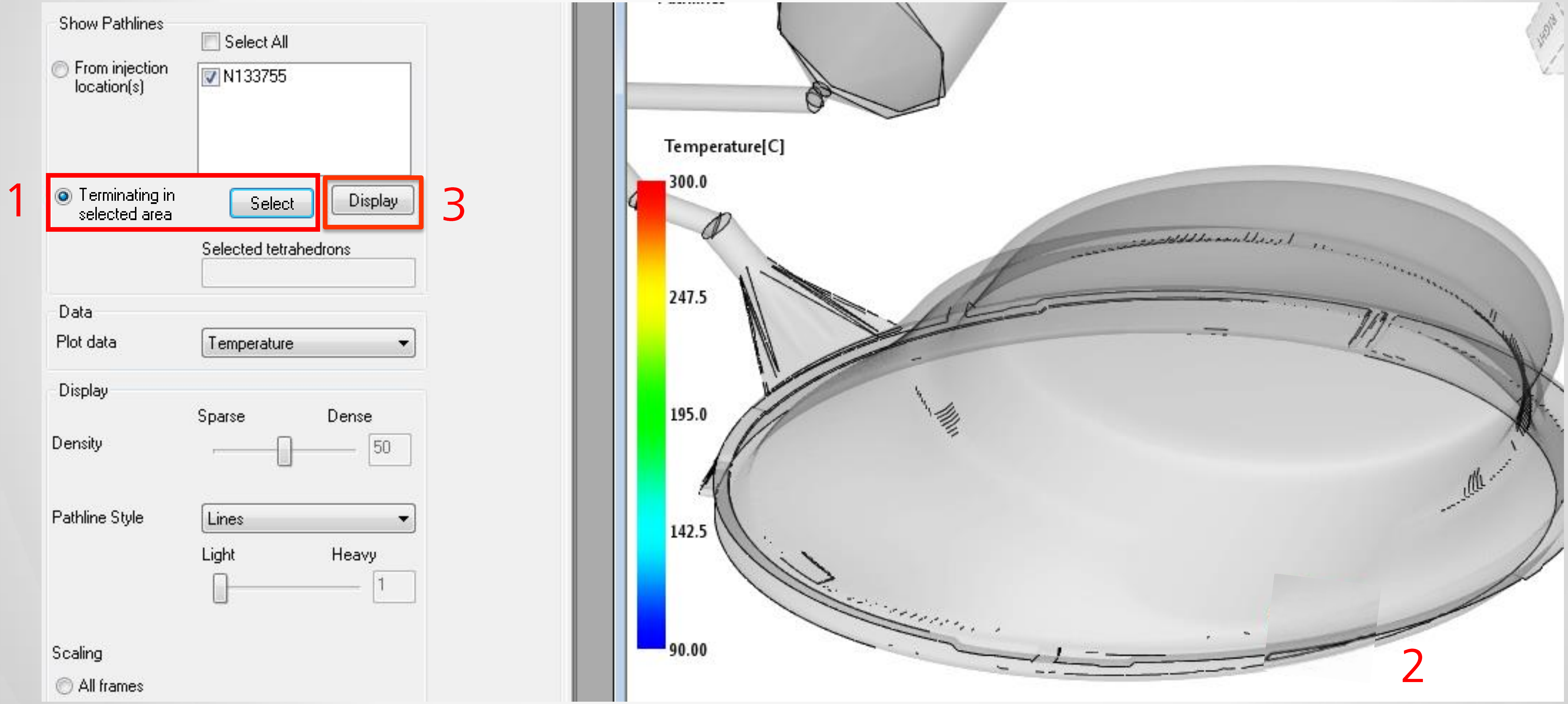
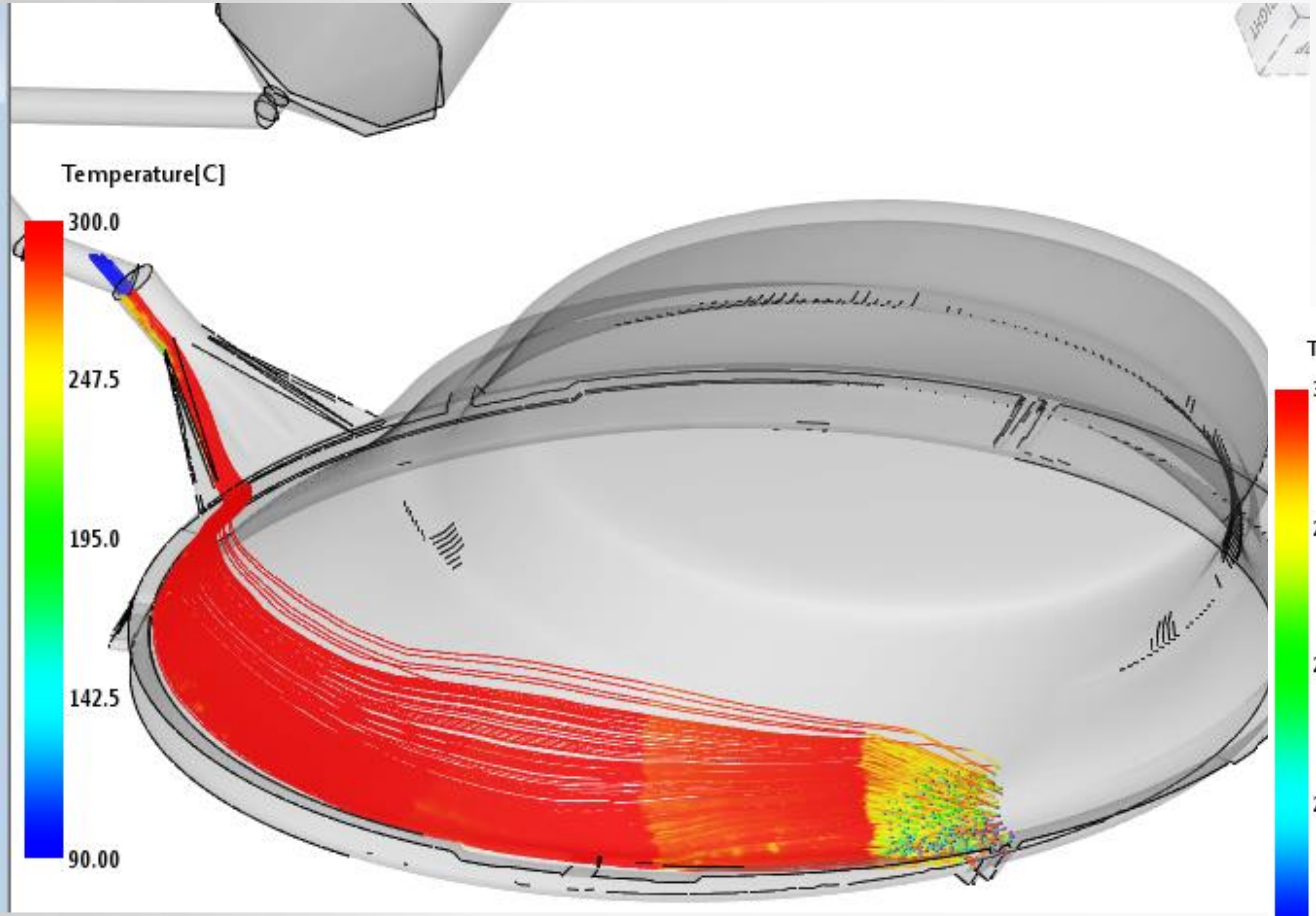
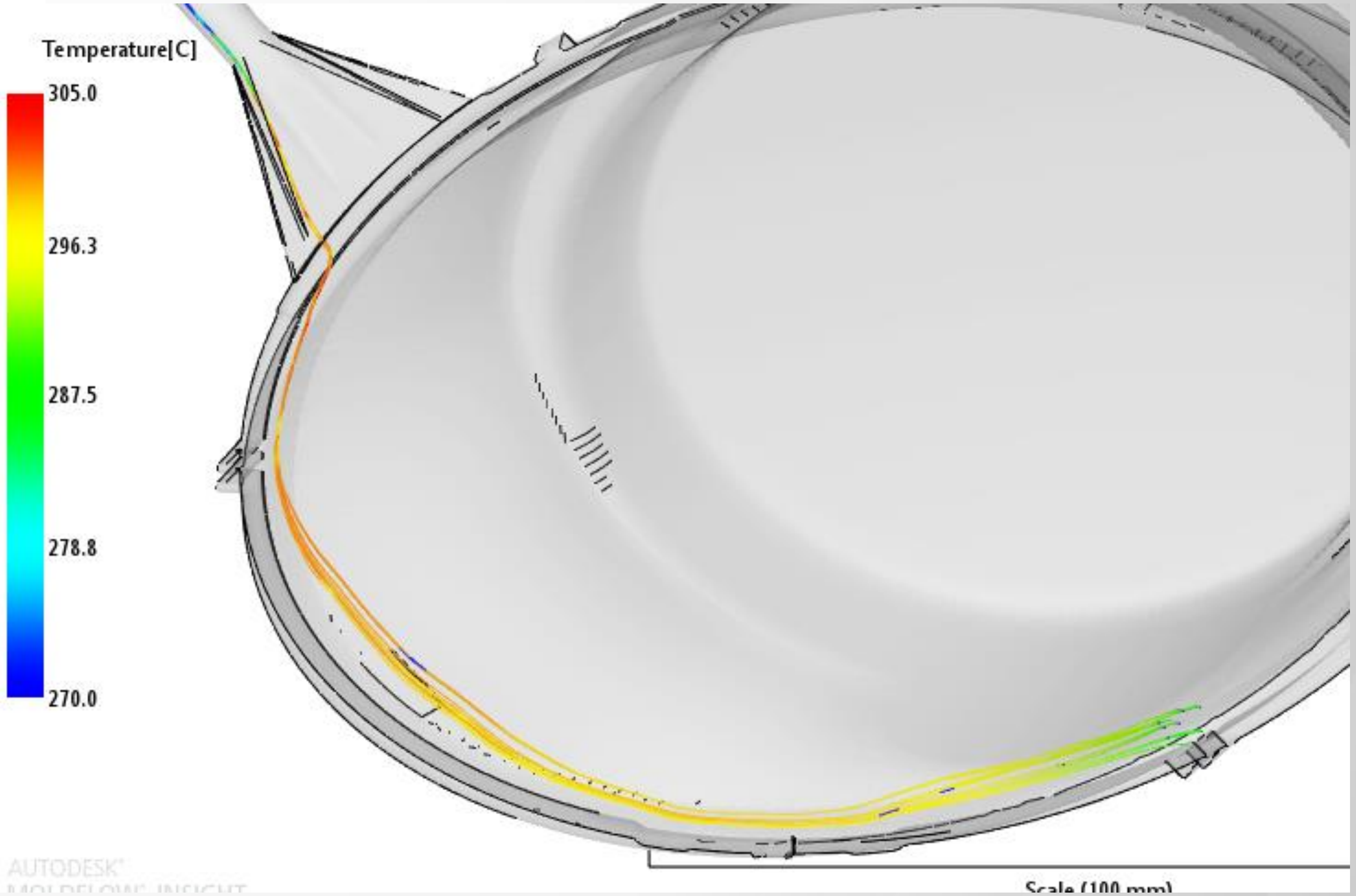


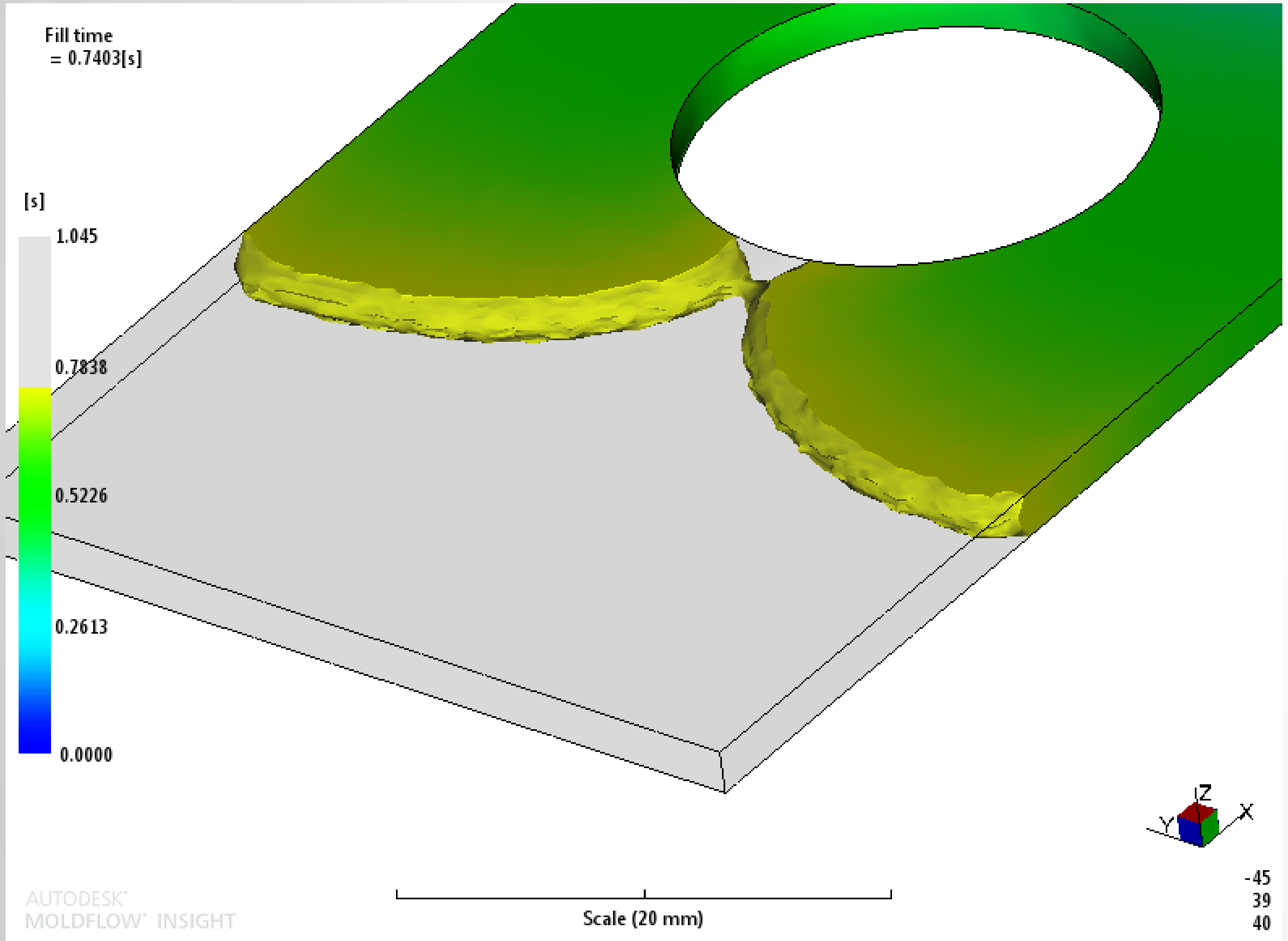
Pathlines: Examine paths terminating in a selected area

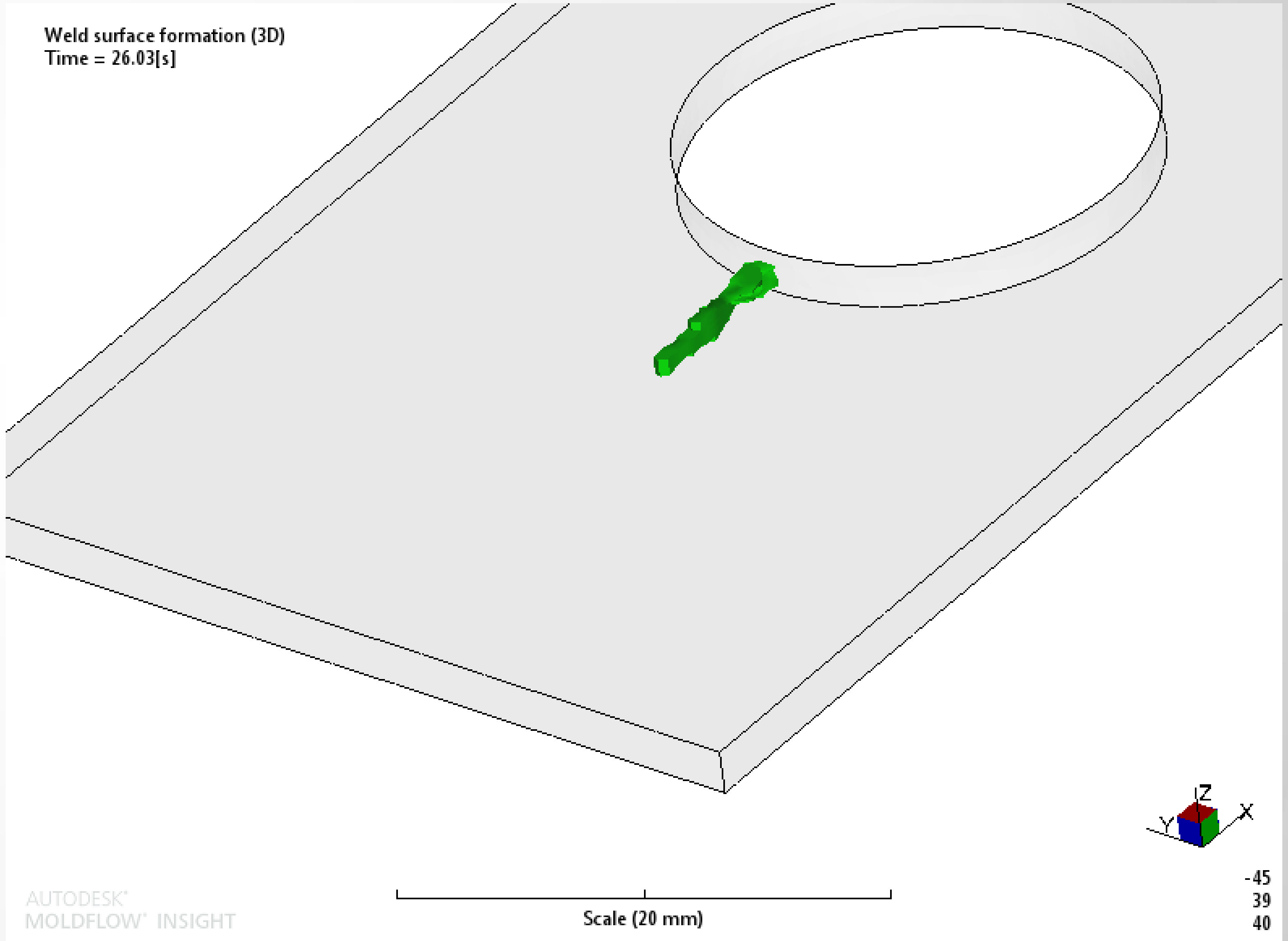




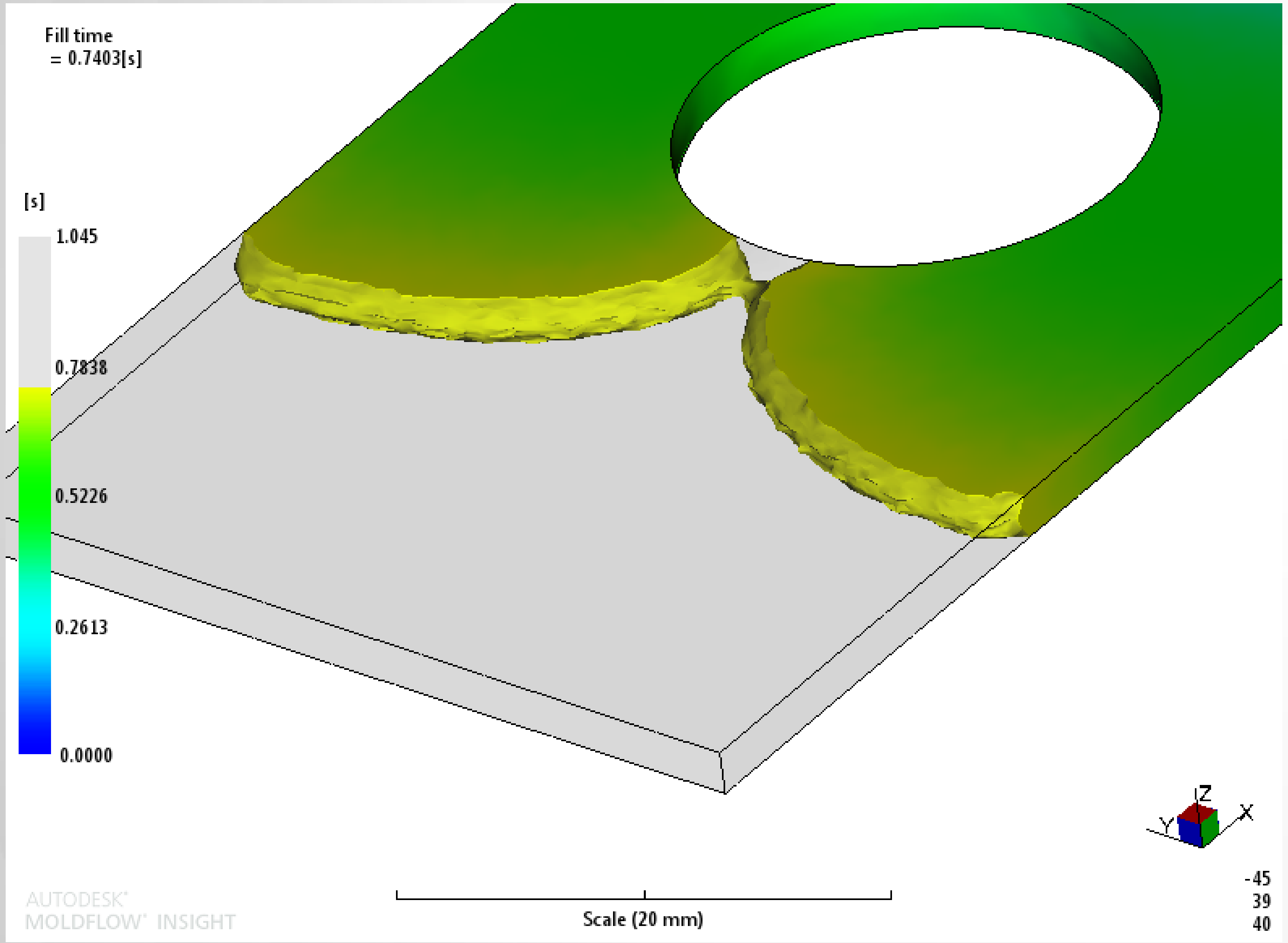
Visualize 3D Weld-Surfaces

Initial Weld Surface Position

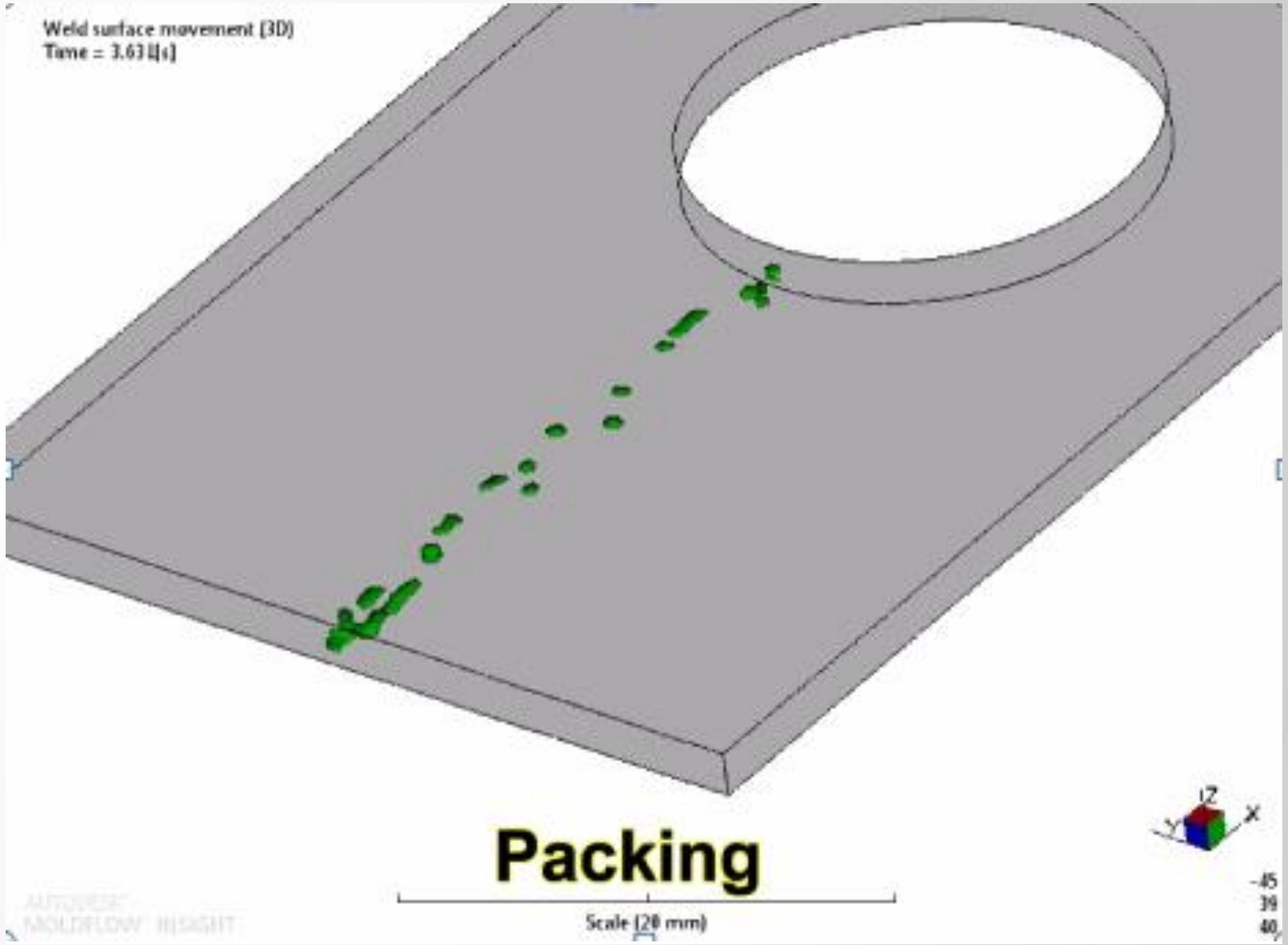




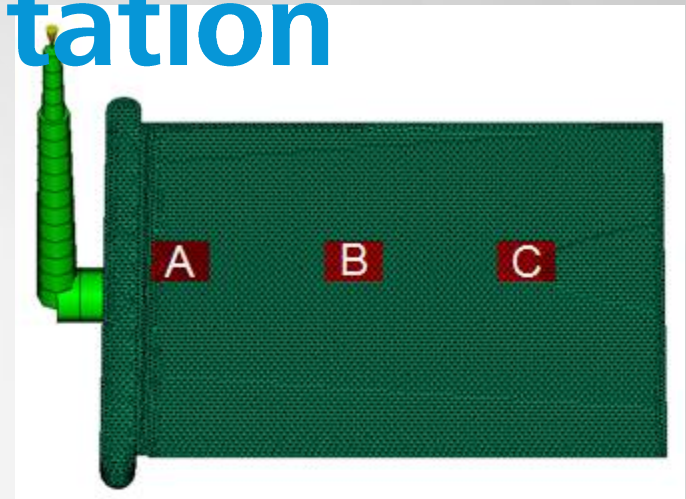
Visualize 3D Weld-Surfaces



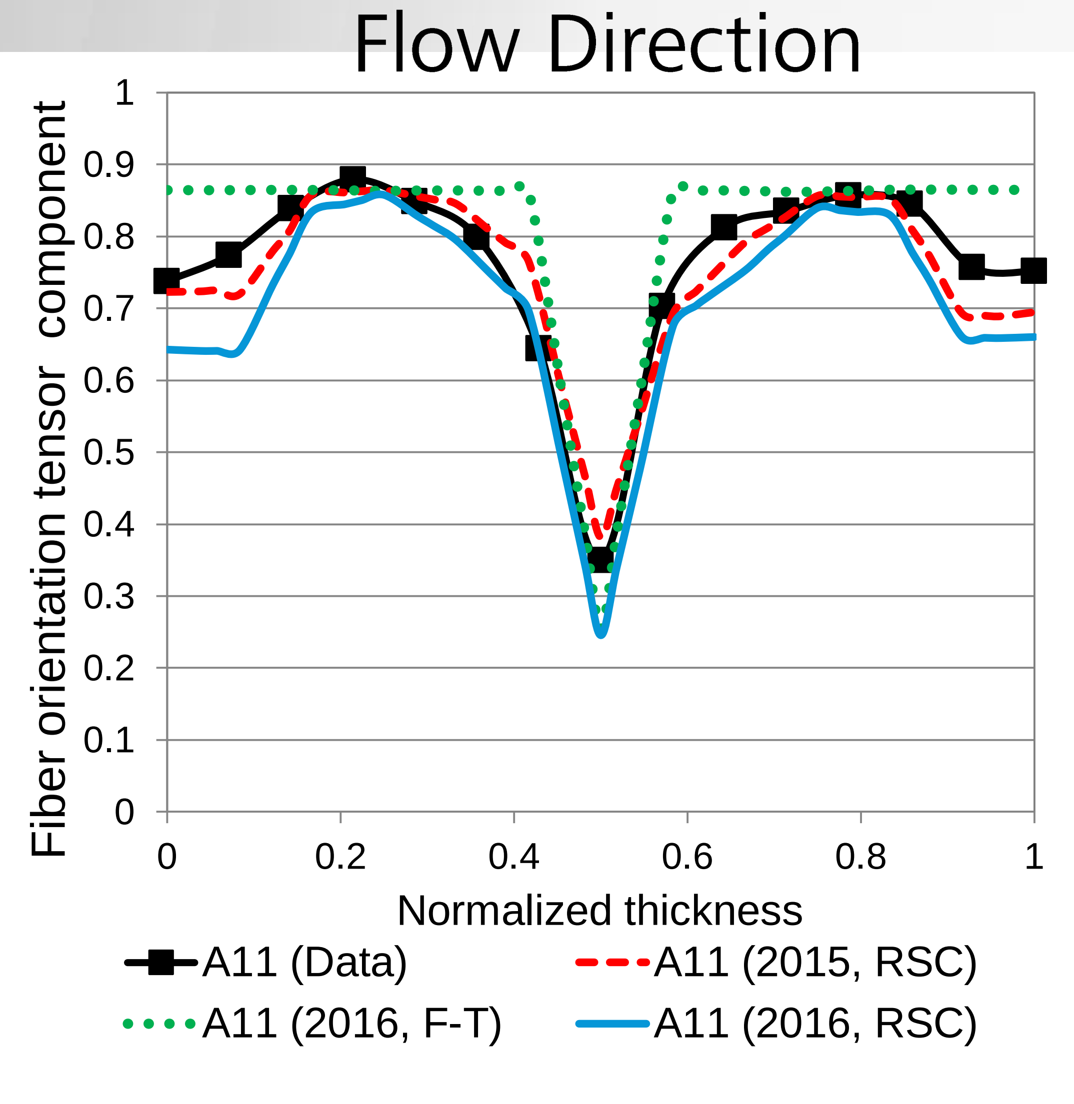
Animate Weld Surface

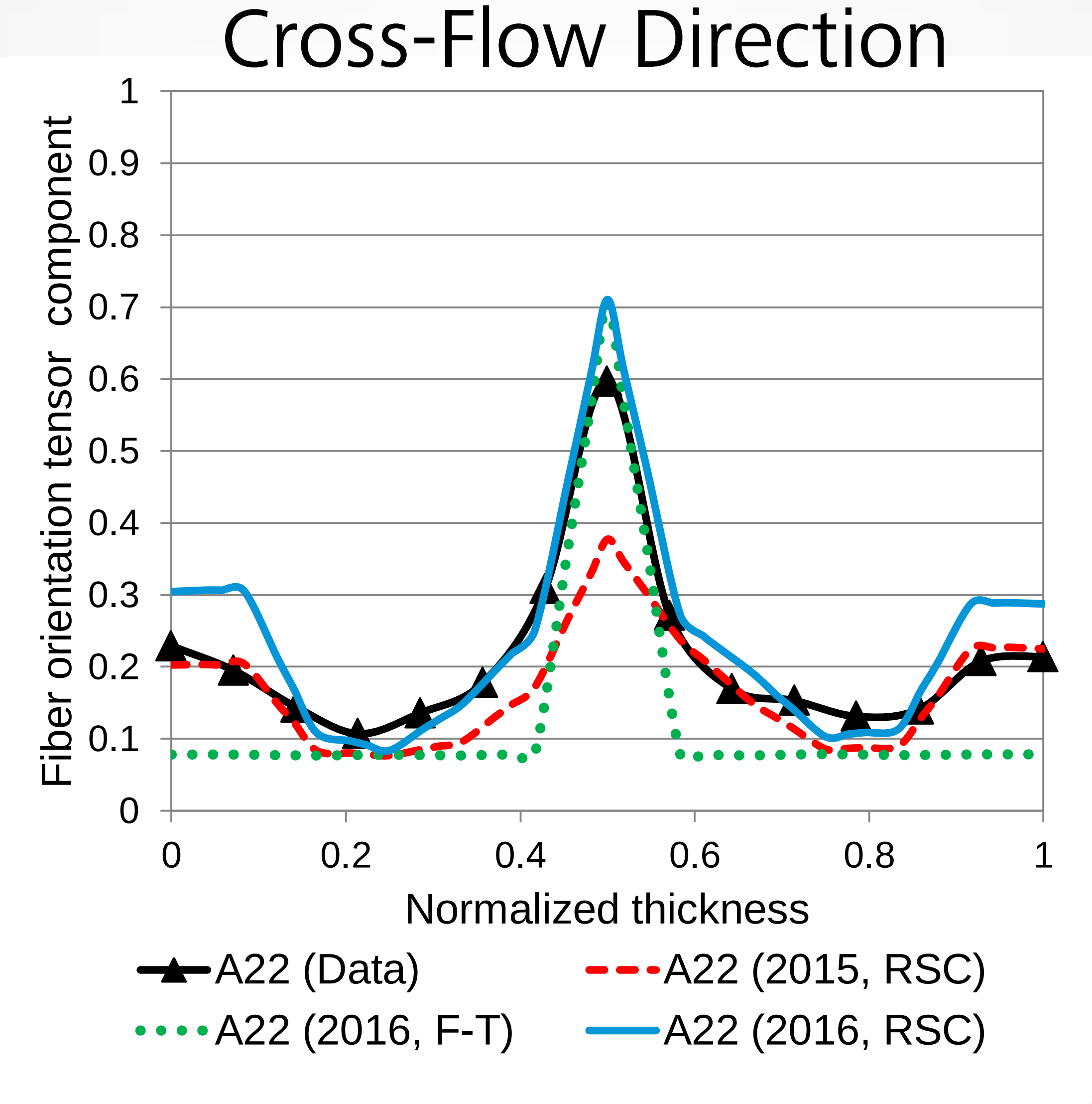


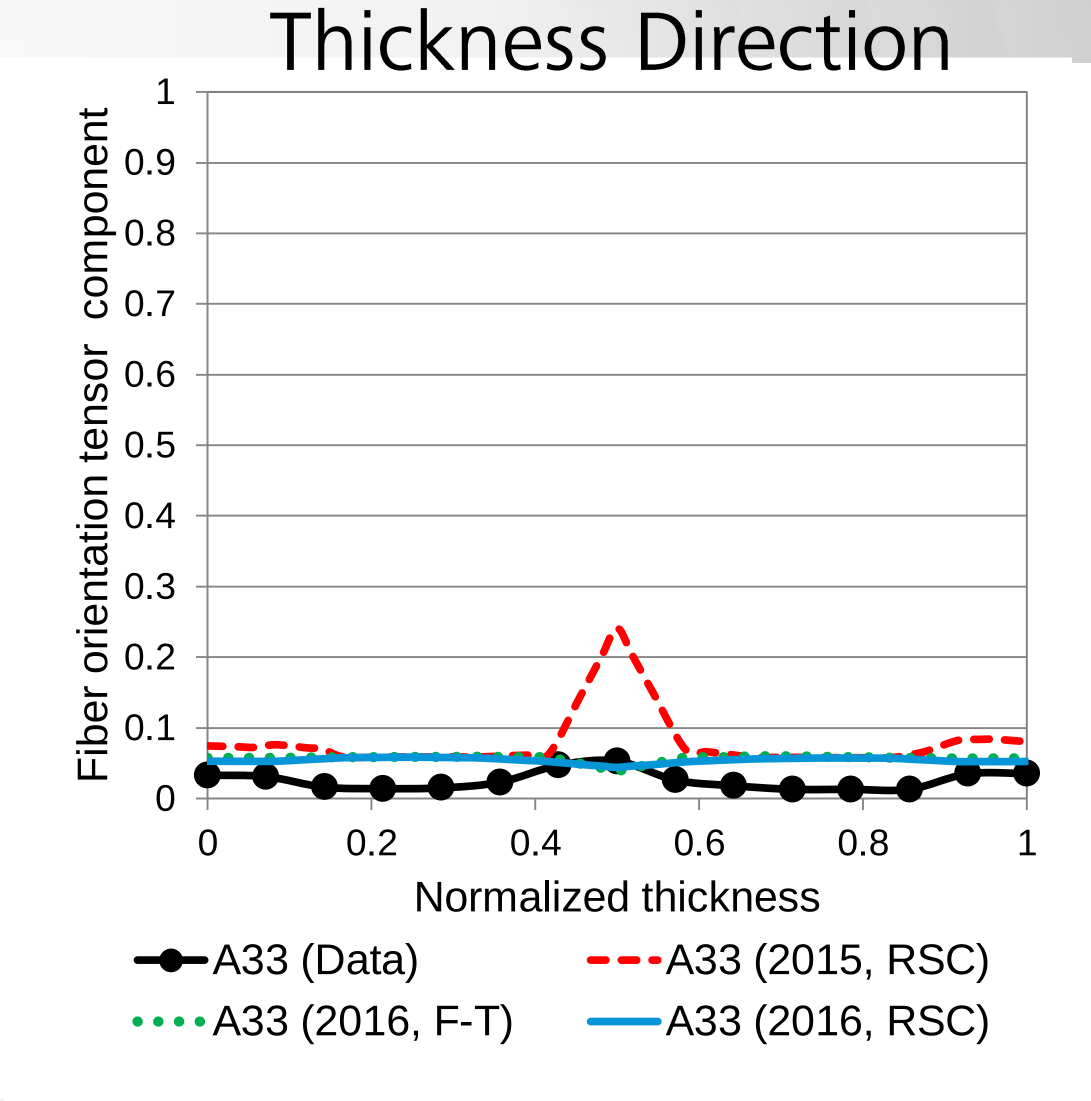
Improved RSC predictions for 3D Fiber Orientation



