Shear-Induced Flow Imbalance and MeltFlipper® in Autodesk® Moldflow® Injection Molding Simulation

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Class Summary

- *Part I*
  - *Overview of the development and impact of shear induced melt imbalances*
  - *Overview of the management of shear induced melt imbalances with MeltFlipper® technologies.*
- *Part II*
  - *Impact of mesh design in predicting shear induced mold filling imbalances*
    - *Mesh density*
    - *Element aspect ratio*
  - *Evaluation of intra-cavity flow prediction within a single cavity mold*
  - *Evaluation of intra-cavity and weld line prediction in two cavity mold*

Learning Objectives

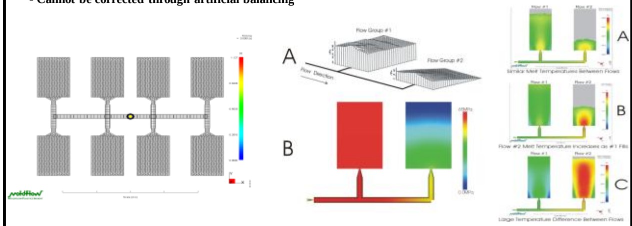
At the end of this class, you will be able to:
- Understand the how shear induced melt variations are developed
- Understand how to anticipate where shear induced melt variations might create a problem with molded parts
- Understand what type of problems result from the development of shear induced melt variations
- Understand the limitations of Moldflow for predicting shear induced melt variations
- How to get the most out of Moldflow when attempting to predict the effects of shear induced melt variations in single and multi-cavity molds

Understanding the Impact & Development of Shear Induced Melt Variations

Why did the industry drift away from Fishbone Runners?

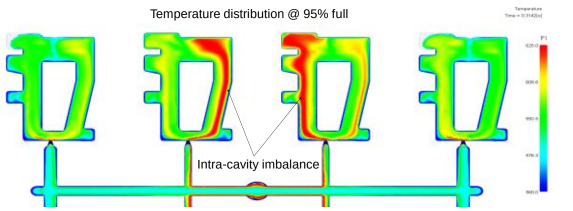
Effect of Runner Induced Filling & Rheological Imbalance

- Cavity-to-cavity process variations include fill rate, shear rate, shear stress, melt temperature, viscosity, cooling time, pack pressure, pack time, crystallinity,
- Influences part quality (dimensions, warp, flash, non-fills, etc…)
- Cannot be corrected through artificial balancing



Artificial Balancing

- Provides Fill Time balance Only.
- Variations still exist with Melt Temperature, Cavity Pressure, Pack Pressure, Pack Time, Fill Velocity, Shear Rate & Shear Stress.



What Controls Cooling Time?

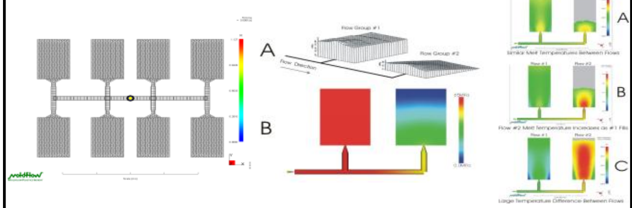
- Cooling time is dictated by the minimum time it takes for a part to reach a given temperature (its freeze temperature, crystallization temp, Tg, etc.).

(True or False)

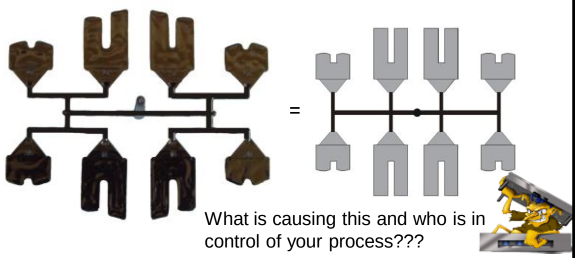
- Cooling time is dictated by the minimum time required for <u>all parts</u> in a mold to achieve their required size, shape and performance specifications.

Cycle Time

Which cavity is controlling cycle time???



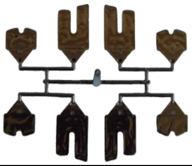
Evolution from Fishbone to "Naturally Balanced"



What is causing this and who is in control of your process???

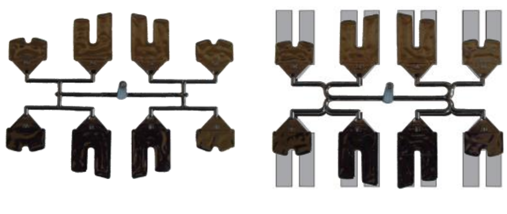
Where is the imbalance coming from??

- Mold deflection
- Higher mold temperature in the center
- Venting variations
- High shear from *sharp corners* in a mold



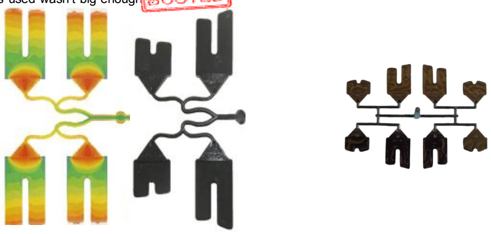
The Solution is to eliminate the sharp corners?

From this …. to this Opps…..



The solution is that you need bigger radii at the corners

- Flow simulation says the radii solved the problem… OR DOES IT?
- But the radius used wasn't big enough BUSTED



- Be careful of putting too much faith in simulation output. Put it through a reality check with your understanding of plastic flow.

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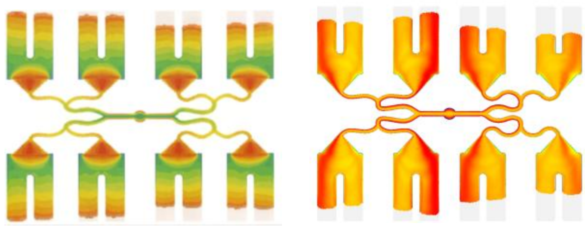
Two different CAE programs, two different results.



Brand X

Moldflow® (Autodesk)

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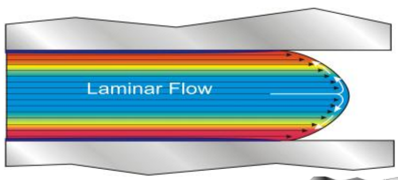
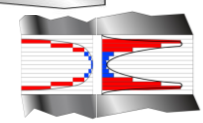
Development of non-Homogeneous Melt Conditions

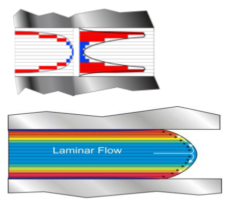


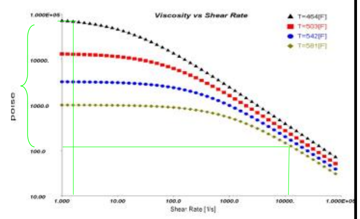
1. Flow is laminar during injection molding
2. Shear rate is developed from the velocity profile



AU Autodesk University –Beaumont Runner Technologies, Inc.

Development of non-Homogeneous Melt Conditions





Viscosity of high sheared hotter outer laminates can be over 100x lower than inner laminates.

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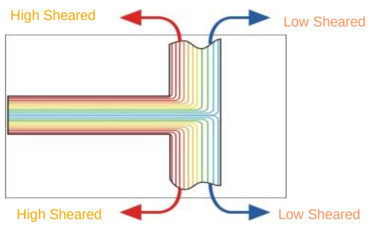
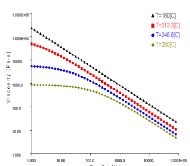
Development of non-Homogeneous Melt Conditions

High and low sheared materials become non-homogeneously distributed as they are split into a branching runner.





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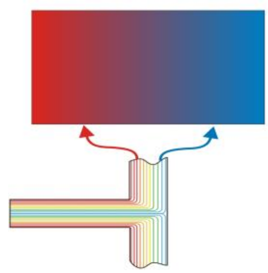
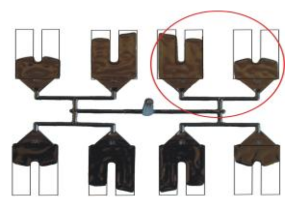
Development of non-Homogeneous Melt Conditions





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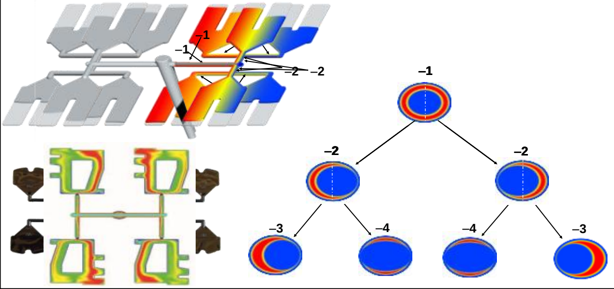
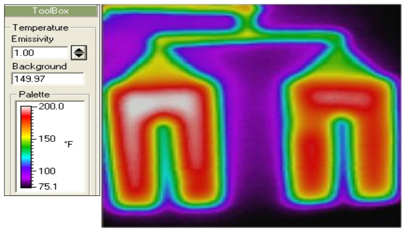
Development of non-Homogeneous Melt Conditions



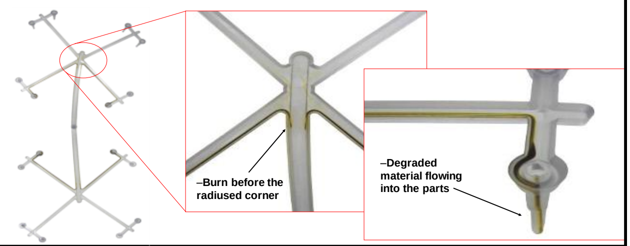
Thermal variations from IR Camera



Resultant product variations include:
- Crystallinity
- Shrinkage
- Residuals stresses
- Warpage

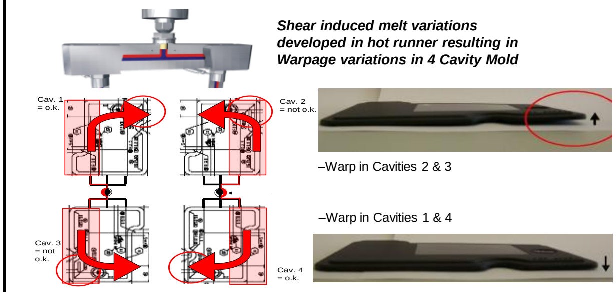
Frictional Heating in Runner Causing Material to Burn

Frictional heating developed prior to the first branch is fed to inner cavities. This creates product variations and rejects.



