Using Autodesk Moldflow Insight to Evaluate Shear-Induced Imbalance

Mark Howards
3D Shapes, Inc.

Class Summary

- Situations That Create Imbalance
- Shear Rate Review
- Meshing & Methodology
- Sensitivities
- Other Ways to Affect Shear Rate

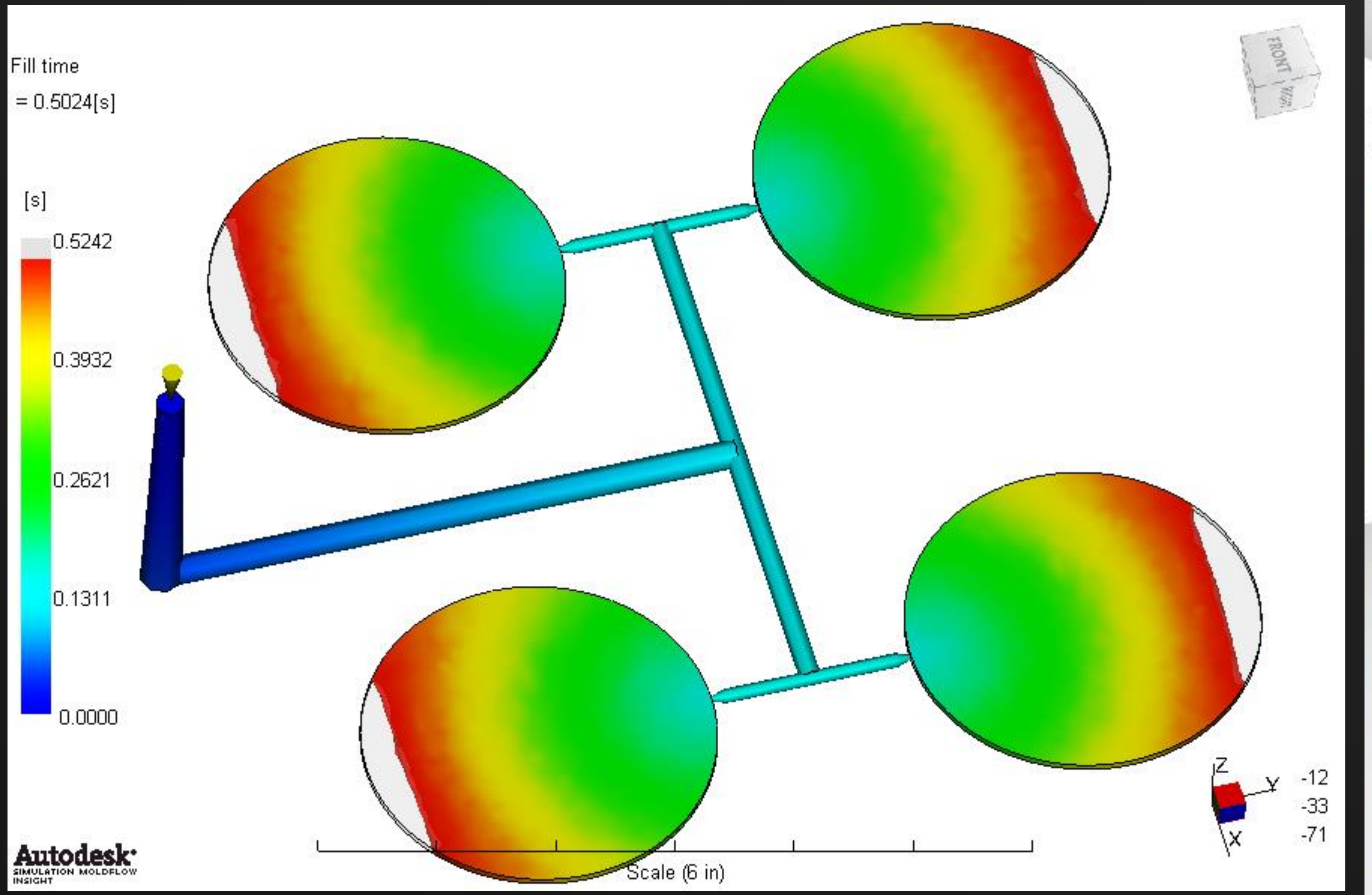
Learning Objectives

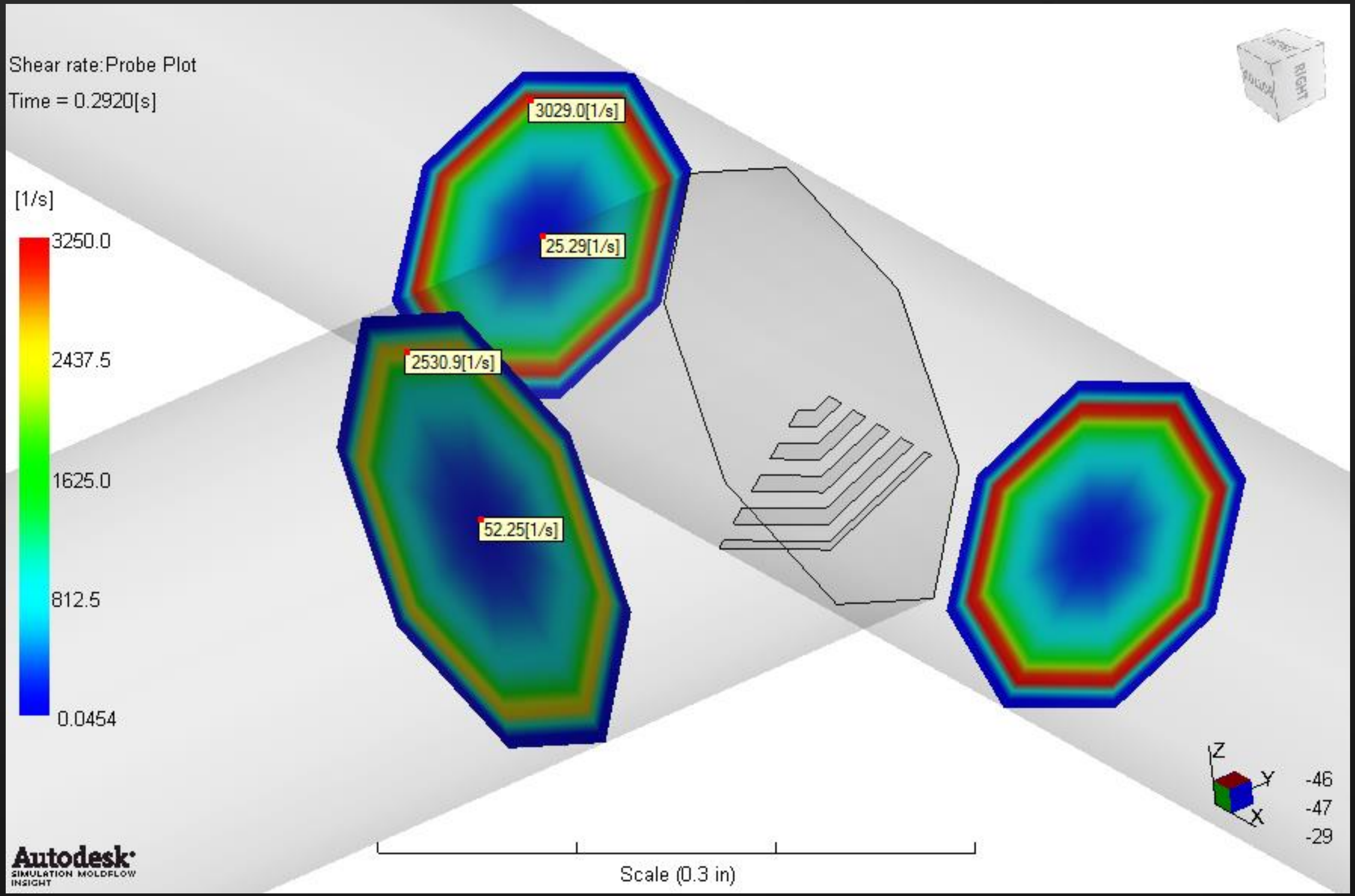
At the end of this class you will be able to:

- Know where to look for shear rate problems
- Know best ways to apply Moldflow to evaluate problems
- Understand modeling requirements for accuracy
- Understand other ways to deal with shear rate problems

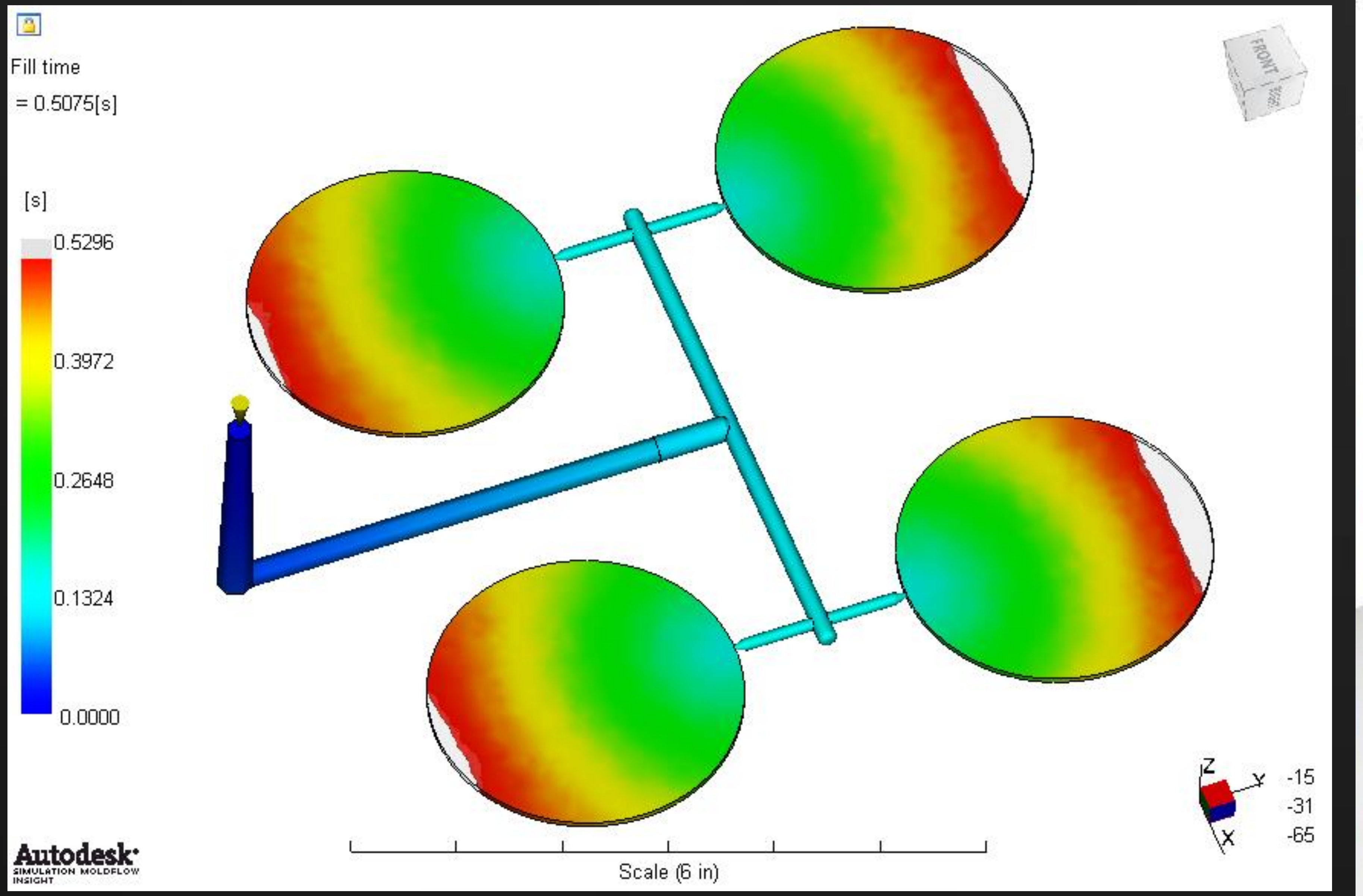
Situations That Create Temperature Imbalance