Delphi Iso-plaque: 2mm thick. 30wt%GF/PBT, Slow fill, Location B



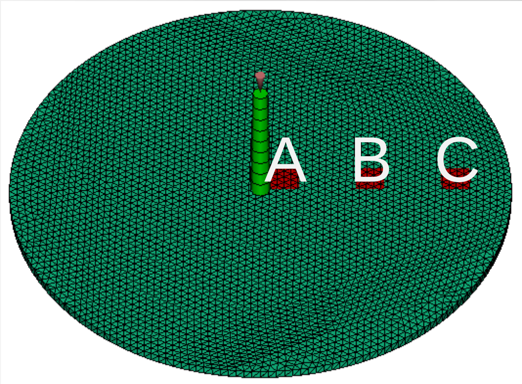


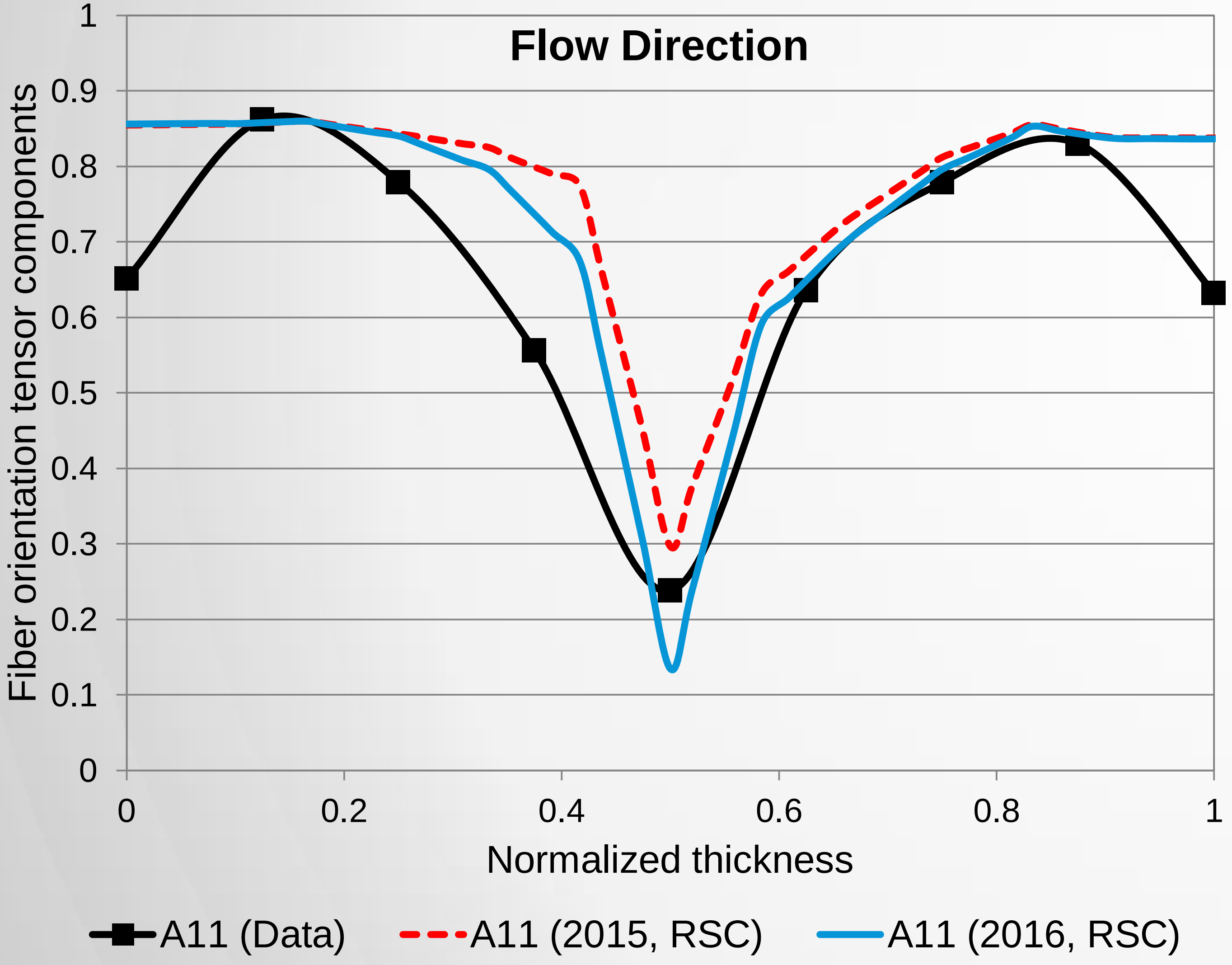


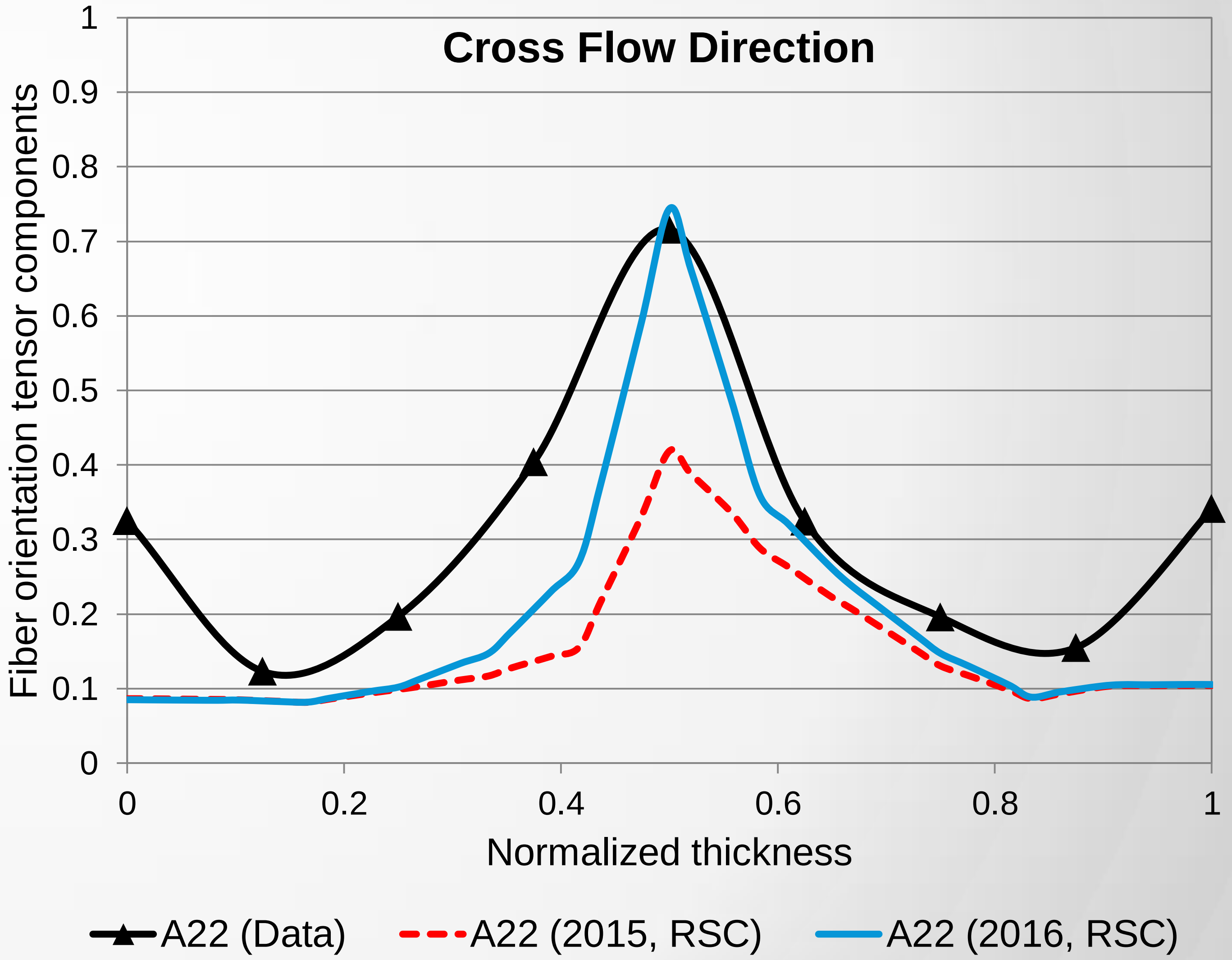
J. Wang, "Improved Fiber Orientation Predictions For Injection-molded Composites," Ph.D. Thesis, UIUC, Urbana, IL, 2007.

Improved RSC predictions for 3D Fiber Orientation

Delphi Disk: 1.5mm thick. 30wt%GF/PBT, Slow fill, Location B



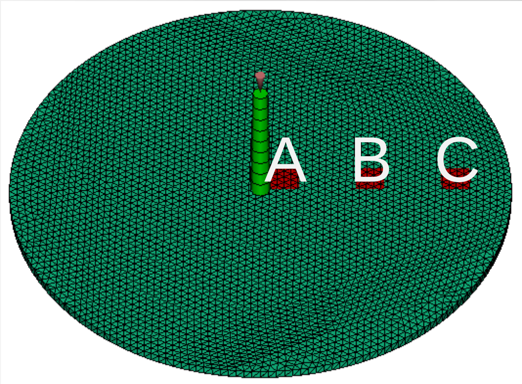


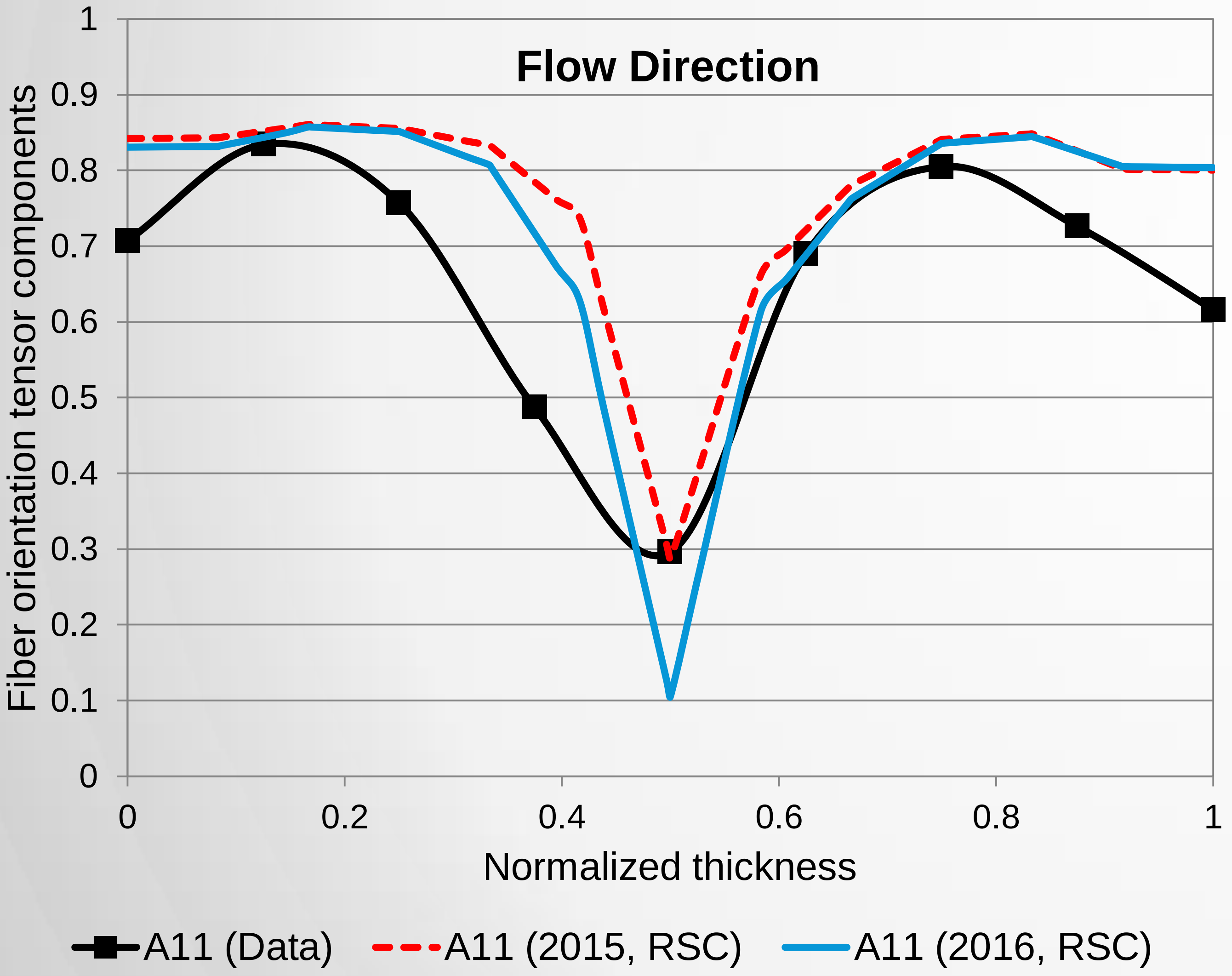


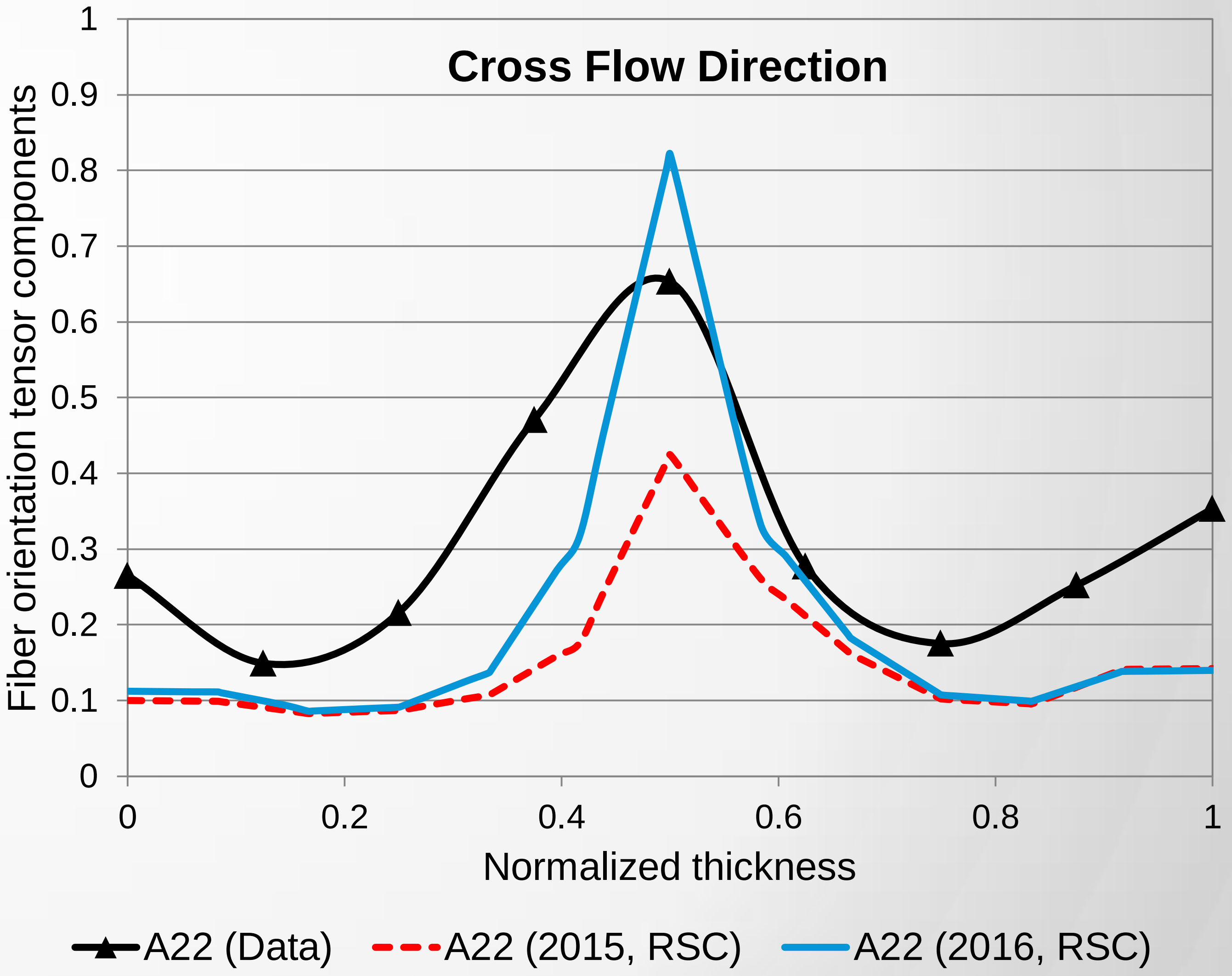
J. Wang, "Improved Fiber Orientation Predictions For Injection-molded Composites," Ph.D. Thesis, UIUC, Urbana, IL, 2007.

Improved RSC predictions for 3D Fiber Orientation

Delphi Disk: 1.5mm thick. 30wt%GF/PBT,
Slow fill, Location C



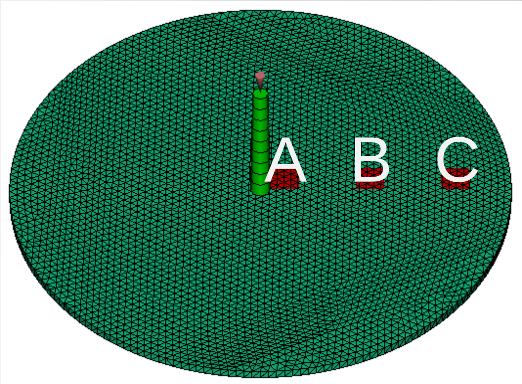


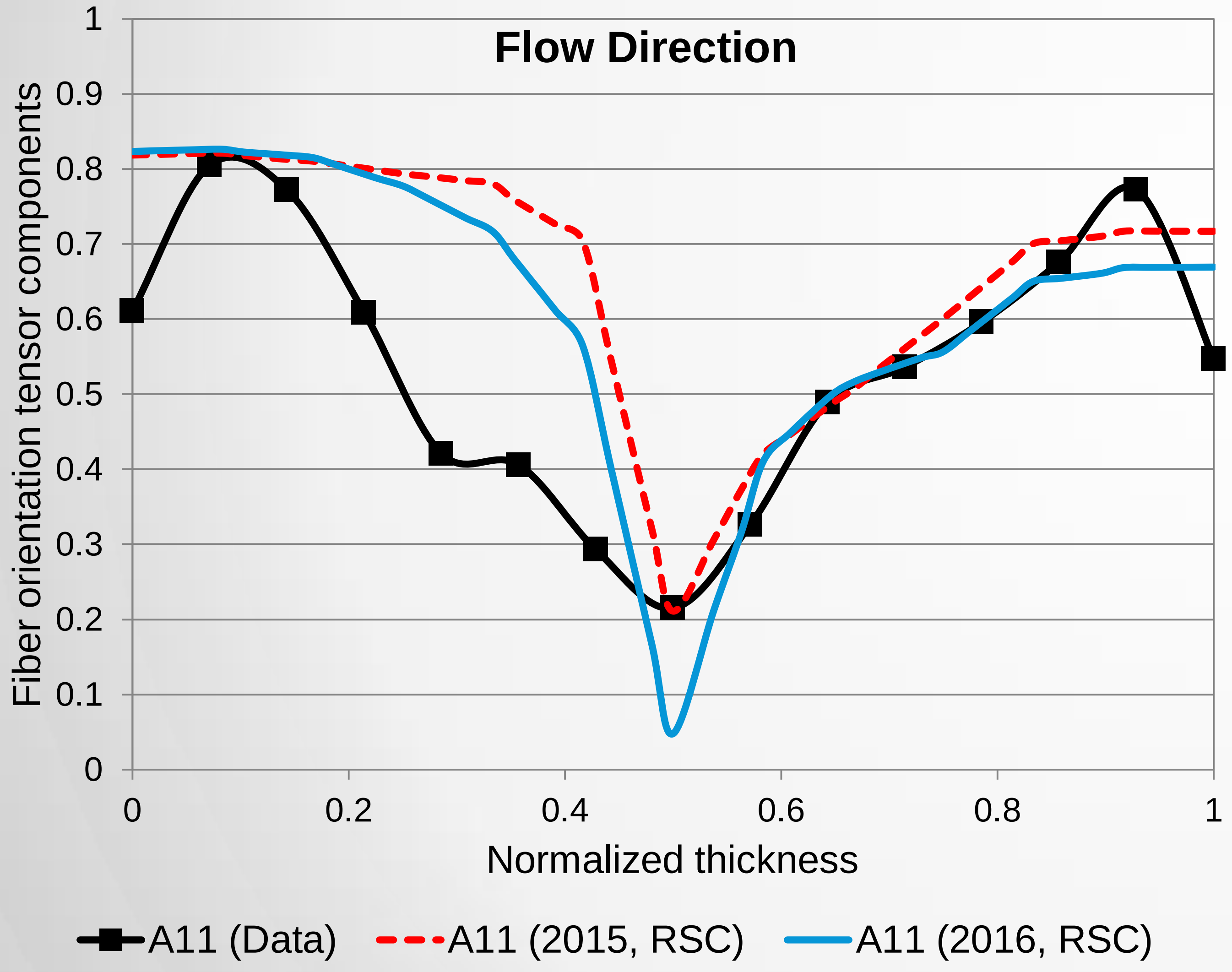


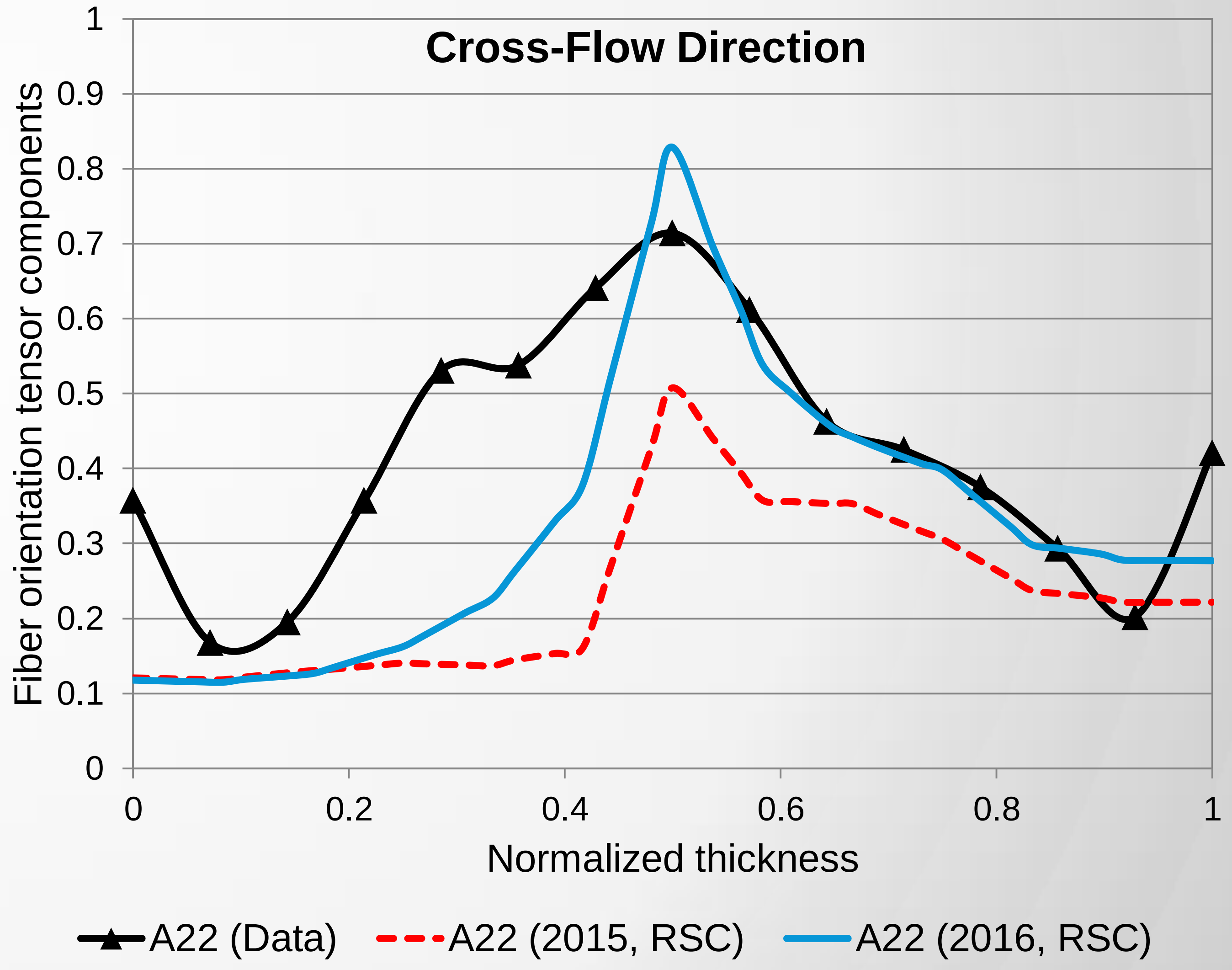
J. Wang, "Improved Fiber Orientation Predictions For Injection-molded Composites," Ph.D. Thesis, UIUC, Urbana, IL, 2007.

Improved RSC predictions for 3D Fiber Orientation

Delphi Disk: 6mm thick. 30wt%GF/PBT,
Medium Flow Rate, Location B



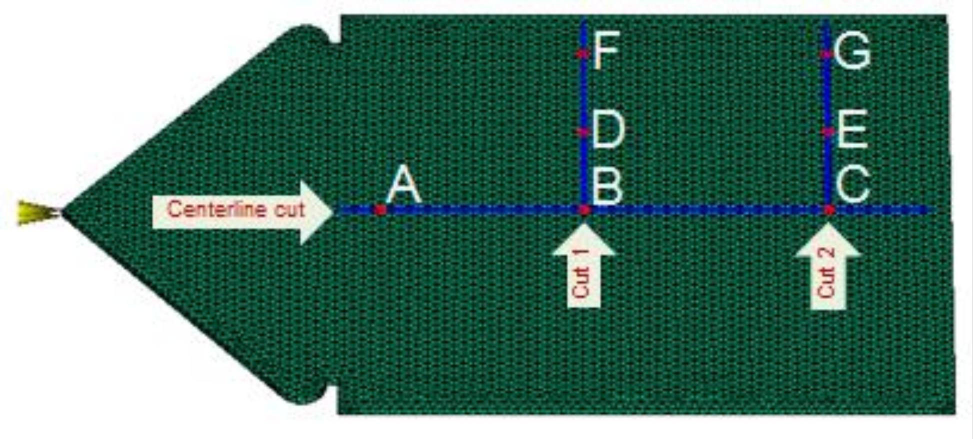


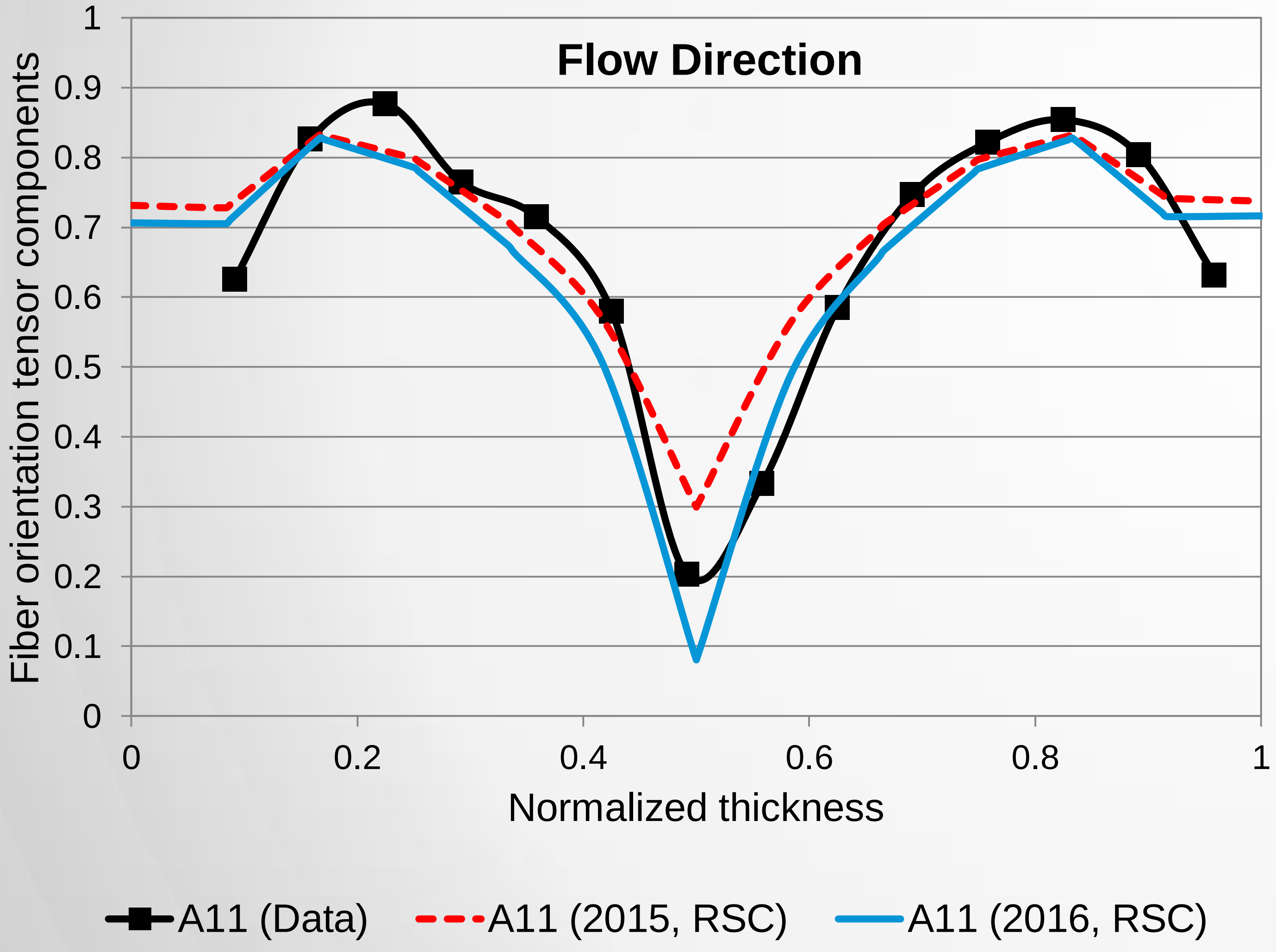


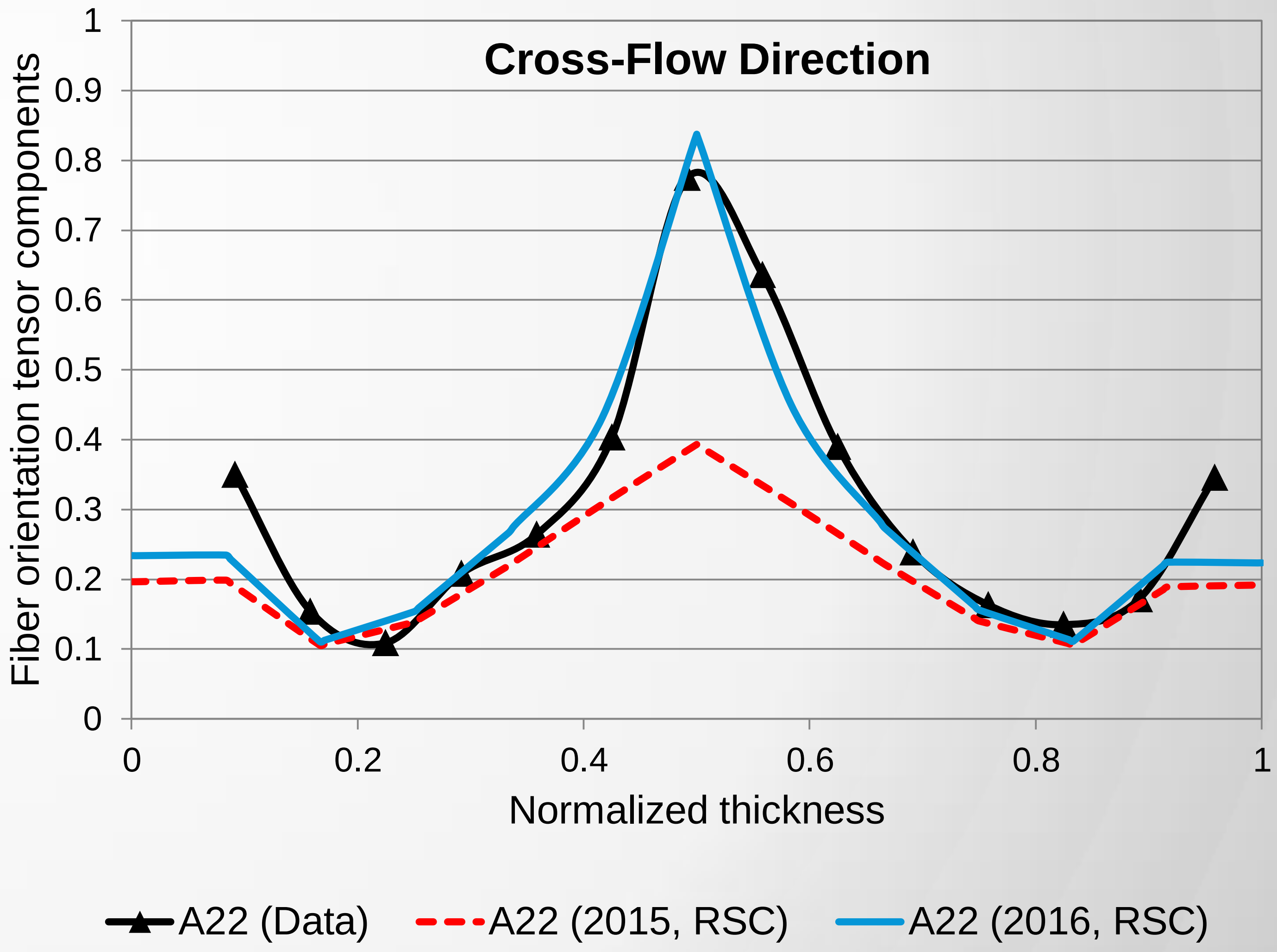
J. Wang, “Improved Fiber Orientation Predictions For Injection-molded Composites,” Ph.D. Thesis, UIUC, Urbana, IL, 2007.