Product Variations Resulting from Material Variations

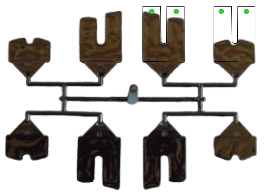
Shear induced melt variations developed in hot runner resulting in Warpage variations in 4 Cavity Mold



Impact on Molding Process Set-up Procedures

Scientific / Decoupled^{SM} Injection Molding

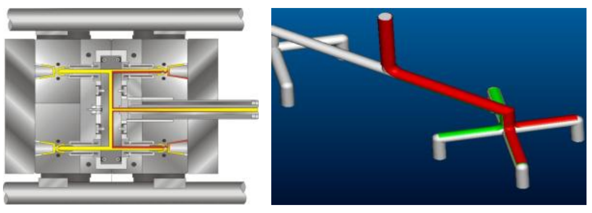
1. *Determine optimum fill rate based on mold trials (Relative Visc. vs. Relative Shear Rate)*
2. *Transfer from Velocity Control to Pack (VP Switchover) when the cavities are 95-99% full*



Which cavity?

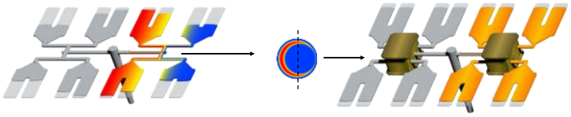
Where within the cavity?

Shear Induced Melt Variations in Hot Runners

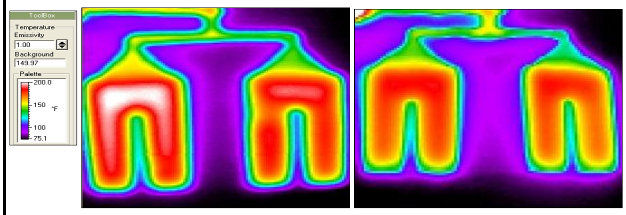


Managing Shear Induced Melt Variations

- MeltFlipper Single axis melt rotation technology rotates asymmetric melt conditions to provide a homogeneous distribution to downstream cavities.

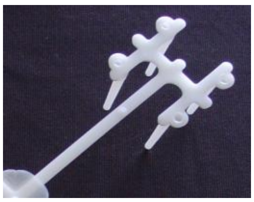


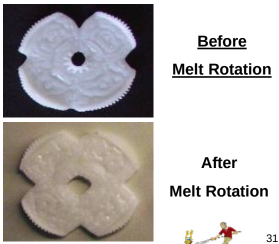
Thermal Imaging on 8 Cavity Mold



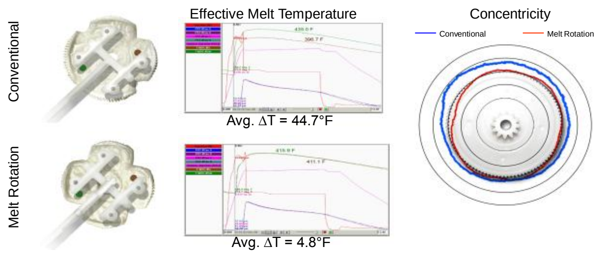
Rheological vs. Geometrical Balance

Winzler Gear's – Standard vs. new
High Precision Gears



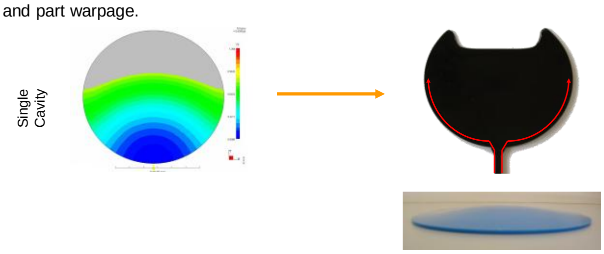


Rheological vs. Geometrical Balance

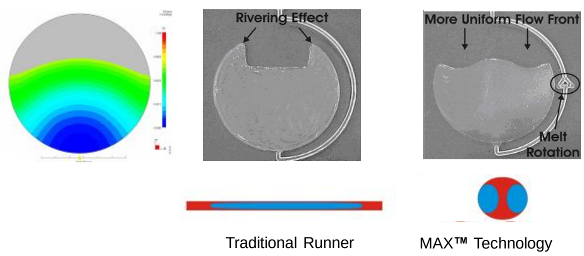


Intra-Cavity Shear Induced Melt Variations

Shear induced melt variations impacting filling pattern and part warpage.



Controlling the Melt Flow Front



Multi-Axis Control (MAX™): Glass Fiber / Cosmetics

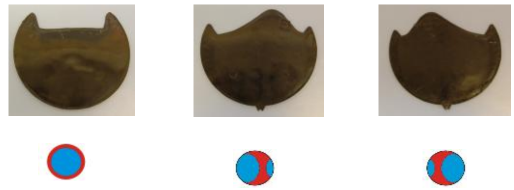
Traditional Runner

MAX Technology

Glass Fiber:
- ✓ Improved distribution
- ✓ Improved cosmetics

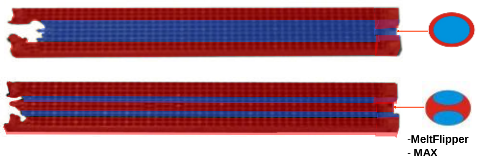
Multi-Axis Control (MAX™)

In mold adjustability allows filling patterns and melt conditions to be dialed in.



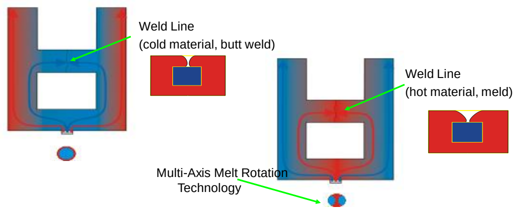
Changing Fill Patterns with MAX™

-Connectors:
- Perimeter filling (shear + part geometry)
- Backfilling; non-fills; weak weld-lines



Controlling Weld Position and Strength

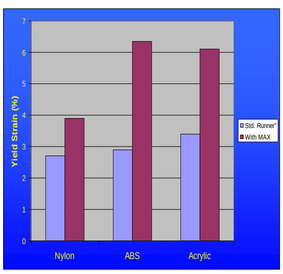
- Strategic positioning of hotter material
- Redefining the melt Front



Controlling Weld Position and Strength

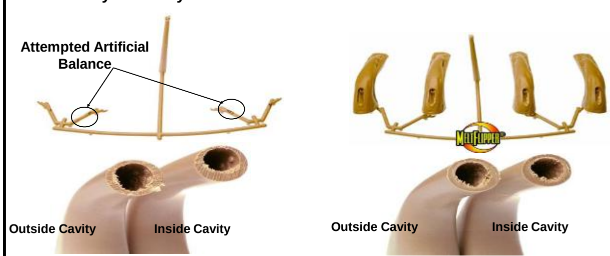
Conventional Weld Line Location

Influence of iMARC on Weld Line Locations



Gas-Assist Injection Molding

Case Study: 4-Cavity Automotive Handle Mold

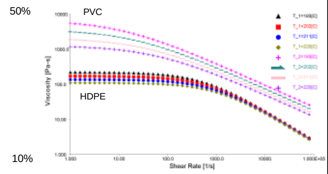


Part II: Modeling Methods and techniques to predict shear induced imbalances.

1. Injection Nodes
2. Beam runners
3. 3D runners, Effect of number of Element layers, Element Layer Bias, Inertia calculation.