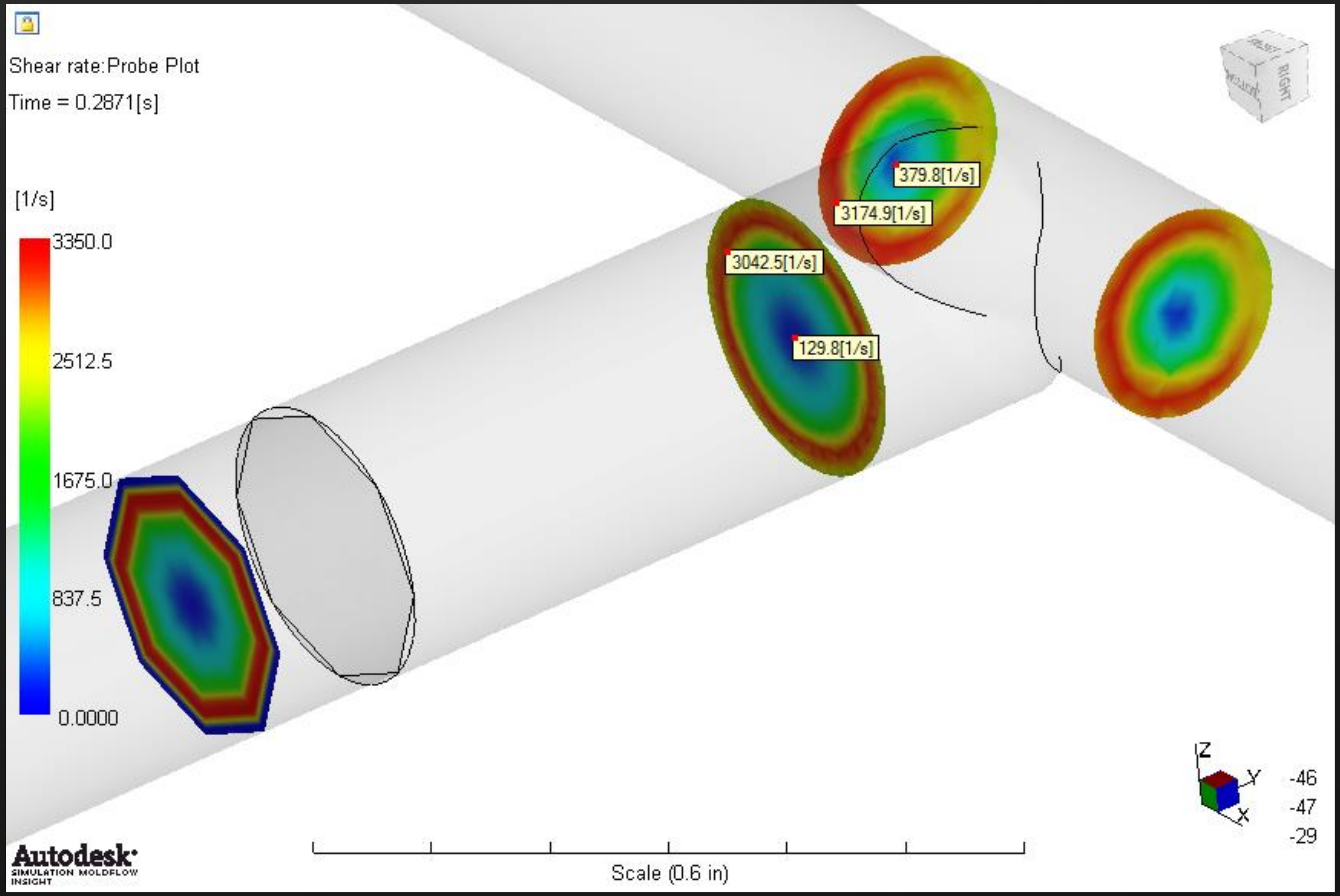
Shear Rate - 1-D Runner/3-D Parts



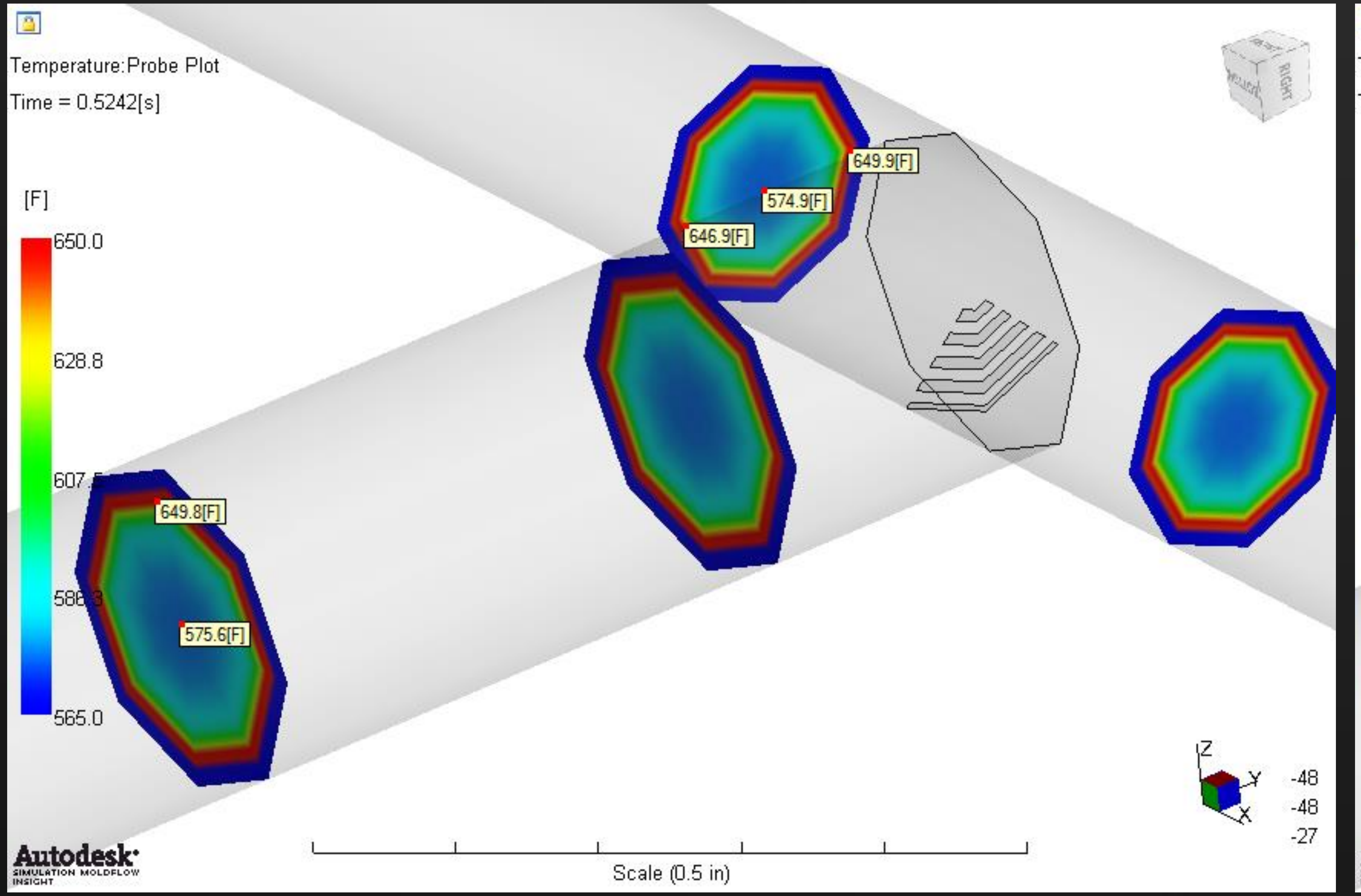


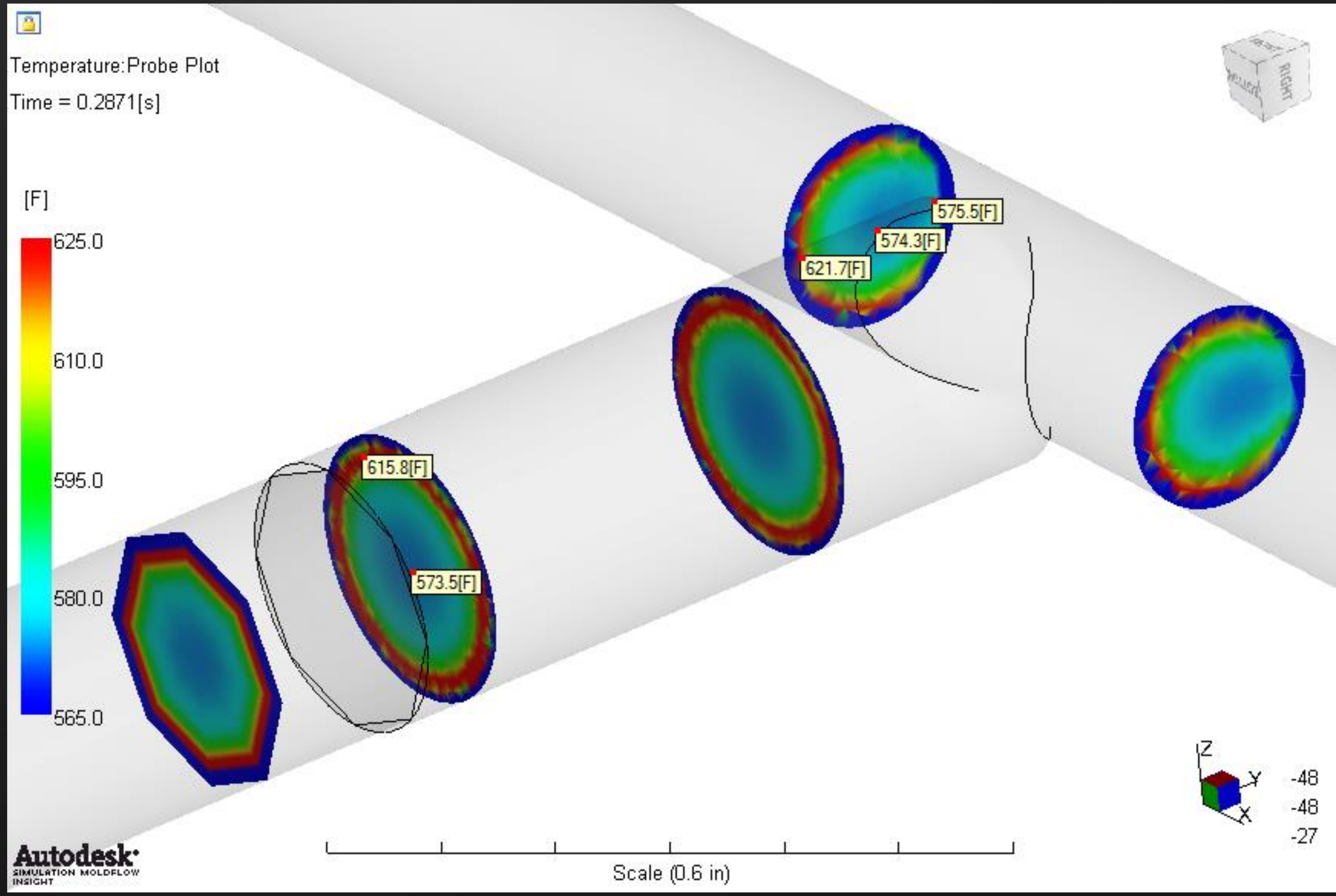