Improved RSC predictions for 3D Fiber Orientation

BASF Plaque: 4mm thick. 30wt%GF PA66, Location B



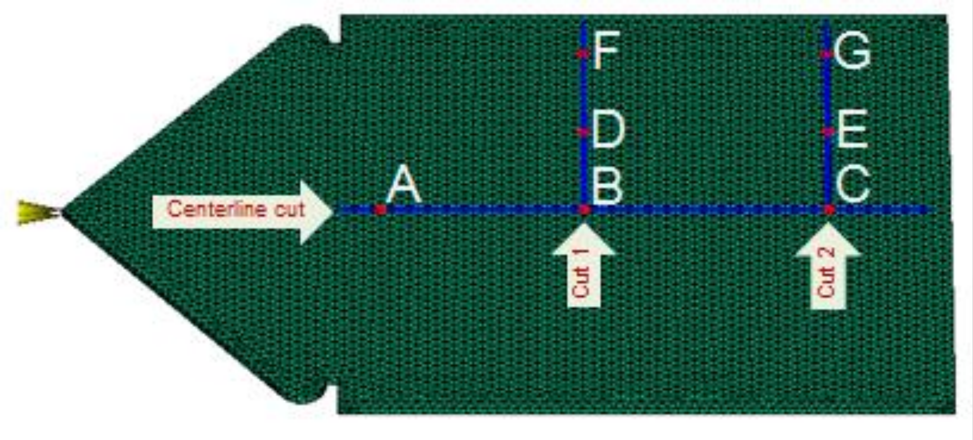


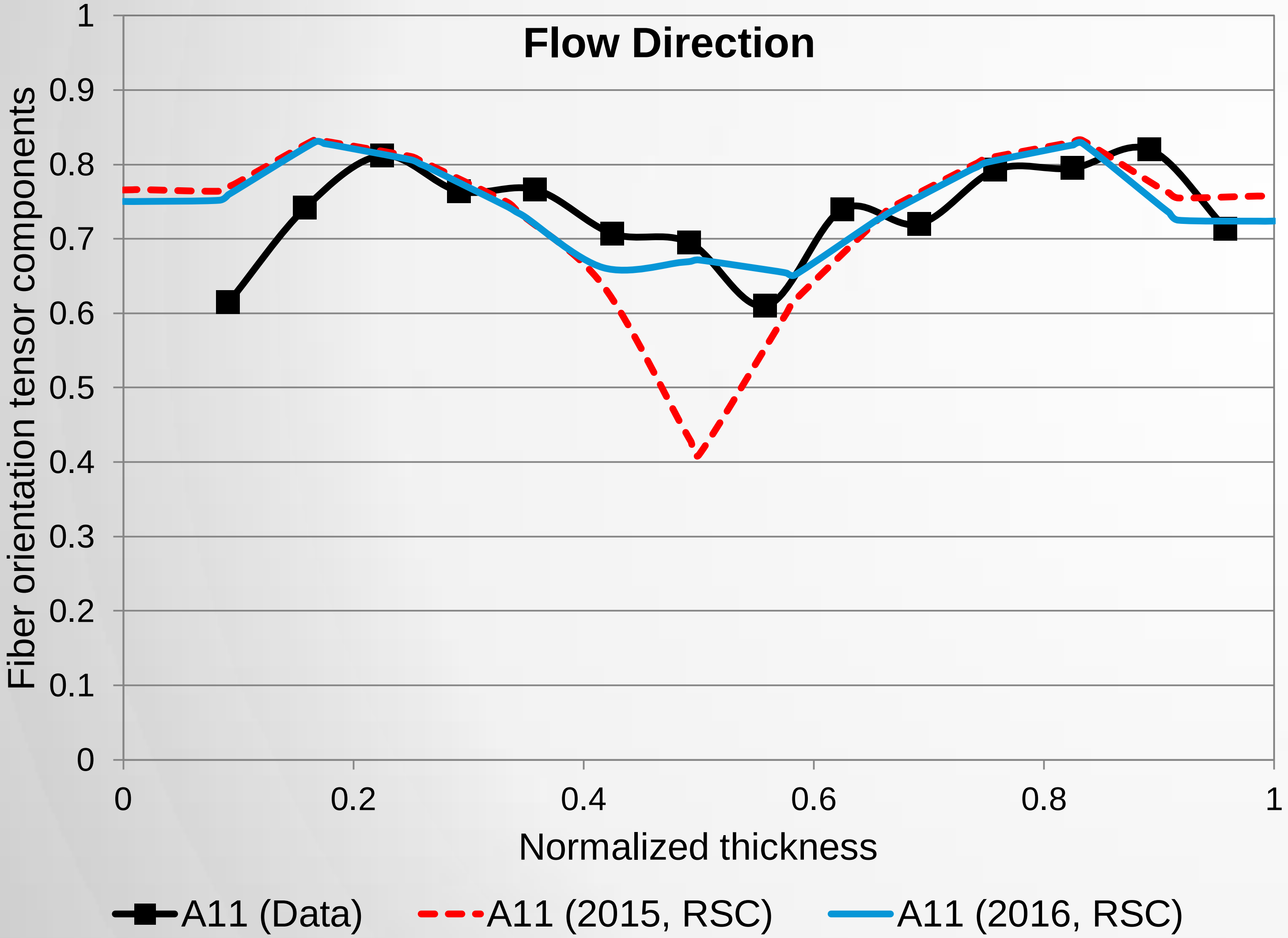


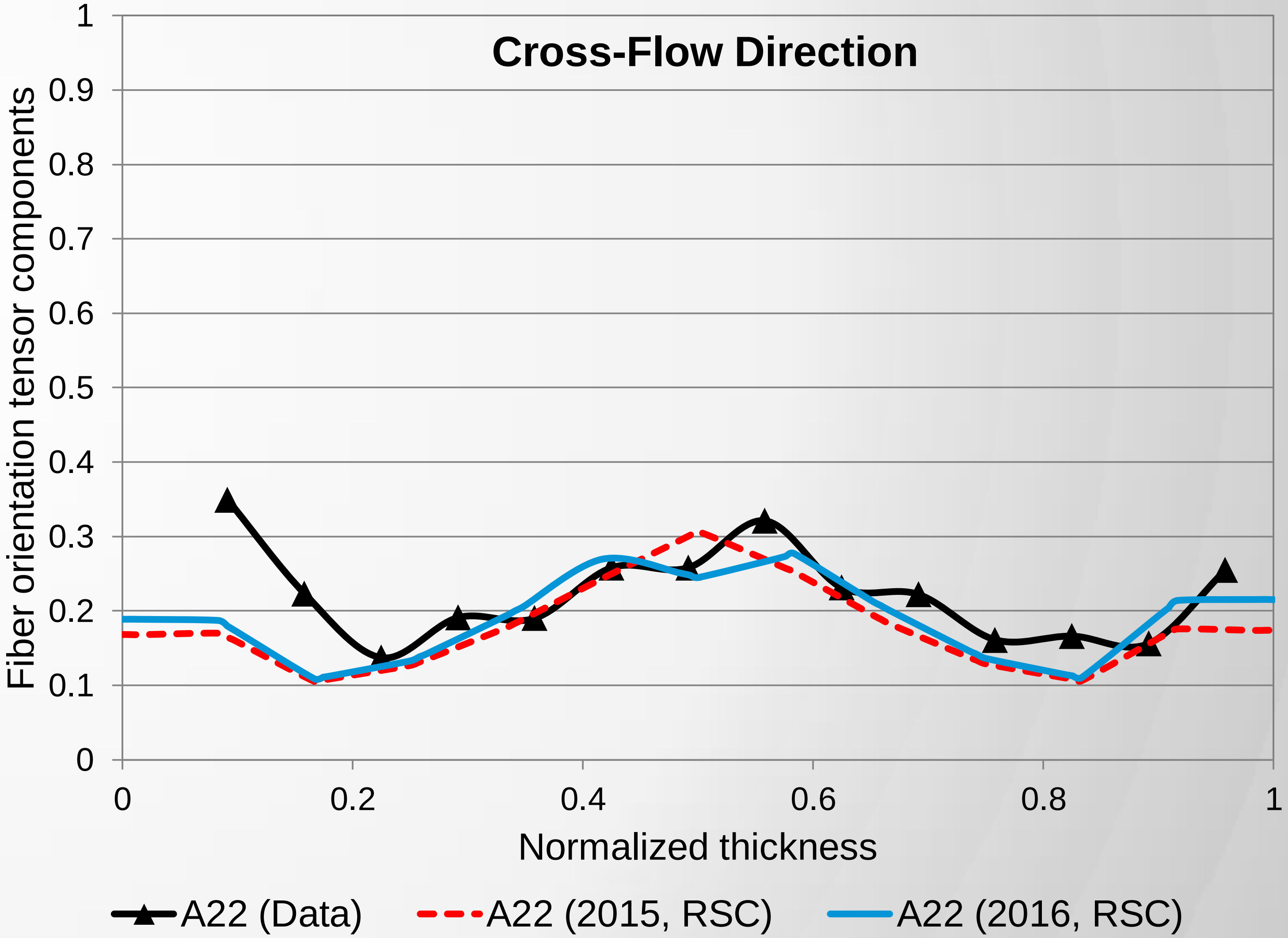
Molding data courtesy of BASF

Improved RSC predictions for 3D Fiber Orientation

BASF Plaque: 4mm thick. 30wt%GF PA66,
Location F

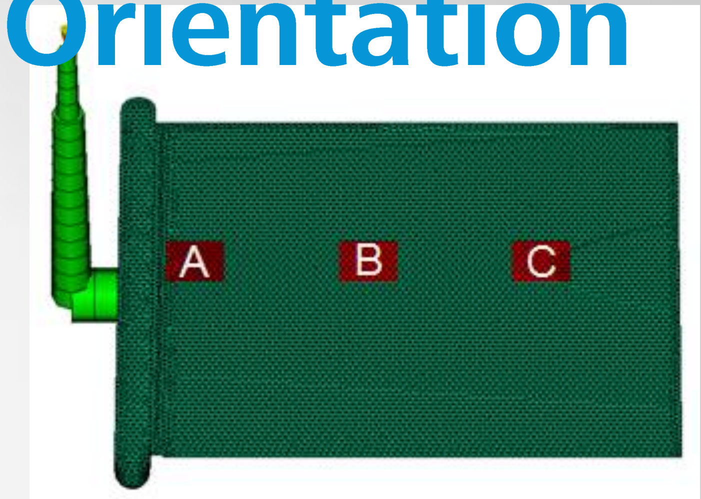




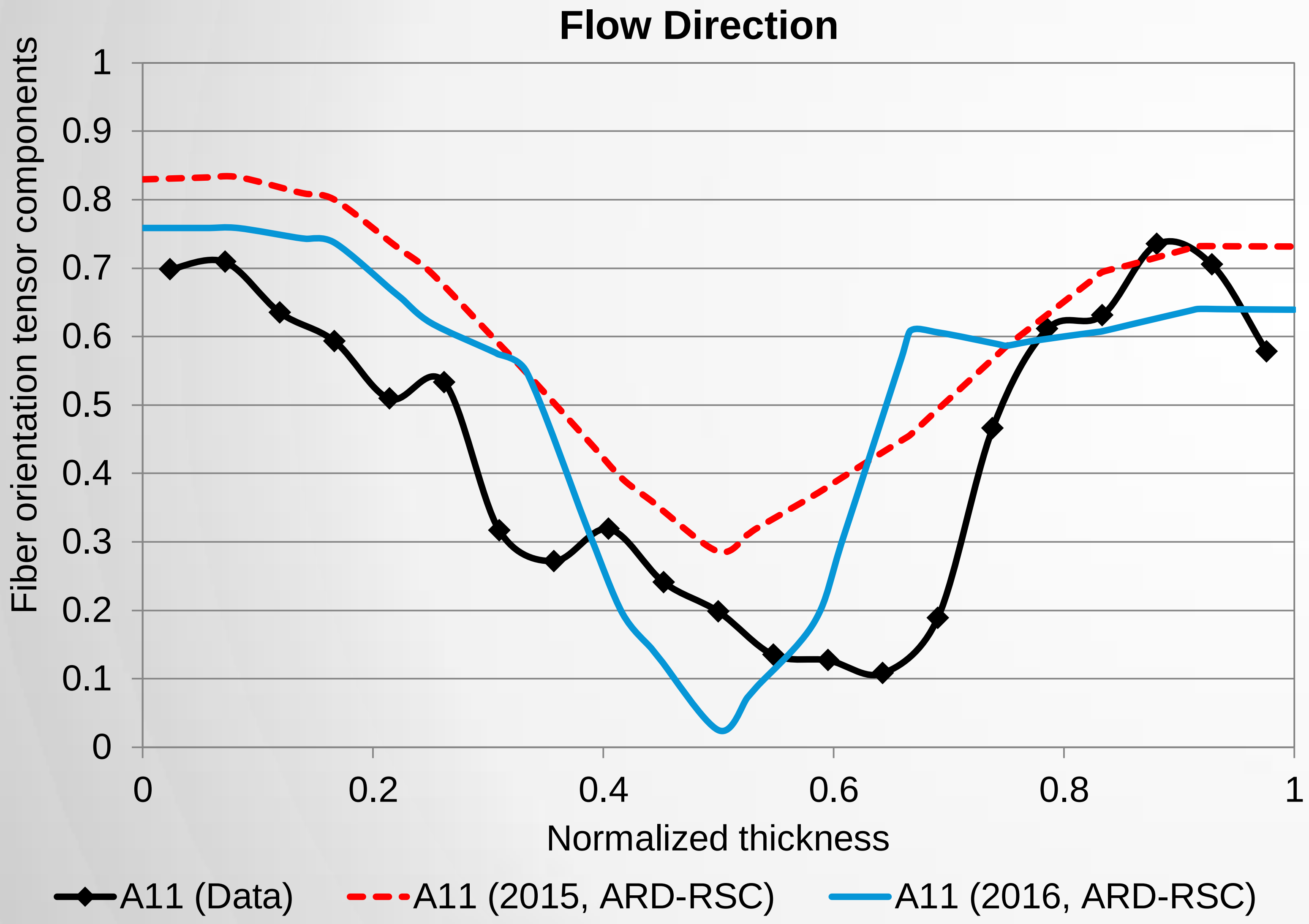


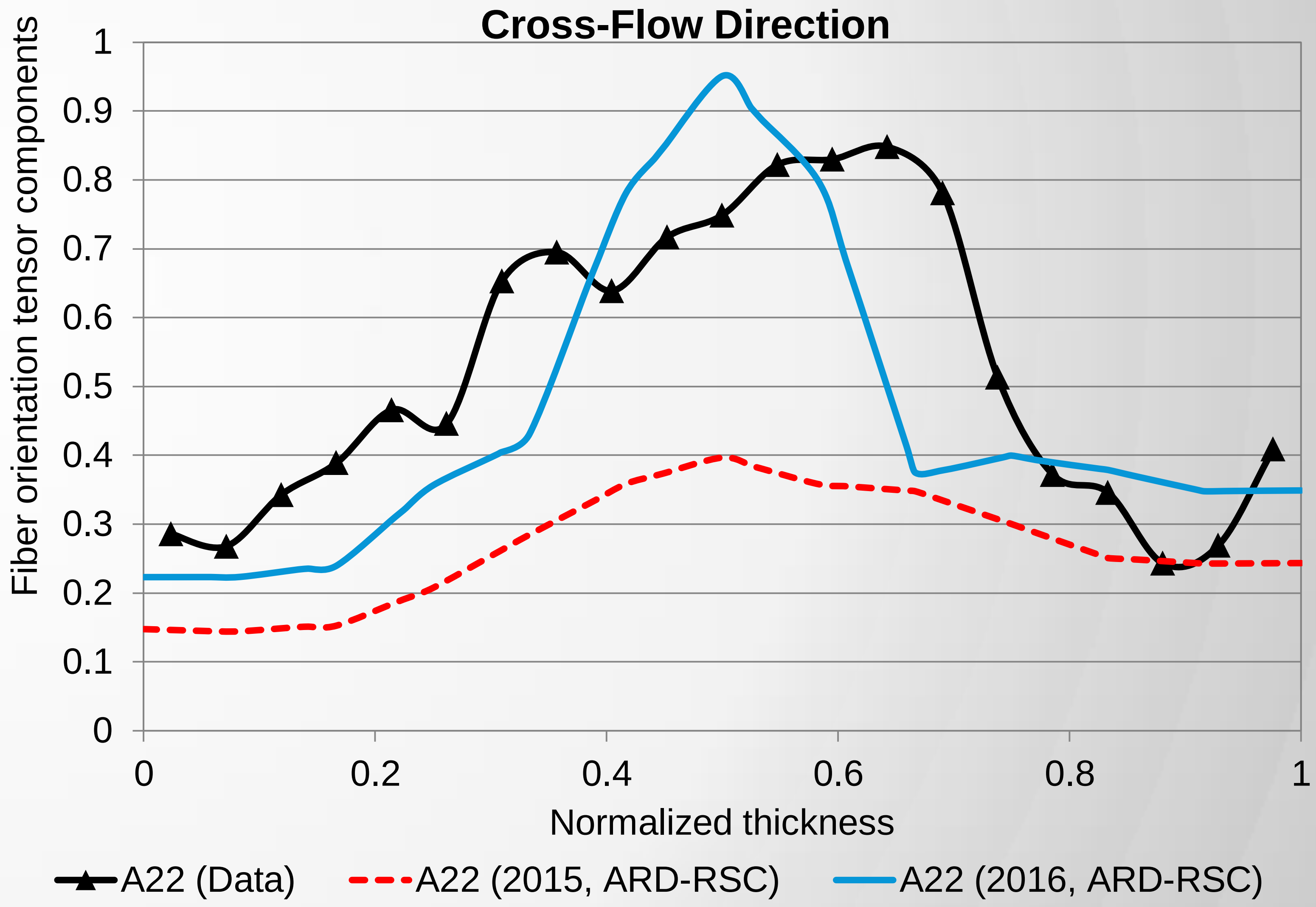
Molding data courtesy of BASF

Improved ARD-RSC predictions for 3D Fiber Orientation



PNNL Plaque: 3mm thick. 40wt%LGF PP,
Location B

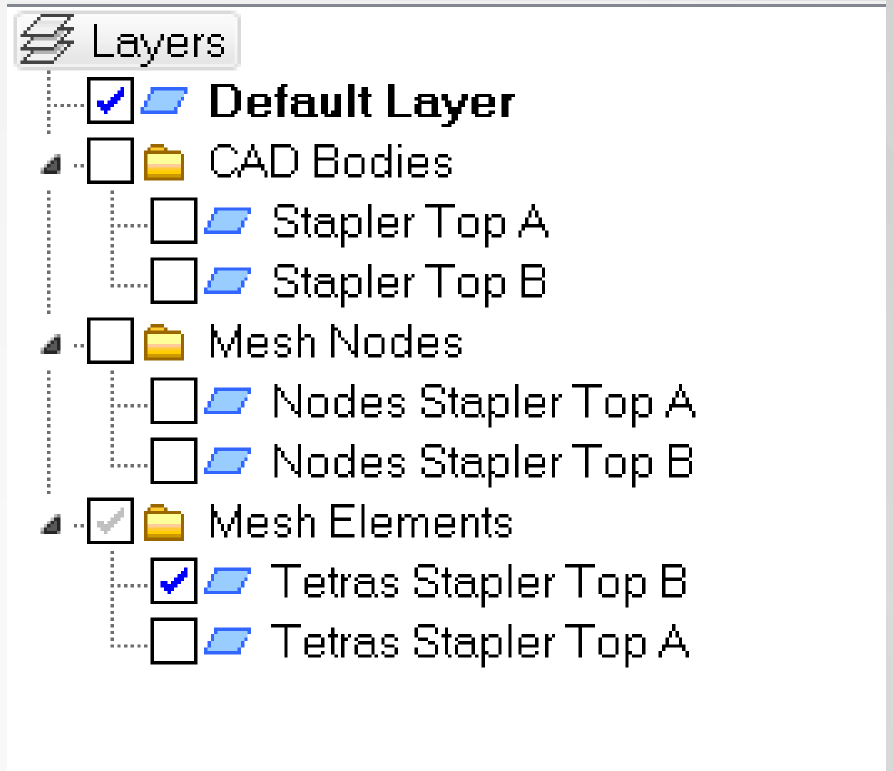


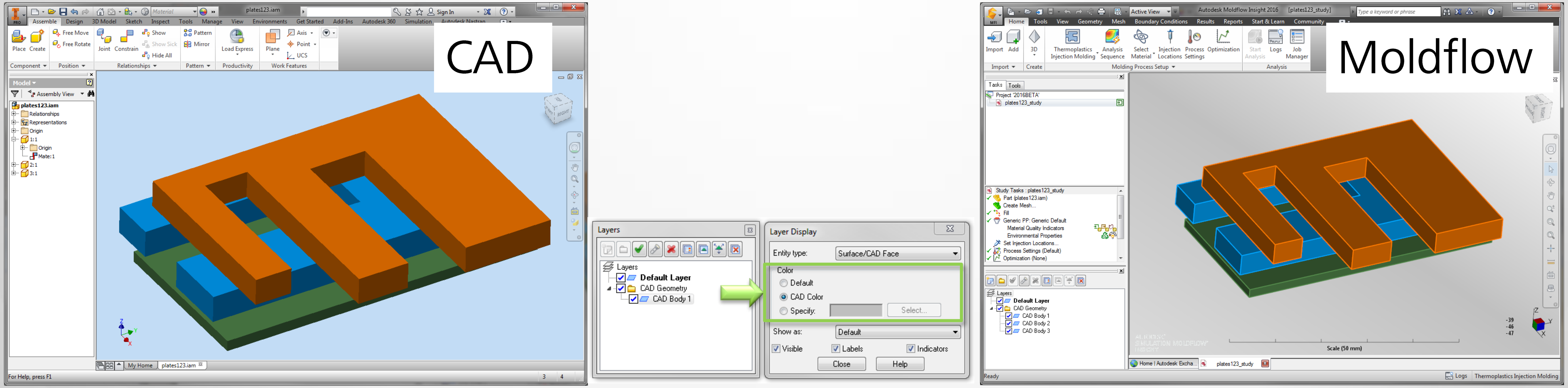


Molding data from PNNL/ORNL

Improved Layer Management

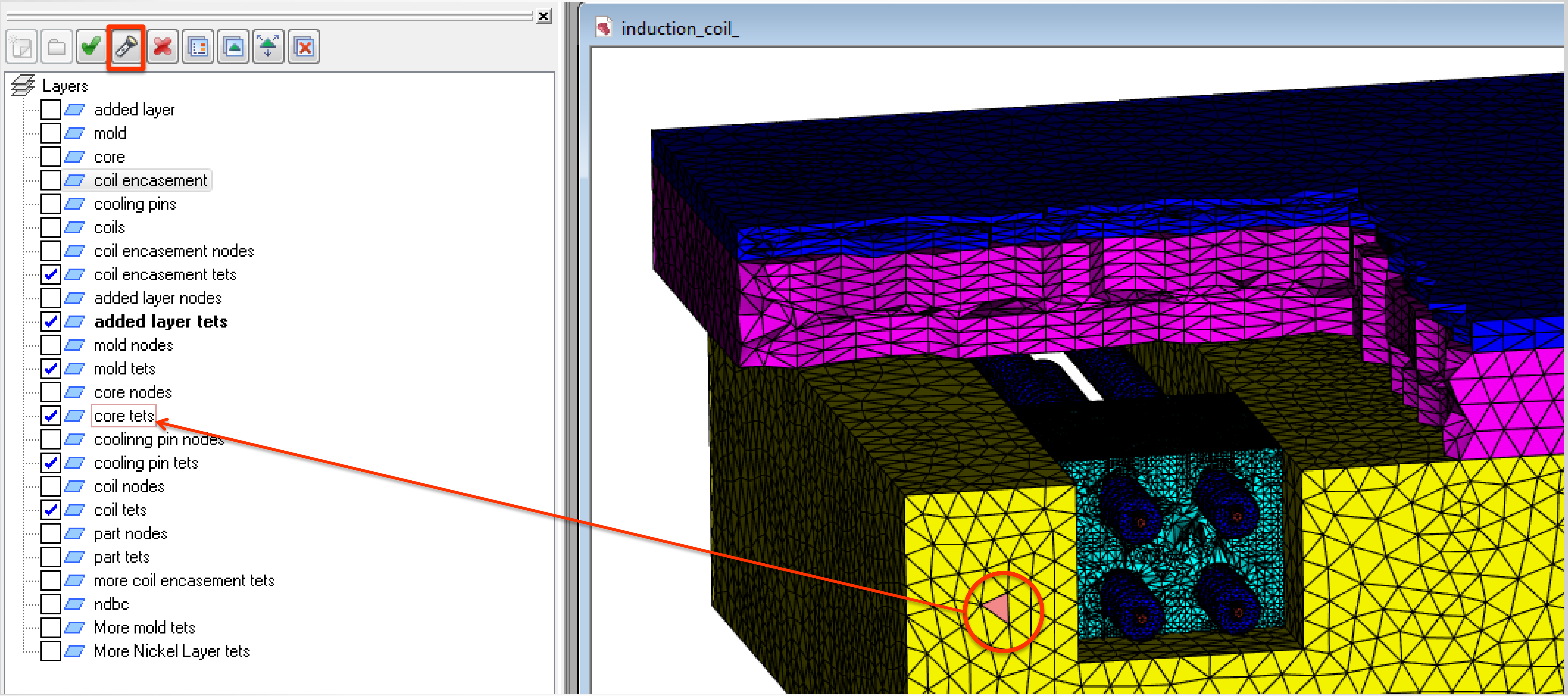
- Turn on/off multiple layers
- Allow layer hierarchy
- Use CAD Body names and colors when importing





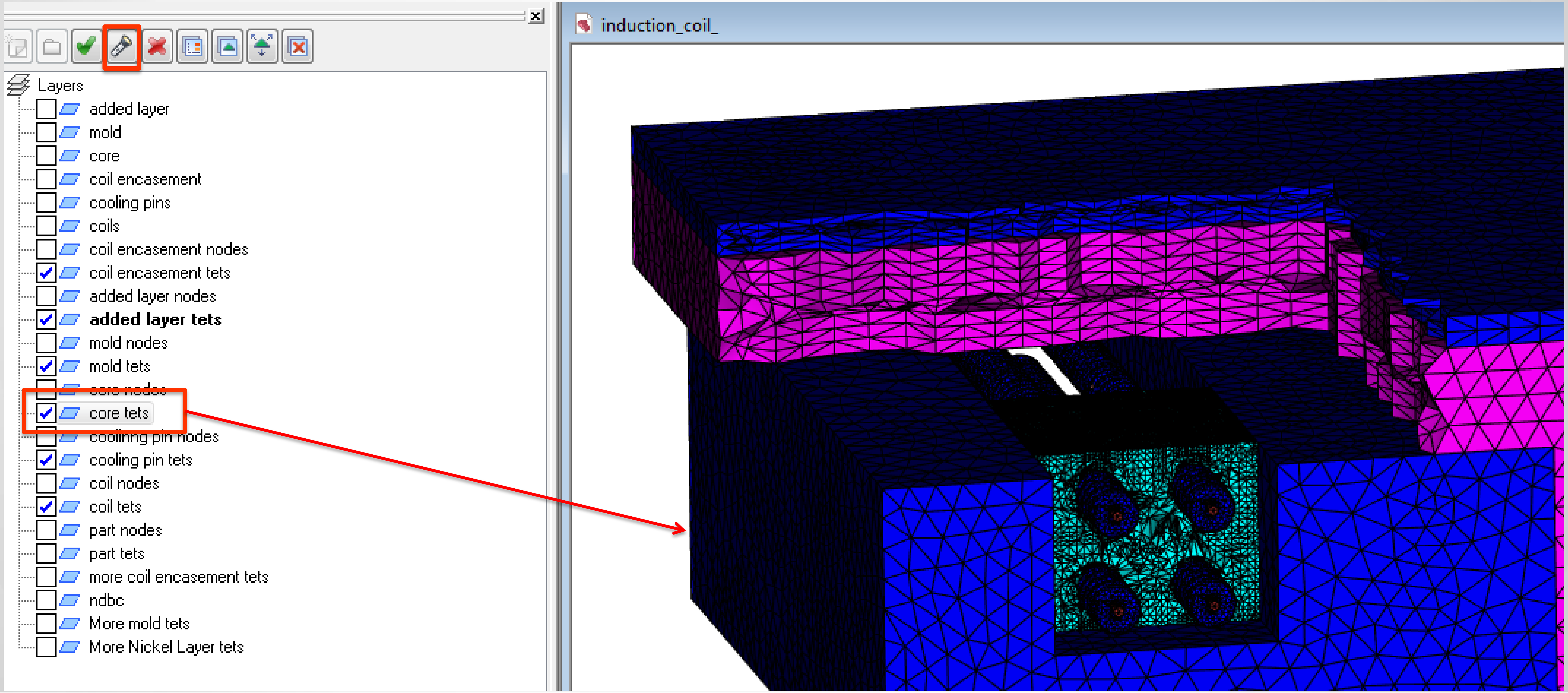
Layer Highlights

1. Select an entity – Layer is highlighted



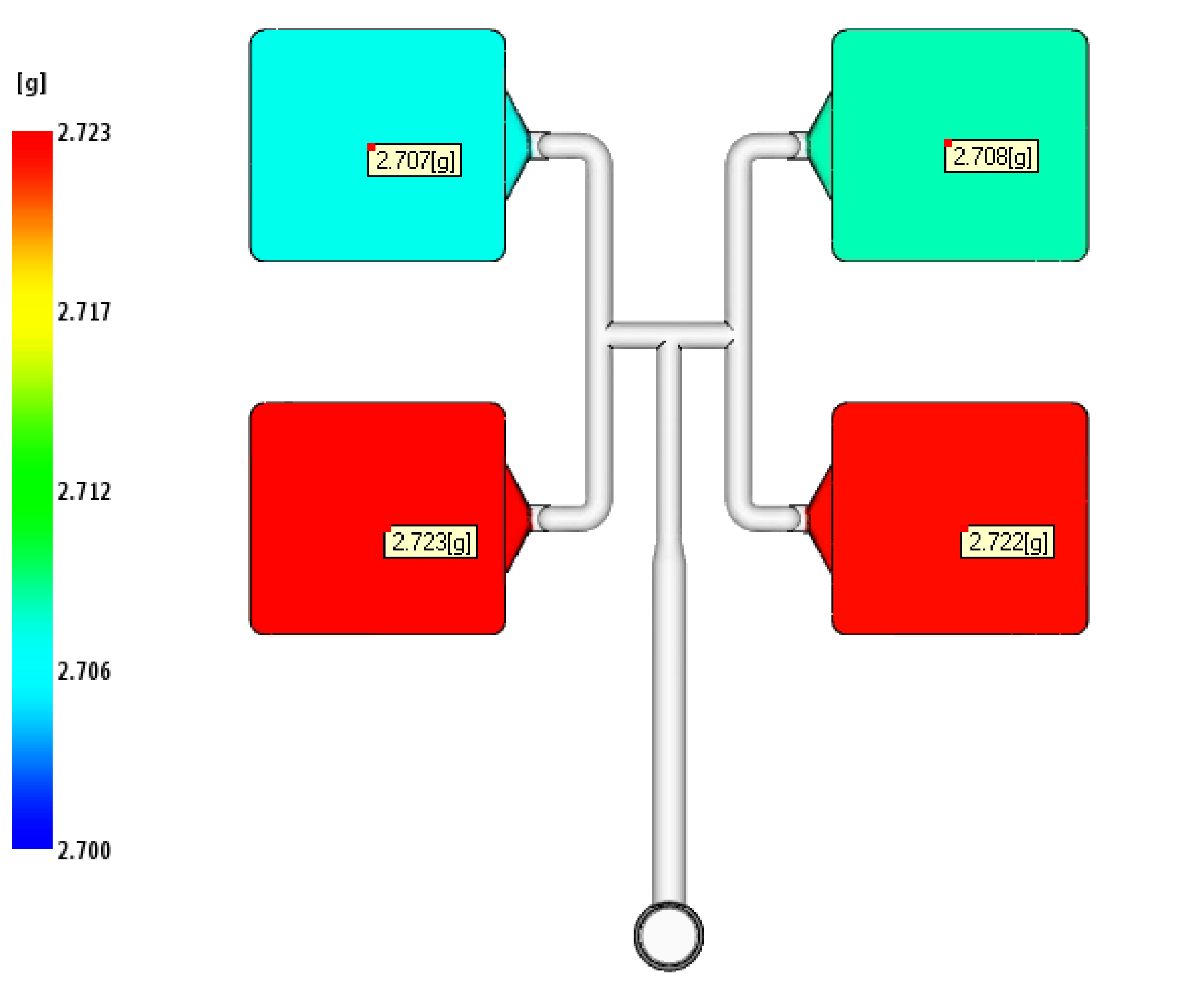
Layer Highlights

1. Select an entity – Layer is highlighted
2. Select a Layer – Entities are highlighted

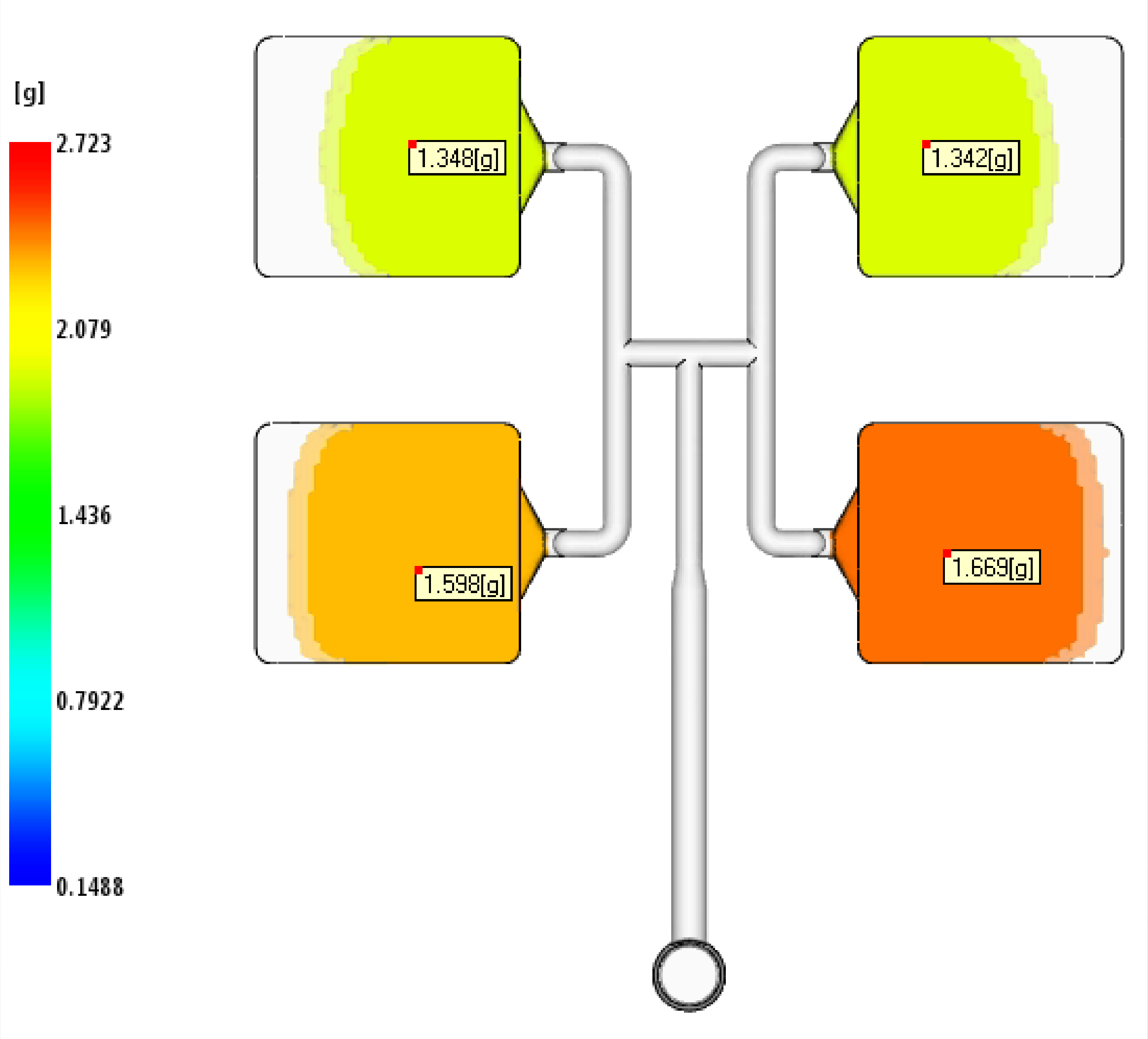


New Cavity Weight Result

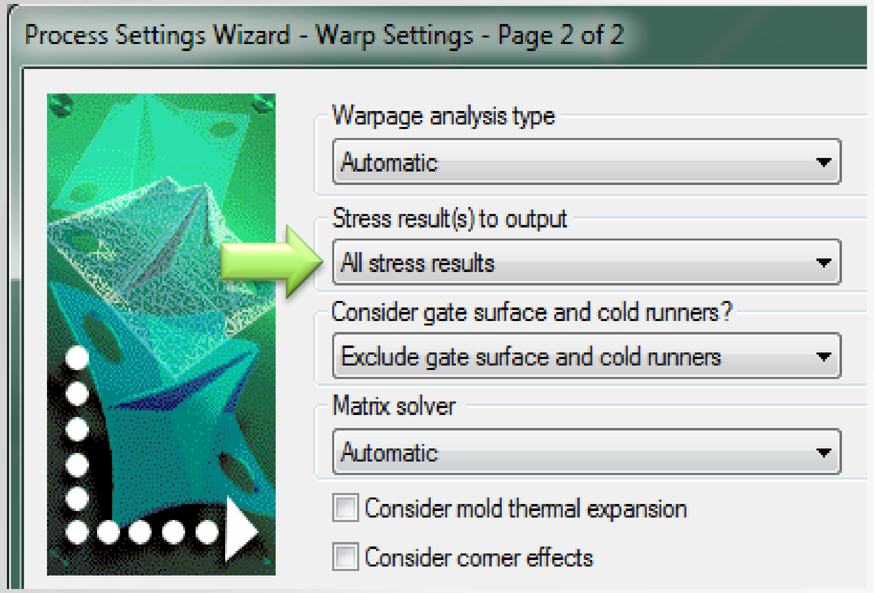
Final Weights

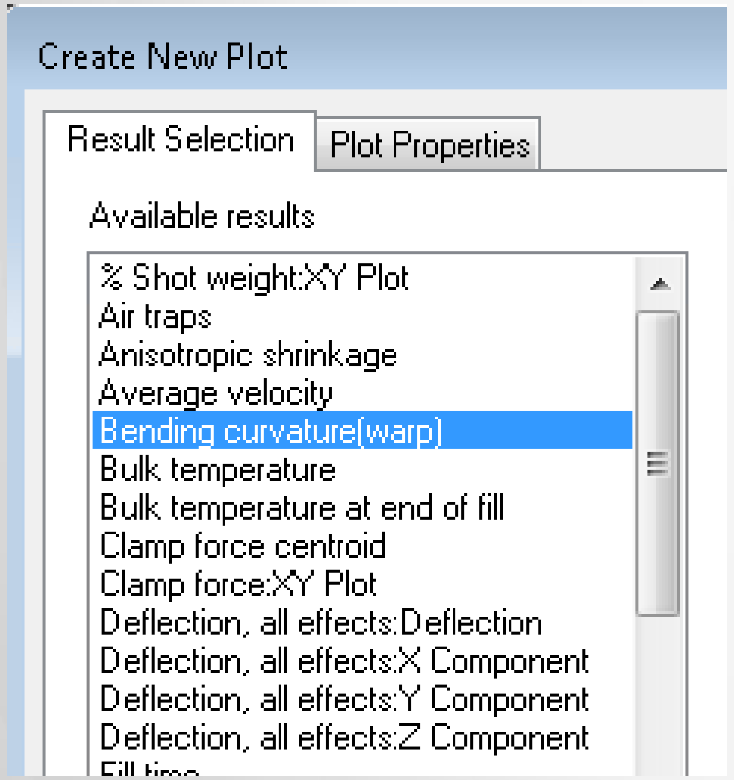


Intermediate Weights

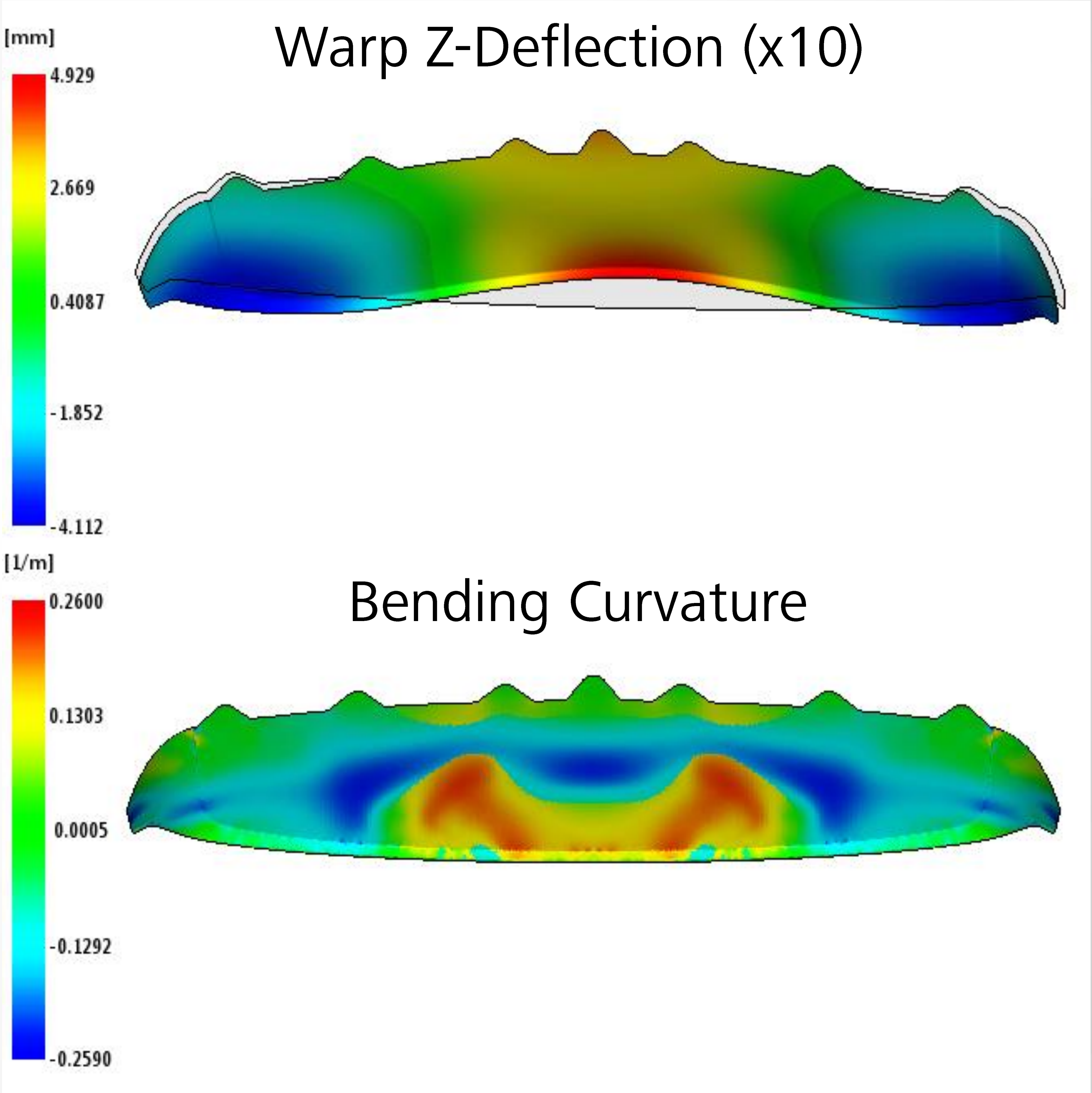


Bending Curvature





Midplane Only

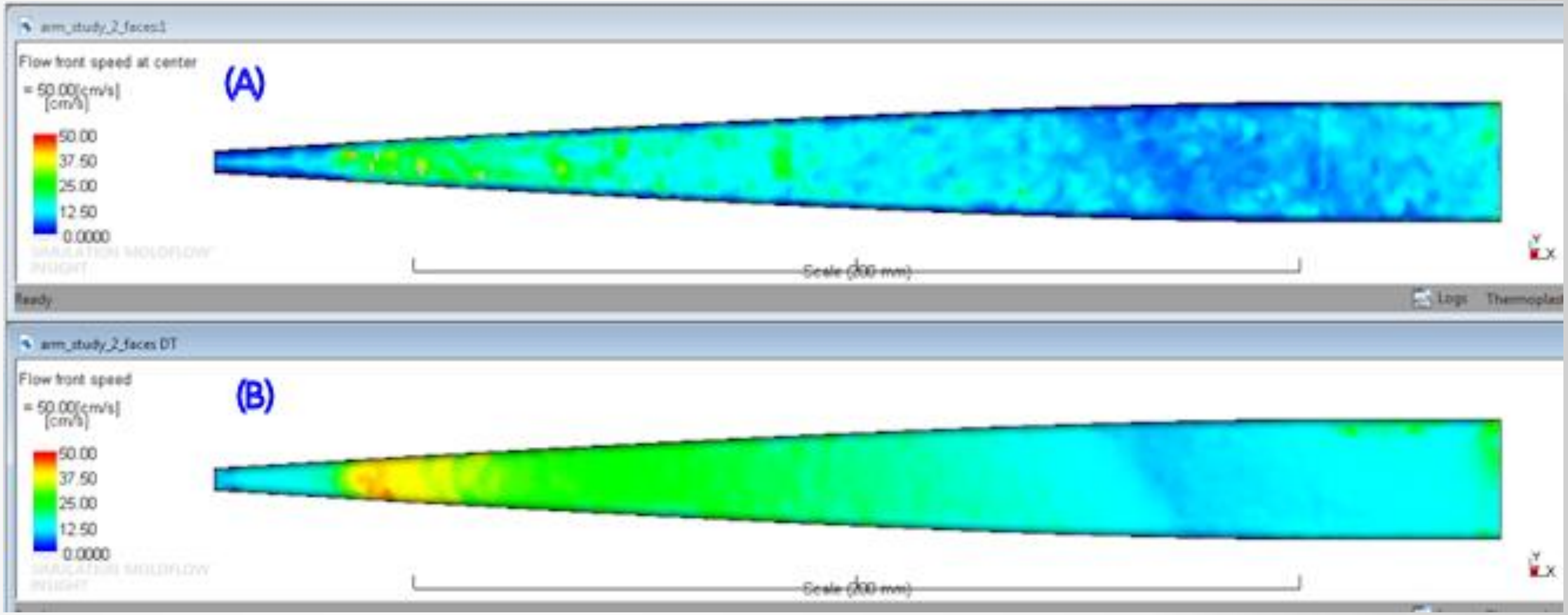


Model courtesy of HRS – Inglass S.p.A

Revised Flow Front Speed Result

Old Result:

- Velocity at Center laminate while filling



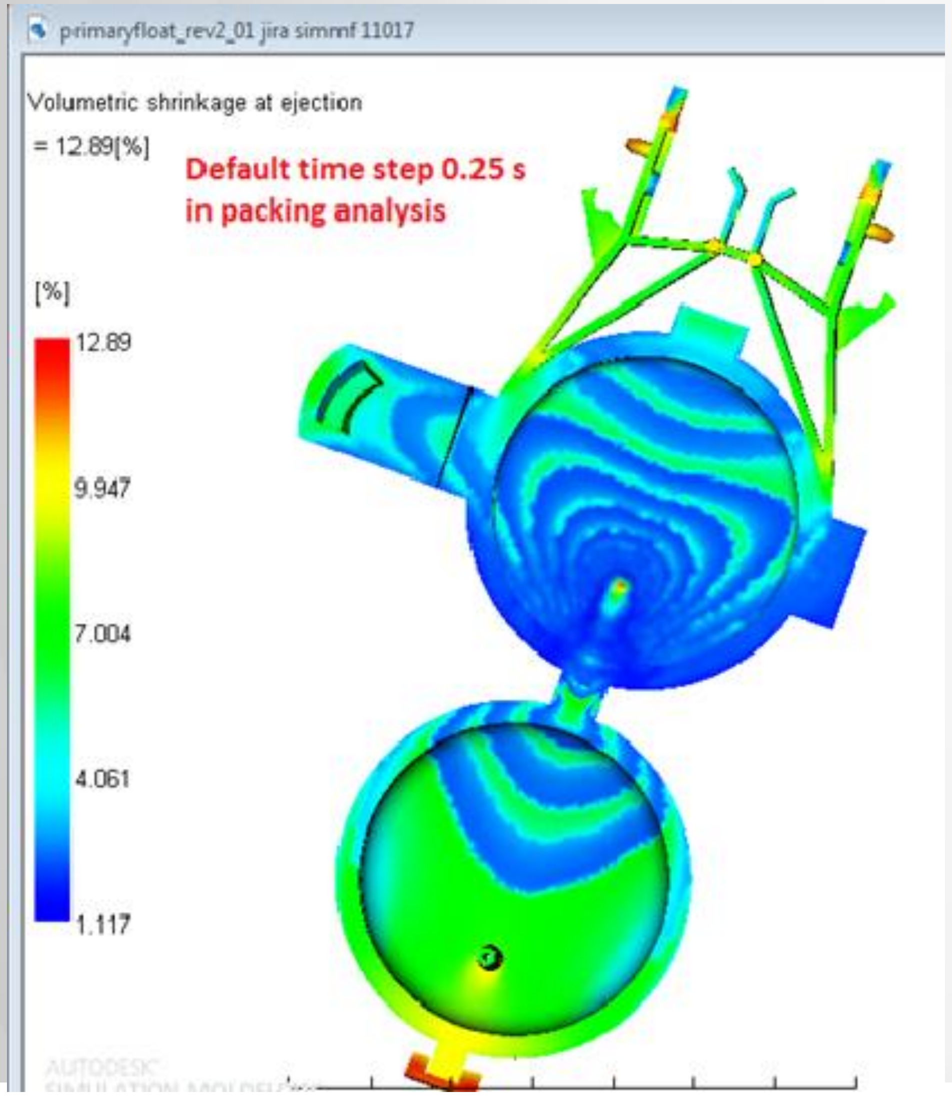
Replace with:

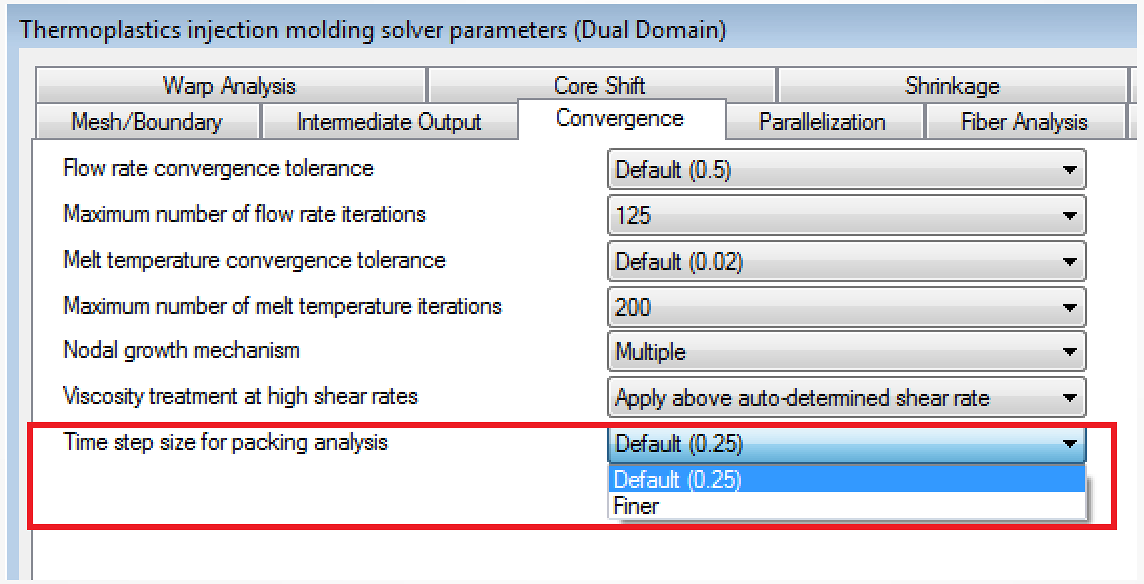
- Bulk Flow Front Speed

Midplane & Dual-domain Only

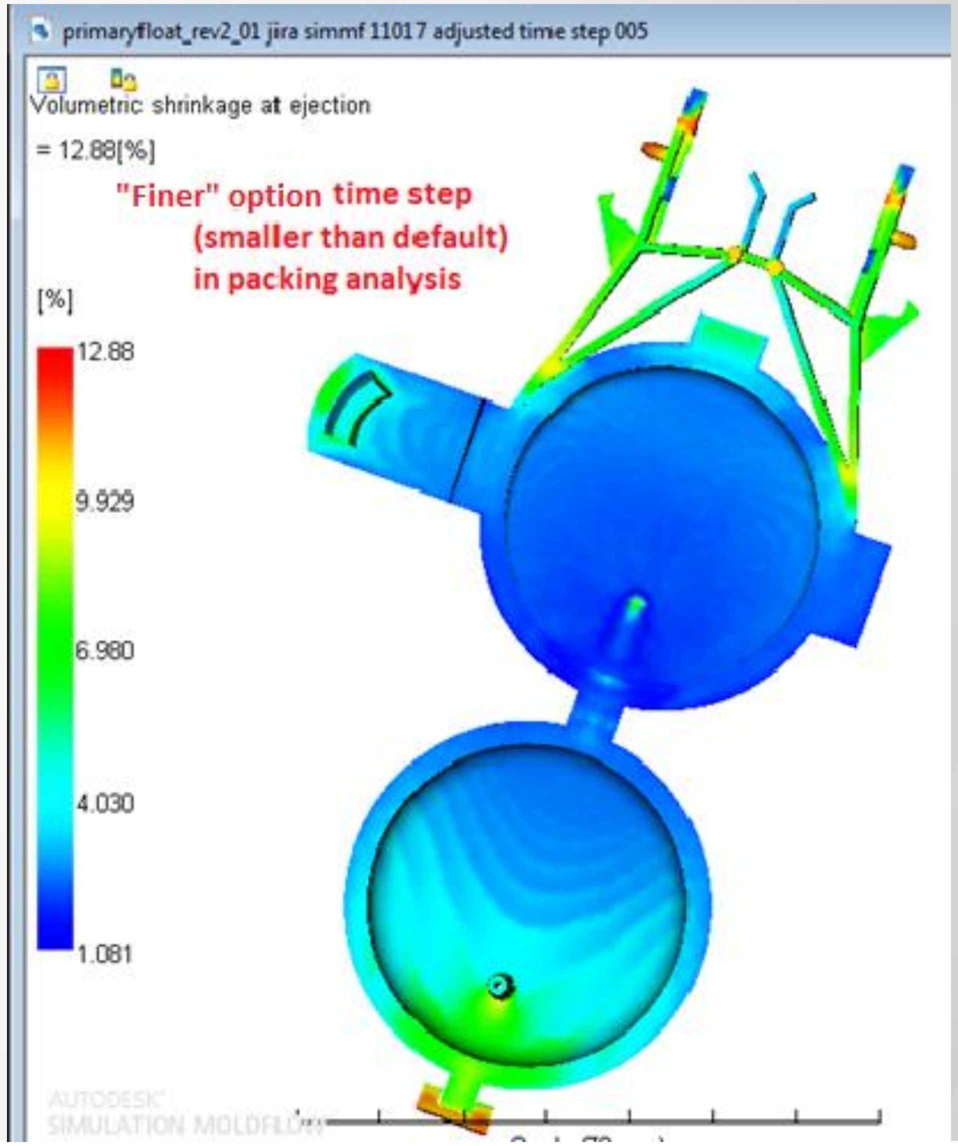
Packing Time Step Control

- Midplane & Dual-Domain flow using fixed packing time-step size
  - Can lead to banded results

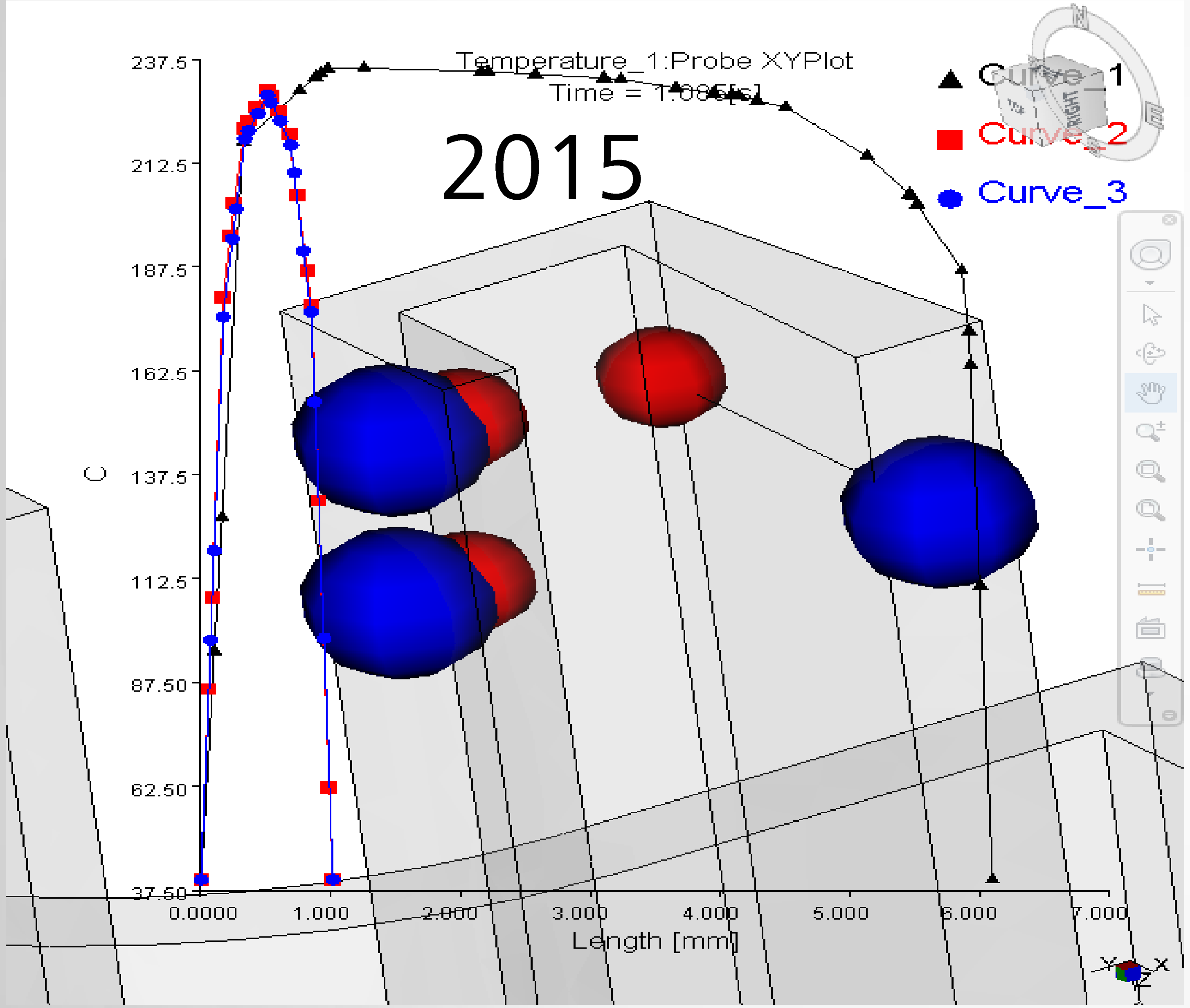


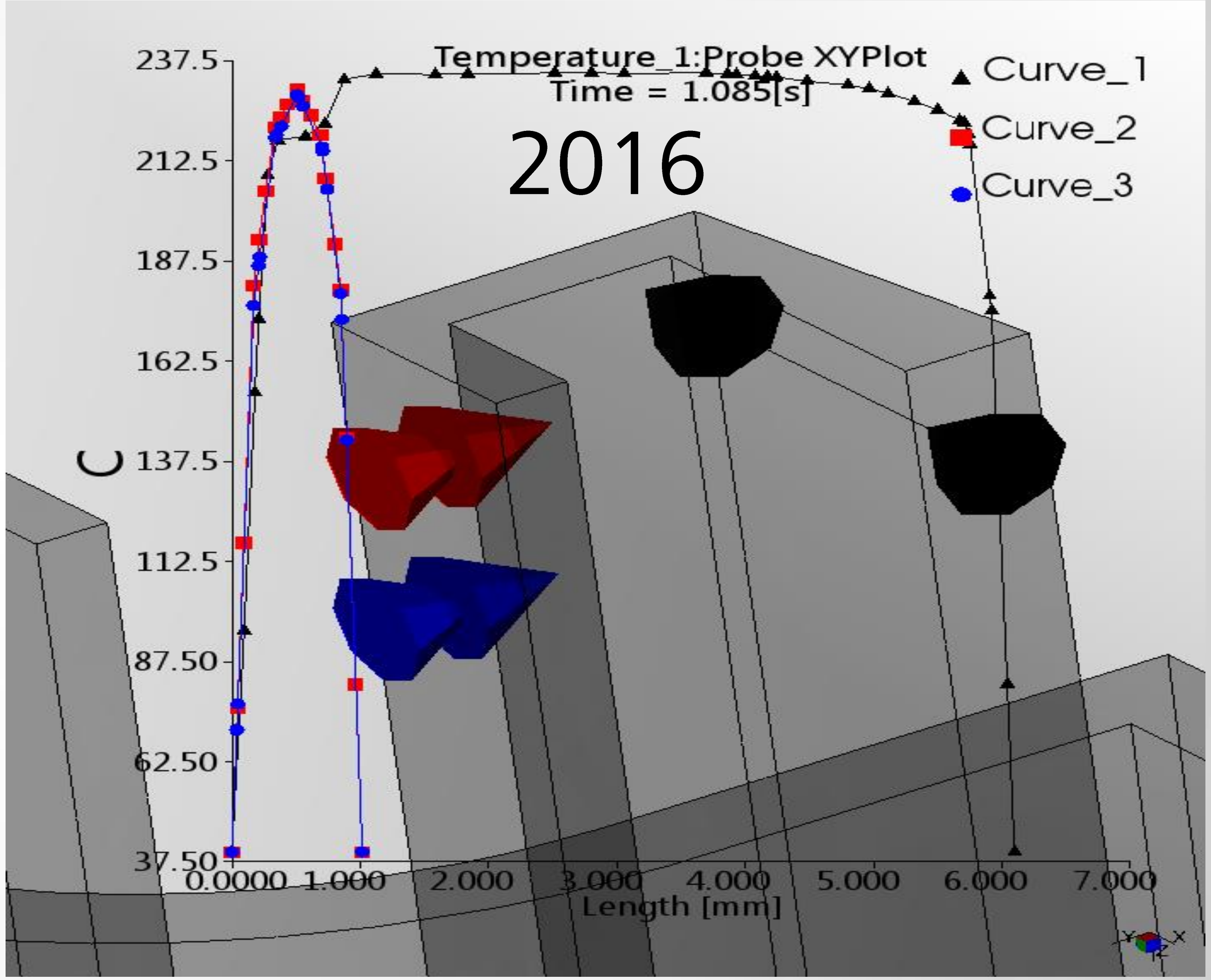


Optional control based on stability criteria
Small time-steps -> longer analysis time



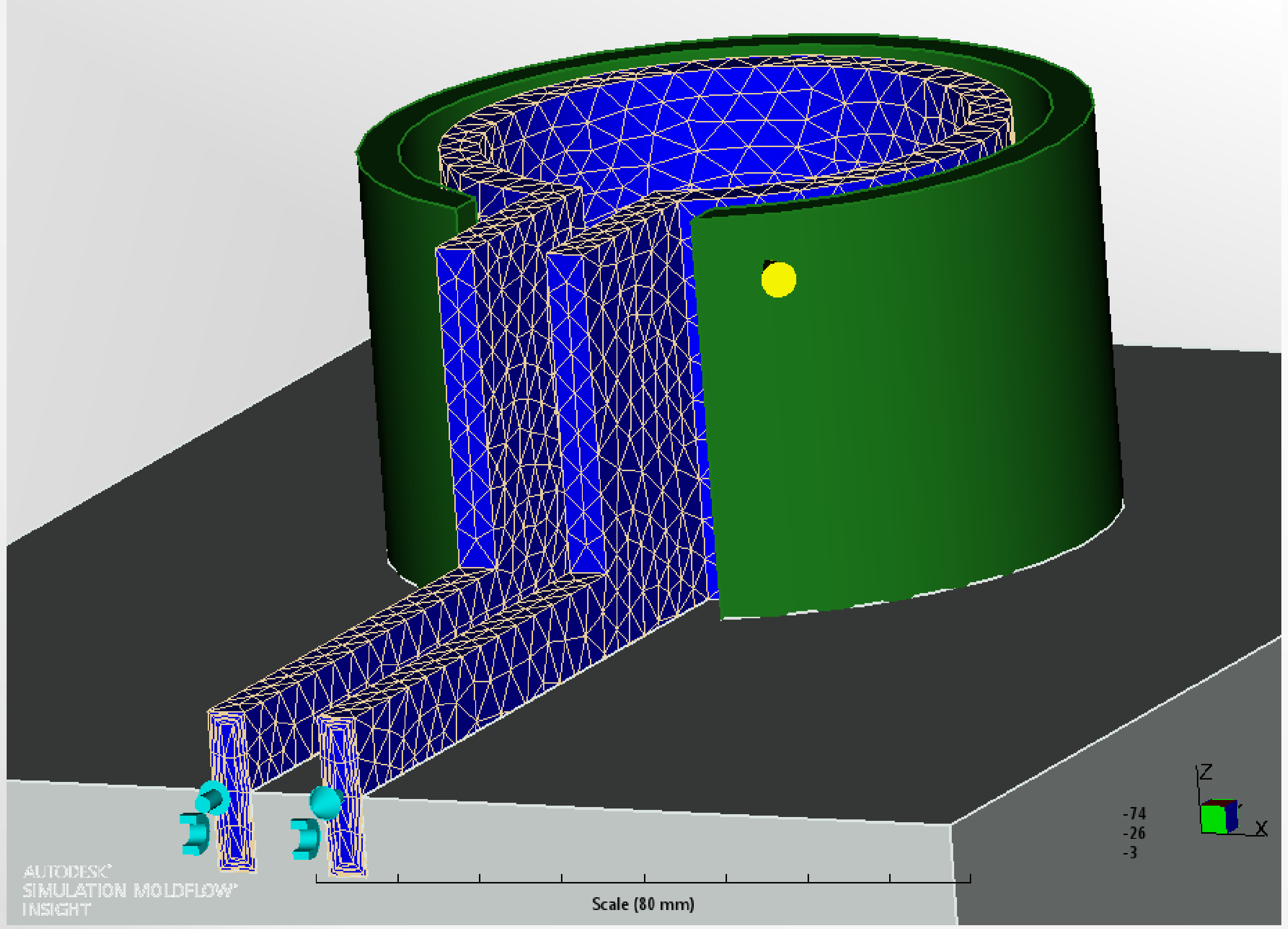
Improved markers for XY Plots





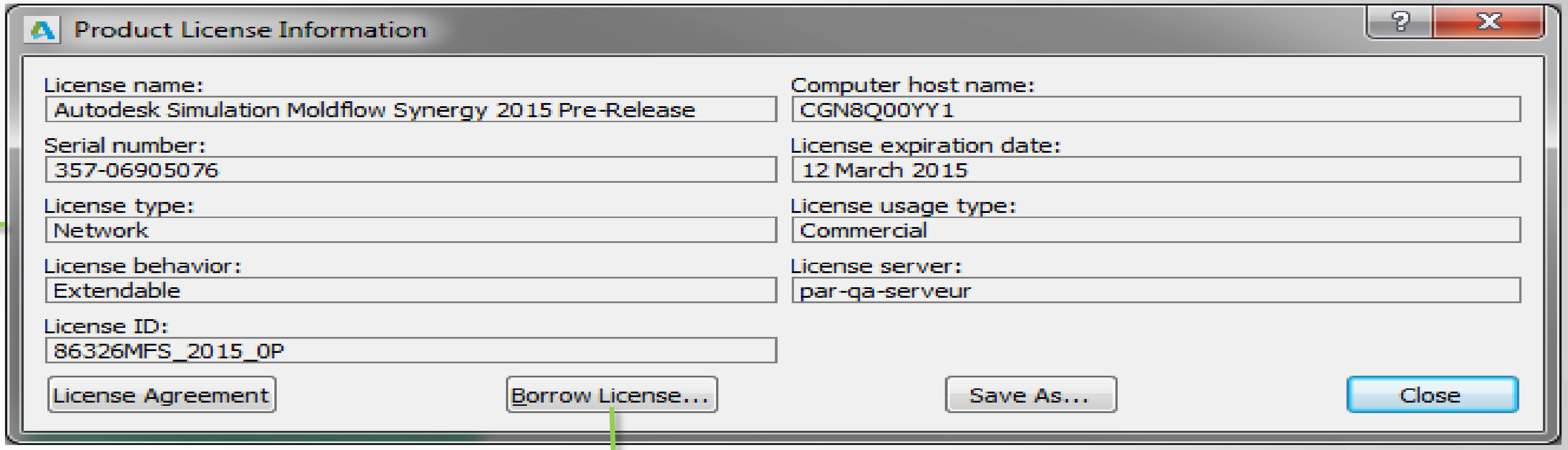
Integrate CFD Mesher for Conformal Cooling

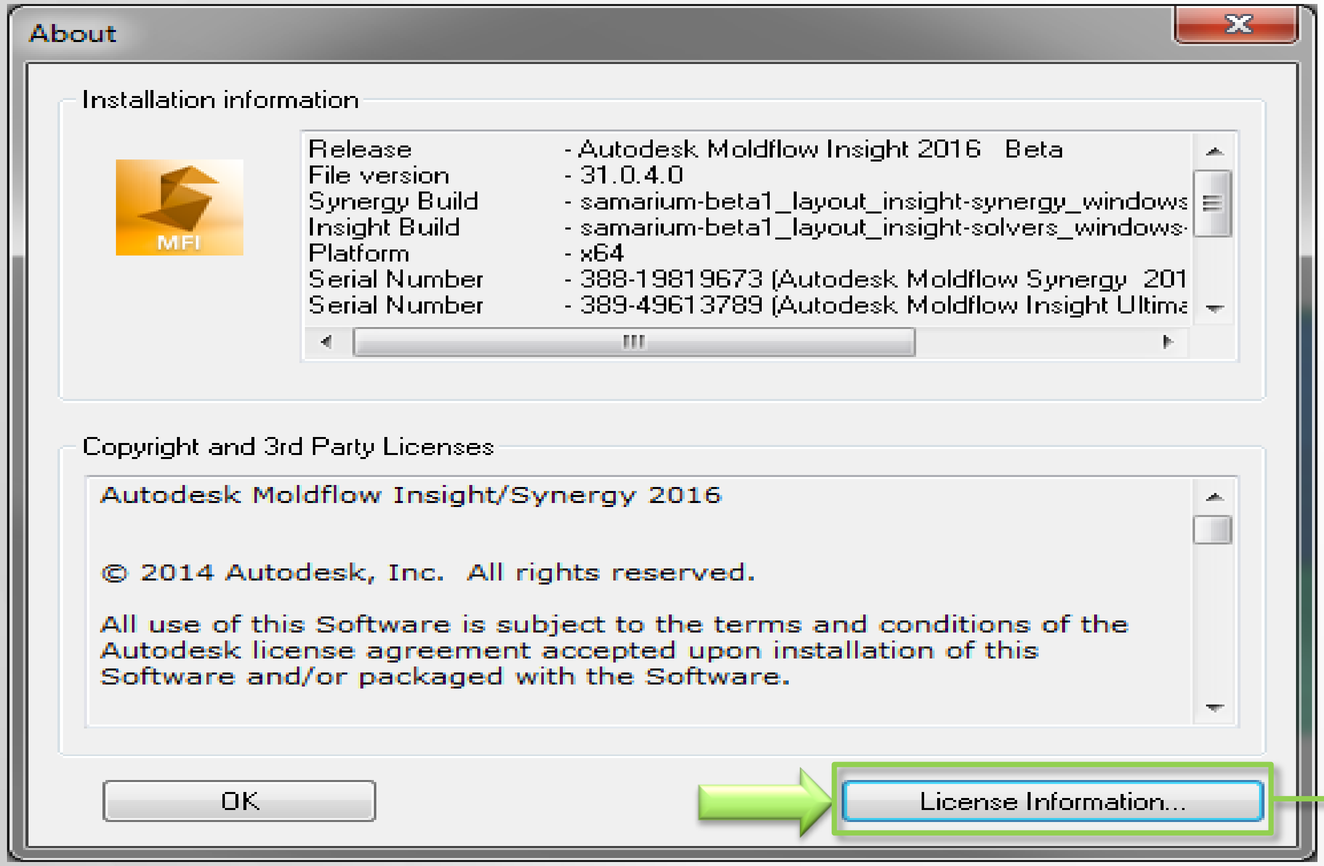
- CFD Software installation & license no longer needed
- Channel meshing is faster

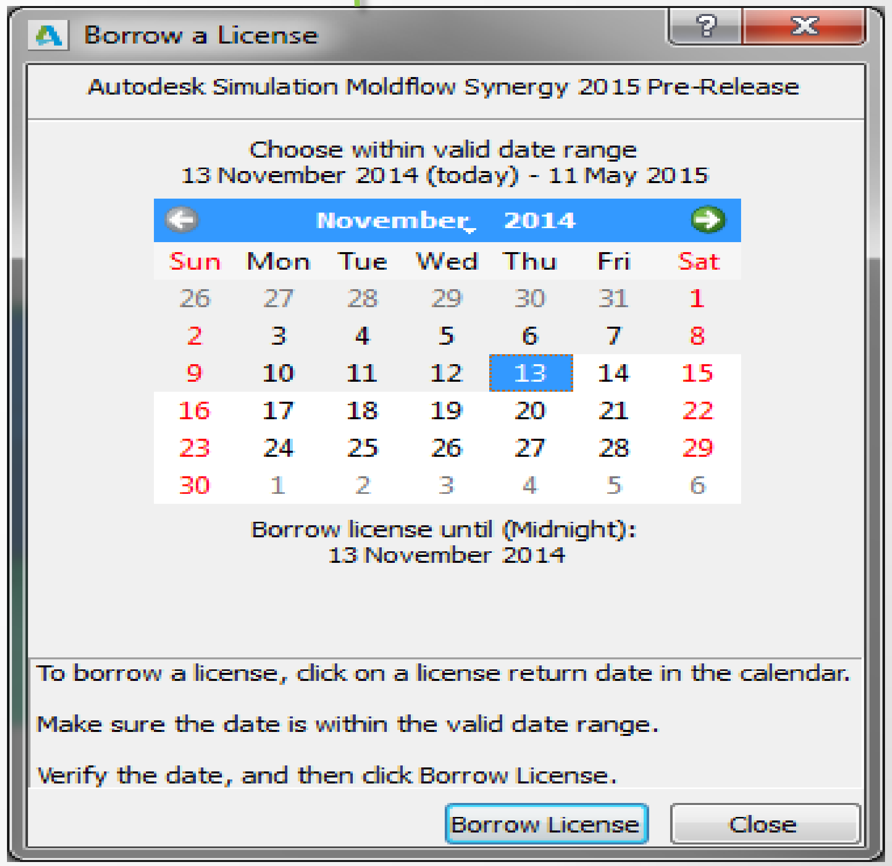


Borrow a License

- Borrow a Synergy License
- Set a return date

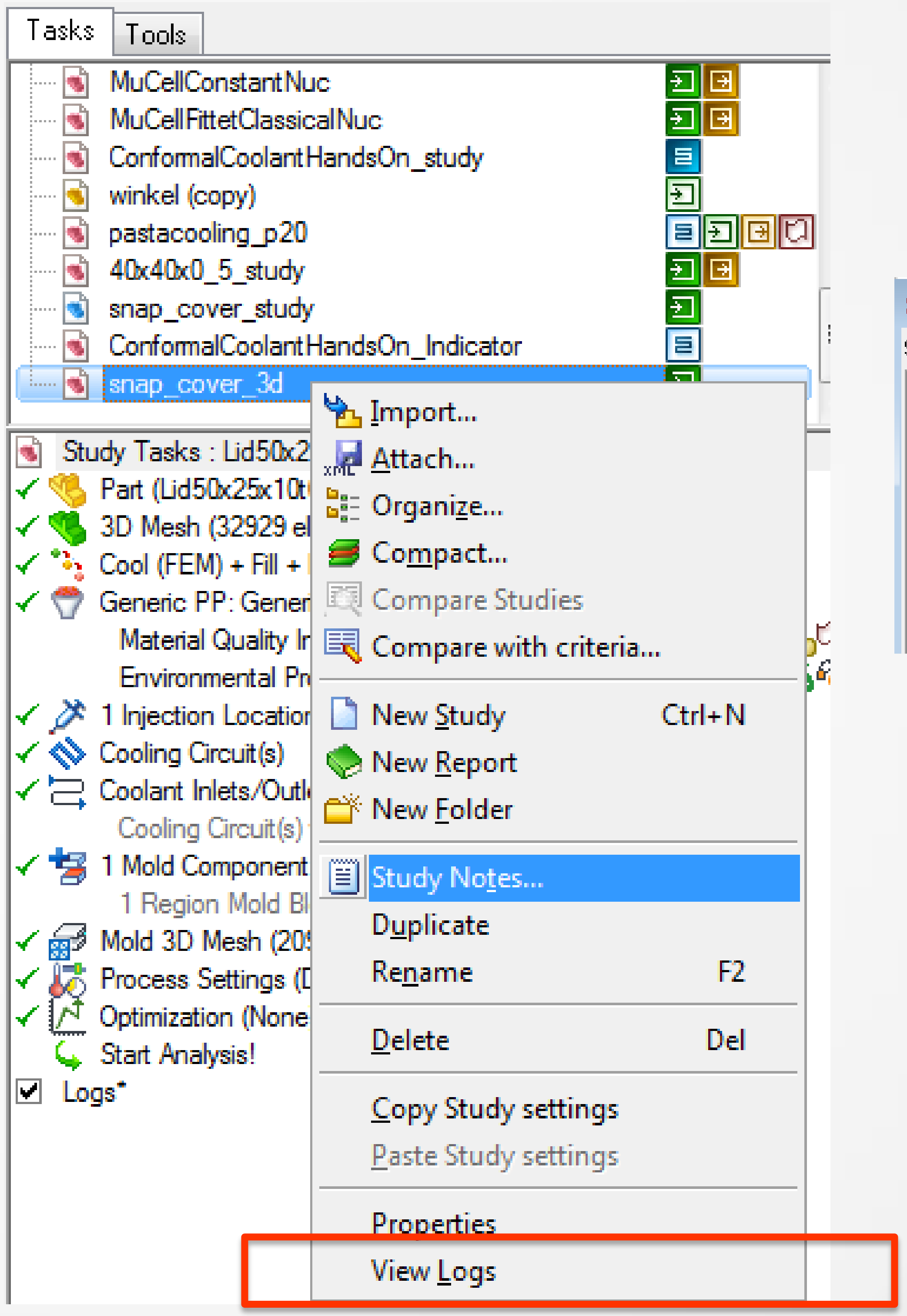


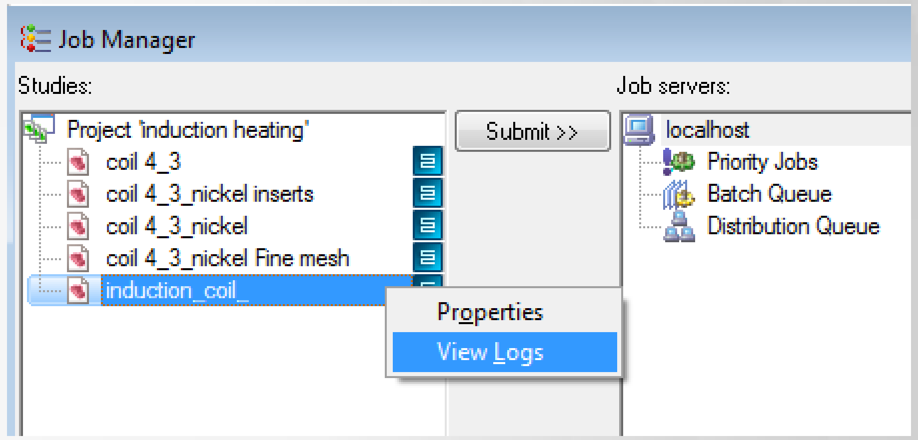




Access analysis information without opening study

- View Study Notes from Project Tree
  - Hover or RMB
- View Analysis Log
  - From Study Tree
  - From Job Manager