Common Material Ranked in relative order of Sensitivity to Shear:

Poly Vinyl chloride (PVC)
Poly Carbonate (PC)
Acrylic (PMMA)
Poly Styrene (PS)
Acetal (POM)
ABS
Polyamide - Nylons (PMA)
PBT
Liquid Crystal Polymers (LCP)
Thermoplastic Elastomers/Urethanes (TPE/TPR)
PP
HDPE



Thermal Conductivity Values	
HDPE	= 0.33 W/m-C @ 210ºC
PC	= 0.26 W/m-C @ 280ºC
PVC	= 0.13 W/m-C @ 180ºC

Example #1: Eight cavity Plaque test mold

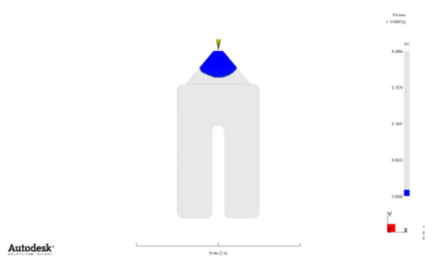
Full Shot

Short Shot

Injection Nodes with Occurrences

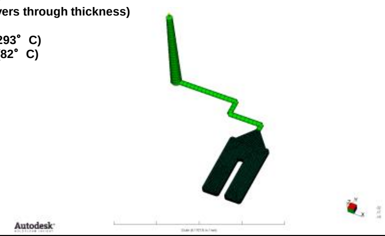
Element Edge Length = 0.017"
 # Elements = 550,537 (12 Layers through thickness)
Process
Melt Temperature = 560° F (293° C)
Mold Temperature = 180° F (82° C)
Flow Rate = 0.75 in³/sec (12.3 cm³/sec)
Fill Time = 0.21 seconds

Part Only Results - Filling

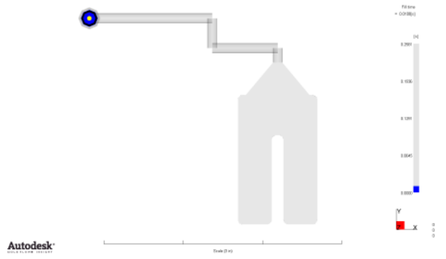


Beam Runners with Occurrences

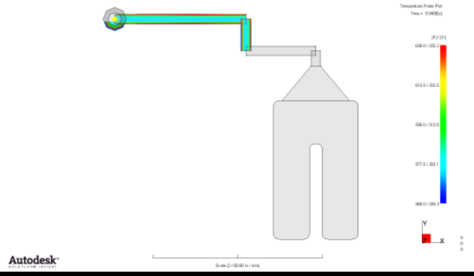
Element Edge Length = 0.017"
 # Elements = 550,537 (12 Layers through thickness)
Process
Melt Temperature = 560° F (293° C)
Mold Temperature = 180° F (82° C)
Fill Time = 0.25 seconds



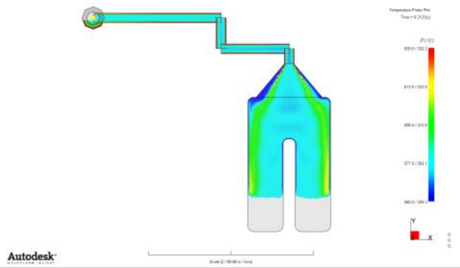
Beam Runner Results - Filling



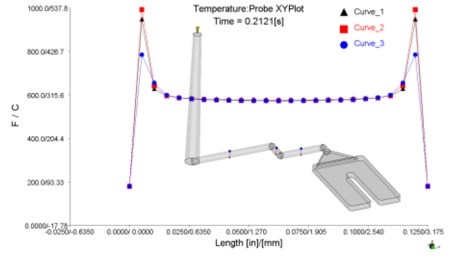
Beam Runner Results - Temperature



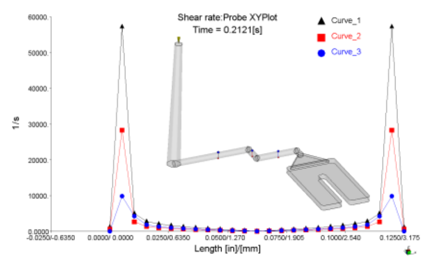
Beam Runner Results - Temperature



Beam Runner Results - Temperature

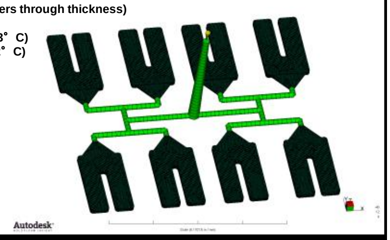


Beam Runner Results – Shear Rates

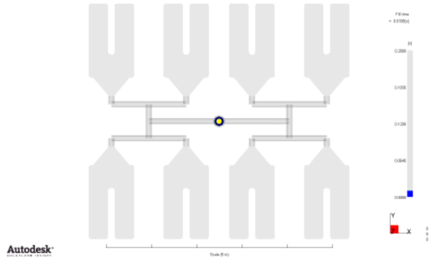


Beam Runners Full Model

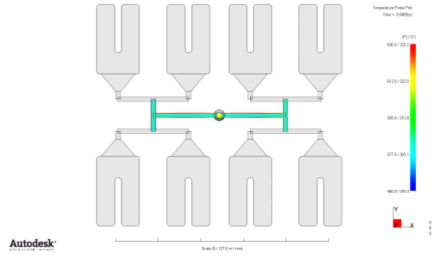
Element Edge Length = 0.017"
 # Elements = 4,404,450 (12 Layers through thickness)
Process
Melt Temperature = 560° F (293° C)
Mold Temperature = 180° F (82° C)
Fill Time = 0.25 seconds



Beam Runner Results - Filling



Beam Runner Results - Temperature



Full 3D Surface Mesh Comparisons

- 2 Different Surface meshes were compared

Surface Mesh 1
- Global Edge Length = 0.017"
- Dual Domain Elements = 330,122

Surface Mesh 2
- Global Edge Length = 0.030"
- Dual Domain Elements = 110,916

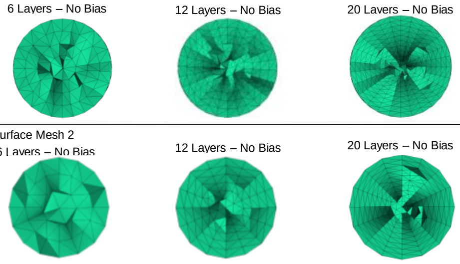
3D Layers Through the Thickness

Surface Mesh 1

6 Layers – No Bias | 12 Layers – No Bias | 20 Layers – No Bias

Surface Mesh 2

6 Layers – No Bias | 12 Layers – No Bias | 20 Layers – No Bias

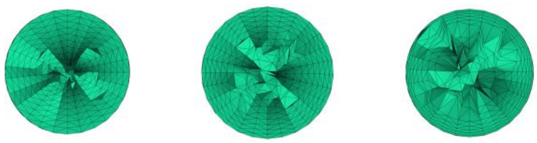


Mesh Bias

Surface Mesh 1
20 Layers –No Bias

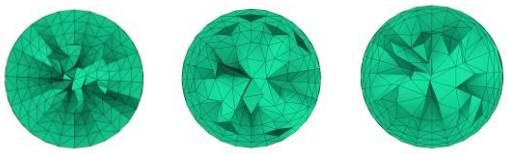
Surface Mesh 1
20 Layers –1.1 Bias

Surface Mesh 1
20 Layers –1.25 Bias



Mesh Bias - Comparison

12 Layers – No Bias | 12 Layers – 1.3 Bias | 12 Layers – 1.5 Bias



Imbalance Calculations

% Imbalance was calculated by adding the 4 flow lengths from each cavity and comparing the inside vs. the outside

Actual Molded sample = 43.33%

Process Set-up for Full 3D Analyses

The following parameters were used to run all 3D trials:

Material: Polycarbonate – Sabic Lexan 121
Melt Temperature: 560˚ F
Mold Temperature: 180˚ F
Injection time: 0.25 seconds

All Analyses were run on:

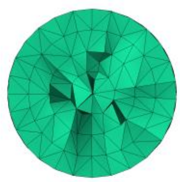
Dell Precision T5500, 2.53 GHZ Quad Core Xeon, 27GB Ram

Software Version: Autodesk Moldflow Insight 2012 SP2

Surface Mesh #1 – 6 Layers – No Bias

Runner Configuration

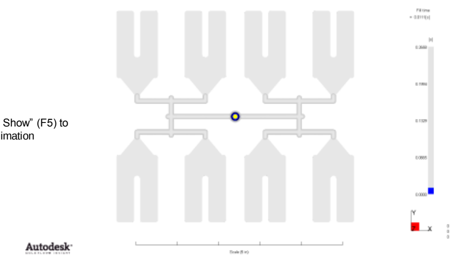
Moldflow File name: t-seg_3D-20-p1
Mesh Diagnostics
Mesh Type: 3D runner and part
Global Edge Length - .017
Dual Domain Elements – 330,122
# of Elements = 2,711,080
Minimum # of Elements through the thickness = 6
Run Time = 1 hour 39 minutes



Fill Time

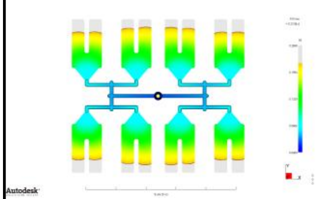
The mold was filled using a constant flow rate that resulted with an injection time of 0.27 seconds.

Activate "Slide Show" (F5) to view animation



Filling Pattern Comparison: Actual vs Moldflow

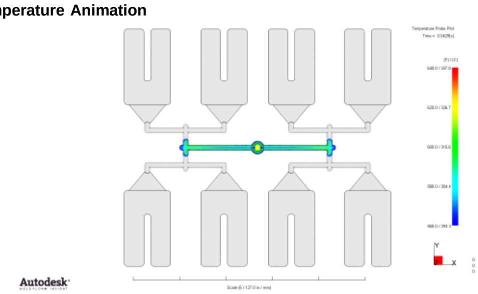
The images below compare the actual molded filling progression and the Moldflow predicted filling pattern.