Shear Rate – 3-D Runner/3-D Parts





Temperature Comparison – 1-D versus 3-D





Formulas for Shear Rate

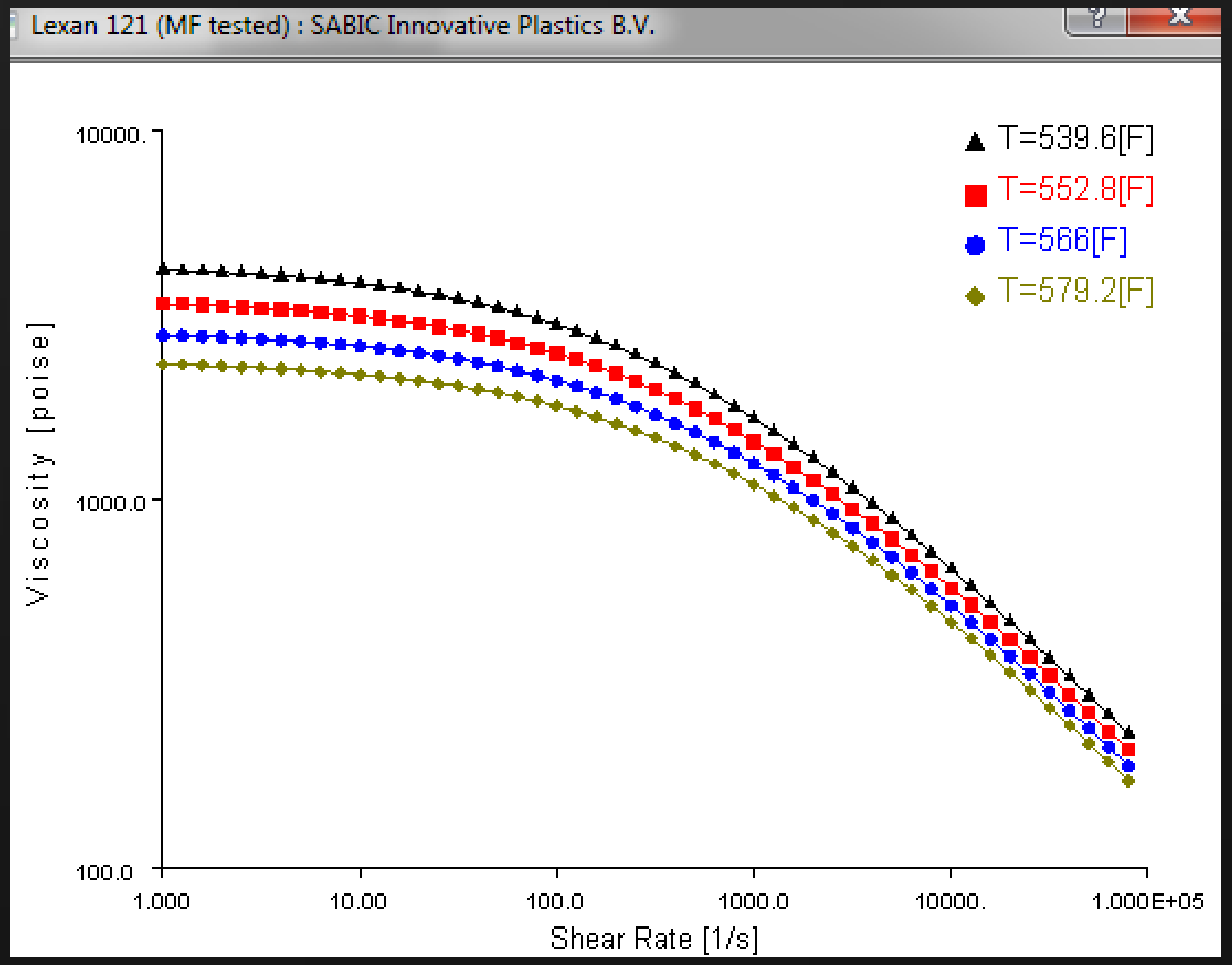
- Shear Rate through a round channel:

$$\gamma = \frac{32Q}{\pi d^3}$$

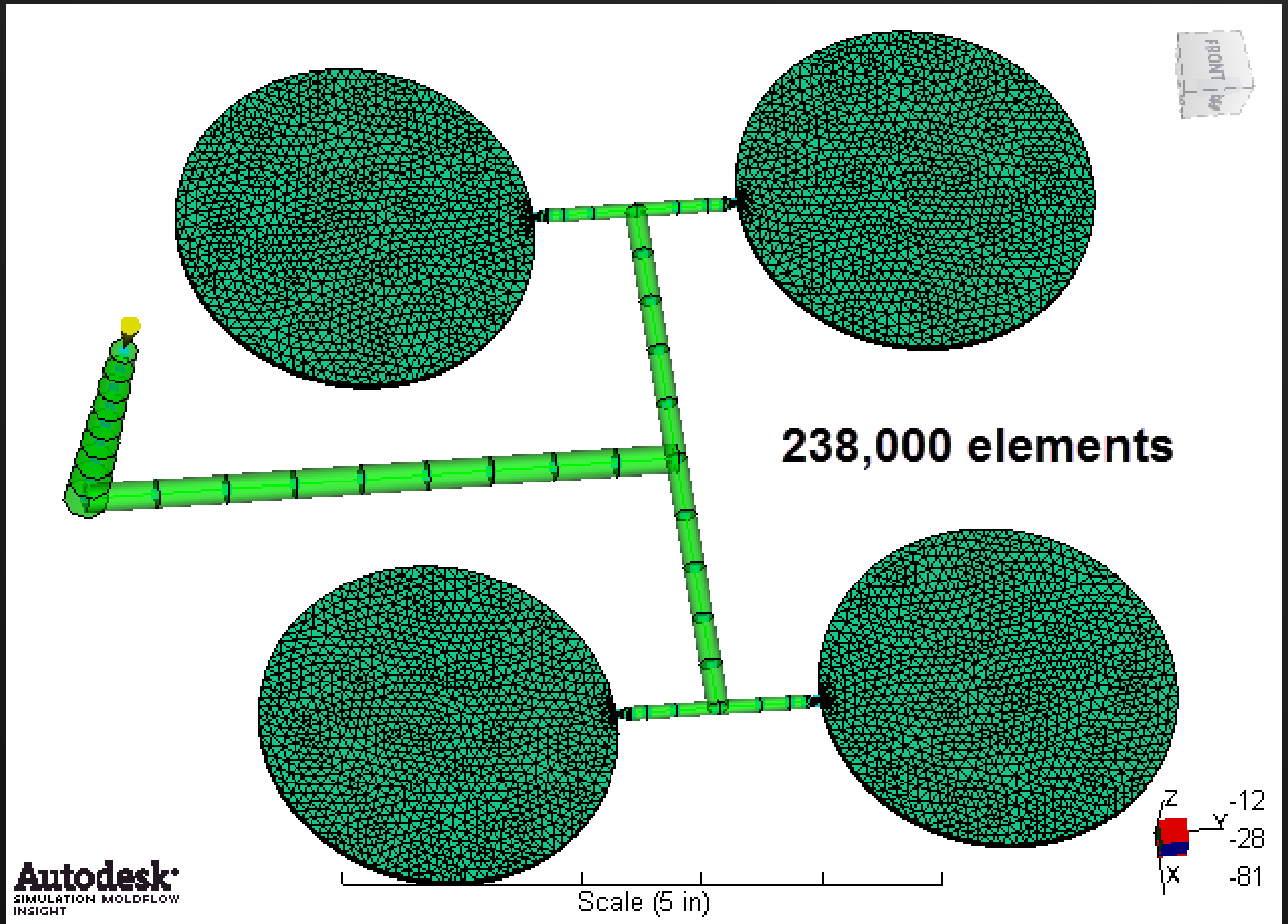
- Shear Rate through a rectangular channel:

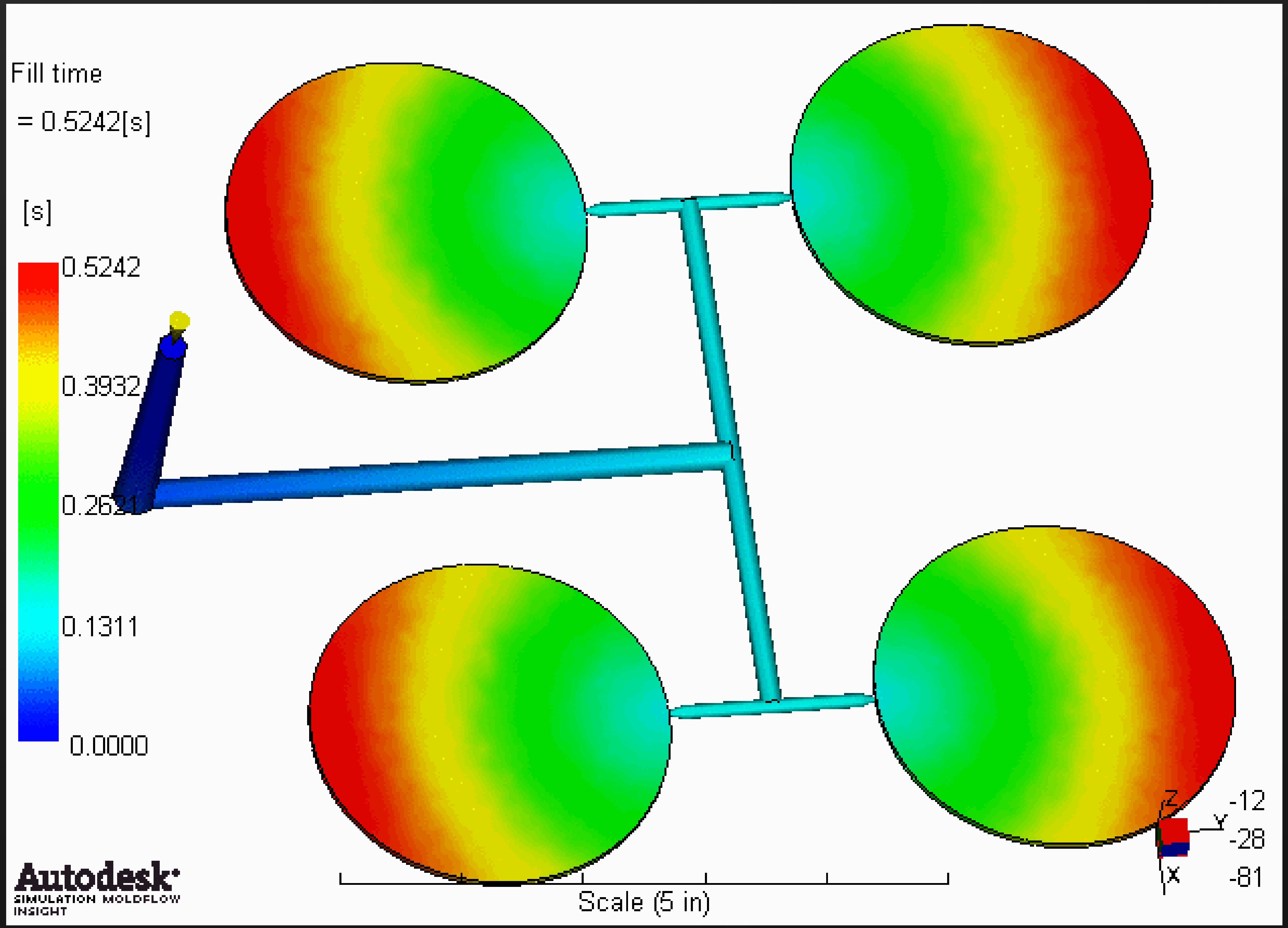
$$\gamma = \frac{6Q}{wh^2}$$

Q is flow rate
d is diameter for round channel
w is width
h is height or thickness