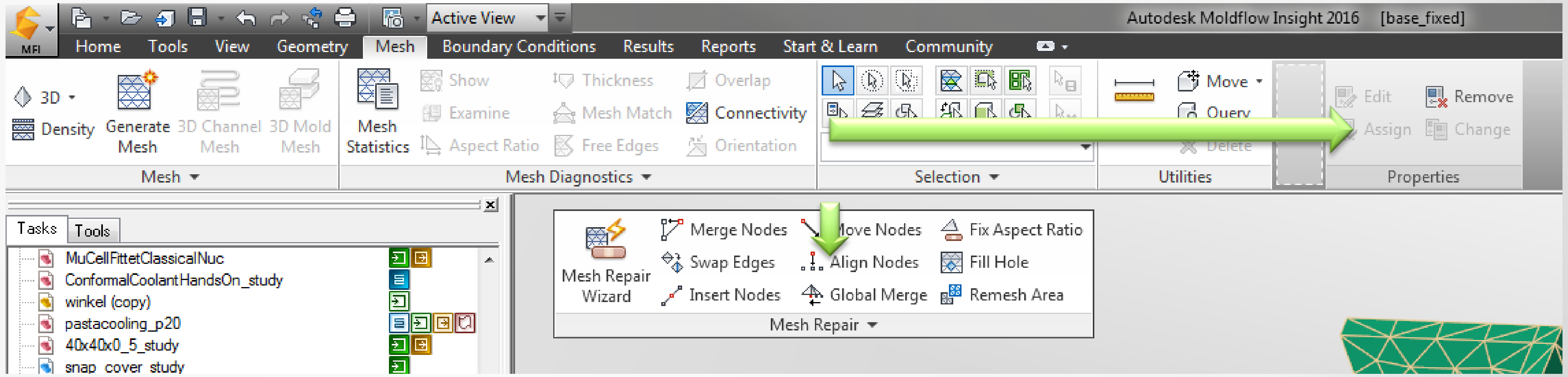
Enhancements to Ribbon Menu

- Permanently Available

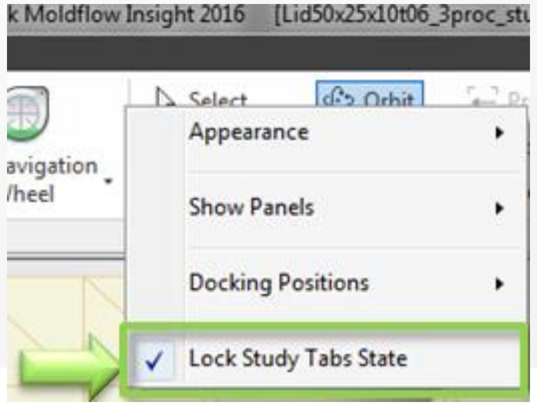
2015

2016

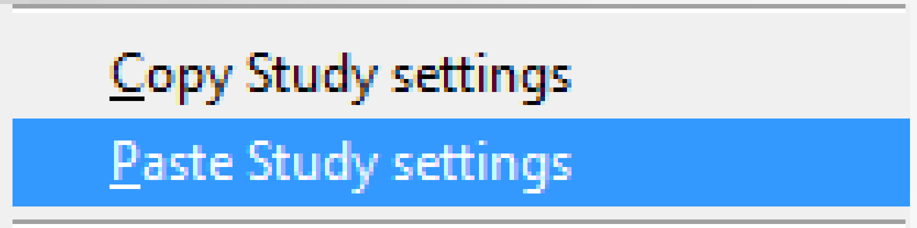
- Customizable

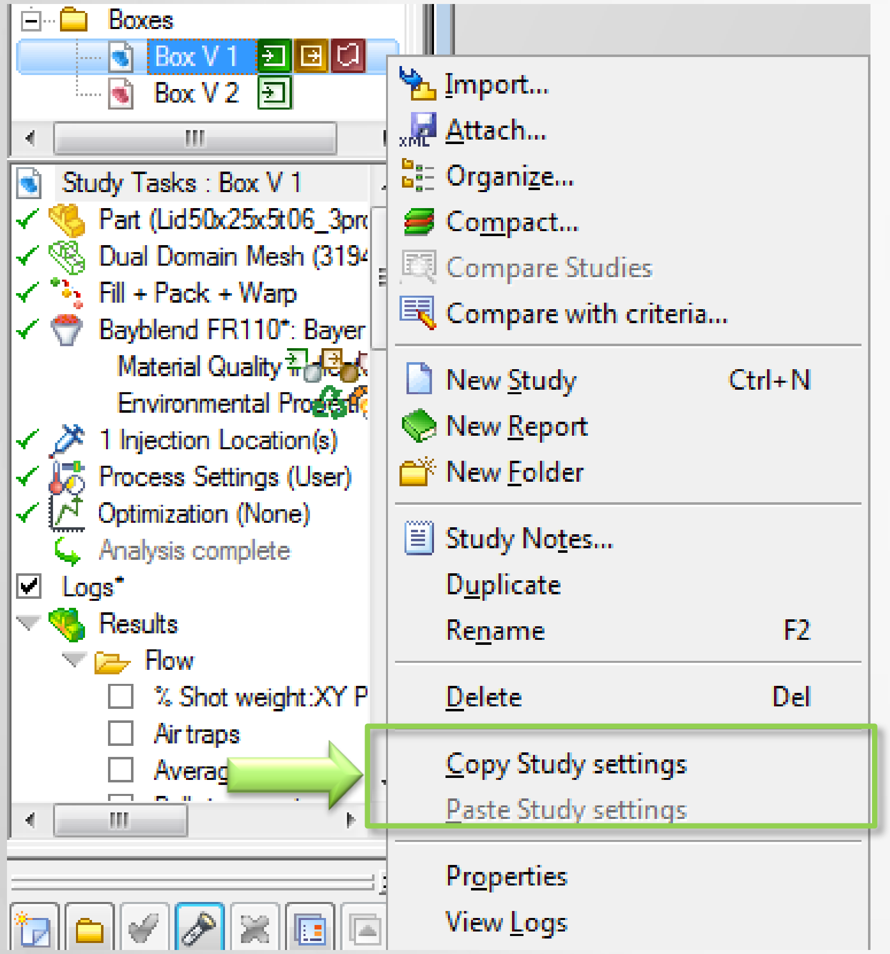


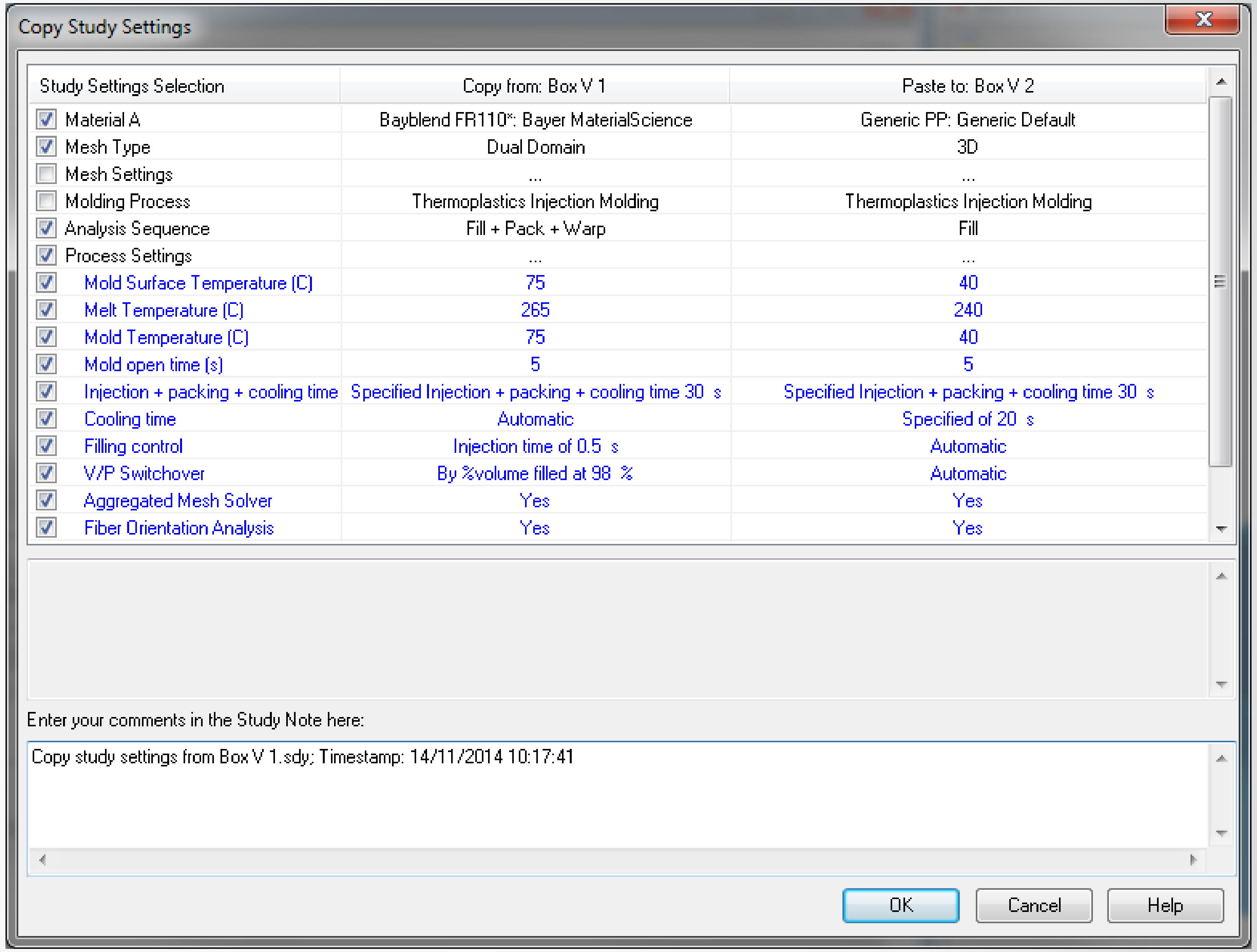
- Synchronize for all studies



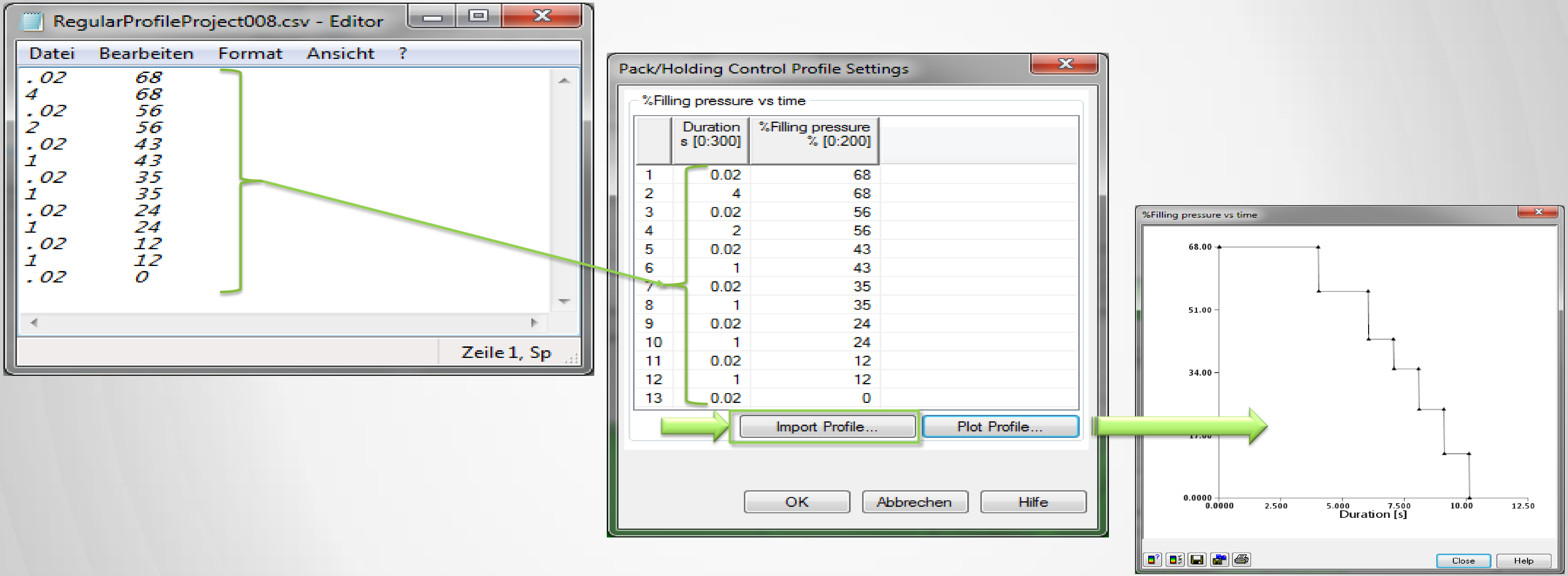
Copy and Paste Study Settings to Another Study





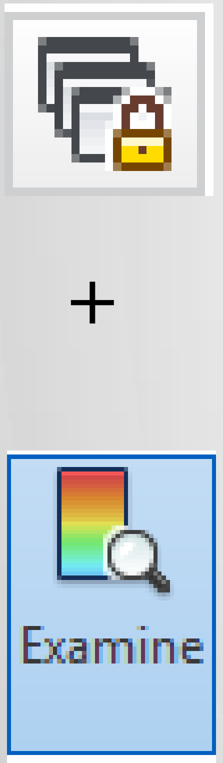


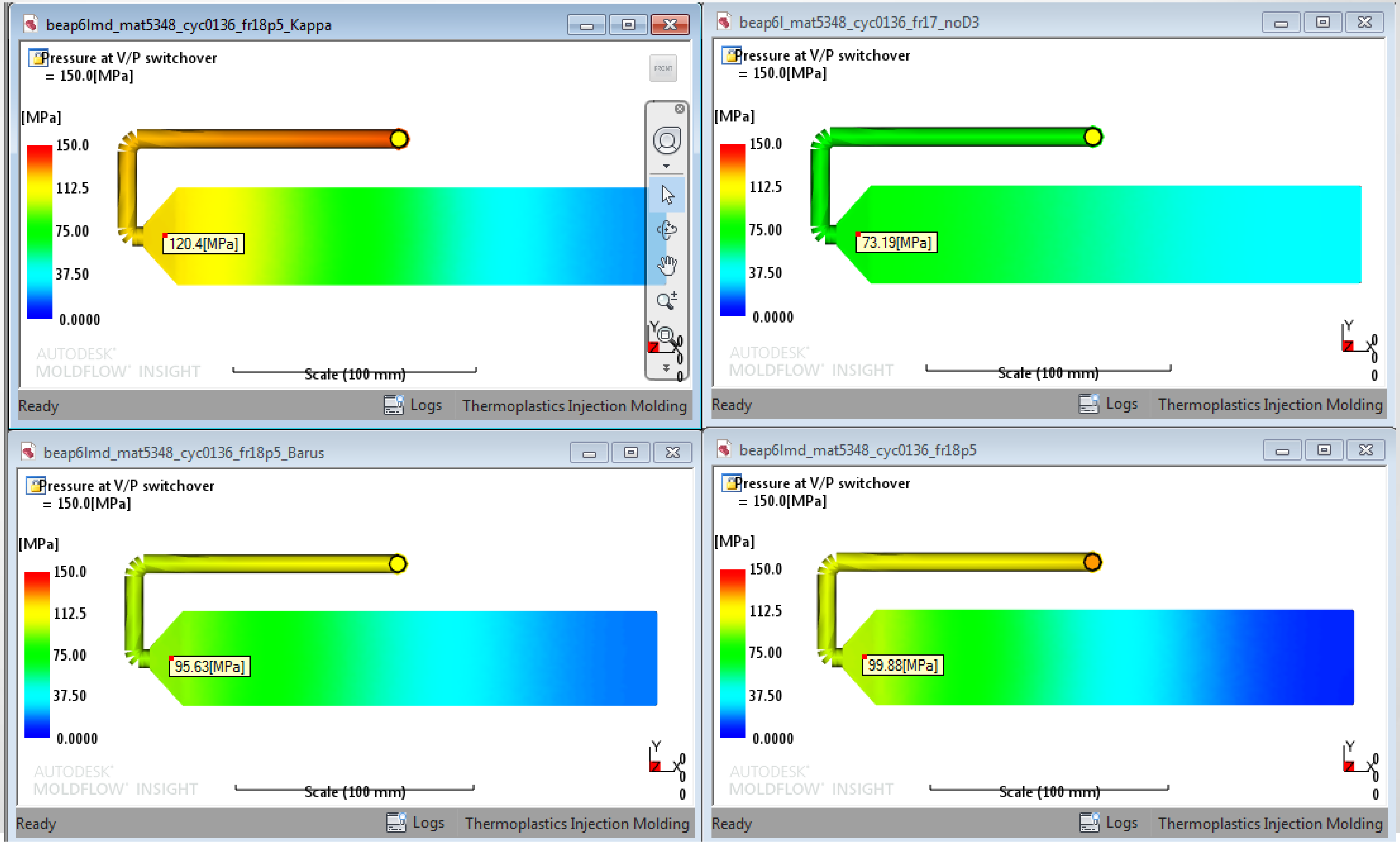
Import Profile from file (*.csv)



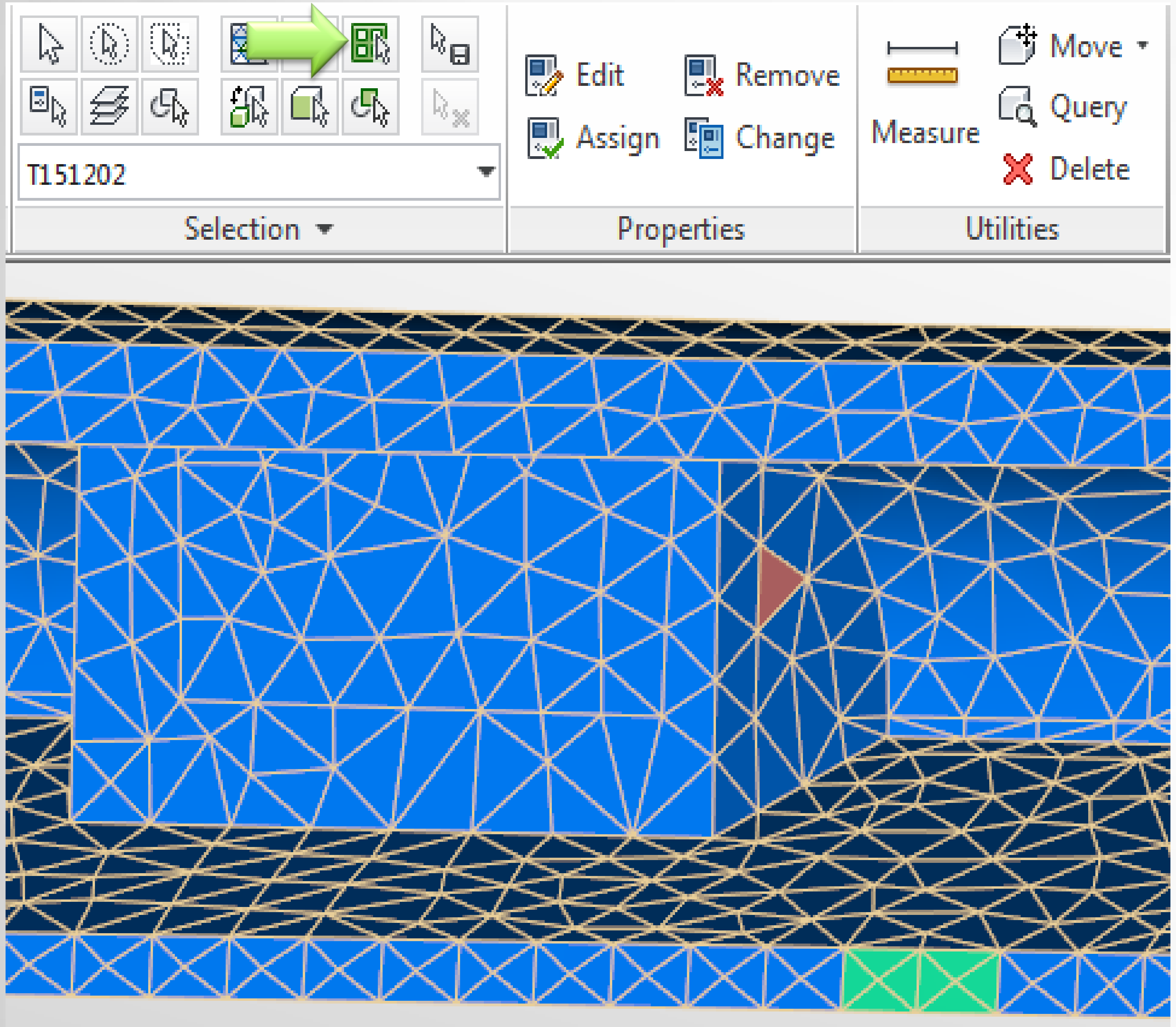
Synchronized Results Examine

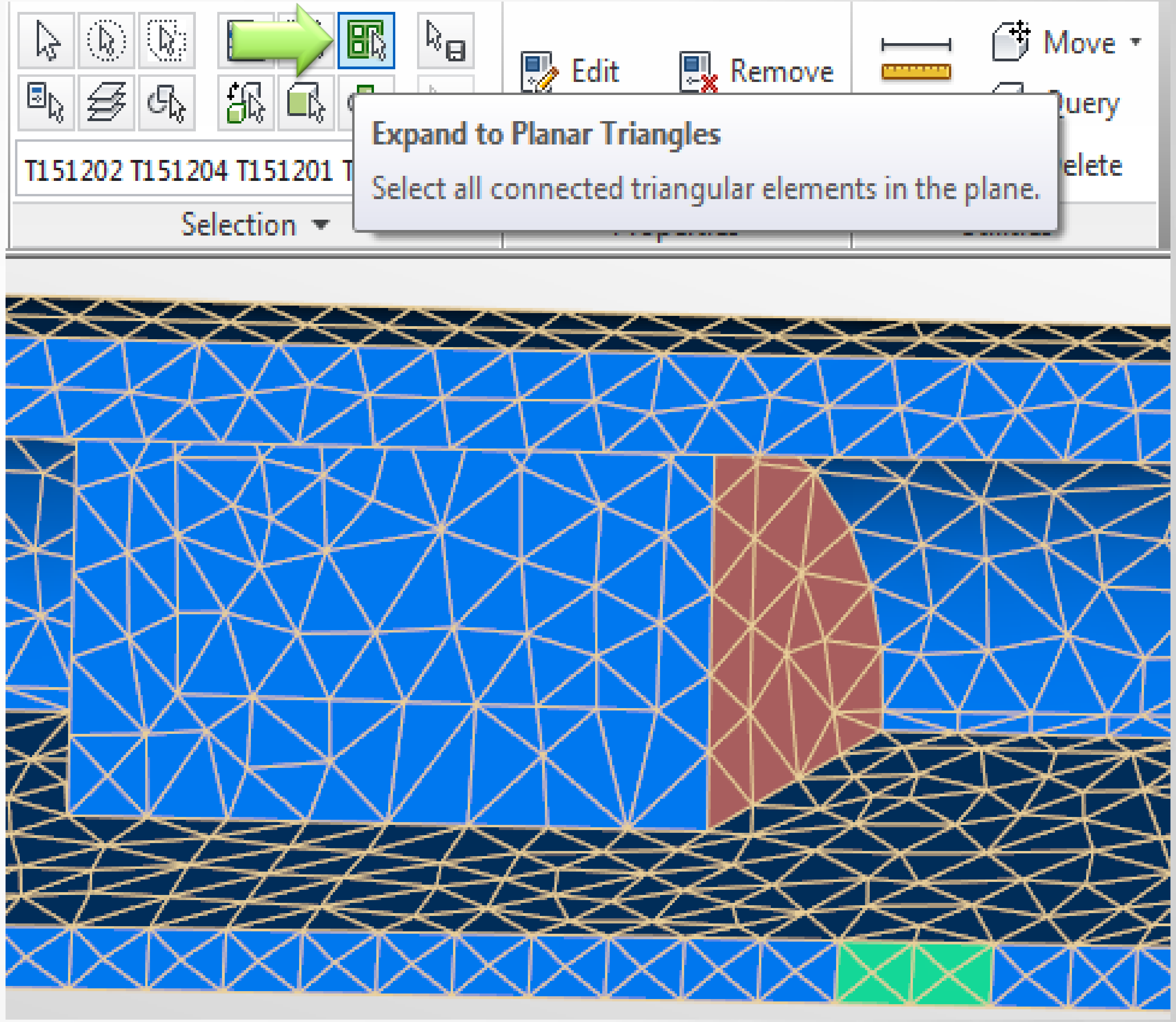
Result examine simultaneously on all locked the displays





Face Selection (Surface Mesh)

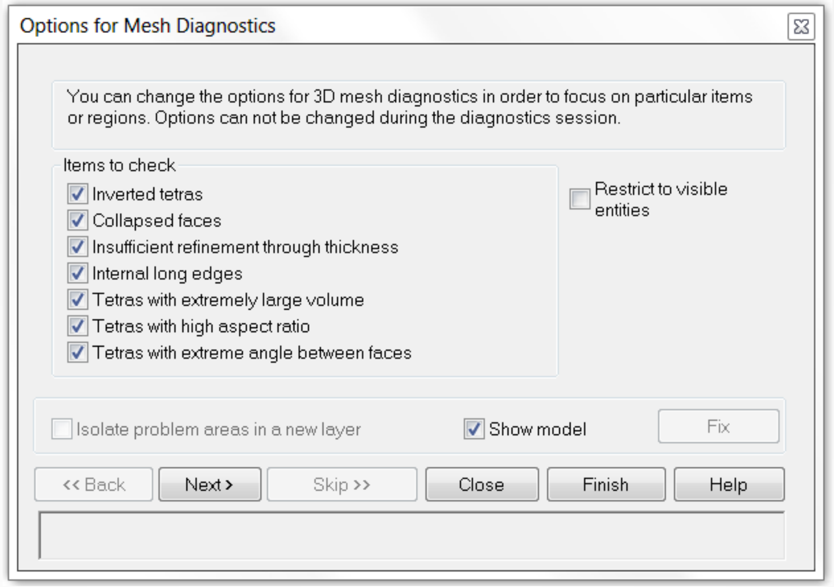


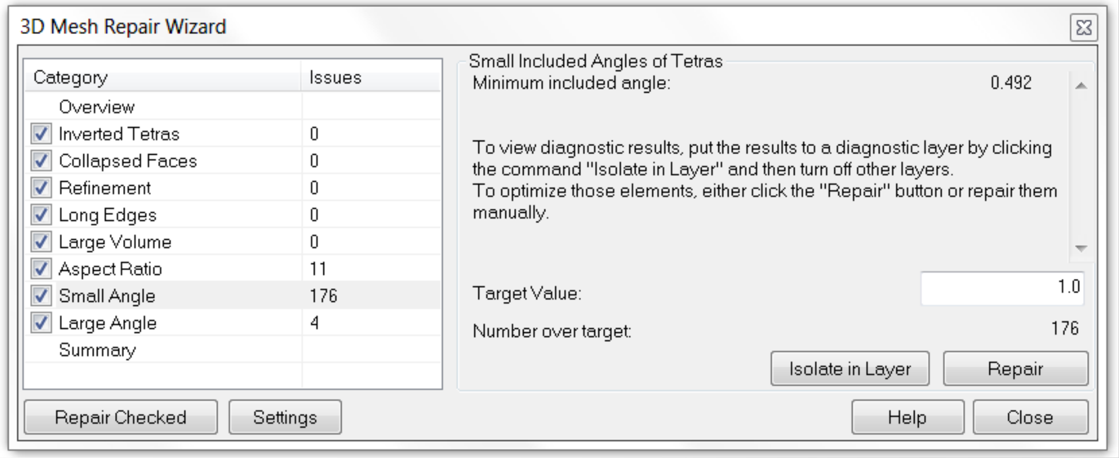


3D Mesh Repair Wizard

2015

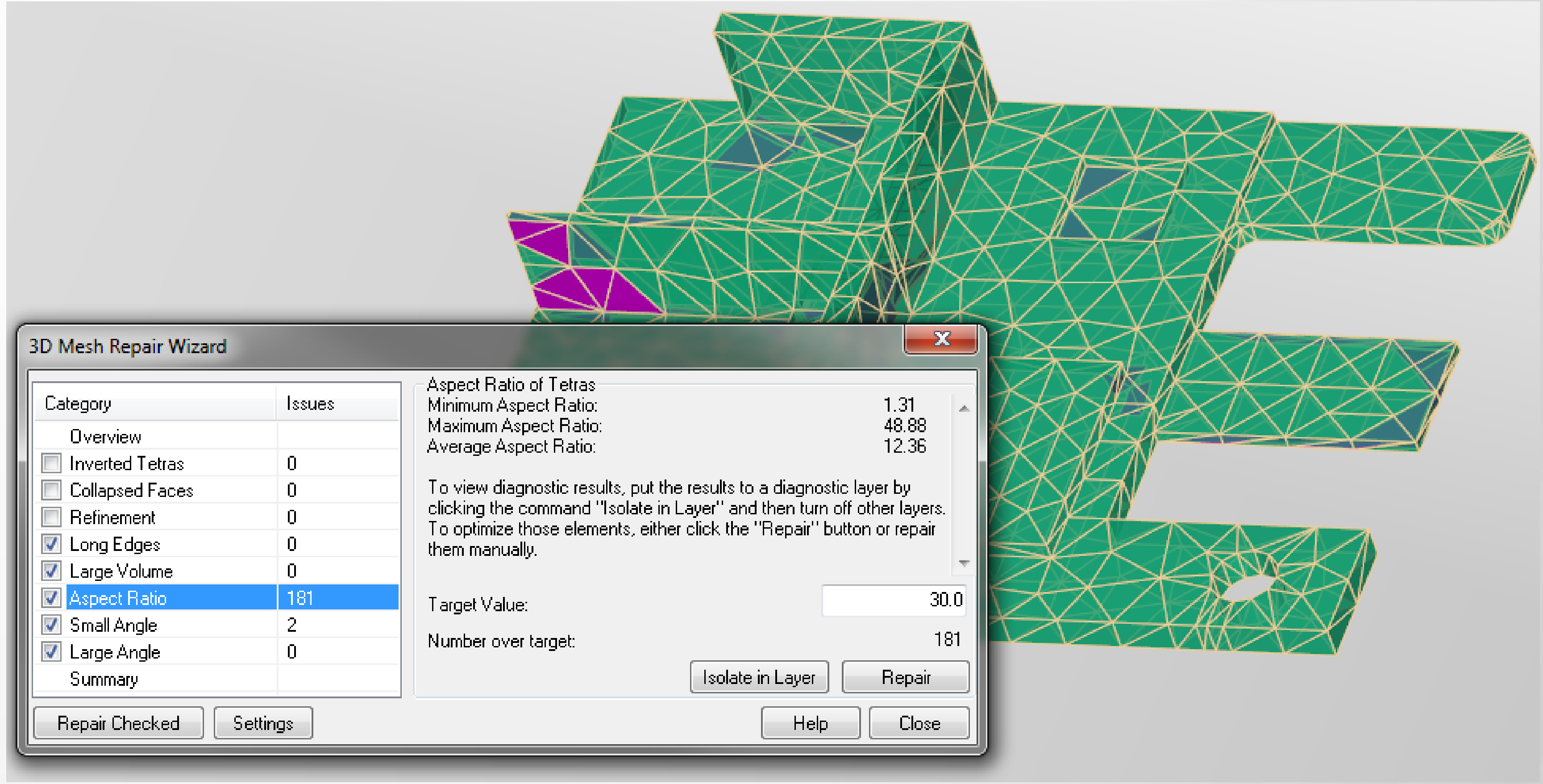
2016





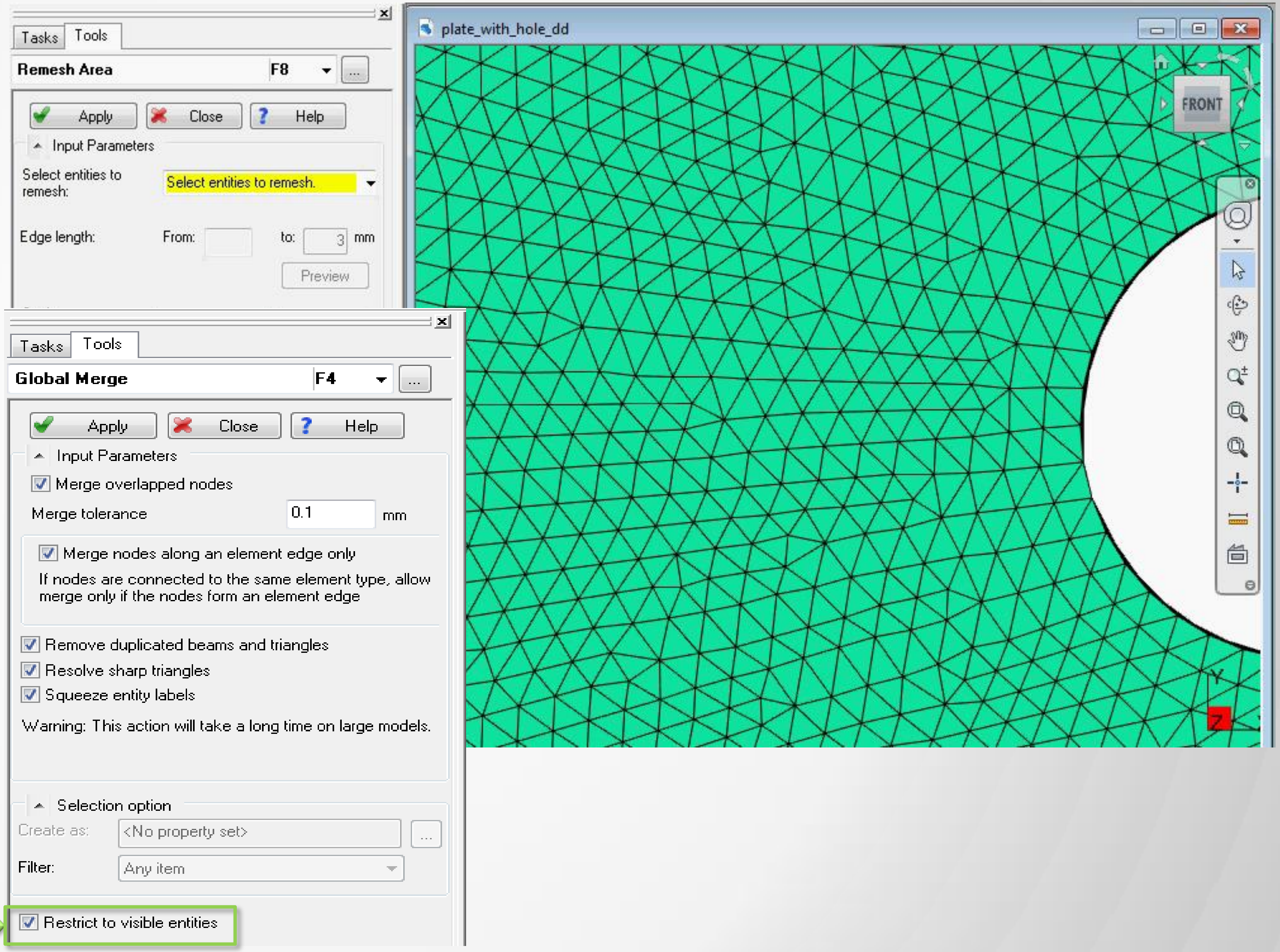
- New Layout

- Highlight defects on model



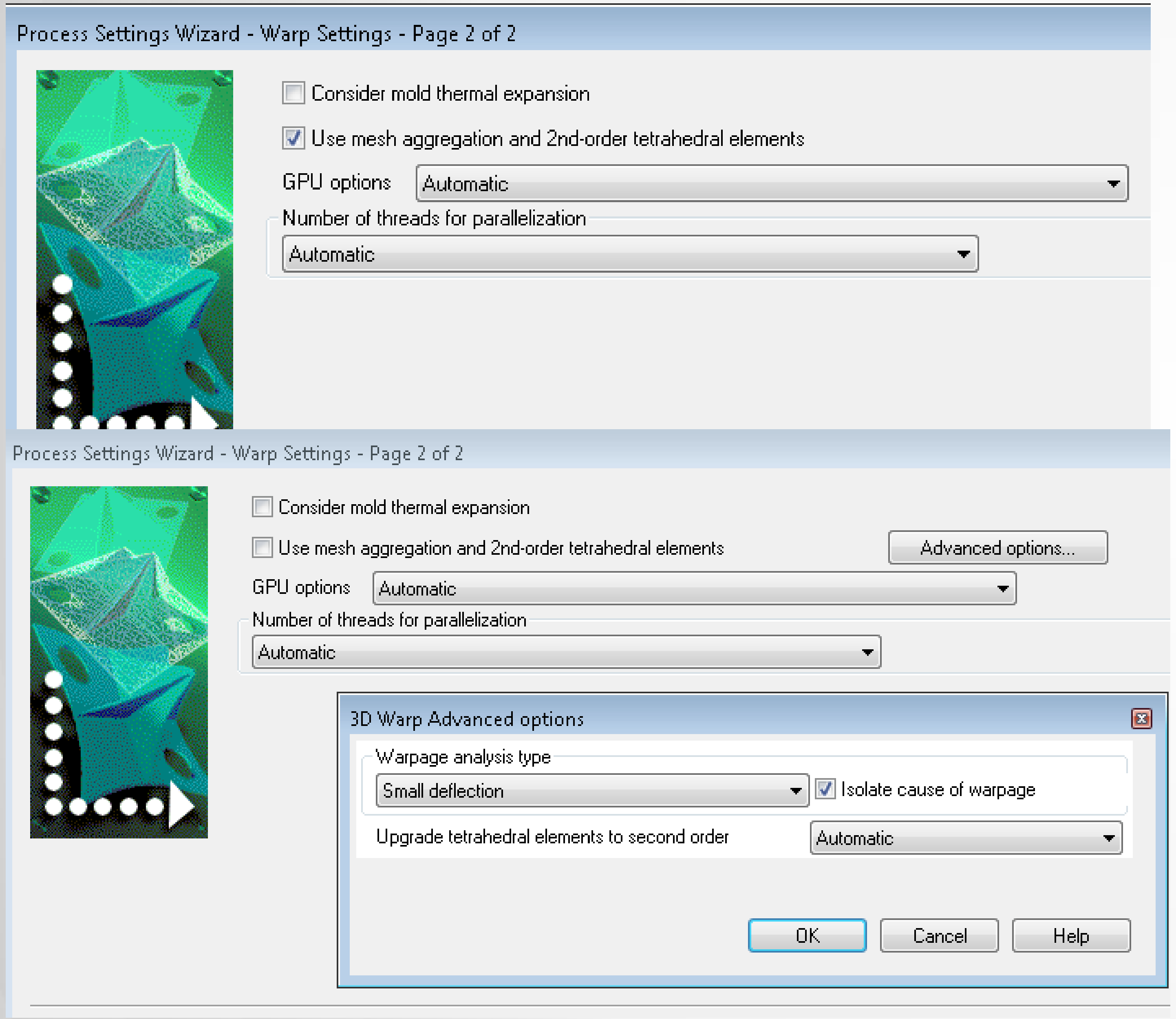
Mesh Usability Enhancements

- Remesh Area Preview
- Global merge can be restricted to visible nodes
- New mesh size controls for 1D (runner and cooling)
- Improved Overlap diagnostic