Result Measured Imbalance = 10.5%

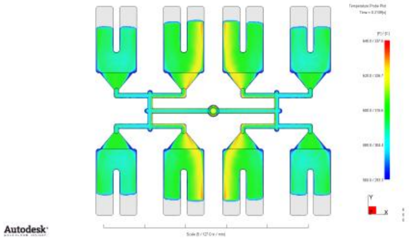
Actual Molded Imbalance = 43.33%

Temperature Animation

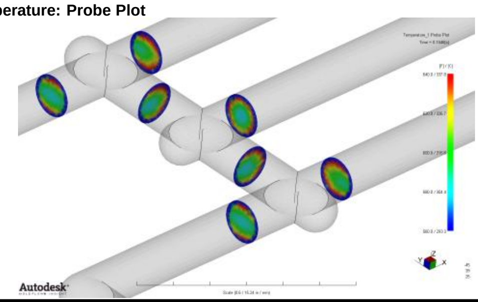


Temperature at 90% Volume

The images below shows the predicted temperature profile in the part. This result shows a cross section through the part thickness at 90% volume.



Temperature: Probe Plot



AU Autodesk University

Surface Mesh - Comparison

6 Layers – Surface Mesh 1
Surface edge length = .017"

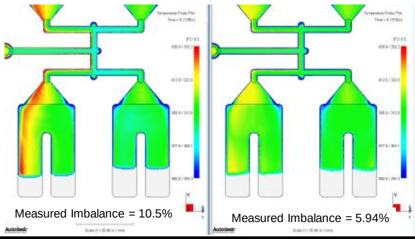
6 Layers – Surface Mesh 2
Surface edge length = .030"

AU Autodesk University

Surface Mesh - Comparison

6 Layers – Surface Mesh 1
Surface edge length = .017"
Elements = 2,711,080
Analysis time = 1 hour 39 minutes

6 Layers – Surface Mesh 2
Surface edge length = .030"
Elements = 908,164
Analysis time = 0 hours 30 minutes



Measured Imbalance = 10.5%

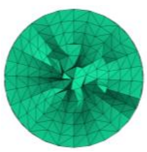
Measured Imbalance = 5.94%

AU Autodesk University

Surface Mesh #1 – 12 Layers – No Bias

Runner Configuration

Moldflow File name: t-seg_3D-12-p1
Mesh Diagnostics
Mesh Type: 3D runner and part
Global Edge Length - .017
Dual Domain Elements – 330,122
# of Elements = 5,224,694
Minimum # of Elements through the thickness = 12
Run Time = 5 hours 8 minutes

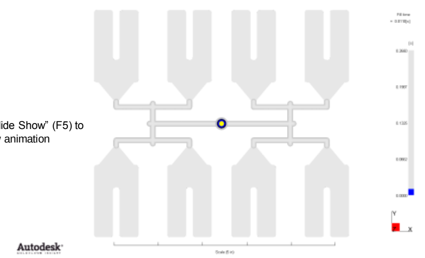


AU Autodesk University

Fill Time

The mold was filled using a constant flow rate that resulted with an injection time of 0.27 seconds.

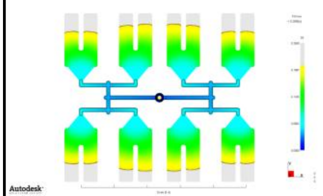
Activate "Slide Show" (F5) to view animation



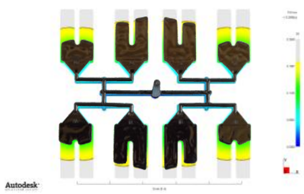
AU Autodesk University

Filling Pattern Comparison: Actual vs Moldflow

The images below compare the actual molded filling progression and the Moldflow predicted filling pattern.

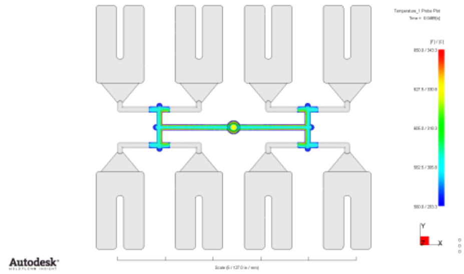


Measured Imbalance = 16.17%



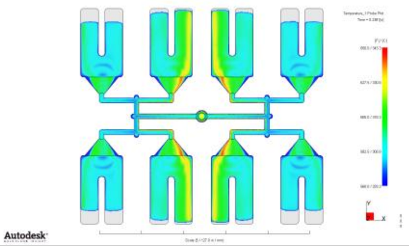
Actual Molded Imbalance = 43.33%

Temperature Animation

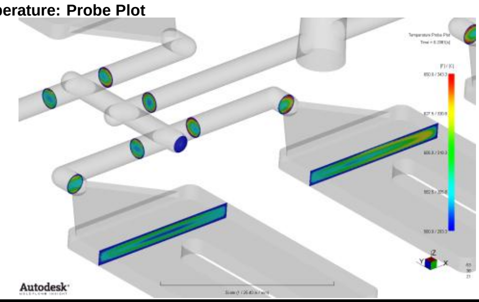


Temperature at 90% Volume

The images below shows the predicted temperature profile in the part. This result shows a cross section through the part thickness at 90% volume.

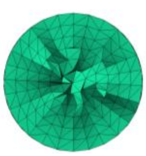


Temperature: Probe Plot



Mesh Bias - Comparison

12 Layers – No Bias

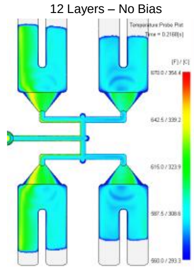


12 Layers – 1.3 Bias

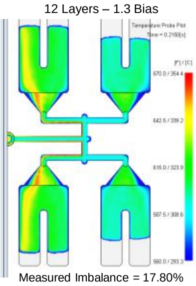
12 Layers – 1.5 Bias

Mesh Bias - Comparison

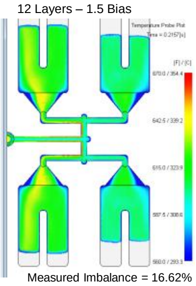
12 Layers – No Bias


Measured Imbalance = 16.49%

12 Layers – 1.3 Bias


Measured Imbalance = 17.80%

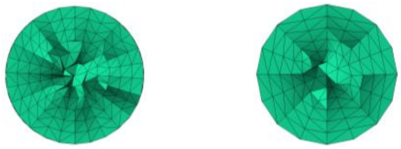
12 Layers – 1.5 Bias


Measured Imbalance = 16.62%

Surface Mesh - Comparison

12 Layers – Surface Mesh 1
Surface edge length = .017"

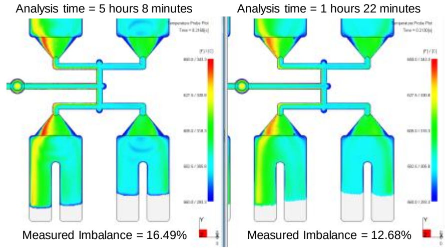
12 Layers – Surface Mesh 2
Surface edge length = .030"



Surface Mesh - Comparison

12 Layers – Surface Mesh 1
Surface edge length = .017"
Elements = 5,224,694
Analysis time = 5 hours 8 minutes

12 Layers – Surface Mesh 2
Surface edge length = .030"
Elements = 1,869,272
Analysis time = 1 hours 22 minutes



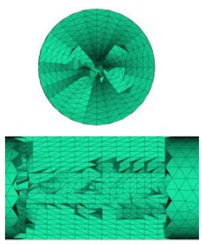
Measured Imbalance = 16.49%

Measured Imbalance = 12.68%

Surface Mesh #1 – 20 Layers – No Bias

Runner Configuration

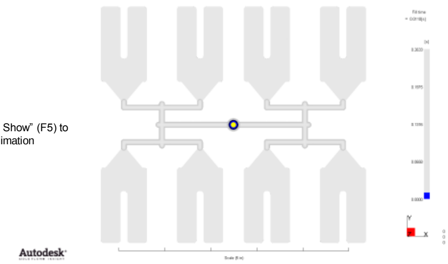
Moldflow File name: t-seg_3D-20-p1
Mesh Diagnostics
Mesh Type: 3D runner and part
Global Edge Length - .017"
Dual Domain Elements – 330,122
# of Elements = 8,934,561
Minimum # of Elements through the thickness = 20
Run Time: 10 hrs - 9 minutes



Fill Time

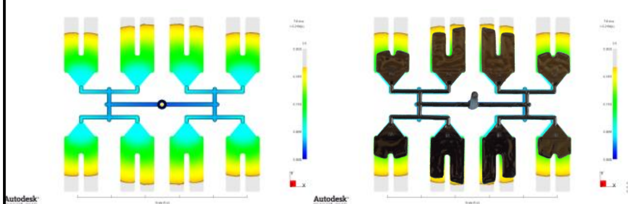
The mold was filled using a constant flow rate that resulted with an injection time of 0.27 seconds.

Activate "Slide Show" (F5) to view animation



Filling Pattern Comparison: Actual vs Moldflow

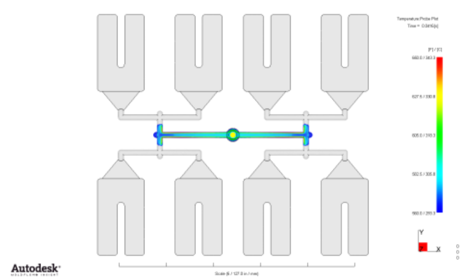
The images below compare the actual molded filling progression and the Moldflow predicted filling pattern.