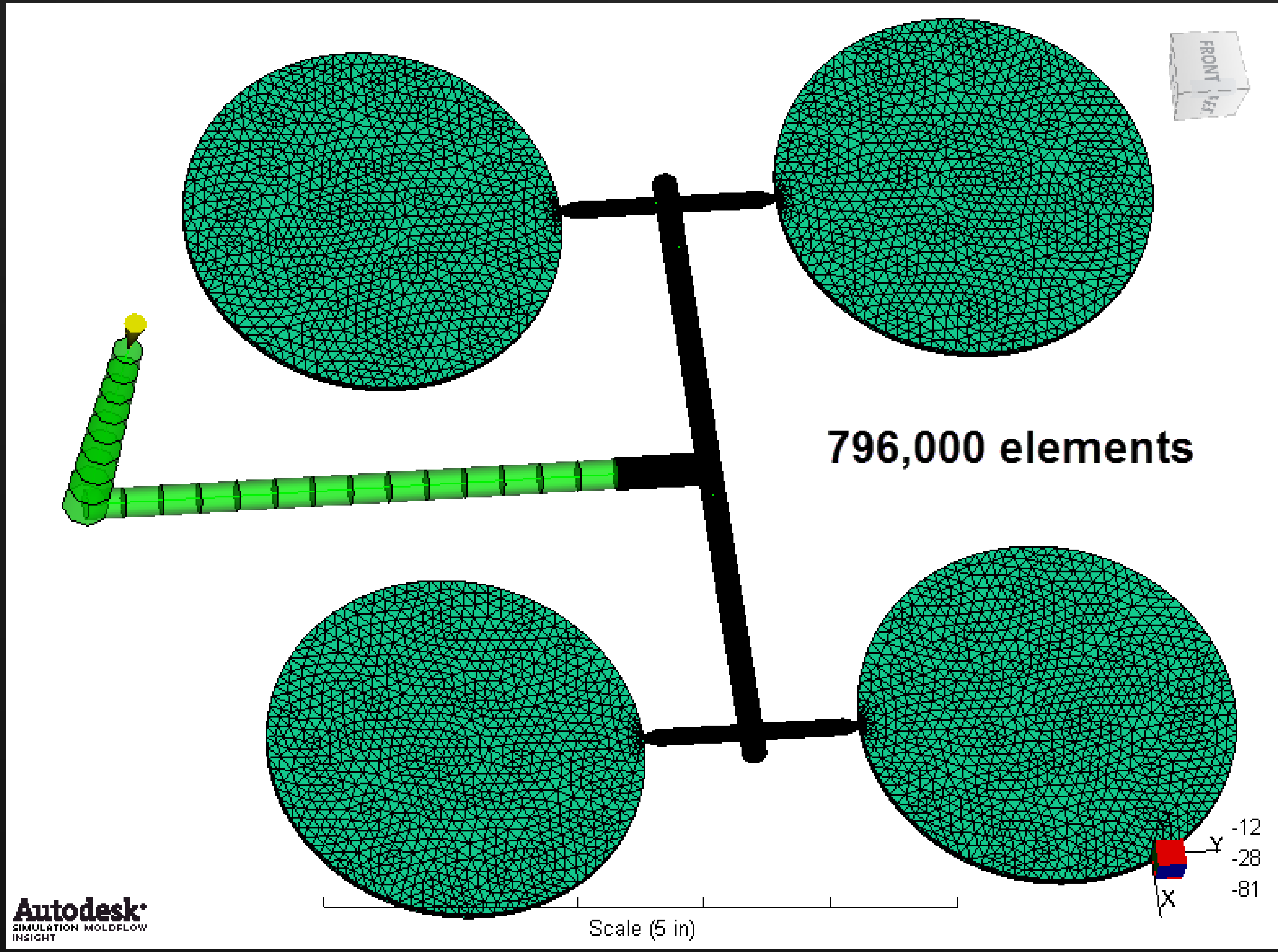


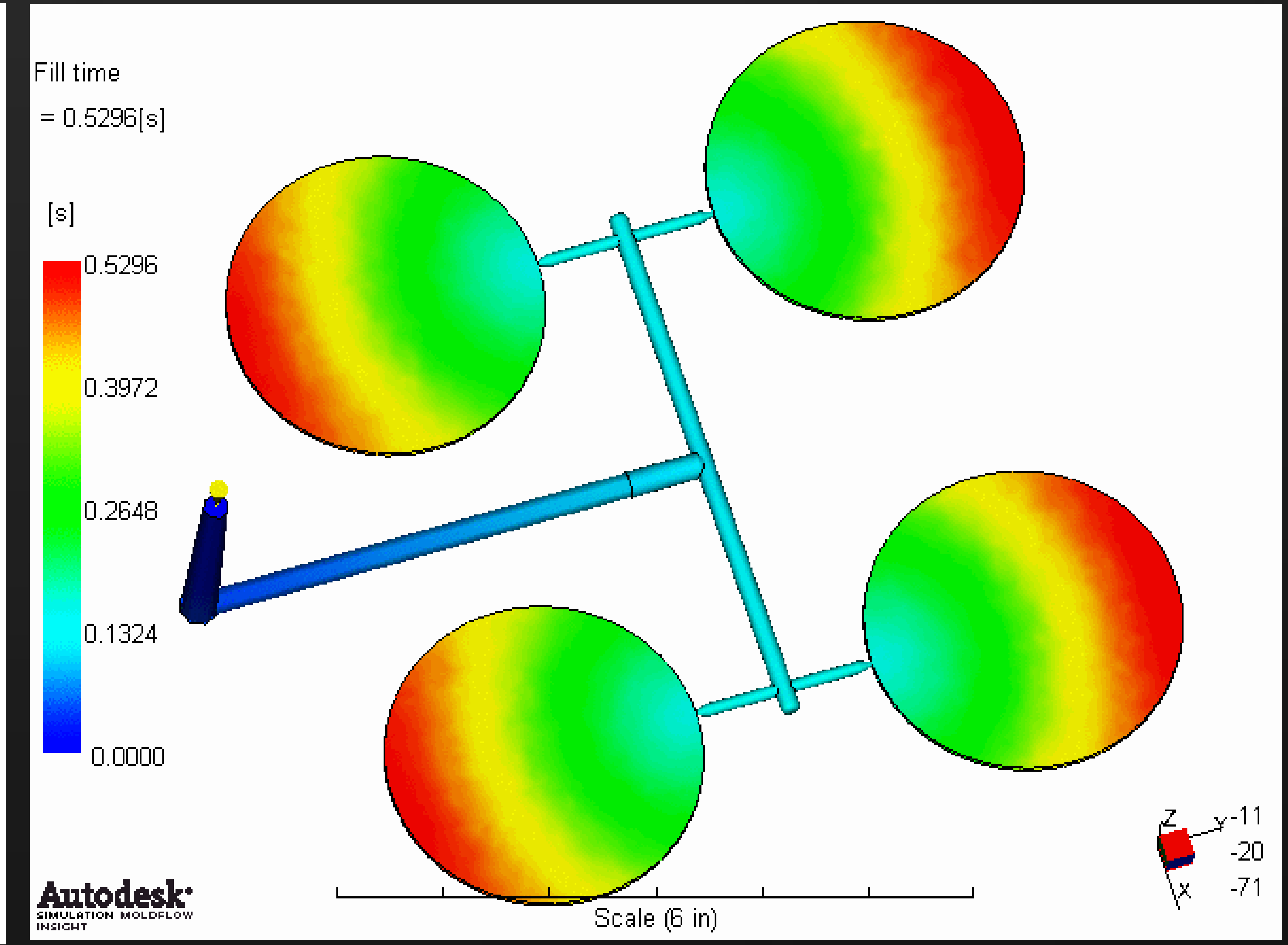
Naturally "Balanced" – Perfection?