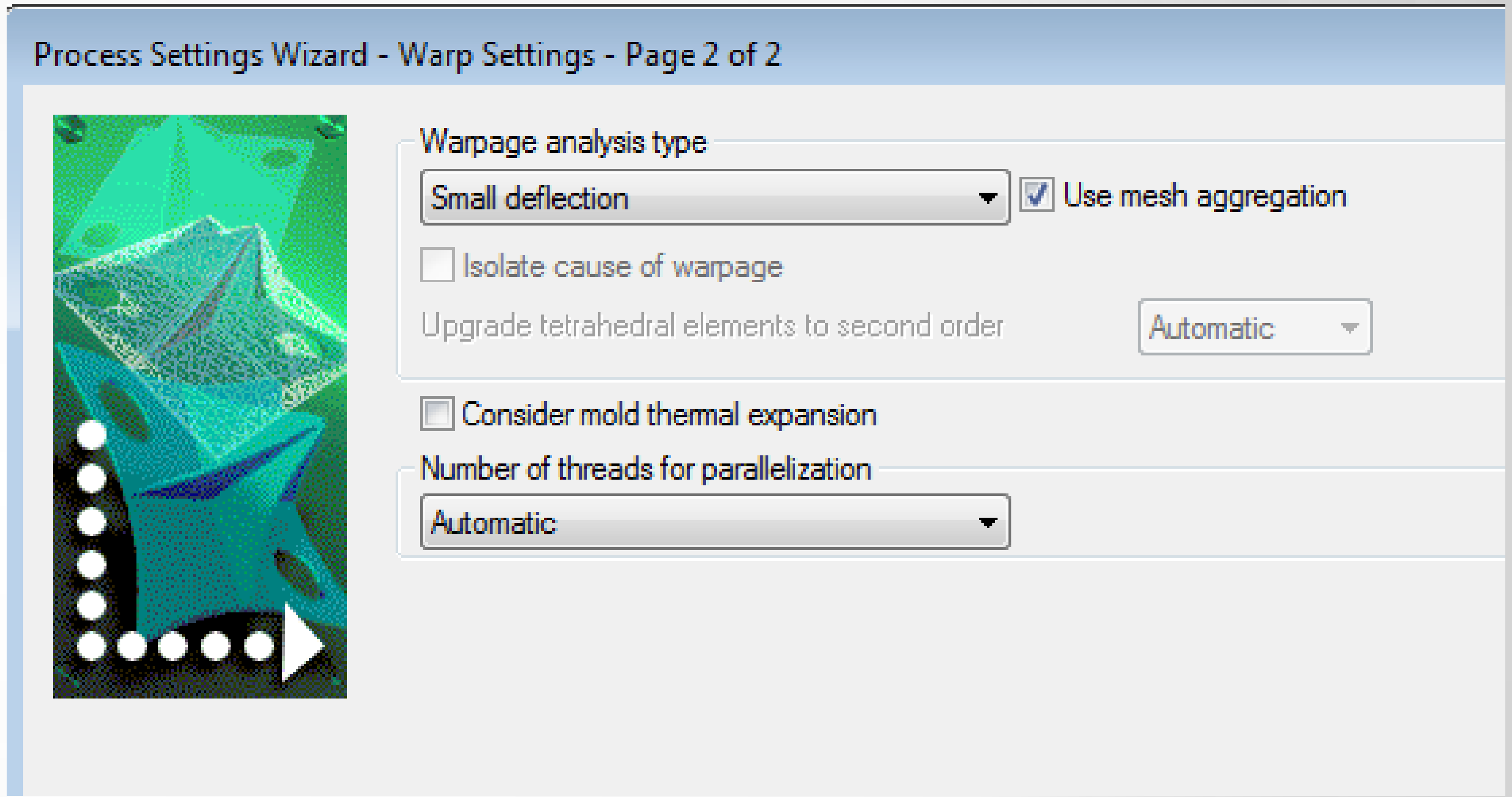


Simplified 3D Warp Process Settings

2015

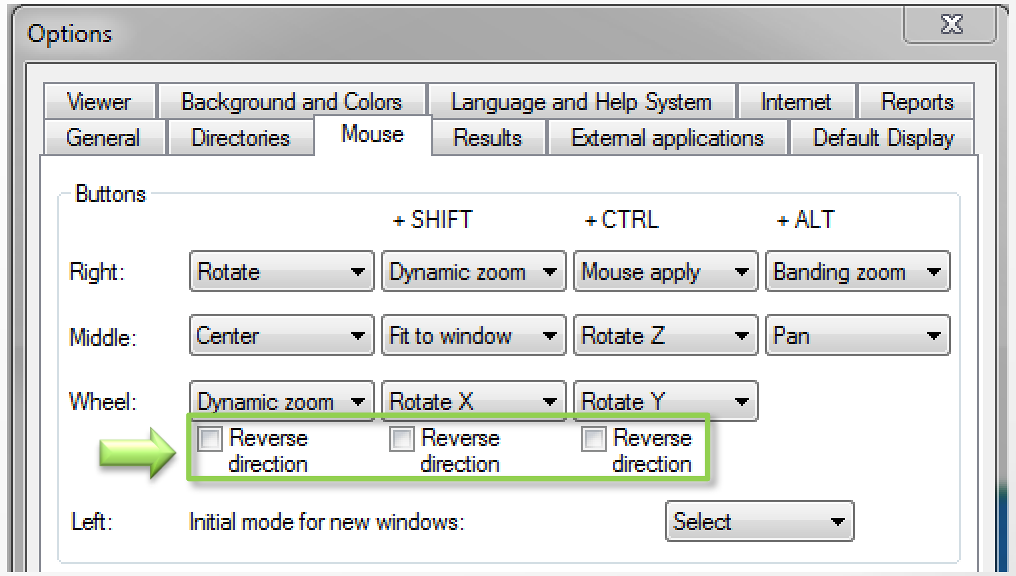


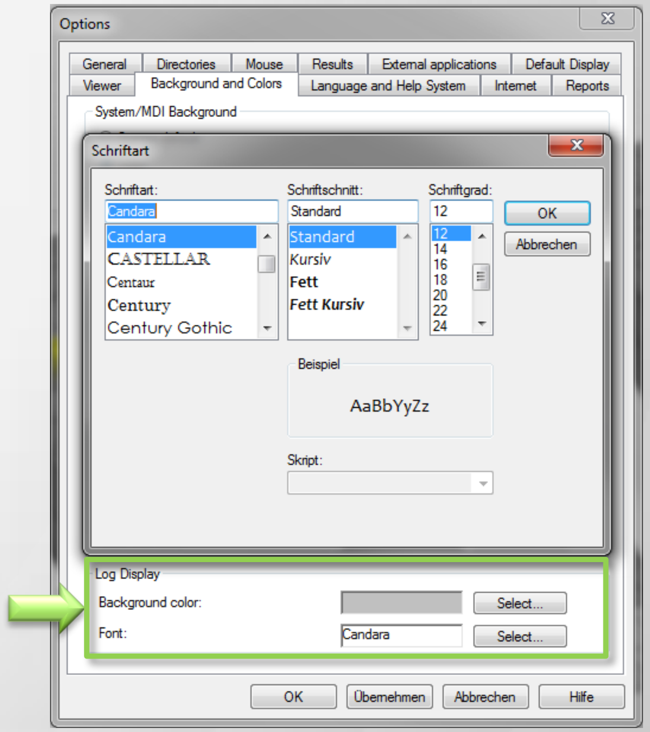
2016



Other Usability Enhancements

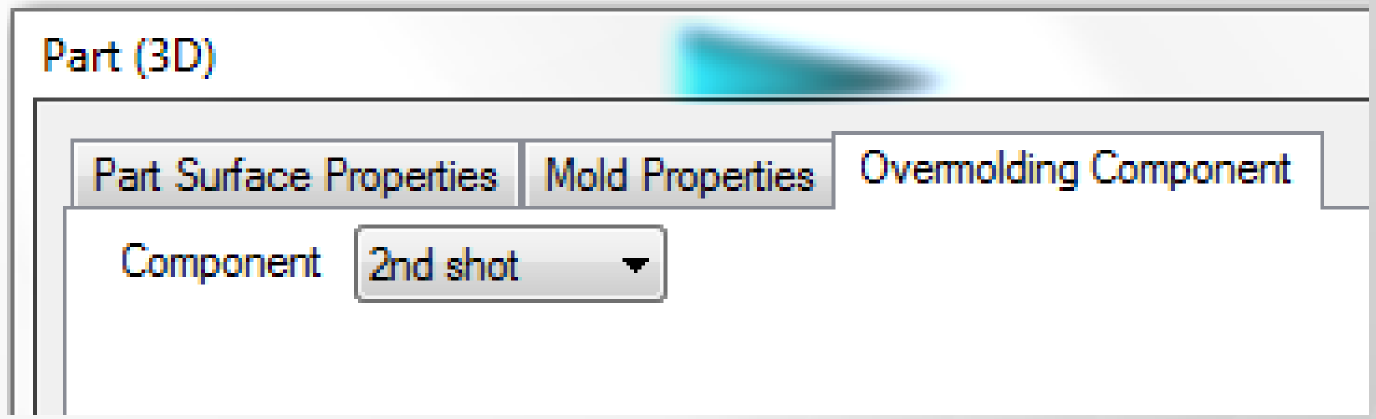
- Speed-up large model handling (up to x2 faster)
  - Faster model display
  - Faster result display
- Enable Synergy-API for multiple instances of Synergy
- Studymod can select material
- Mouse wheel direction choice
- Log file color & font
- Synchronized XY Plot animations





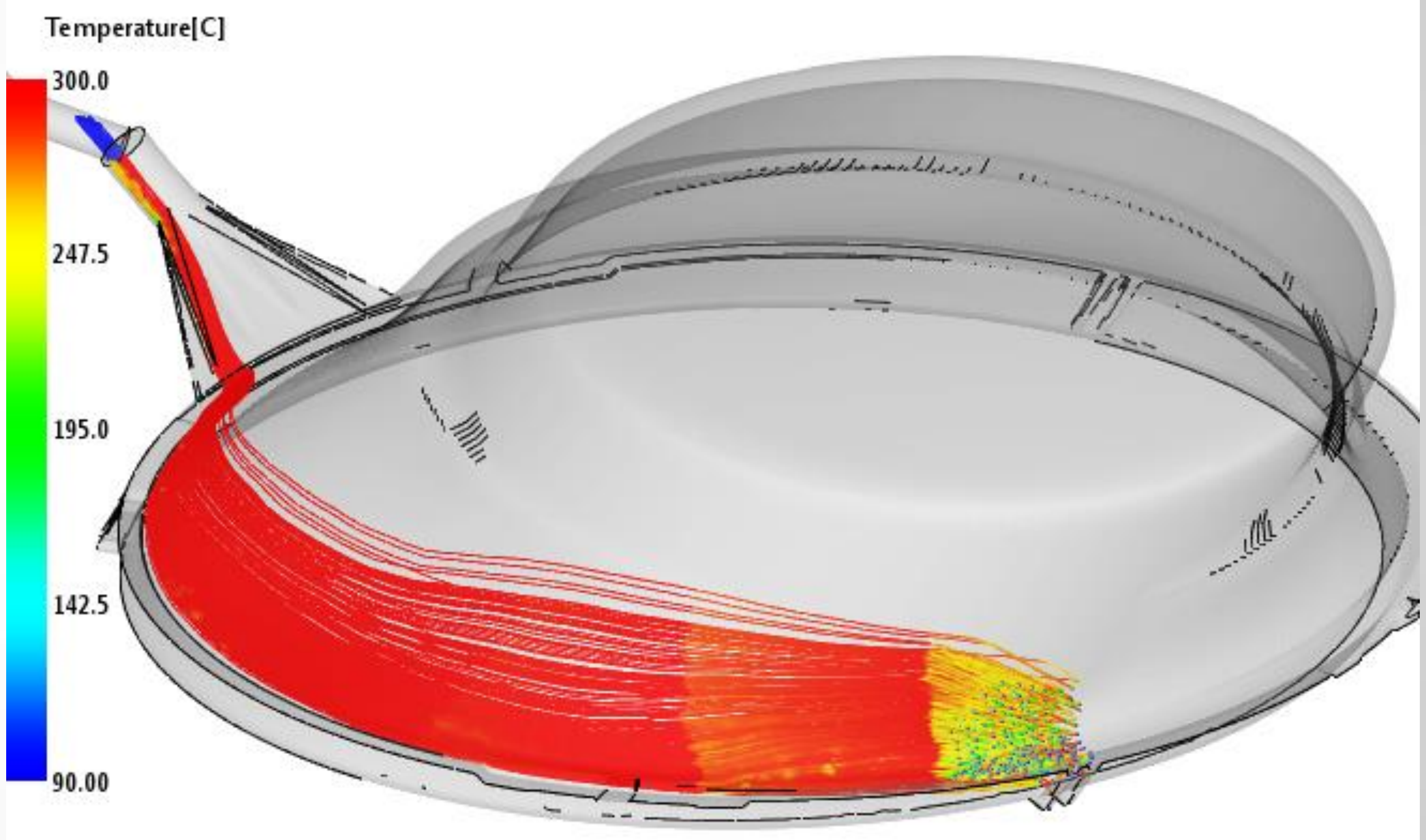
Other Solver Enhancements

- Fiber Breakage enabled for thermoset processes
- Improved 3D Automatic injection time
- Maximum Clamp Force Limit extended to 3D Flow
- Valve gate control by ram positions extended to 3D Flow
- Remove the "Legacy Overmolding Second Component" element types
  - Instead use regular part elements



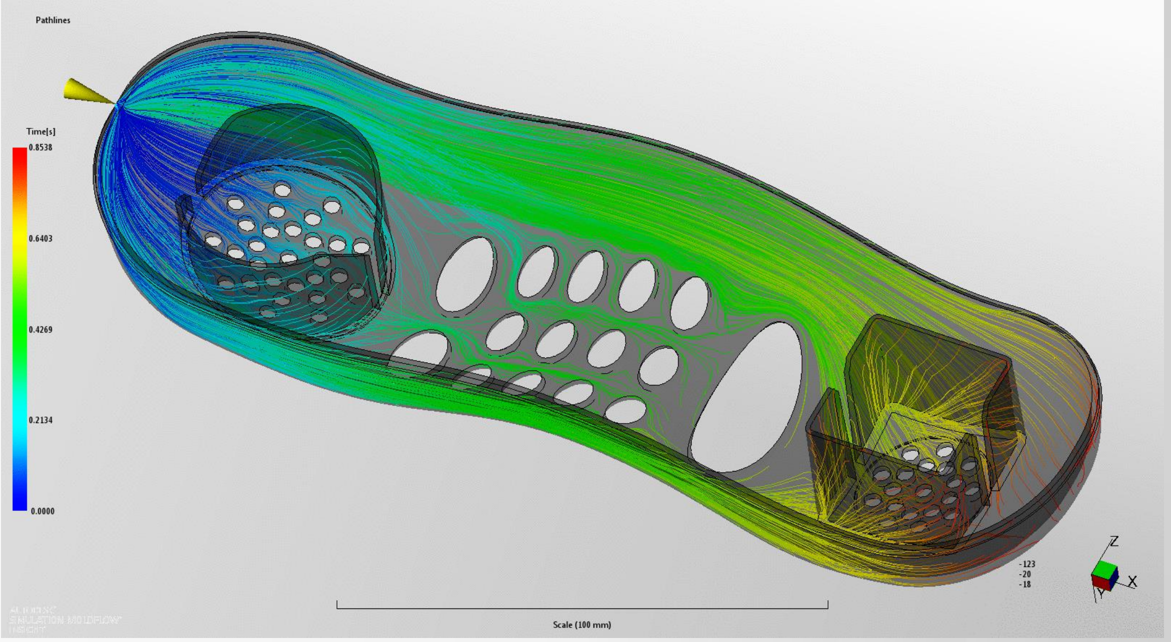
Summary

- Moldflow Insight 2016 Beta
  - Pathlines
  - 3D Weld-surface
  - 3D RSC Fiber Orientation
  - New Results
    - Cavity Weights
    - Bending Curvature, …..
  - Usability Improvements
    - Layer Management
    - License Borrowing
    - Face Selection, ….



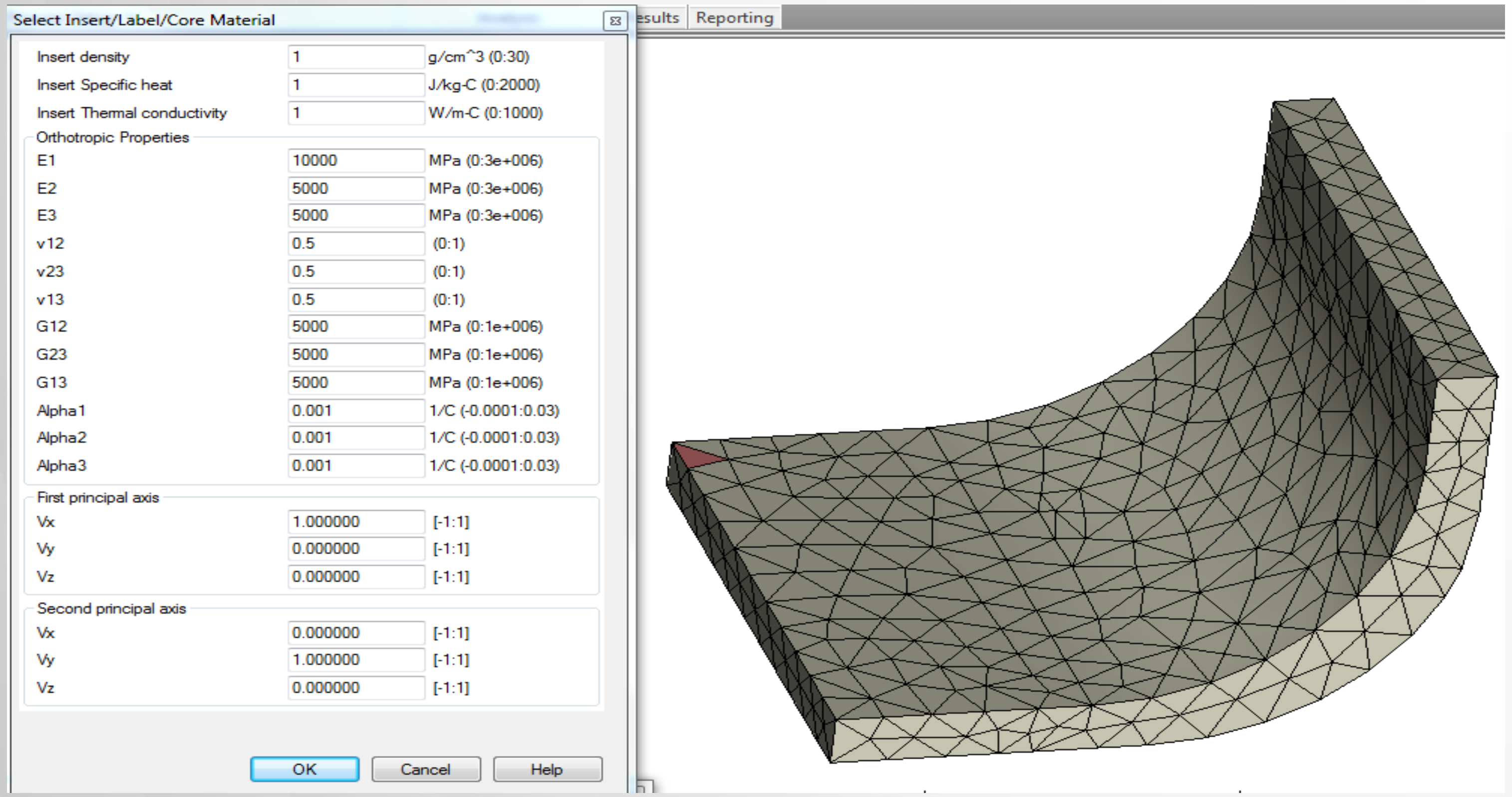
Agenda

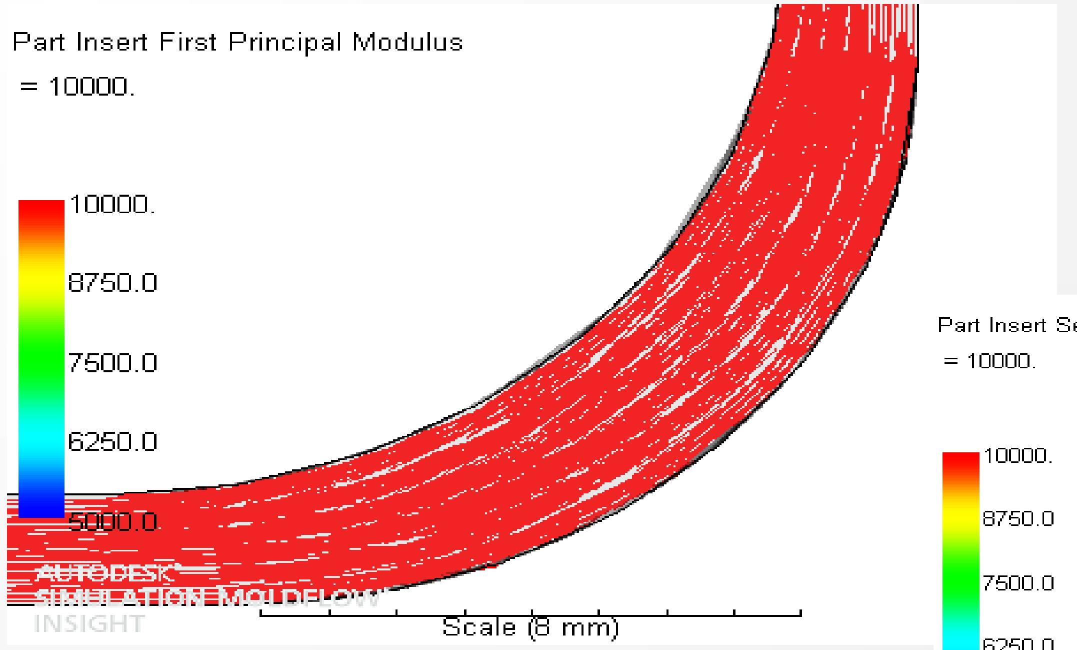
- 2015 Scandium Technology Preview
- Moldflow Insight 2016 Beta
- Some API Tools
- Long Term Research Collaborations

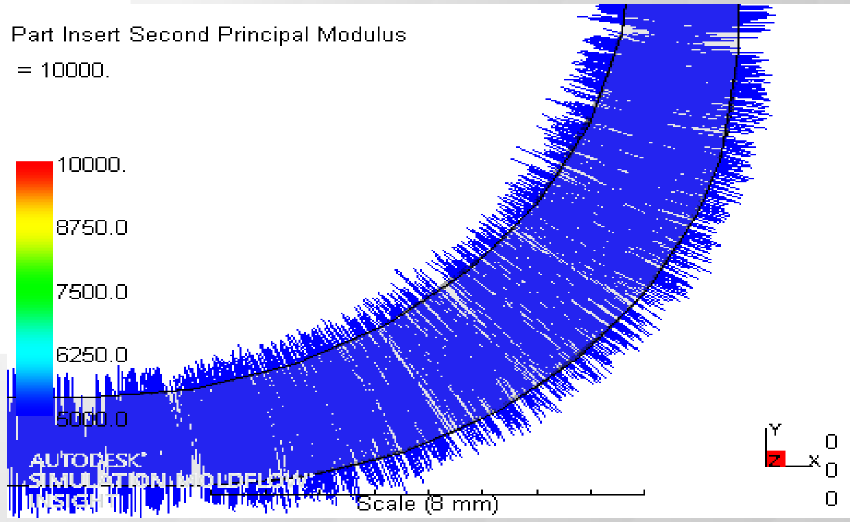


Draping Orthotropic properties over a curved insert

- First set the properties correctly on one element
- Run: SetOrthotropicProperties.vbs
  - Copies and rotates those properties to all connect elements
- Currently posted on Beyond Moldflow Insight blog:
  - http://autodesk.typepad.com/beyondmoldflowinsight/

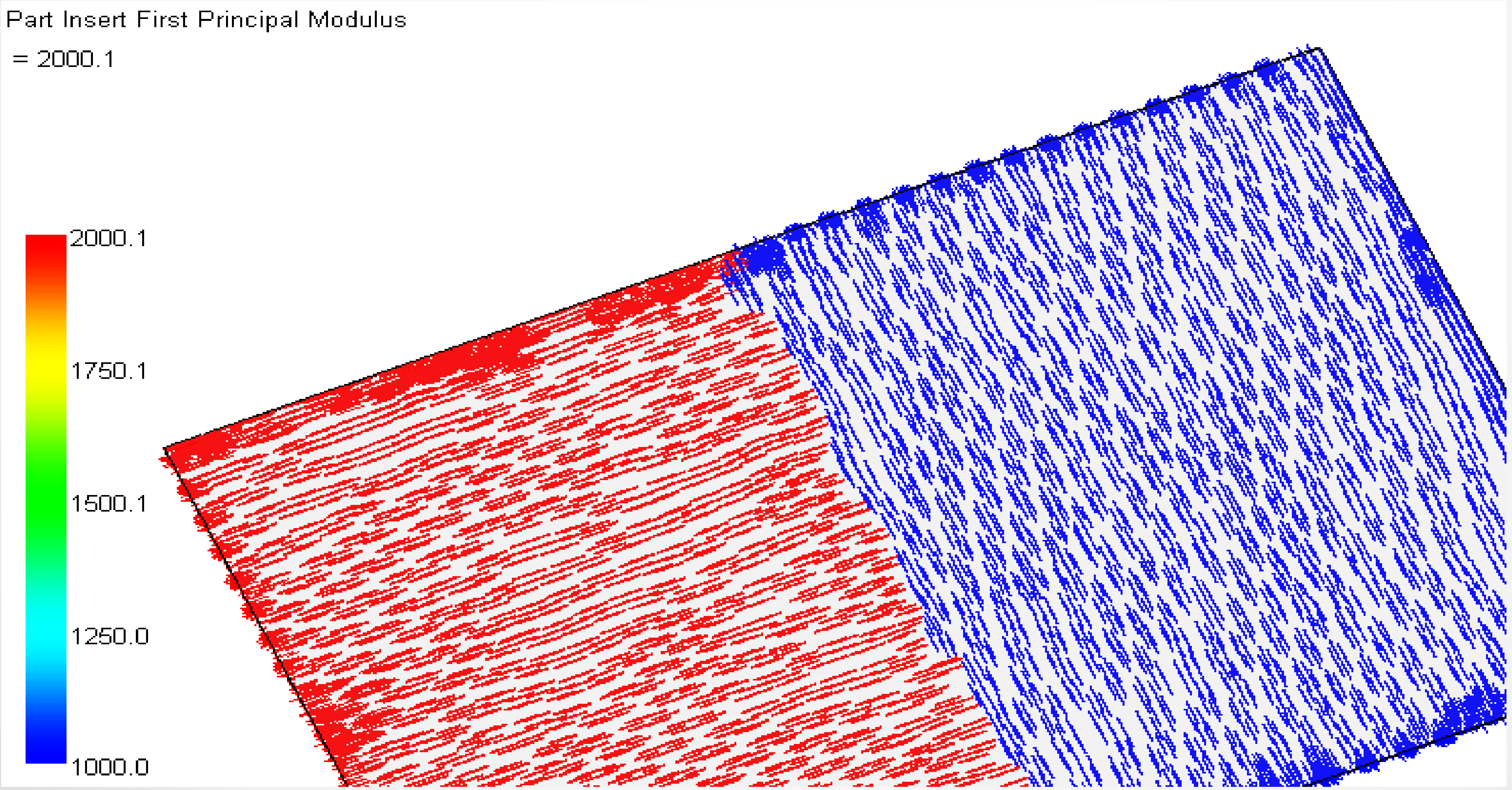






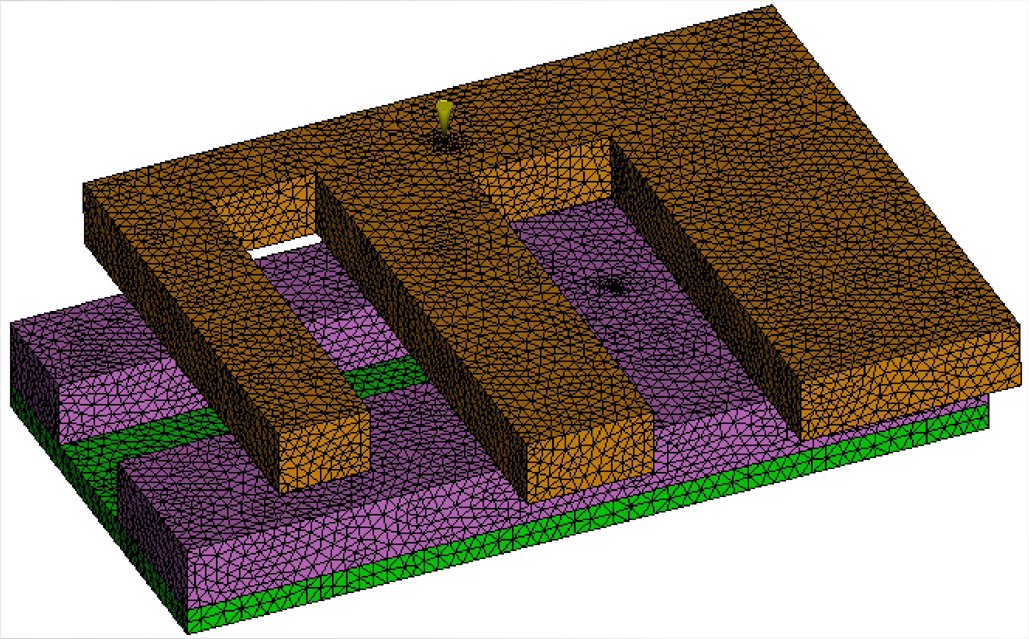
Displaying Orthotropic Properties after setup

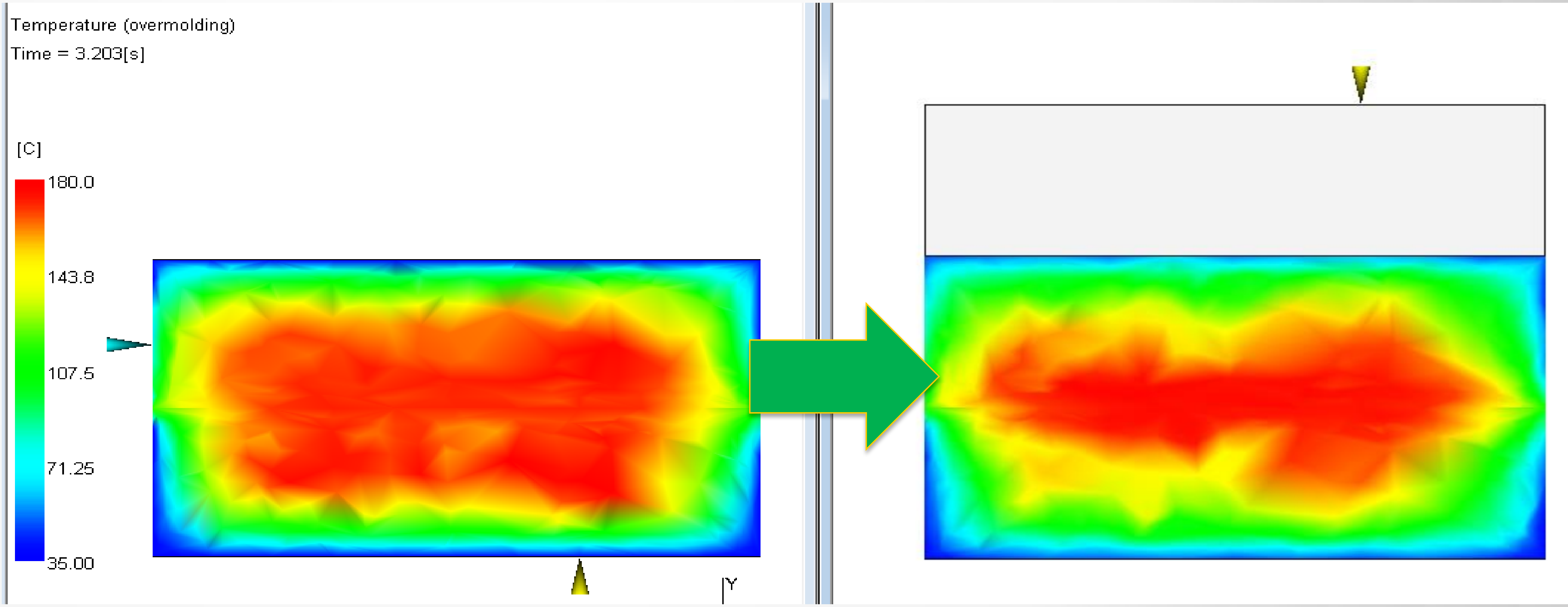
- Run: DisplayOrthotropicProperties.vbs
- Included in the “commands” folder during install



Multi-shot over molding: API Macro

- Copy temperature results to a new study as initial insert temperatures for the subsequent shots

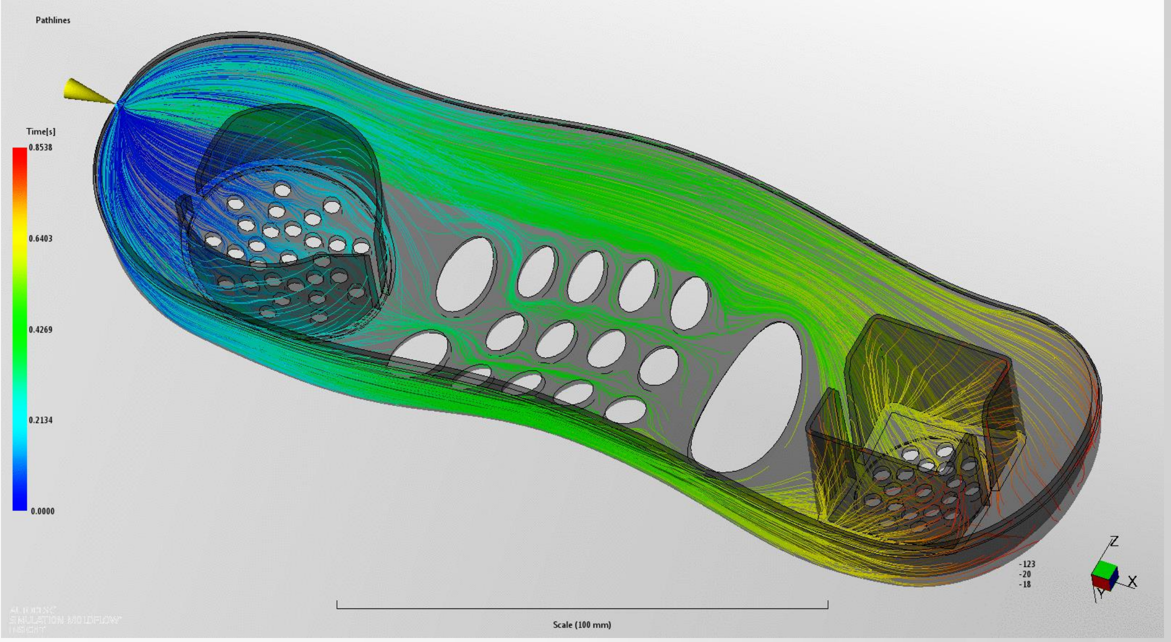




http://autodesk.typepad.com/beyondmoldflowinsight/2014/11/script-for-multi-shot-overmoldings.html