Measured Imbalance = 17.09%

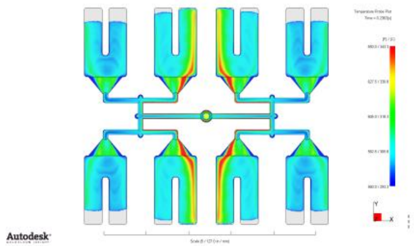
Actual Molded Imbalance = 43.33%

Temperature Animation

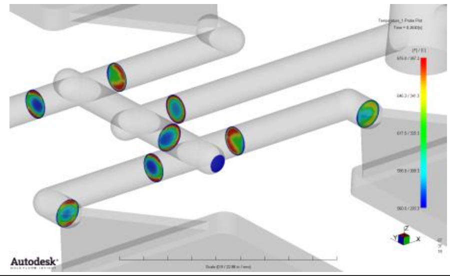


Temperature at 90% Volume

The images below shows the predicted temperature profile in the part. This result shows a cross section through the part thickness at 90% volume.

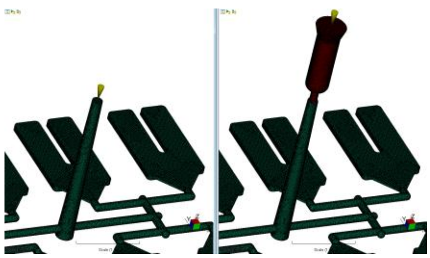


Temperature: Probe Plot

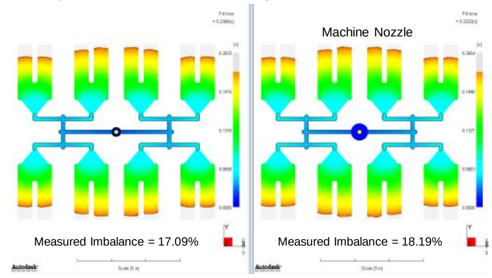


Representing the Machine Nozzle - Comparison

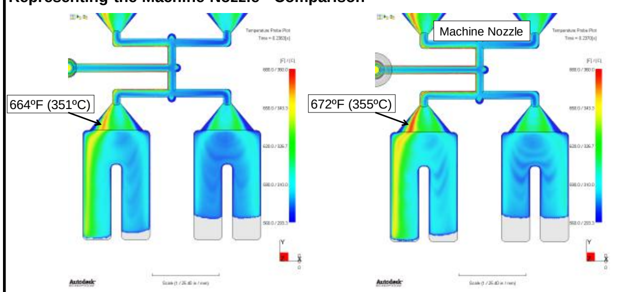
The machine nozzle was modeled as hot runner properties to account for the additional pressure and shear build up through this section.



Representing the Machine Nozzle - Comparison

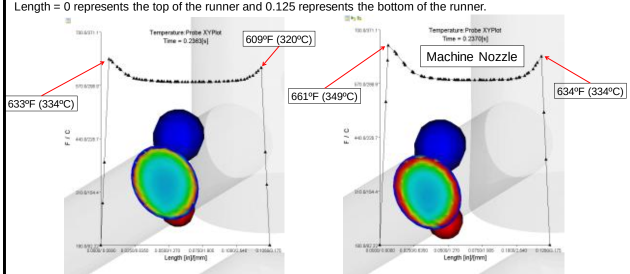


Representing the Machine Nozzle - Comparison



Representing the Machine Nozzle - Comparison

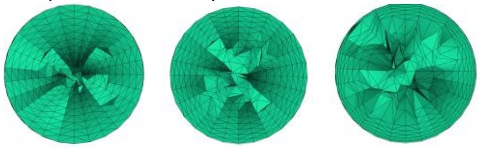
Both curves represent the temperature profile through the primary runner.
Length = 0 represents the top of the runner and 0.125 represents the bottom of the runner.



Mesh Bias - Comparison

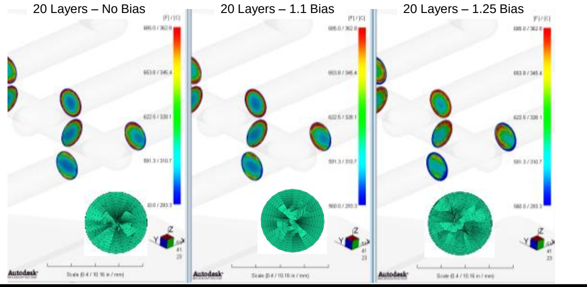
Based on the Temperature results, the mesh with 20 layers through the thickness without a bias, shows a more defined distribution across the layers, but the 1.25 bias predicts a higher % imbalance.

20 Layers – No Bias | 20 Layers – 1.1 Bias | 20 Layers – 1.25 Bias



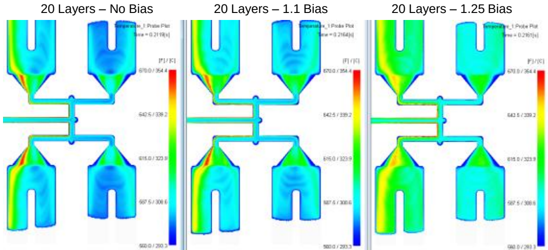
Mesh Bias - Comparison

20 Layers – No Bias | 20 Layers – 1.1 Bias | 20 Layers – 1.25 Bias



Mesh Bias - Comparison

20 Layers – No Bias | 20 Layers – 1.1 Bias | 20 Layers – 1.25 Bias

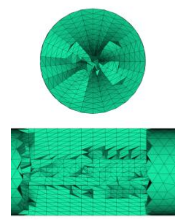


Measured Imbalance = 17.09% | Measured Imbalance = 18.50% | Measured Imbalance = 19.34%

Surface Mesh #1 – 20 Layers – No Bias – Inertia Option - Nozzle

Runner Configuration

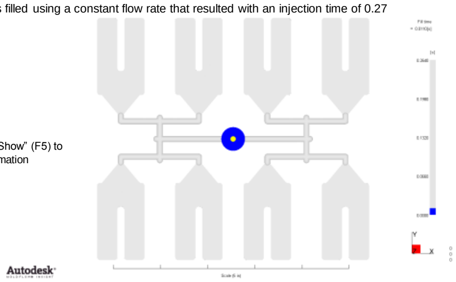
Moldflow File name:
Mesh Diagnostics
Mesh Type: 3D runner and part
Global Edge Length - .017
Dual Domain Elements – 330,122
\# of Elements = 9,248,154
Minimum # of Elements through the thickness = 20
Nozzle modeled
Inertia Option Turned On
Run Time: 27 hours – 54 minutes



Fill Time

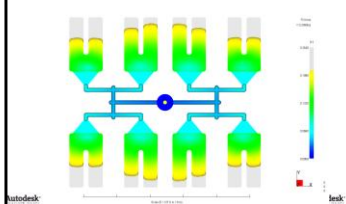
The mold was filled using a constant flow rate that resulted with an injection time of 0.27 seconds.

Activate "Slide Show" (F5) to view animation

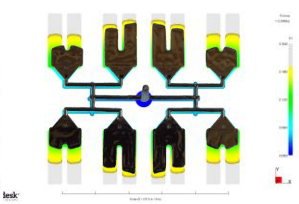


Filling Pattern Comparison: Actual vs. Moldflow

The images below compare the actual molded filling progression and the Moldflow predicted filling pattern.

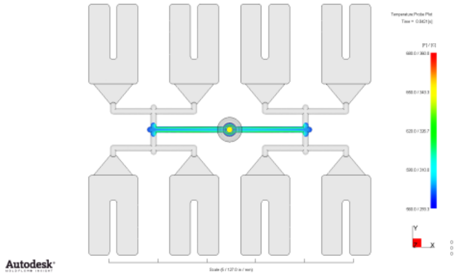


Measured Imbalance = 26.47%



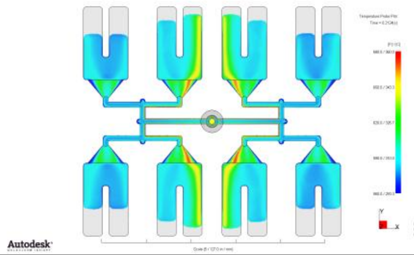
Actual Molded Imbalance = 43.33%

Temperature Animation

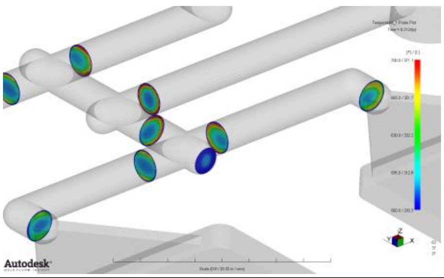


Temperature at 90% Volume

The images below shows the predicted temperature profile in the part. This result shows a cross section through the part thickness at 90% volume.