Naturally "Balanced" – No Such Thing

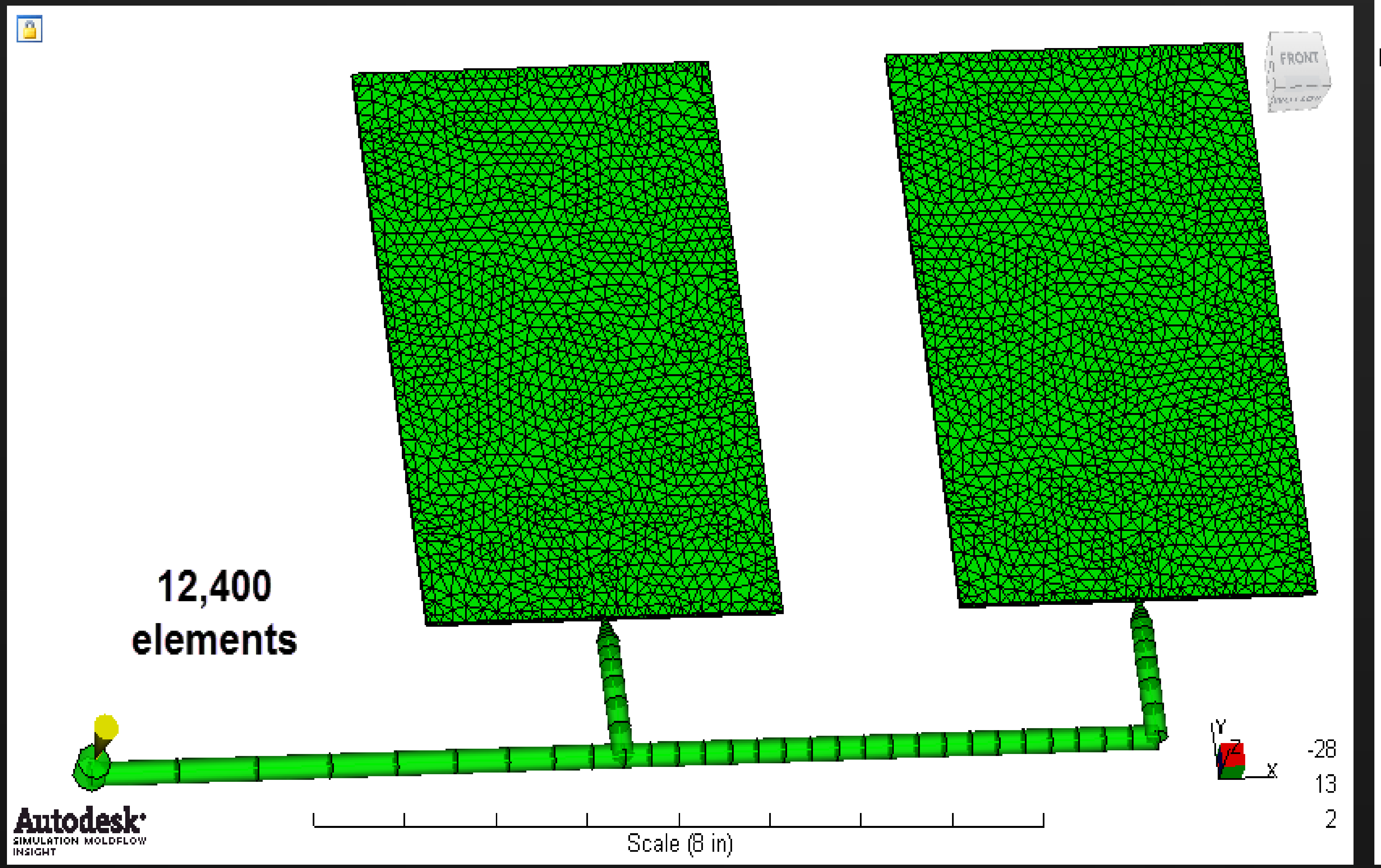


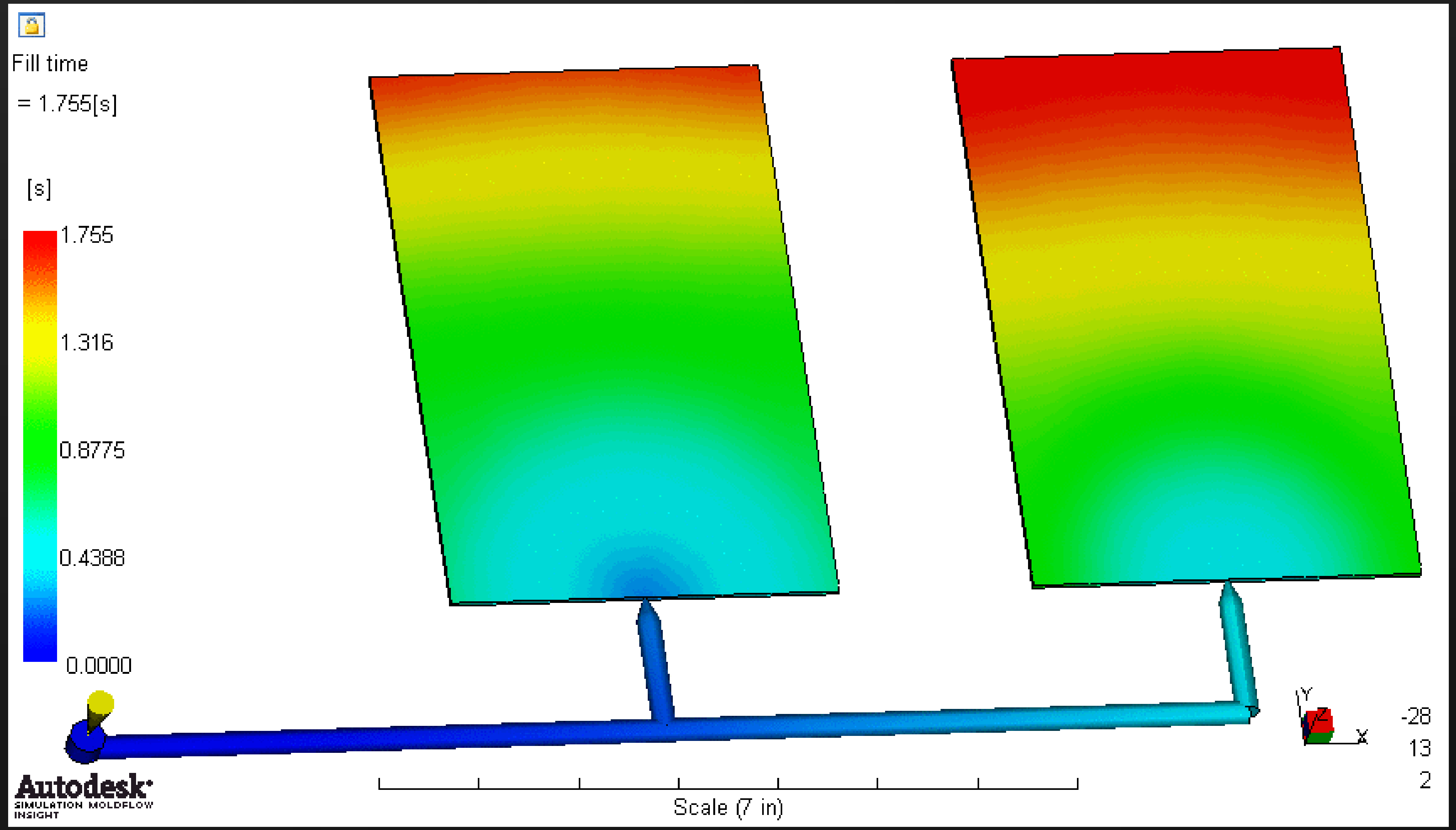


Unbalanced Layout

1-D Runner/Dual Domain Part