Agenda

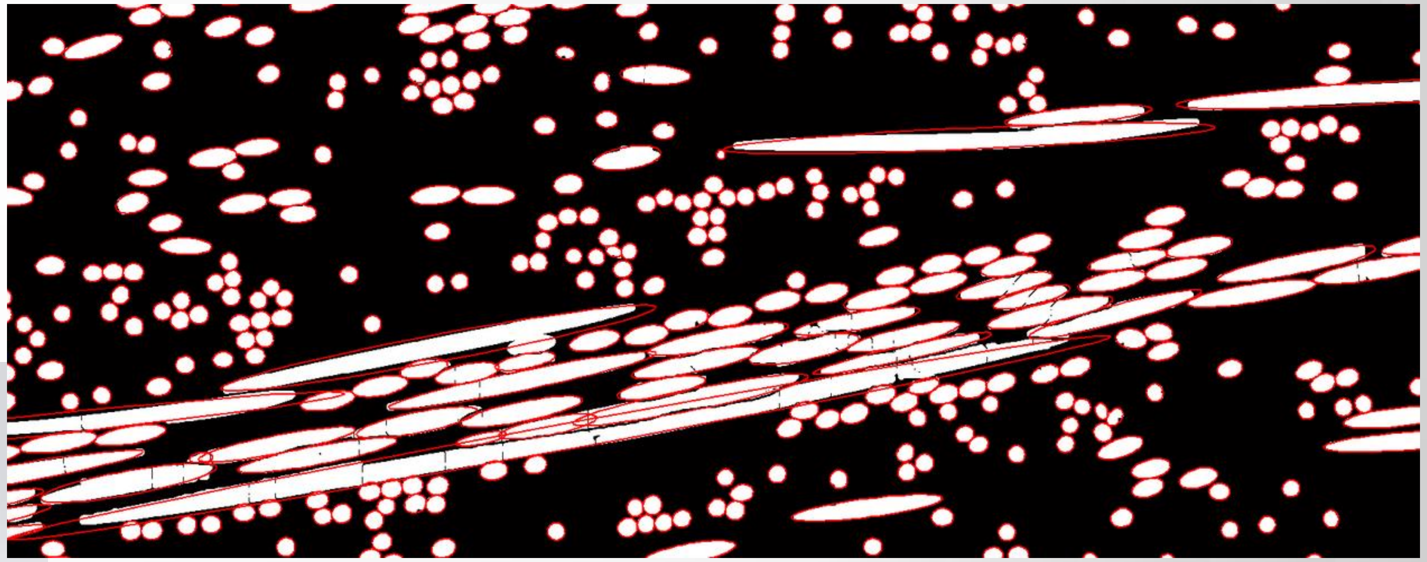
- 2015 Scandium Technology Preview
- Moldflow Insight 2016 Beta
- Some API Tools
- Long Term Research Collaborations



Long Carbon Fiber Injection Molded: PNNL, Toyota, UIUC, Plasticomp, Magna, Purdue Univ

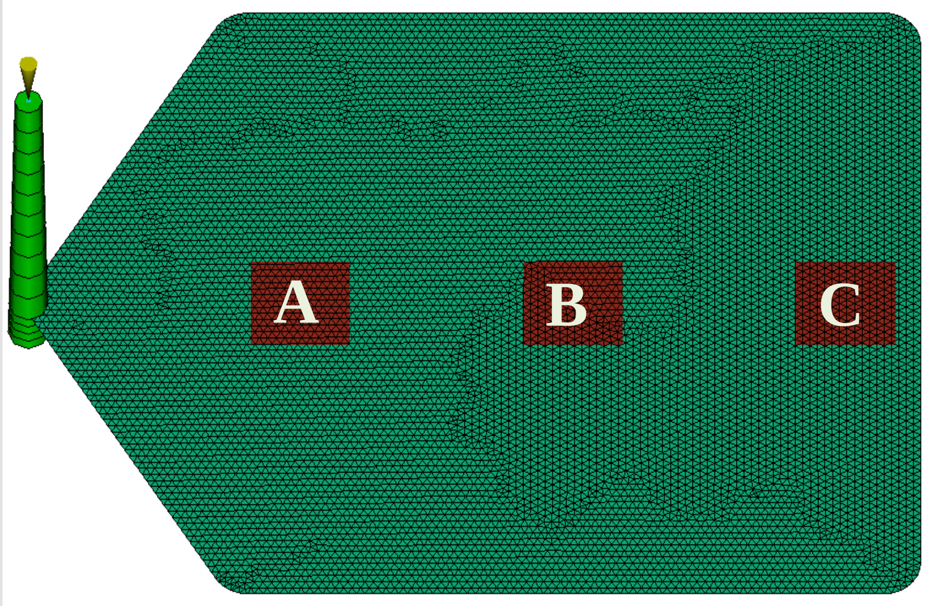
Prediction of fiber orientation and breakage during injection molding of “long” carbon fiber thermoplastics

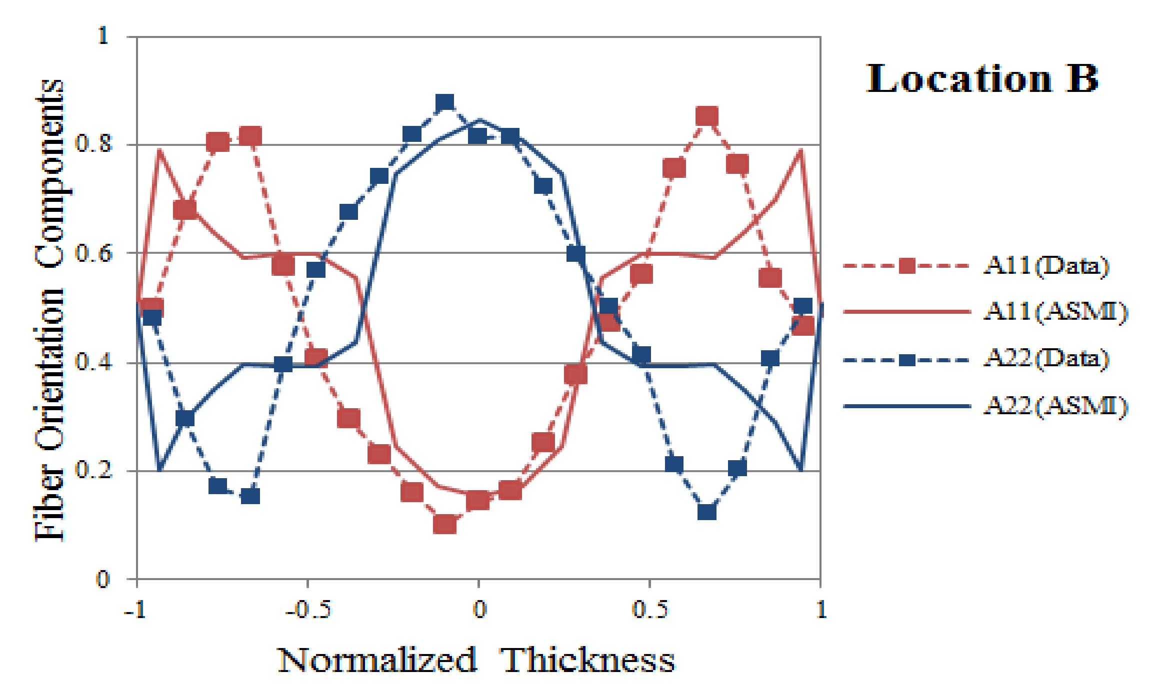
2mm to 12mm

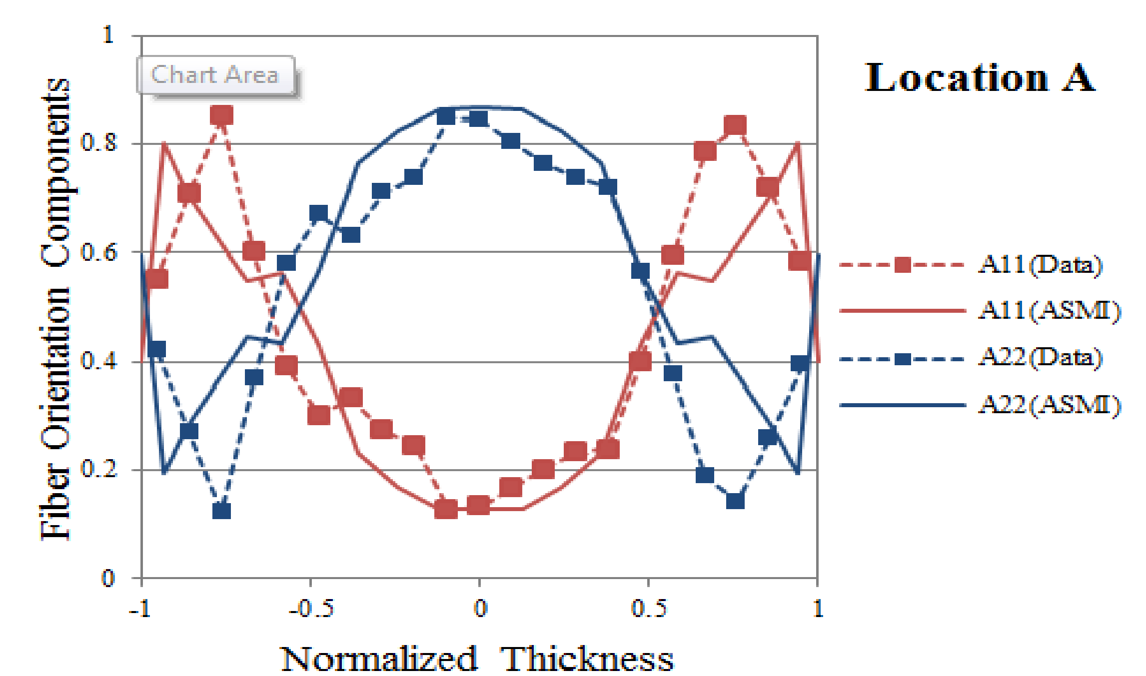


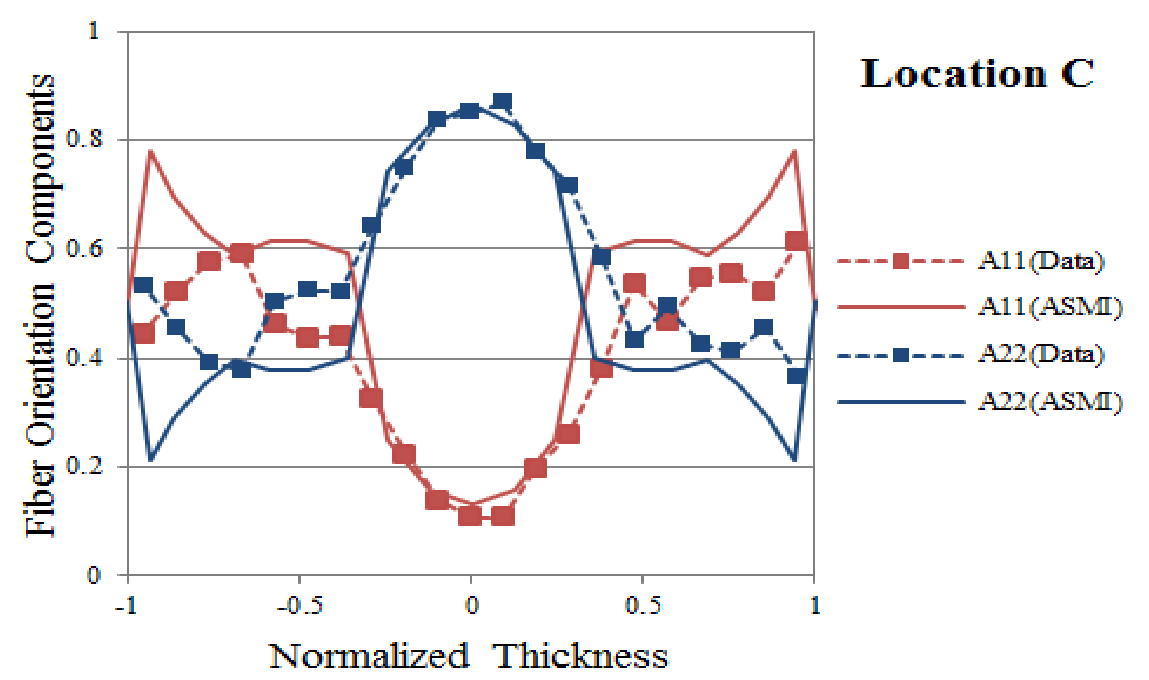
Long Carbon Fiber Orientation Validation: Edge Gated

50%wt LCF/PP (Midplane)



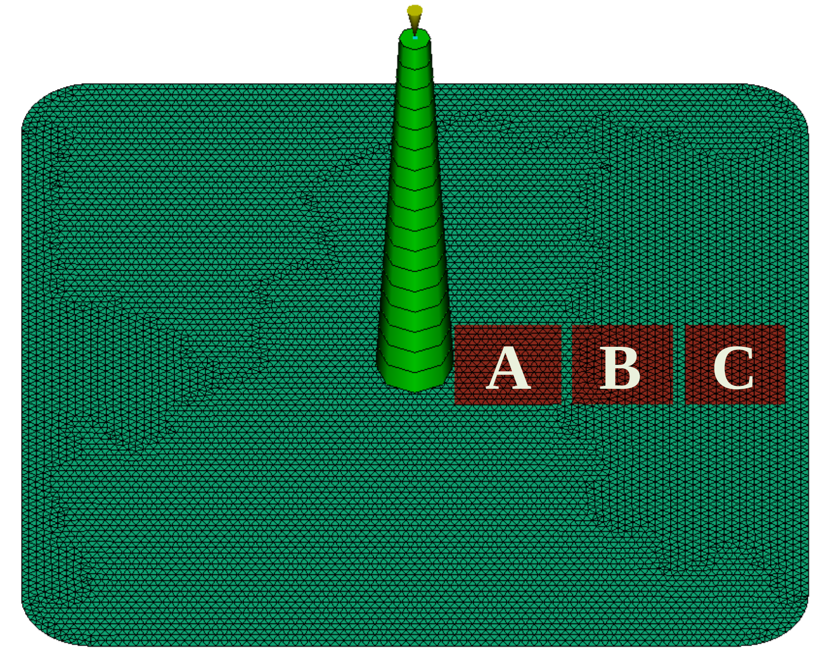


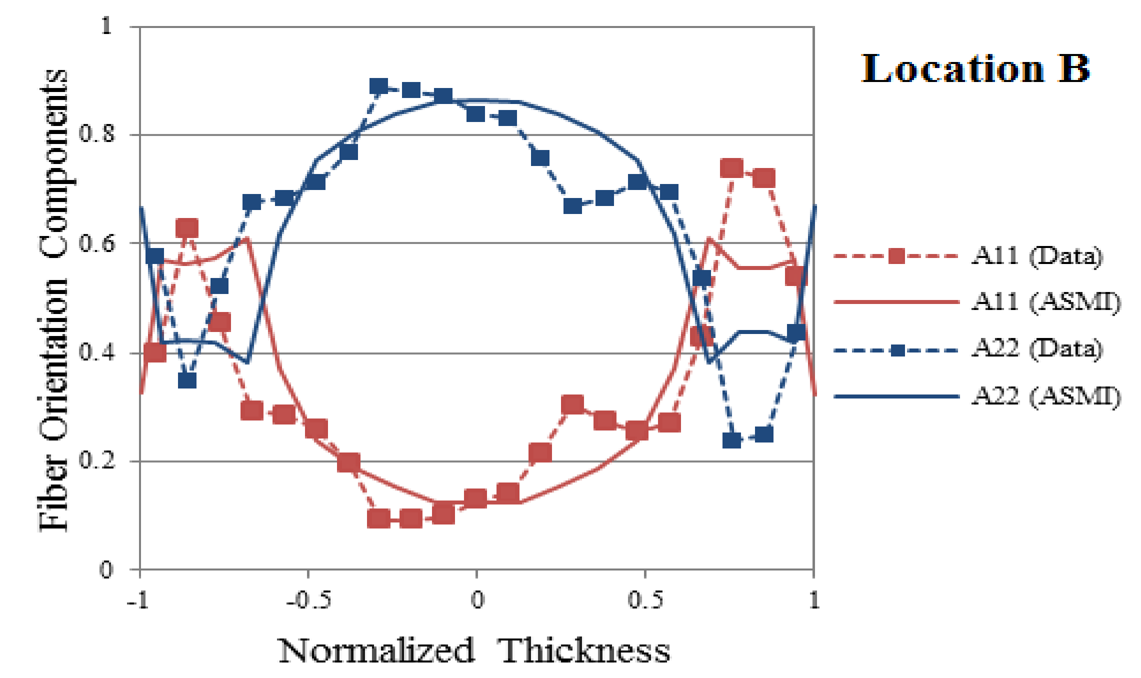


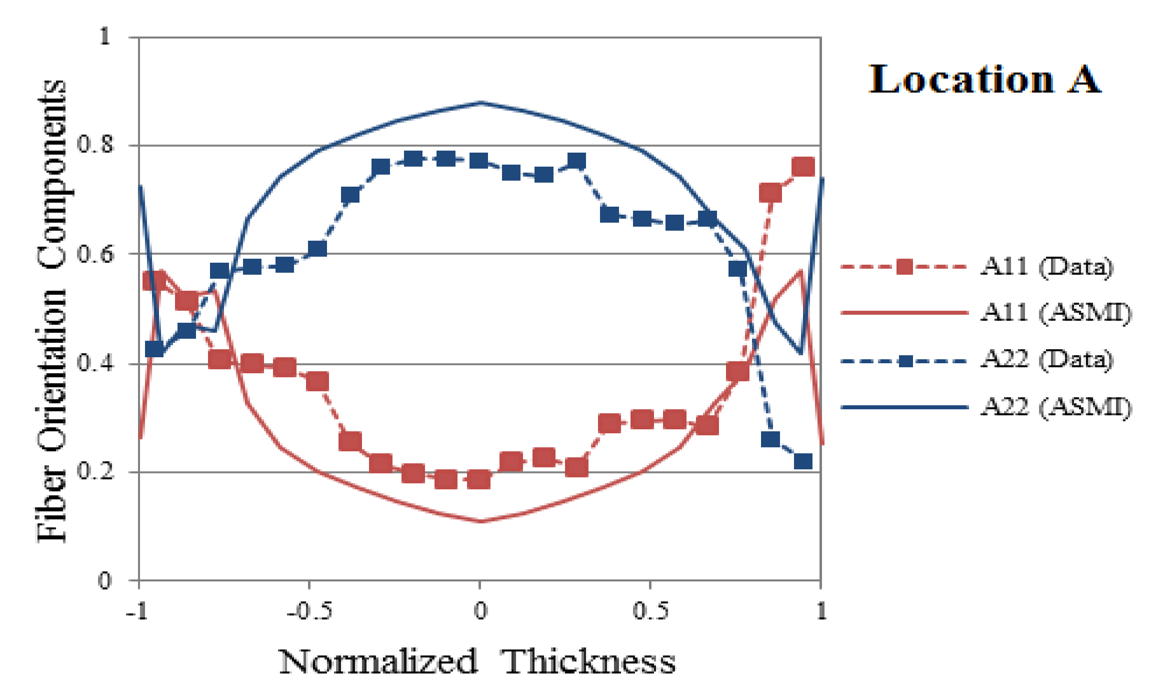


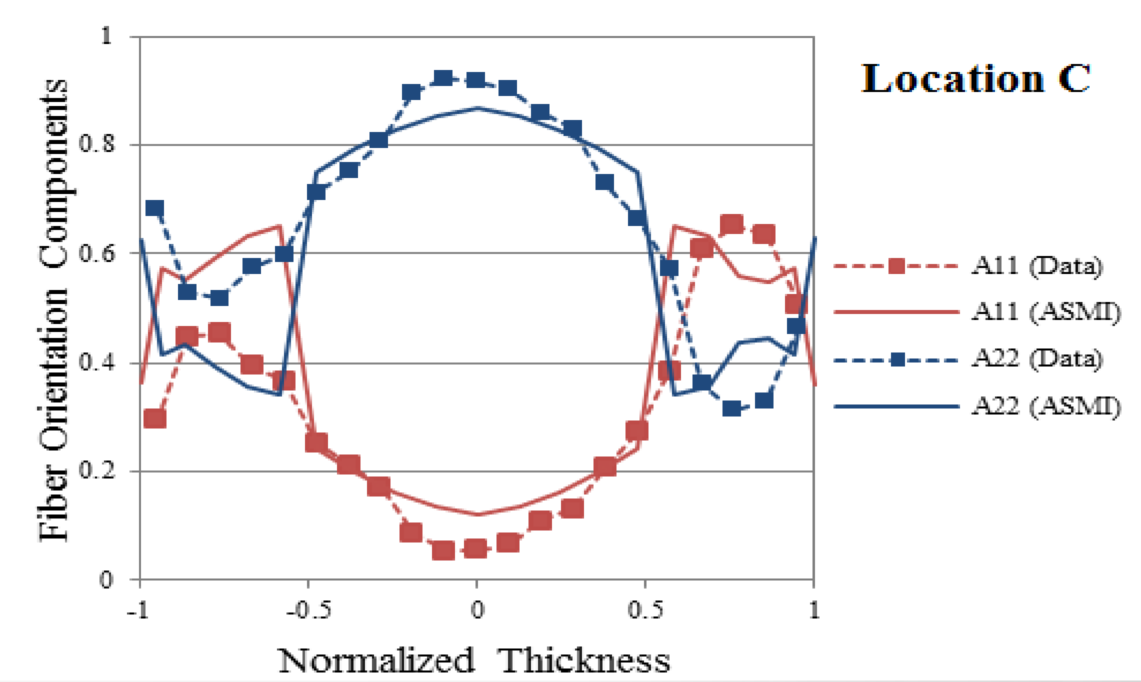
Long Carbon Fiber Orientation Validation: Center Gated

50%wt LCF/PP (Midplane)



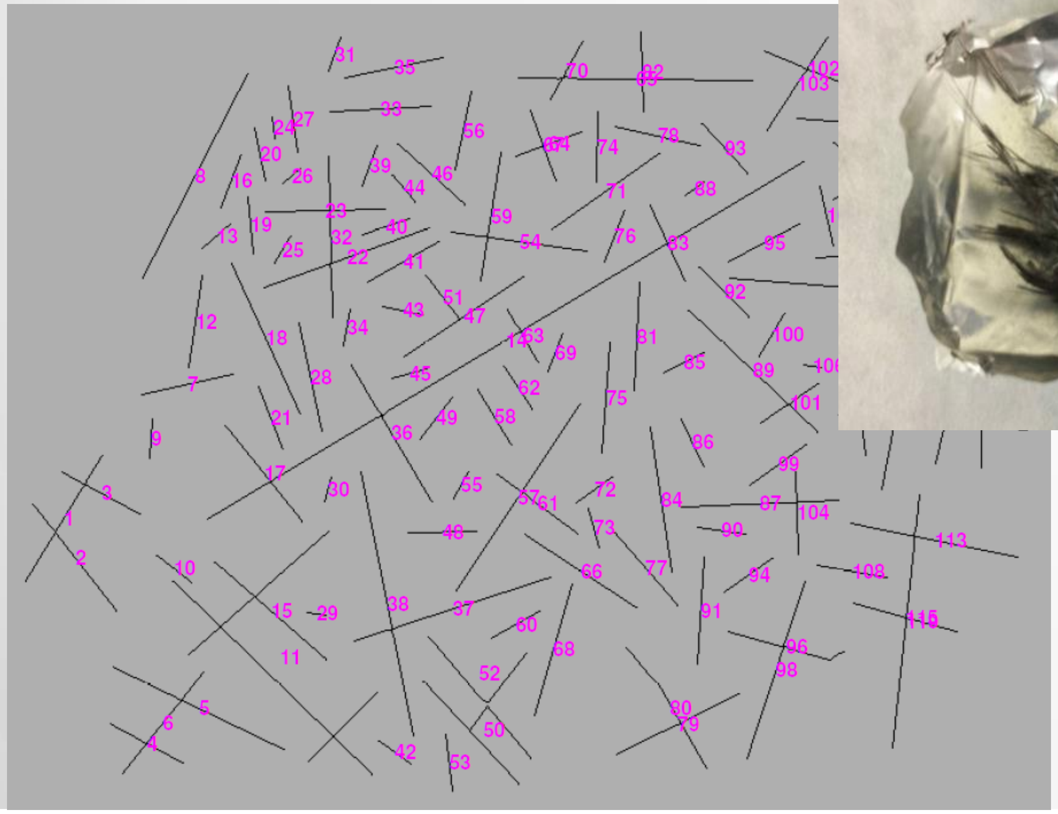


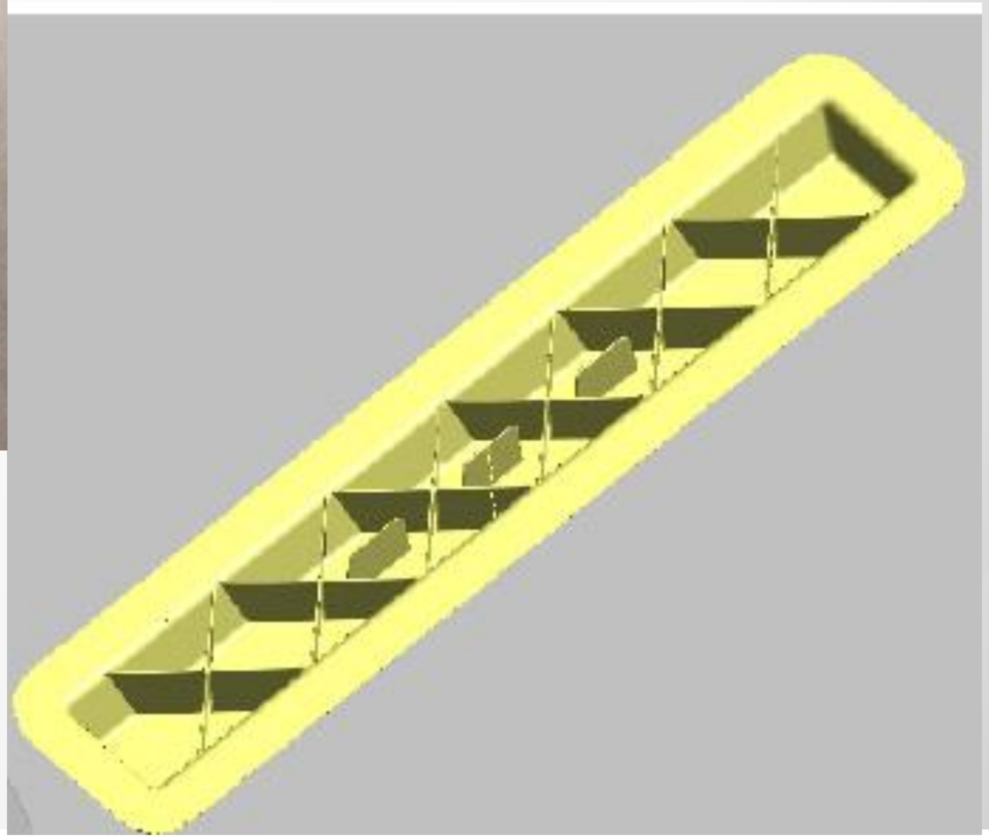




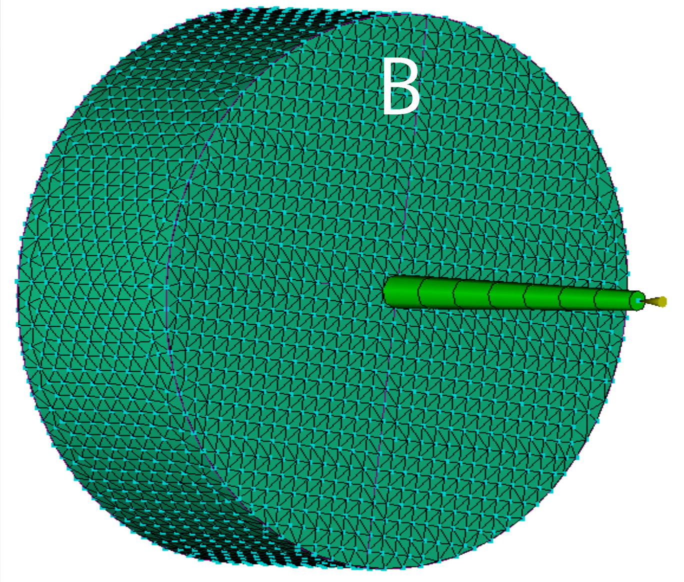
Long Carbon Fiber Thermoplastic: Predictive Eng Tool

- Working to validate 3D long fiber orientation predictions
- Waiting for fiber length (breakage) data to be available
  - Improved Fiber Breakage Model
- Phase 2: Molding of complex structural part

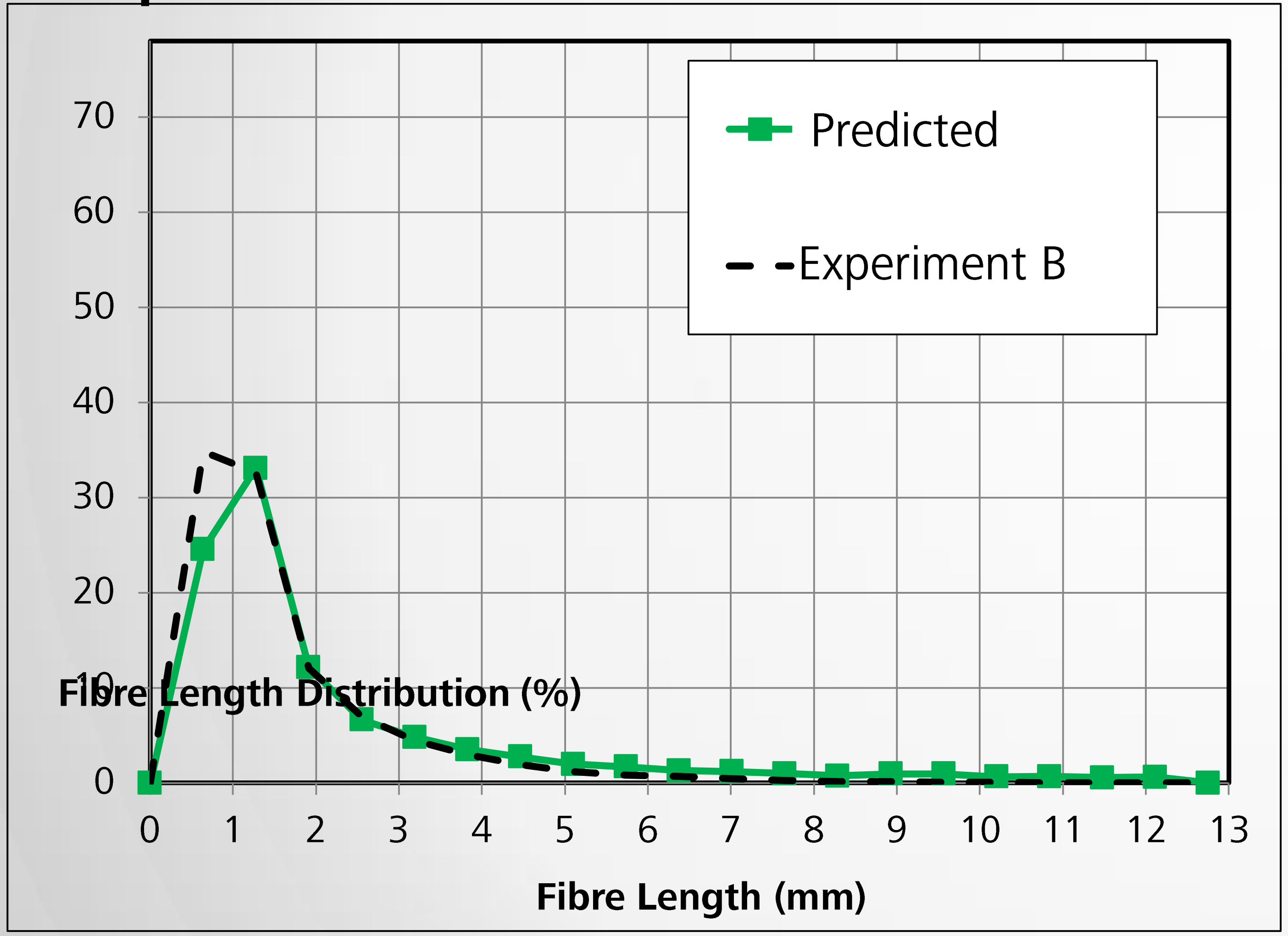




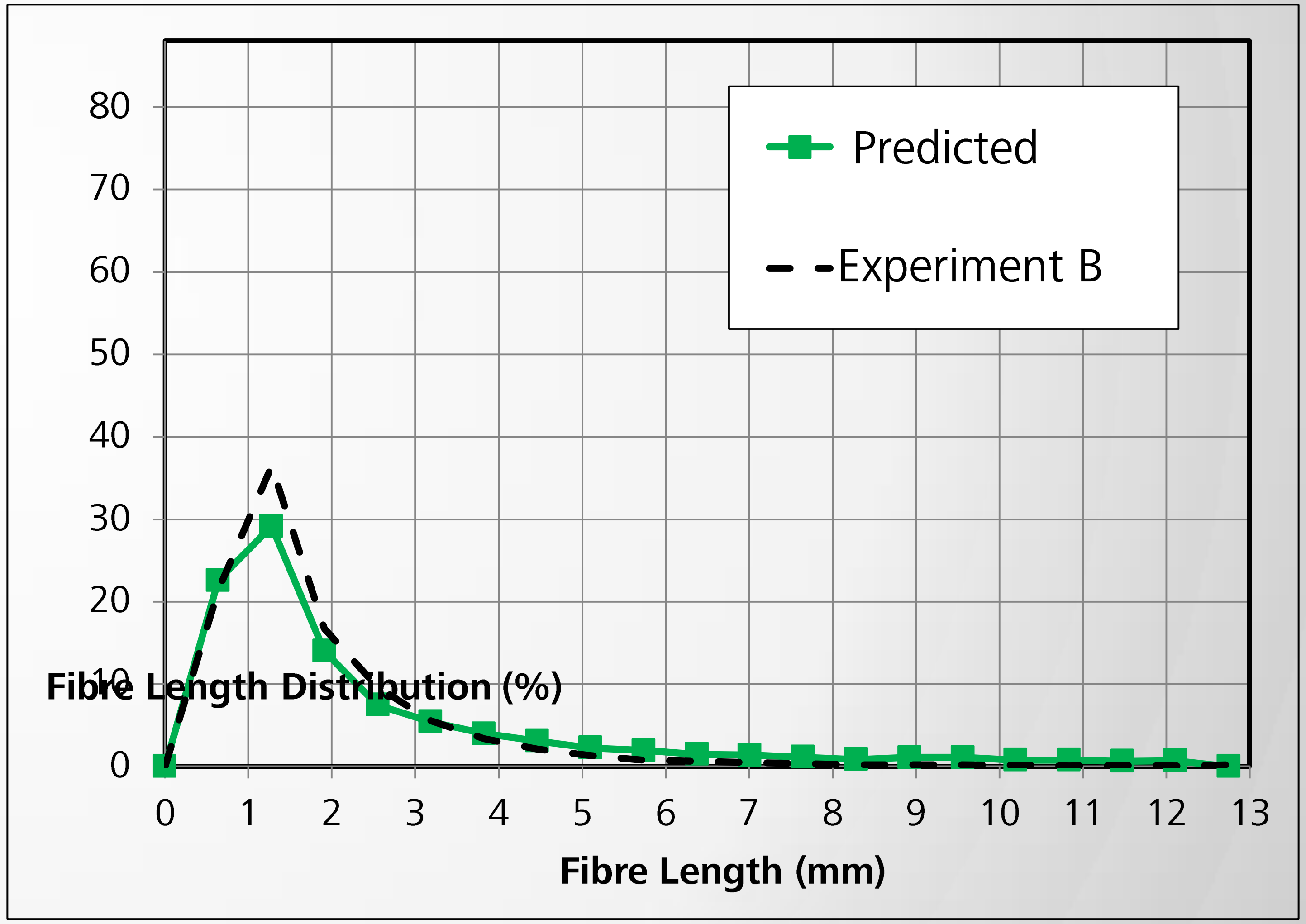
University of Bradford: Long Fiber Breakage



30%wt LGF/PP. Initial Fiber Length 12.5mm Midplane



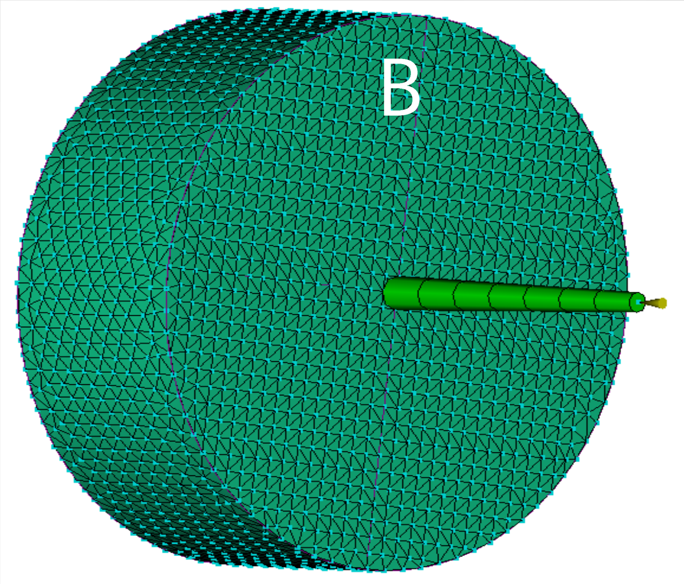
1mm Thick



2mm Thick

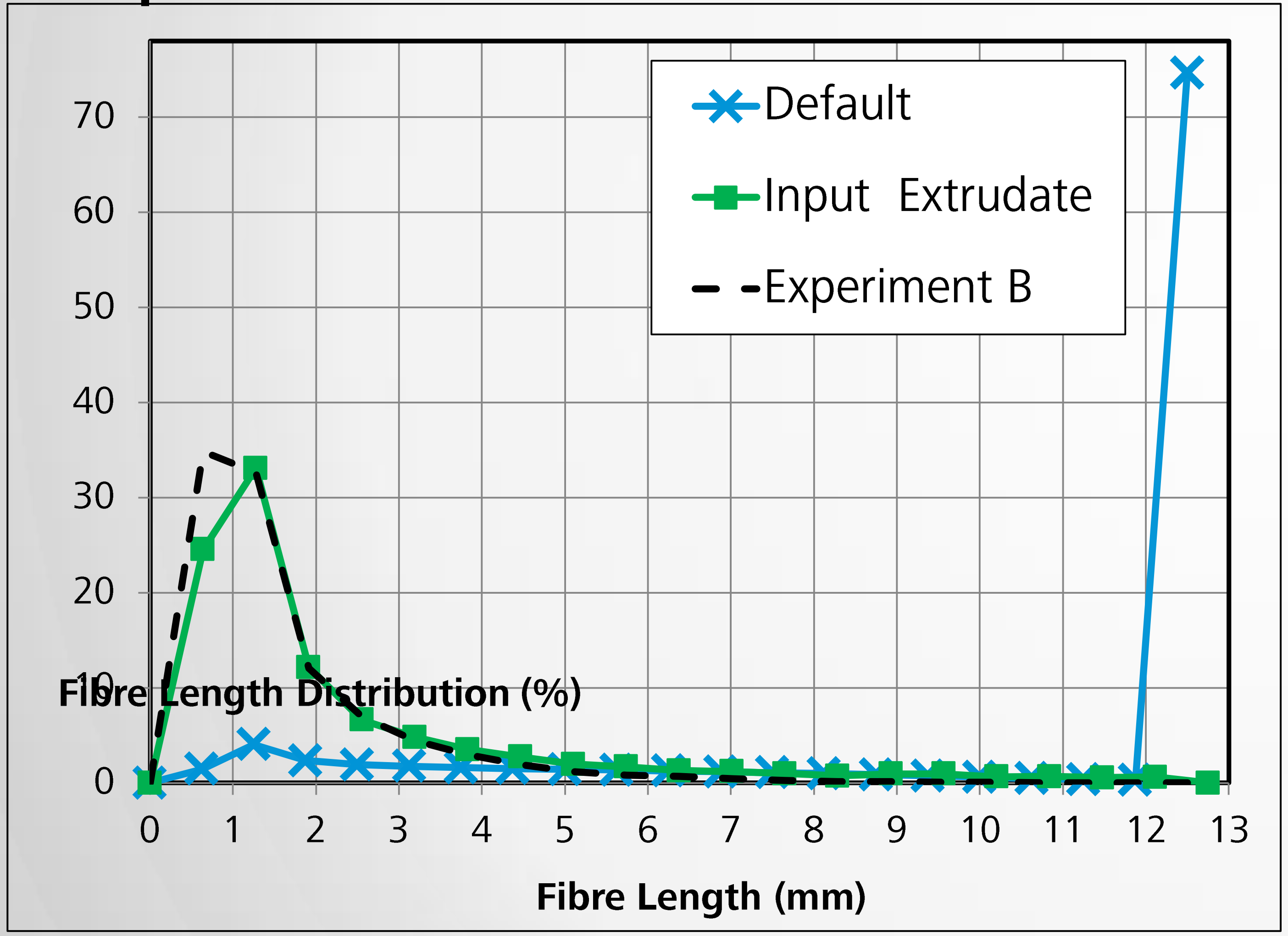
B. Parveen, Ph.D. Thesis, University of Bradford, 2014