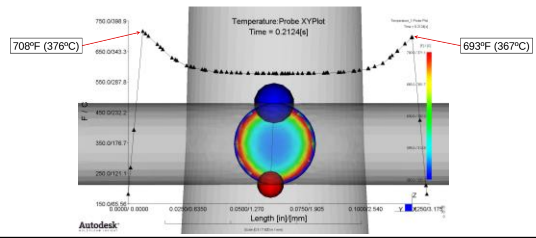


Temperature: Probe Plot



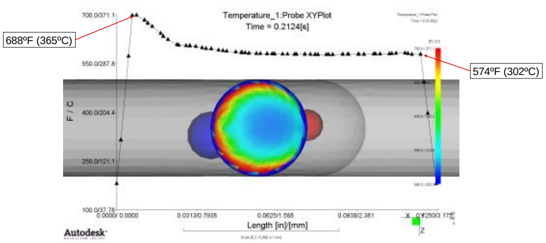
Temperature: Probe Plot XY Plot

Temperature profile of the Primary runner
Length = 0 represents the top of the runner (blue point)
Length = .125 represents the bottom of the runner (red point)



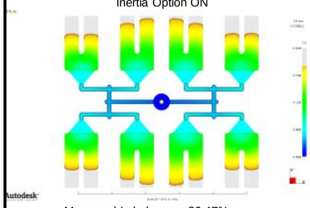
Temperature: Probe Plot XY Plot

Temperature profile of the Secondary Runner
Length = 0 represents the left side of the runner (blue point)
Length = .125 represents the right side of the runner (red point)



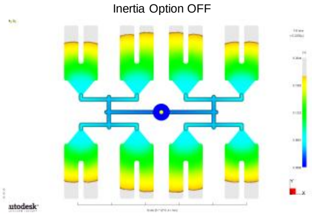
Filling Imbalance Comparison

Inertia Option ON



Measured Imbalance = 26.47%
Analysis time = 27 hours 54 minutes

Inertia Option OFF

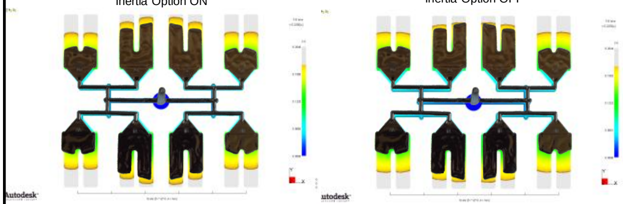


Measured Imbalance = 19.00%
Analysis time = 10 hours 9 minutes

Filling Imbalance Comparison

Inertia Option ON

Inertia Option OFF



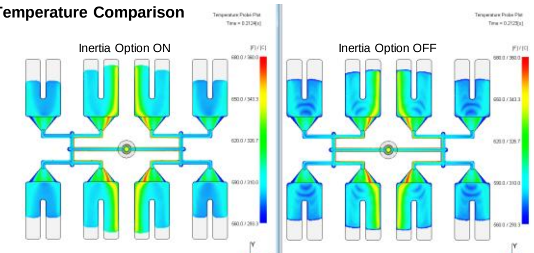
Measured Imbalance = 26.47%
Analysis time = 27 hours 54 minutes

Measured Imbalance = 19.00%
Analysis time = 10 hours 9 minutes

Temperature Comparison

Inertia Option ON

Inertia Option OFF



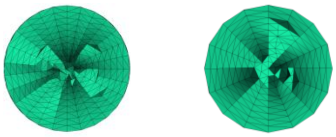
Measured Imbalance = 26.47%

Measured Imbalance = 19.00%

Surface Mesh - Comparison

20 Layers – Surface Mesh 1
Surface edge length = .017"

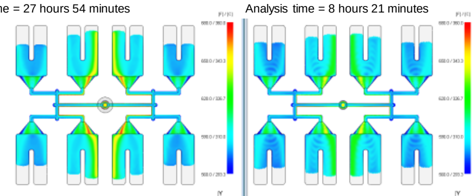
20 Layers – Surface Mesh 2
Surface edge length = .030"



Surface Mesh – Comparison (Inertia ON)

20 Layers – Surface Mesh 1
Surface edge length = .017"
Elements = 8,934,561
Analysis time = 27 hours 54 minutes

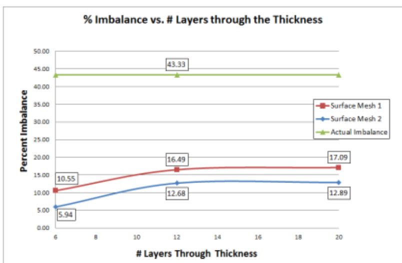
20 Layers – Surface Mesh 2
Surface edge length = .030"
Elements = 3,370,402
Analysis time = 8 hours 21 minutes



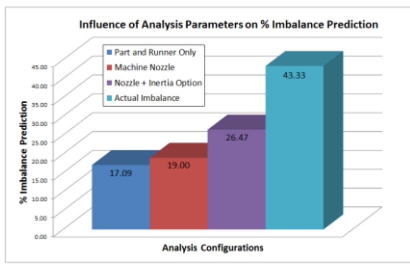
Measured Imbalance = 26.47%

Measured Imbalance = 18.09%

Summary



% Imbalance Comparison



Summary of results

Example #2: Single Cavity Disk Mold – Predicting Intra-cavity Imbalances

Single cavity disk mold

Overlay of Molded Samples

As Molded Filling Progression

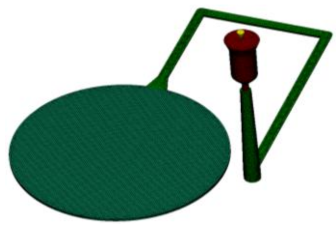
Process Set-up for Analysis

The following parameters were used to run the analysis:

Material: SABIC Lexan 121
Melt Temperature: 560˚ F (293.3˚ C)
Mold Temperature: 180˚ F (82.2˚ C)
Injection Time: 1.0 seconds
V/P Switchover: 99% full parts

SURFACE MESH Information:
Global Edge Length: .030" (.762mm)
Dual Domain Elements: 67,376

Dell Precision T5500
Processor: Intel Xeon E5630 2.53GHz
RAM: 27.0 GB
Autodesk Moldflow Insight 2012 SP2



Machine nozzle, cold sprue, cold runner, & part are represented with three mesh densities.

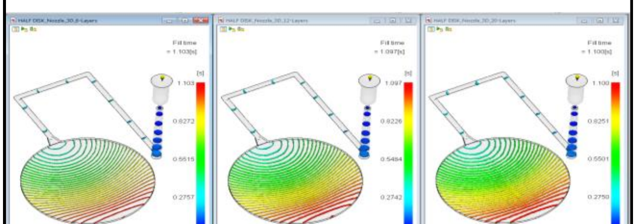
6 Layers
565,500 Elements

12 Layers
1,157,600 Elements

20 Layers
2,097,213 Elements

Fill Time Plots

All models predict a "flat" flow front near the end of fill.
All molded samples exhibit filling patterns with the perimeter flow lagging behind the center.

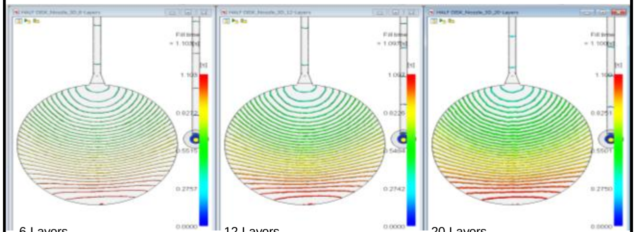


6 Layers

12 Layers

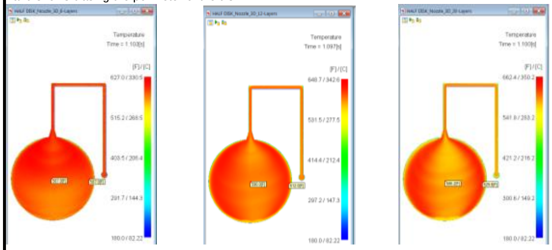
20 Layers

Fill Time (Cont.)

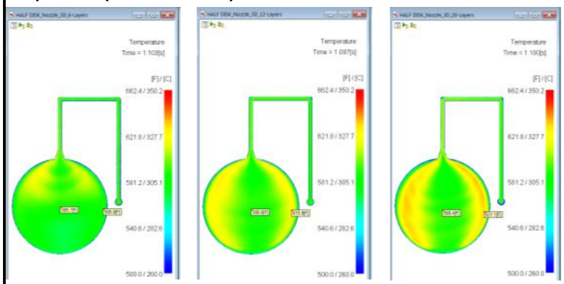


Temperature (default range)

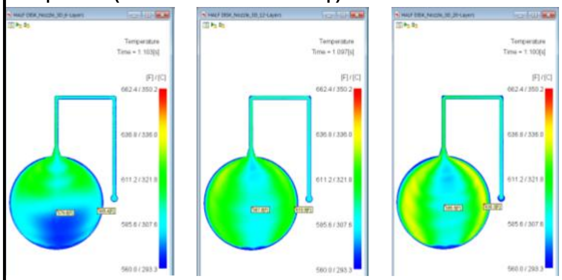
More layers though the thickness provided predictions with hotter maximum temperatures and shows biasing the perimeter of the disk.



Temperature (scaled Min 500F)

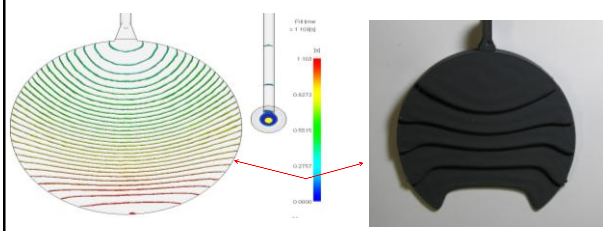


Temperature (scaled Min 560F = Melt Temp)



Moldflow vs. Actual Comparison

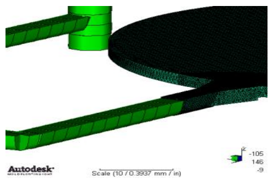
The simulation is not picking up on the shear induced "racetrack" filling effect using standard analysis input variables.