University of Bradford:
Long Fiber Breakage

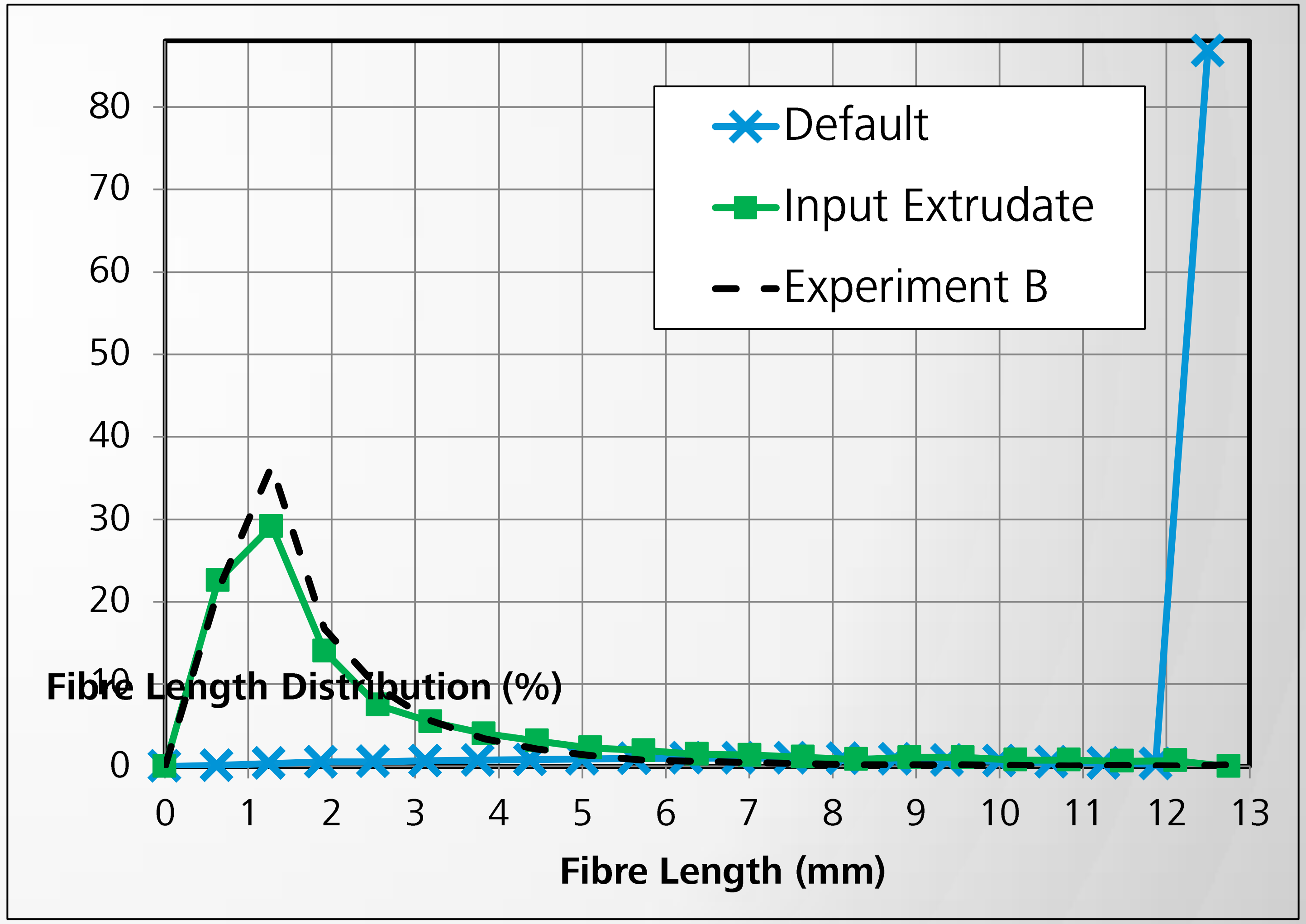


30%wt LGF/PP. Initial Fiber Length 12.5mm

Midplane



1mm Thick



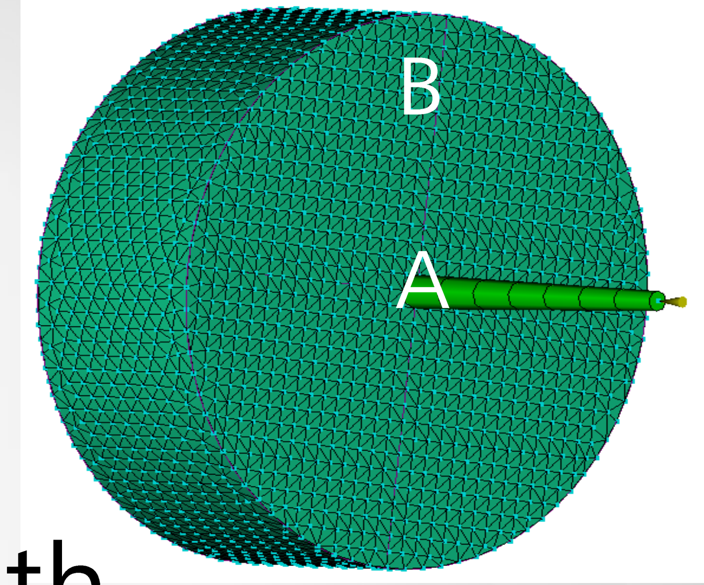
2mm Thick

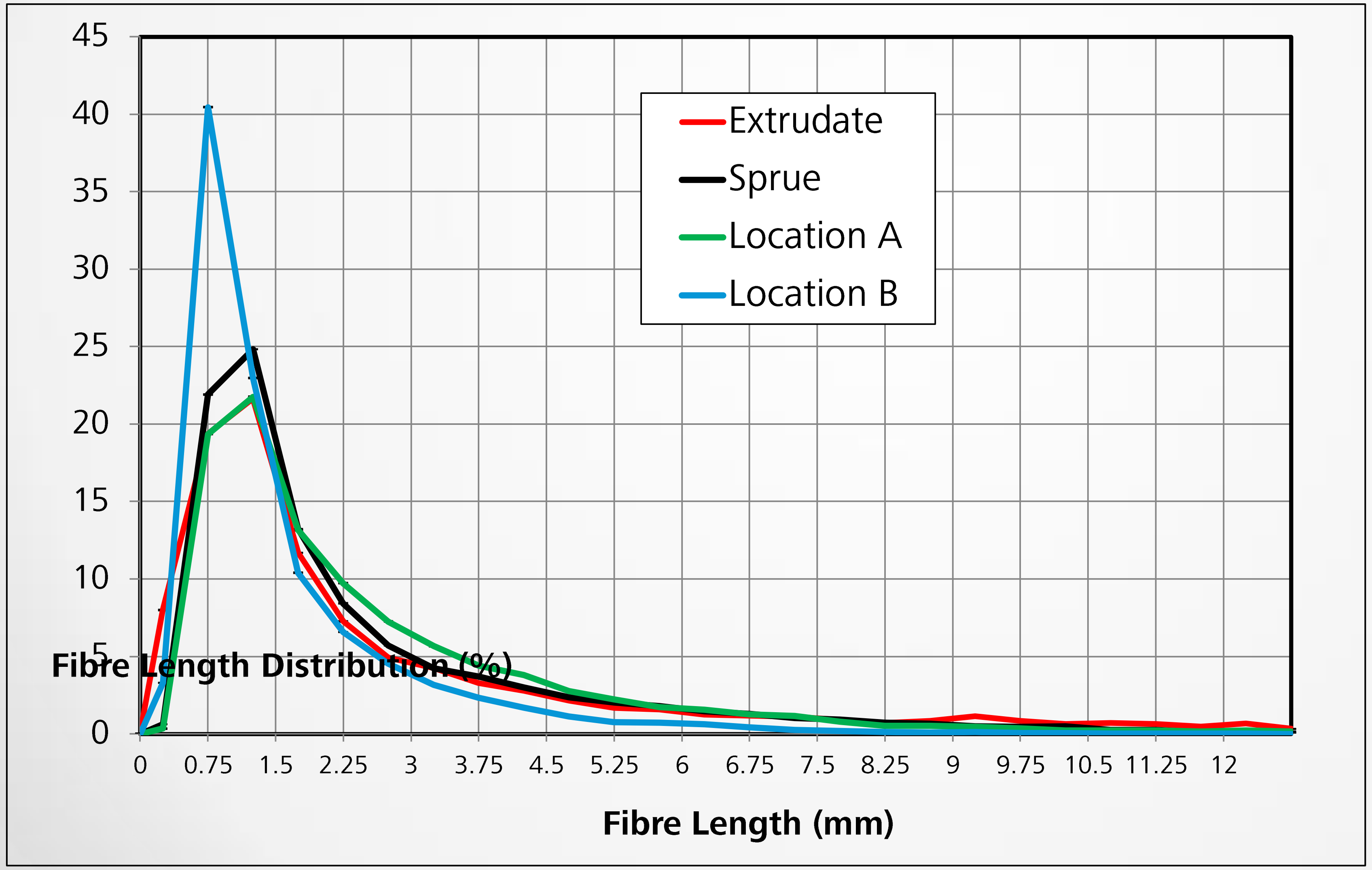
B. Parveen, Ph.D. Thesis, University of Bradford, 2014

University of Bradford:
Long Fiber Breakage

30%wt LGF/PP. Initial Fiber Length 12.5mm

Measured FLD at various points along flow path



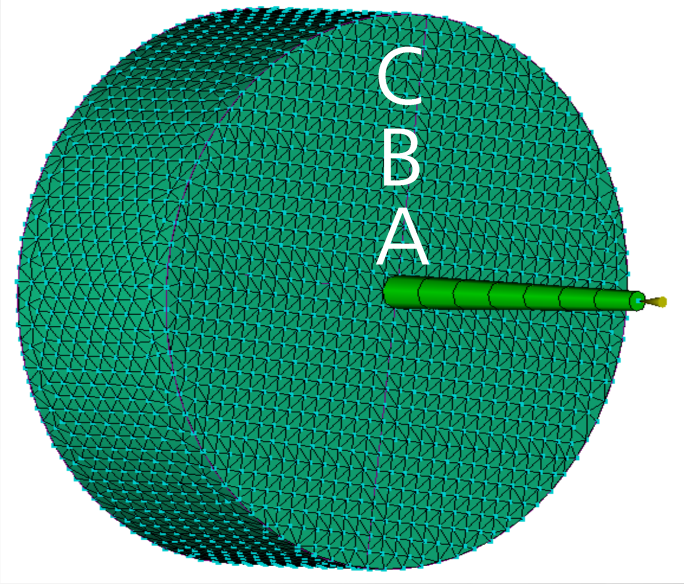


1mm Thick Part

3.5mm Sprue

B. Parveen, Ph.D. Thesis, University of Bradford, 2014

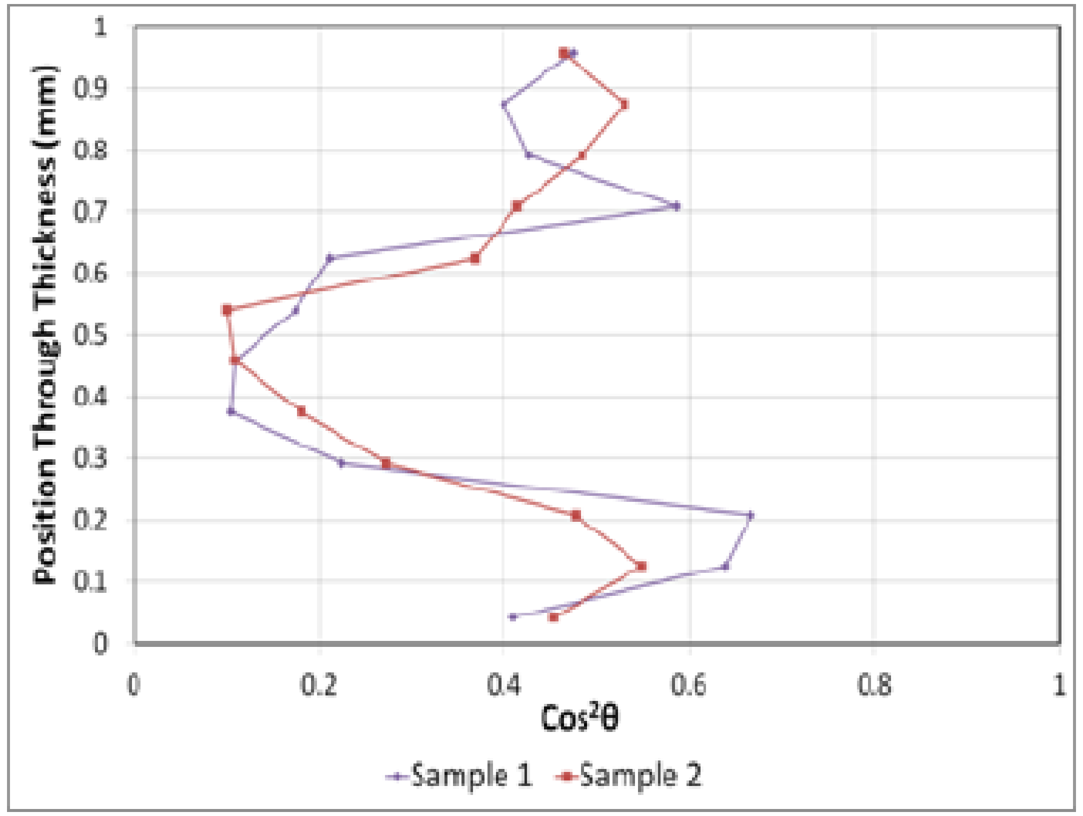
University of Bradford: Long Fiber Orientation



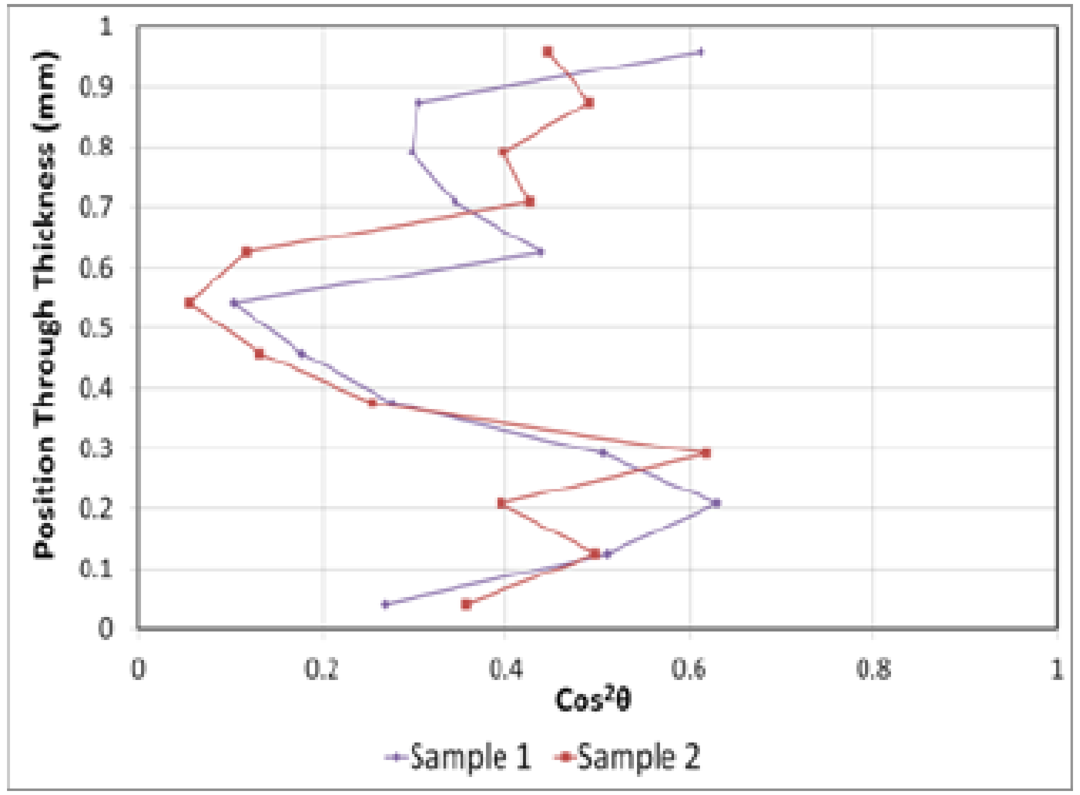
30%wt LGF/PP. Initial Fiber Length 12.5mm

Measured Orientation in Repeat Samples

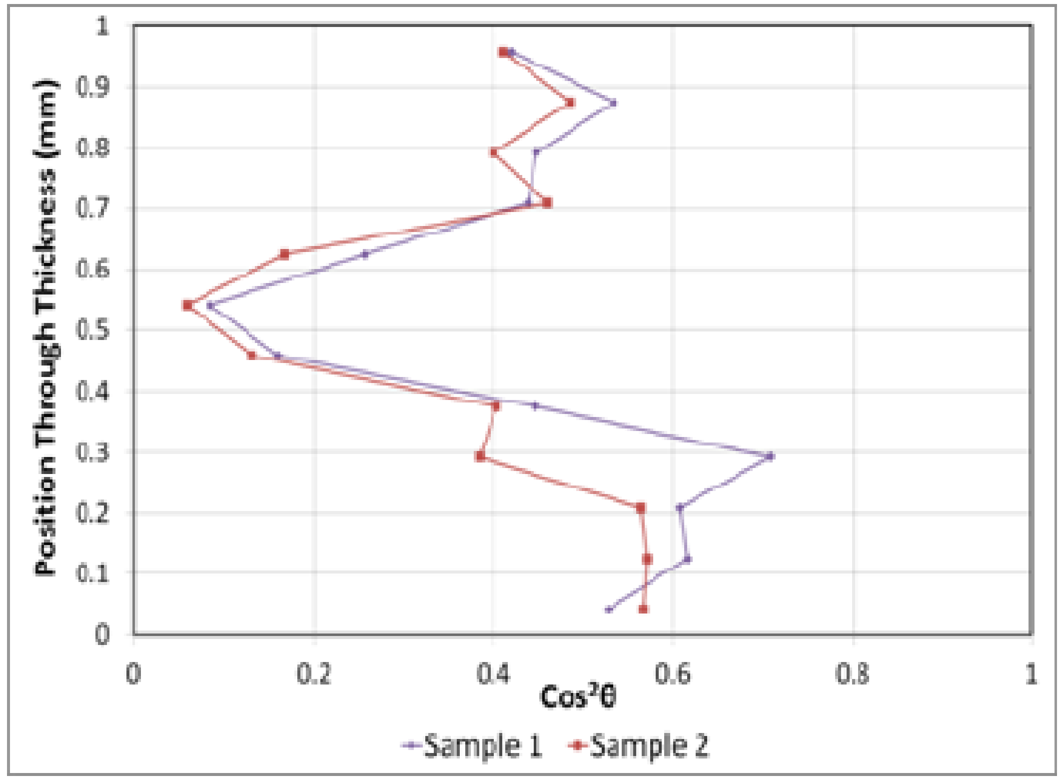
1mm Thick Part, 3.5mm Sprue



Location A



Location B

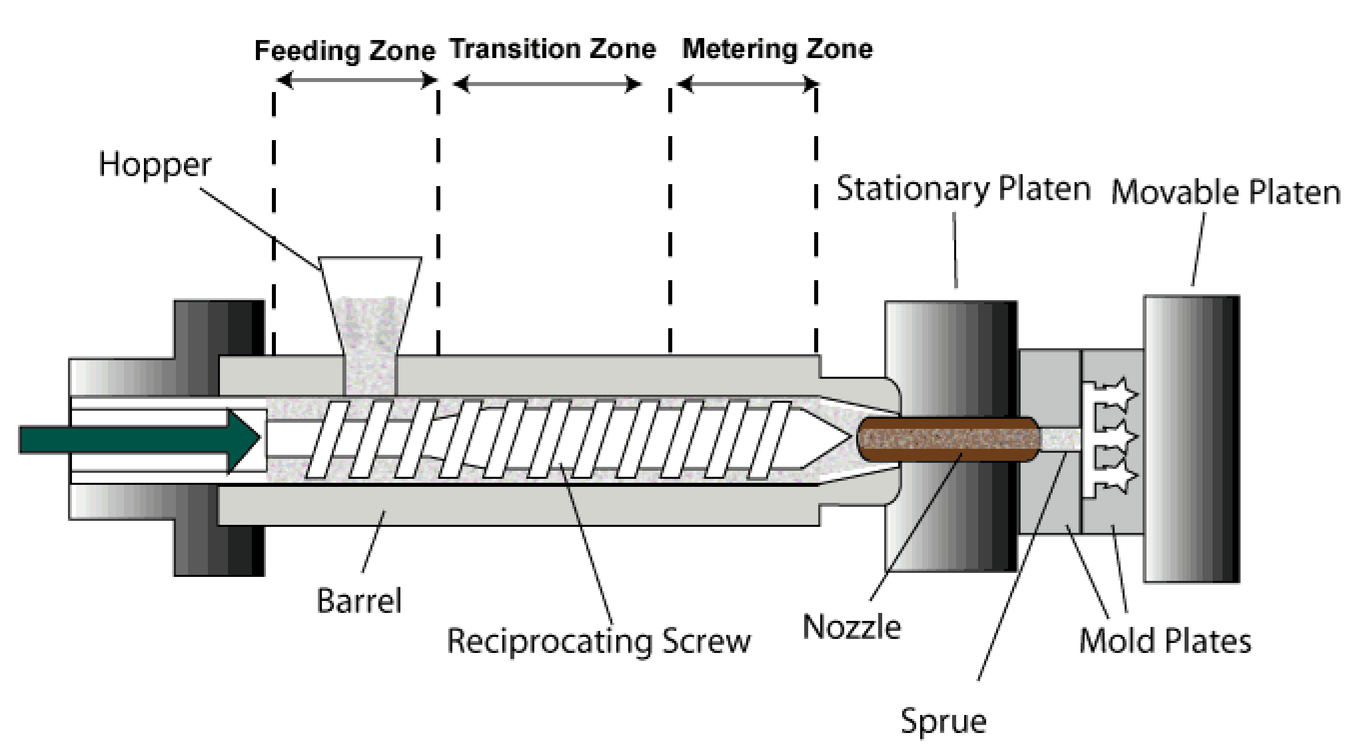


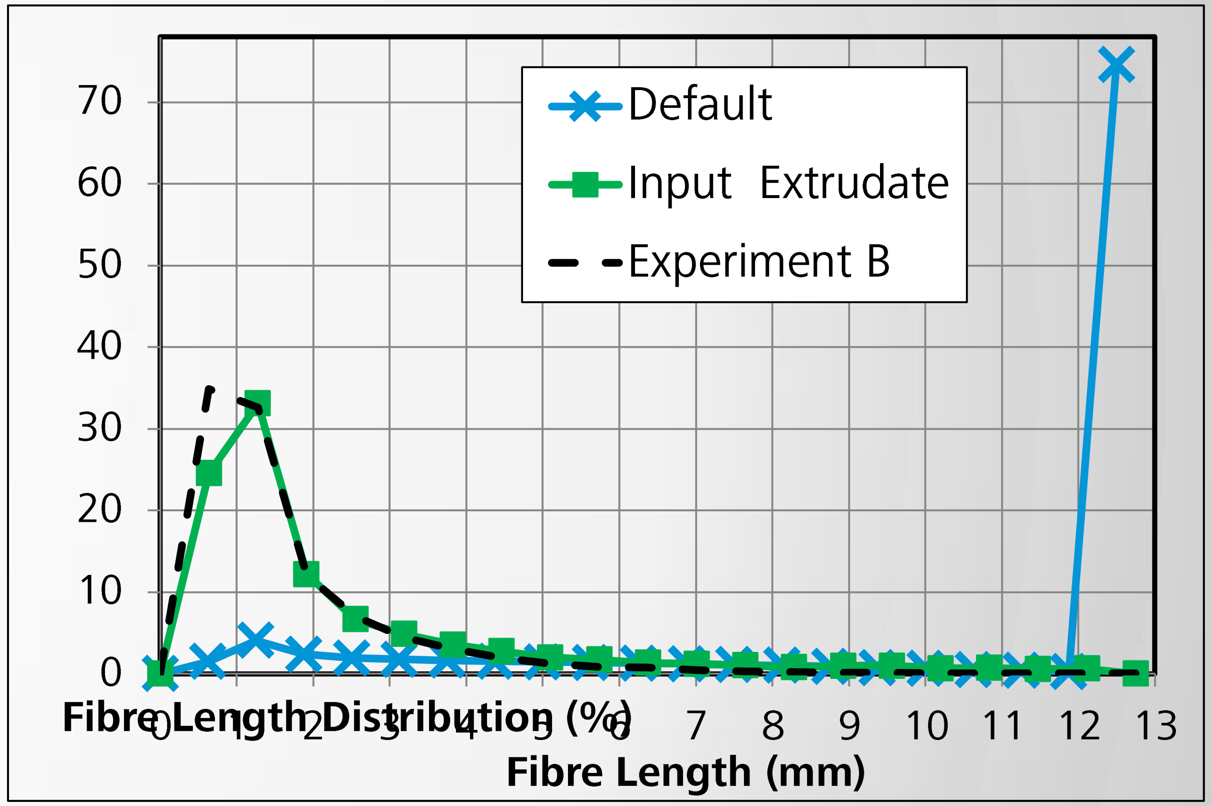
Location C

B. Parveen, Ph.D. Thesis, University of Bradford, 2014

Fiber Breakage in Barrel – University of Bradford

Measurement and Prediction of long fiber breakage during melting in injection barrel

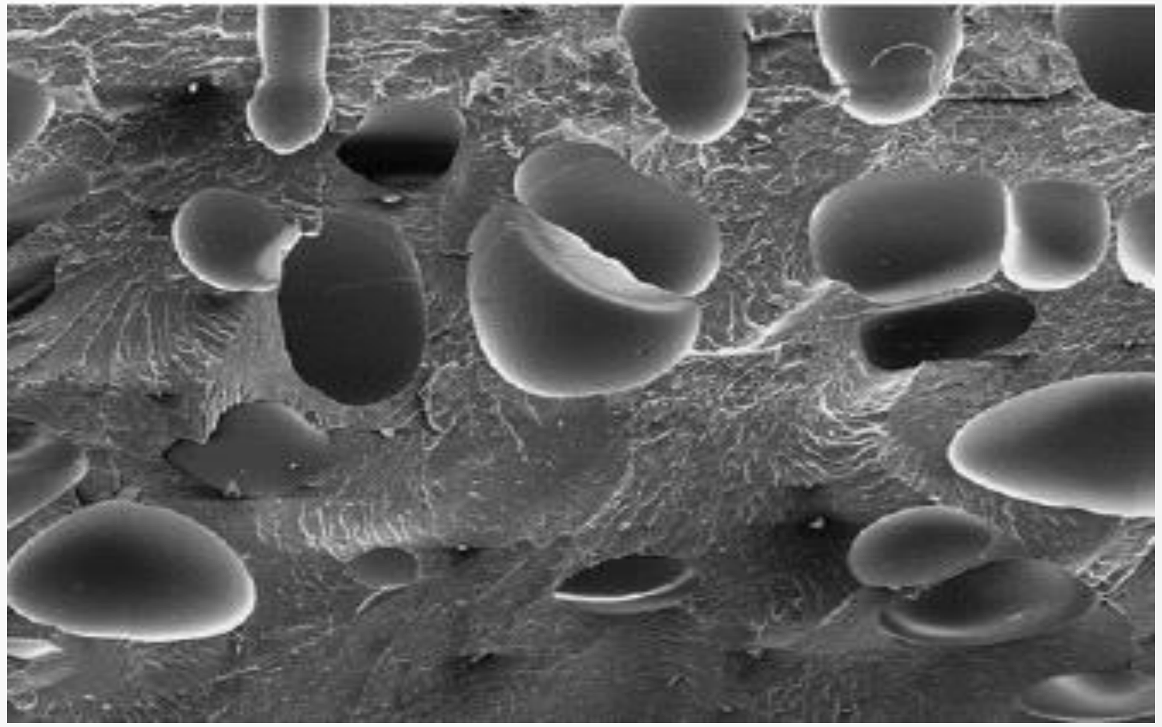




New Project: Started Oct 2014

Microcellular Foaming Bubble Nucleation University of Toronto

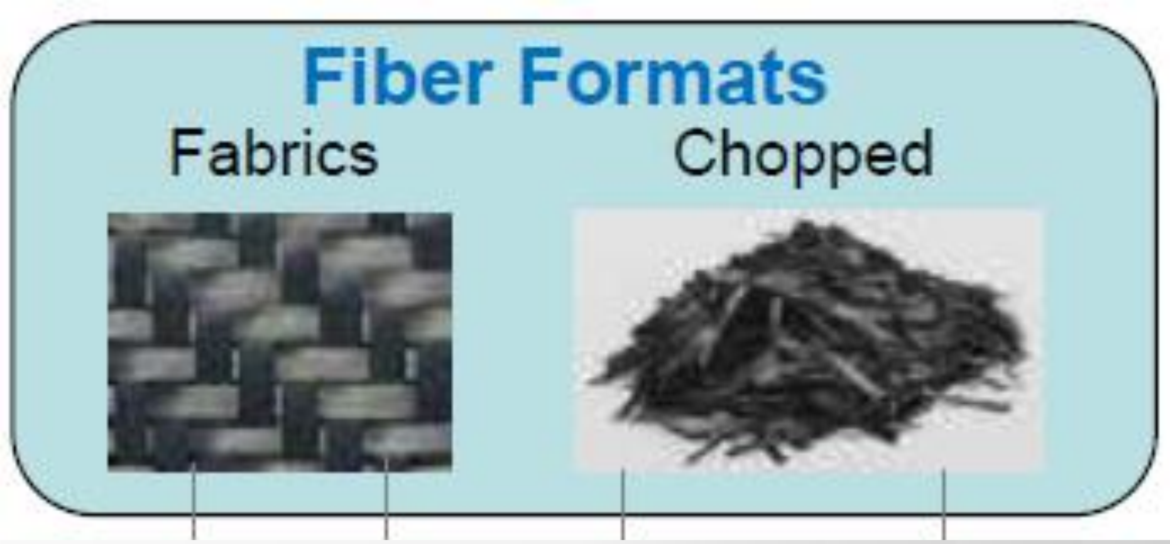
New models and validation to predict cell nucleation, dependent on pressure history, and local stresses around fillers (talc, fiber, etc)



New Project: Starting Dec 2014

Chopped Carbon Fiber Compression FORD

US DOE funding to develop predictive models for carbon fiber draping and compression molding



- Started Oct 2014 (4 year project)

Autodesk involved for process modeling

Compression molding

Fiber Orientation

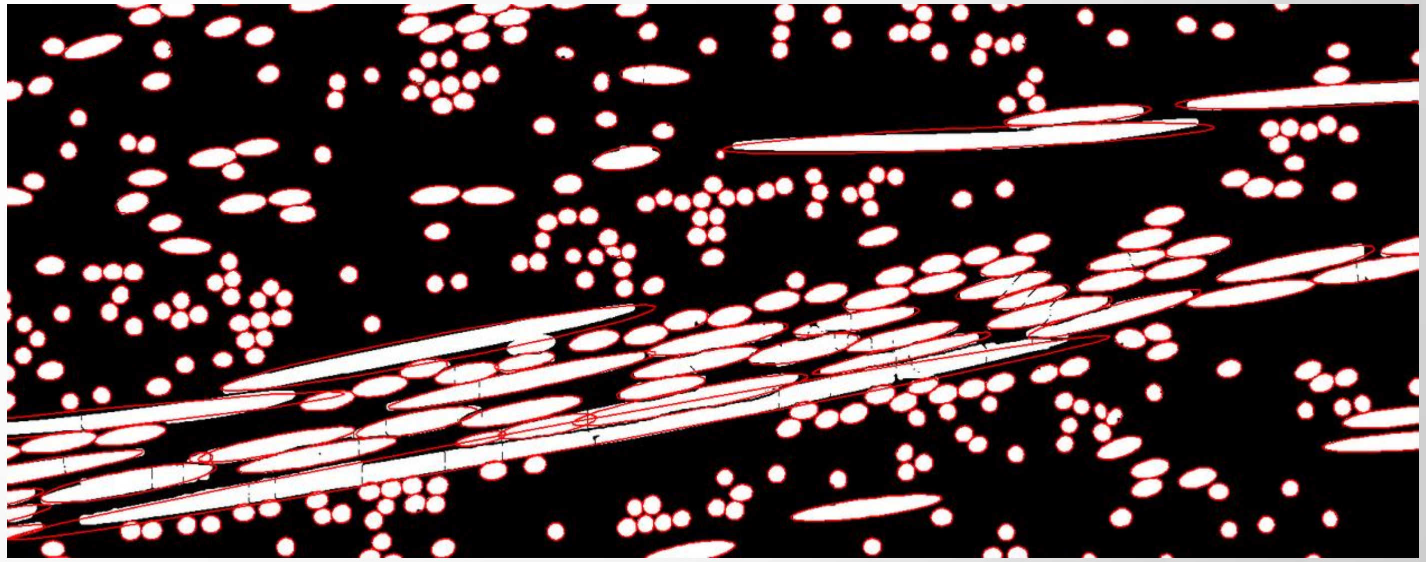
May include Infusion of resin into fiber bundles (tows)

Notice

- Four slides containing sensitive information regarding internal and some external collaborations are not included in this download

Summary

- Long Term Research Collaborations
  - Long Carbon Fiber Inj Molding
  - Long Fiber Breakage & Orientation
  - Flow advancement at part edges
  - Microcellular Foaming
  - Composite Overmolding
  - Viscosity Effects



Questions

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- Moldflow Insight 2016 Beta
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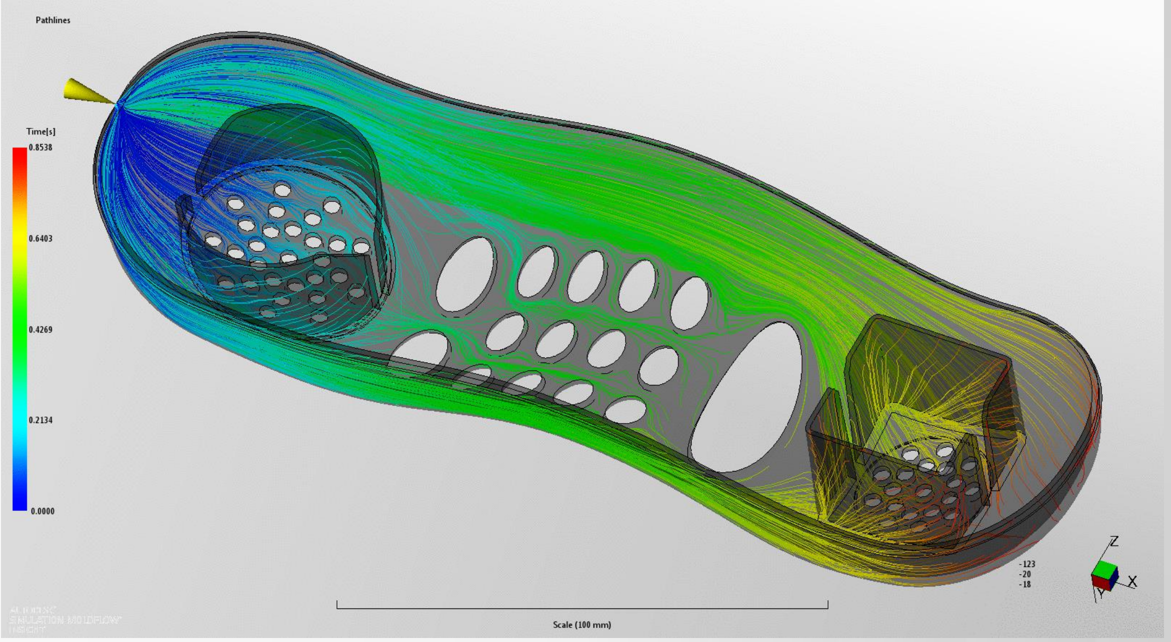

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