Alternate Methods for Prediction: Model Feed System as Beam Elements

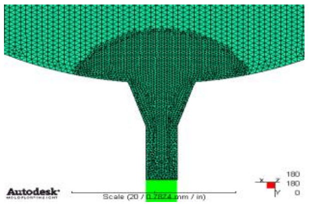
(Contributed by Franco Costa)

- Beam Elements ensure less false diffusion between layers/laminates
  - Can use up to 20 laminates in radial direction
  - VERY computationally efficient
  - Assign same U-Shape
- Beam elements are valid so long as the flow remains one-dimensional with no branching
- Use fine mesh tetrahedral elements at the gate



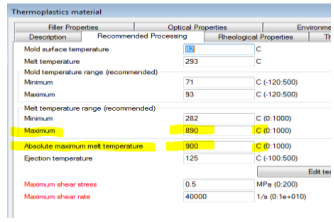
Refine Gate Mesh

- Use "Remesh Tetra" tool to refine the gate mesh size to 0.37 mm
  - Gate has 20 layers of element through thickness
  - Cavity mesh has 12 layers through thickness



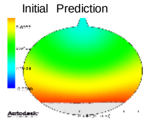
Avoid Temperature Cap Limit

- Allow shear heating to increase melt temperature practically without limit by raising the absolute maximum melt temperature

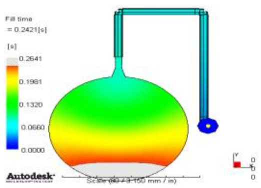


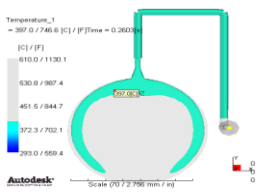
New Prediction

Initial Prediction



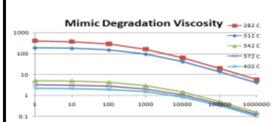
- Fill Pattern shows some race-track effect (better than initial)
  - Not as much as actual moldings
- Temperatures rises very high: up to 610° C (1130K) !
  - Iso-surface shows melt region above 397° C (747K)

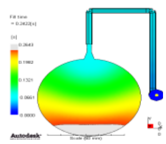


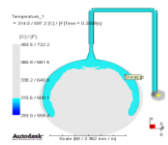


Are such high temperatures realistic?

- In reality, the material will degrade at such high temperatures
  - This results in reduced molecular weight
  - This will cause an irreversible viscosity decrease
  - Lower viscosity would mean less shear heat is generated above degradation temperature
  - Modify viscosity to mimic degradation (Not based on measurements)
    - Racetrack effect without excessive temperatures (Isosurface at 314° C (597K))

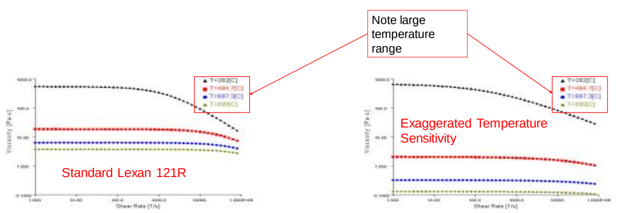






Viscosity Sensitivity to Temperature

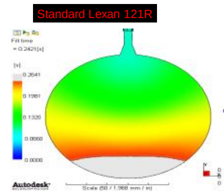
- What if the viscosity's temperature sensitivity is greatly exaggerated (sensitivity study)



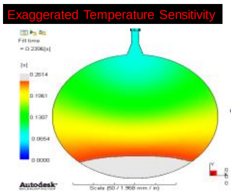
Viscosity Sensitivity to Temperature

- Slight difference in flow front shape

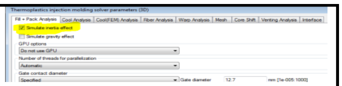
Standard Lexan 121R



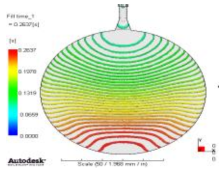
Exaggerated Temperature Sensitivity



Turn on Inertia

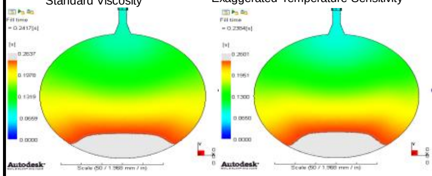


- Include the inertia term in the momentum equation
- Also turns on a more accurate method for calculating the flow front velocity (Longer computation time)
  - Race-track effect is improved



Inertia plus high temperature sensitivity

- Race-track shape is slightly better than with standard viscosity coefficients
  => Accurately modelling the temperature sensitivity will have some effect



Conclusions

- Race-Track Effect can be observed when:
  - Correct Flow Rate is applied
    - To have the correct amount of shear heating
  - Beam elements are used to capture shear-heating fully
  - Gate refinement is used
  - Temperature Cap is eliminated
  - Inertia effect is on, enabling accurate flow front velocity calculation
- Temperatures can go unrealistically high, but this may be because material degradation is not being considered which would lower the viscosity

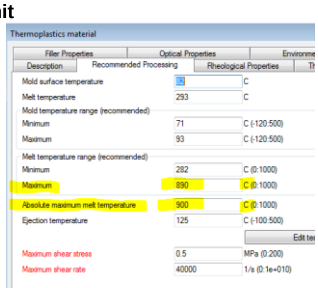
Steps to Improve Accuracy

- Full shear heating effect
  - Check Flow Rate
  - Temperature Limits
  - Layer Resolution
  - Beam Elements
  - Gate Refinement
- Flow Front Solution

- Process Settings:
  - Injection Speed is 150 mm/s
  - Stroke Length (for a near full shot) is: 37 mm
- Therefore: Set injection time is 0.25 sec

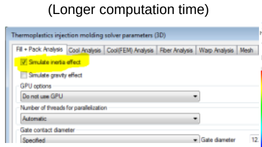
Avoid Temperature Cap Limit

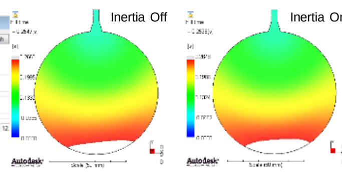
- Avoid Temperature Cap by raising the "Absolute maximum melt temperature"



Turn on Inertia

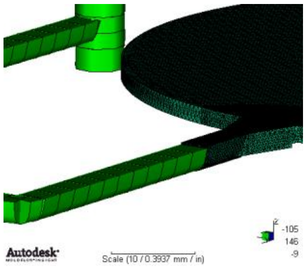
- Using 0.25 sec filling time, 16 Layers
- Slightly more Race-track effect observed with Inertia On
  - Inertia also turns on a more accurate method for calculating the flow front velocity (Longer computation time)





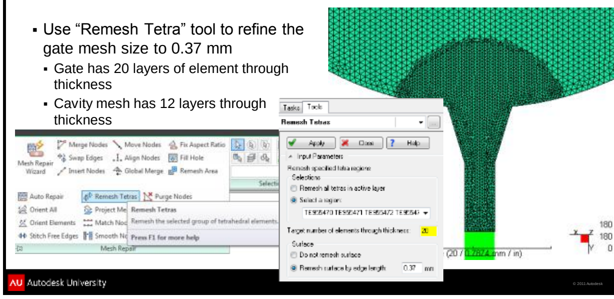
Model Feed System as Beam Elements

- Beam Elements ensure less false diffusion between layers/laminates
  - Can use up to 20 laminates in radial direction
  - VERY computationally efficient
  - Assign same U-Shape
- Beam elements are valid so long as the flow remains one-dimensional
  - No branching
- Use tetrahedral elements at the gate



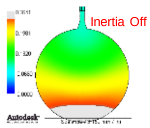
Refine Gate Mesh

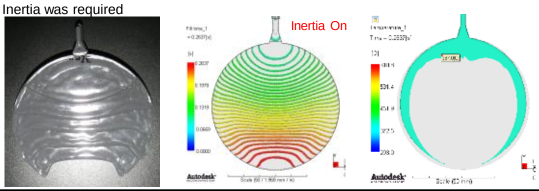
- Use "Remesh Tetra" tool to refine the gate mesh size to 0.37 mm
  - Gate has 20 layers of element through thickness
  - Cavity mesh has 12 layers through thickness



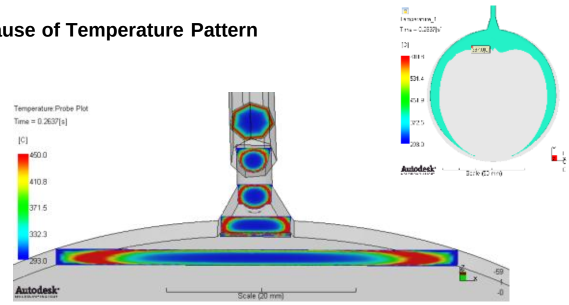
Improved Result

- Fill Pattern is much improved !
- Temperatures rises very high: up to 610° C (1130K)
  - Iso-surface shows melt region above 397° C (747K)
  - Inertia was required





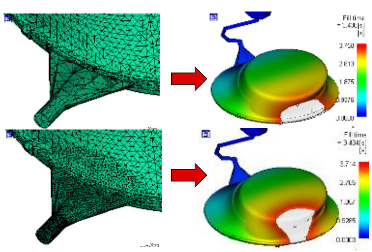
Cause of Temperature Pattern



Same pattern has been seen previously in Industrial Parts

PC Lens

PPS-22 (2006)
Yamagata, Japan
Costa *et al*



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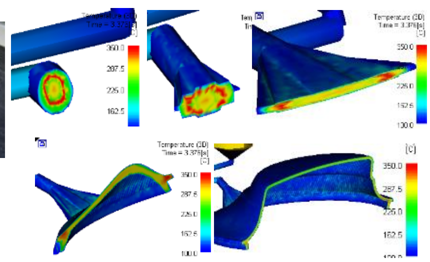

Intermediate Conclusion

- To predicted the Racetrack effect:
  - Turn on Inertia
  - Injection speed
  - Use beam elements to have high resolution of shear heating
  - Refine gate mesh (3D) to correctly convect heat pattern into the cavity
- Branching in the feed system? => Cannot use beam elements
  - Can use beam elements for the sprue, where the greatest shear heating is occurring.

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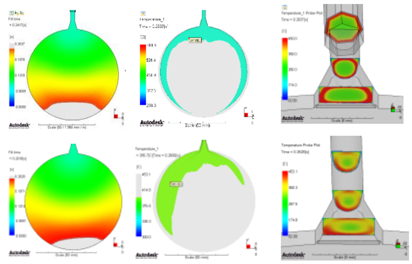
Could we get the same result with 16 layers of Tetrahedra?

Beam Feed System
20 laminates (radius)

Tetra Feed System
16 layers (diameter)



Maximum Temperature: 616˚C

Maximum Temperature: 453˚C

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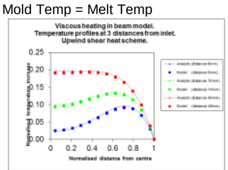
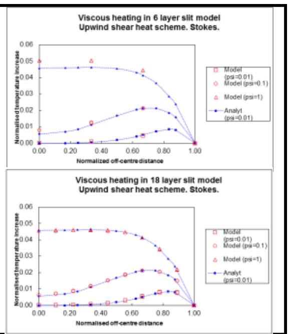
Validation of Shear Heating

- Cylindrical or Slit Flow
- Compare with analytical solution
  - Incompressible Fluid
  - Viscosity is not temperature sensitive
  - Mold Temp = Melt Temp





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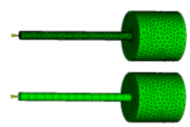
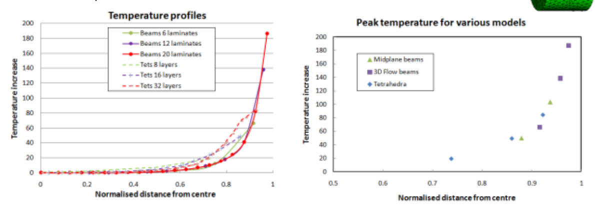
Comparison of Peak Temperatures



- Cylindrical Flow: Beams and Tetrahedra
  - Peak Temperature increases as resolution increases



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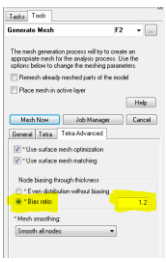
Can Mesh Bias Help?

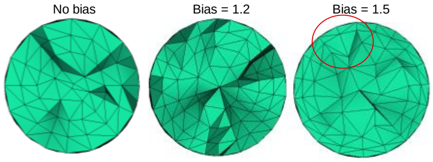


- Bias Ratio is the thickness ratio of adjacent layers
  - The bias scheme breaks down if the bias is too high
    - Depends on the number of layers

No bias

Bias = 1.2

Bias = 1.5



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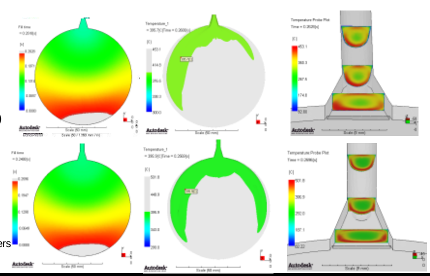
More layers of Tetrahedra with bias?

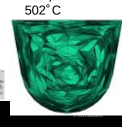
Tetra Feed System
16 layers (diameter)

Tetra Feed System
40 layers with bias
Cavity: 12 layers



Maximum Temperature: 453˚C

Maximum Temperature: 502˚C



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Conclusion

- To predicted the Racetrack effect:
  - Turn on Inertia
  - Check Injection speed
  - Use beam elements to have high resolution of shear heating
  - Refine gate mesh (3D) to correctly convect heat pattern into the cavity
- Branching in the feed system
  - Use beam elements for the sprue, where the greatest shear heating is occurring.
  - Use high mesh resolution in tetrahedral elements for other parts of the feed system

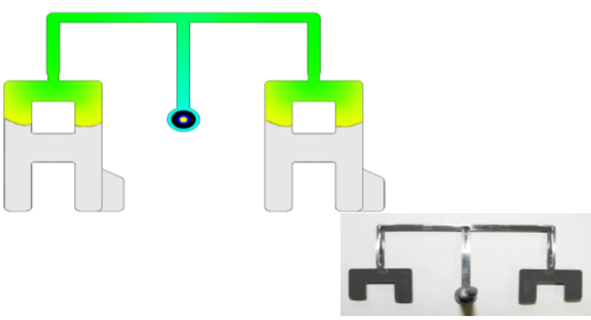
Example #3: Two Cavity with asymmetric features Intra-cavity)

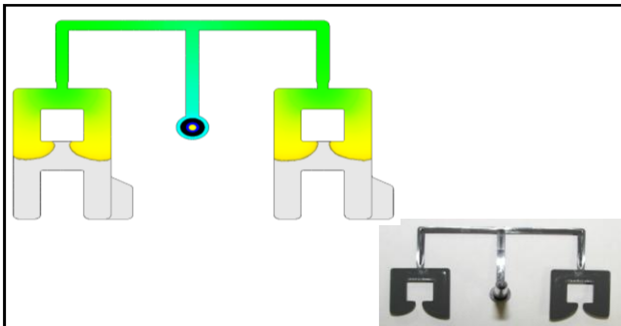
The following parameters were used to run the analysis:

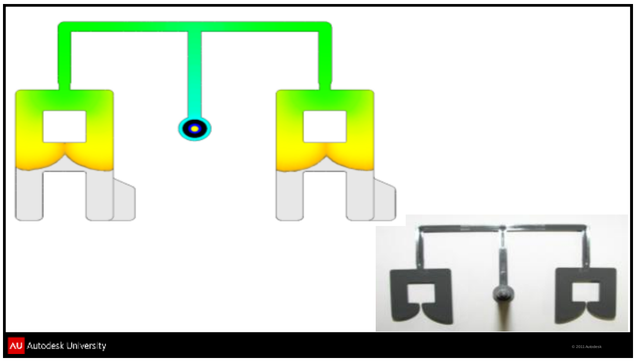
Material: Lexan 121R: Sabic Innovative Plastics

Melt Temperature = 560˚ F
Mold Temperature = 180˚ F
Injection time = 0.25 seconds

Dual Domain Mesh = .015” (148,748 elements)
3D Mesh = 20 Layers (4,549,363 elements)



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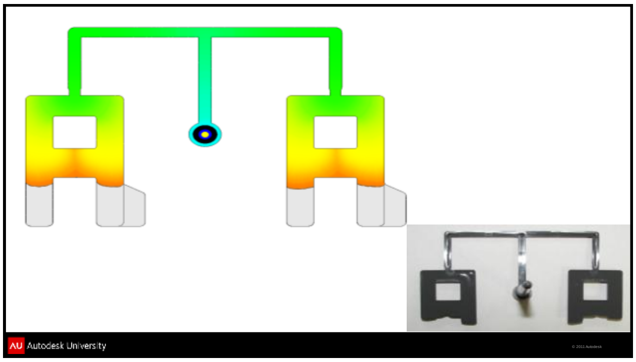
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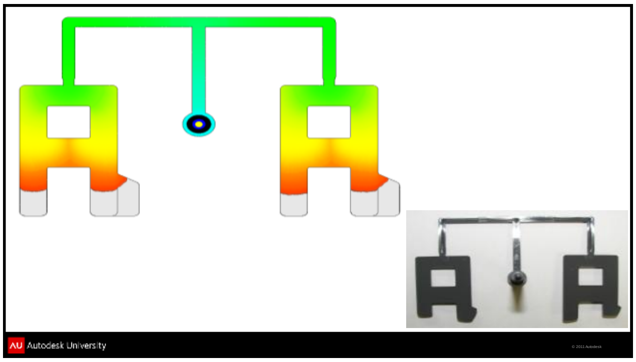
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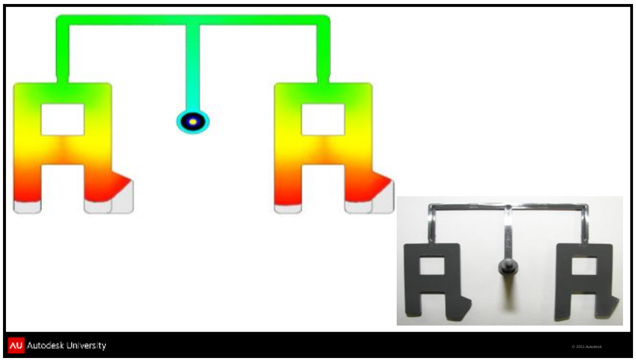
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