P_{max} = 22,570 psi

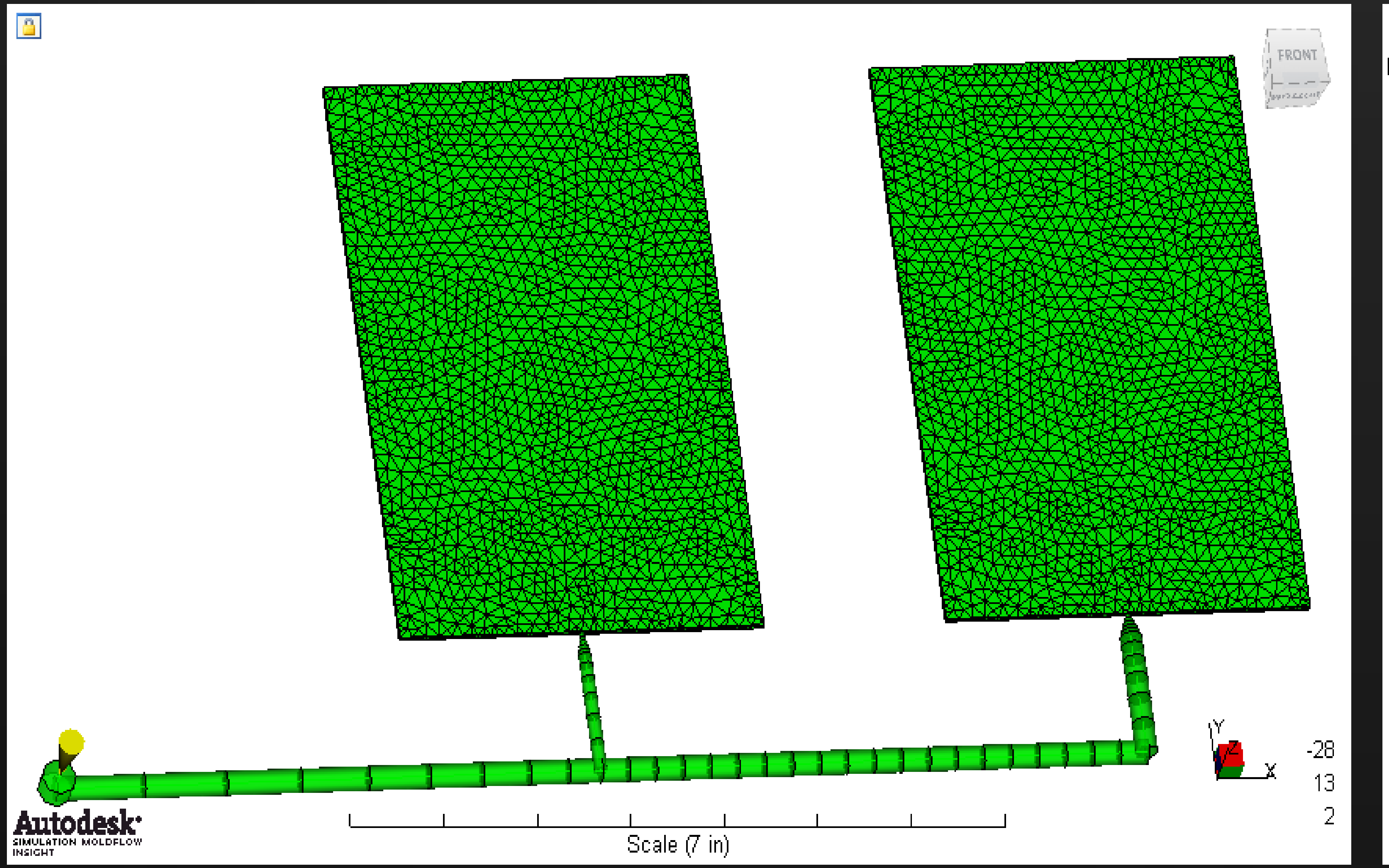


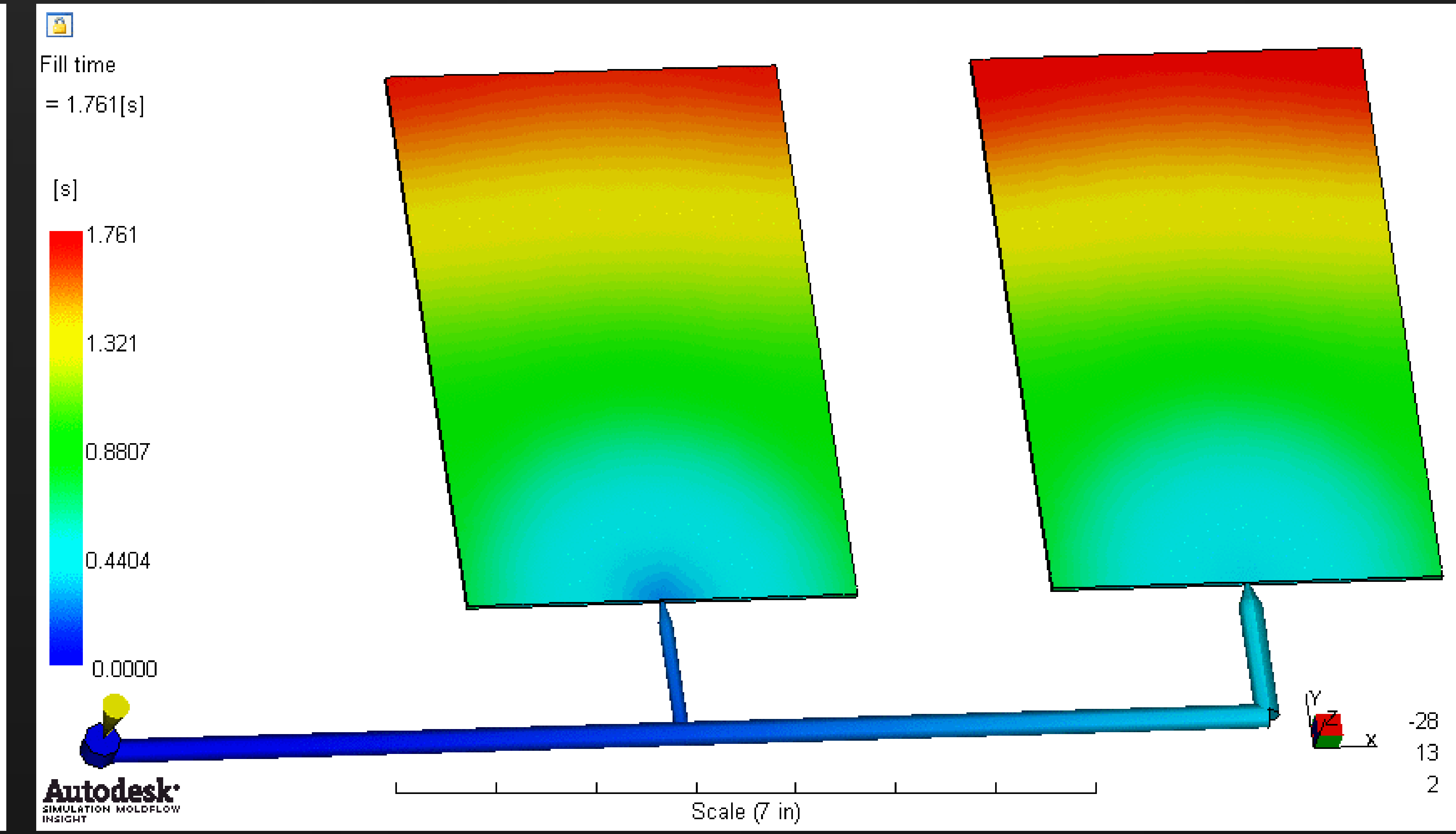


Unbalanced Layout - “Balanced”

1-D Runner/Dual Domain Part

P_{max} = 21,573 psi

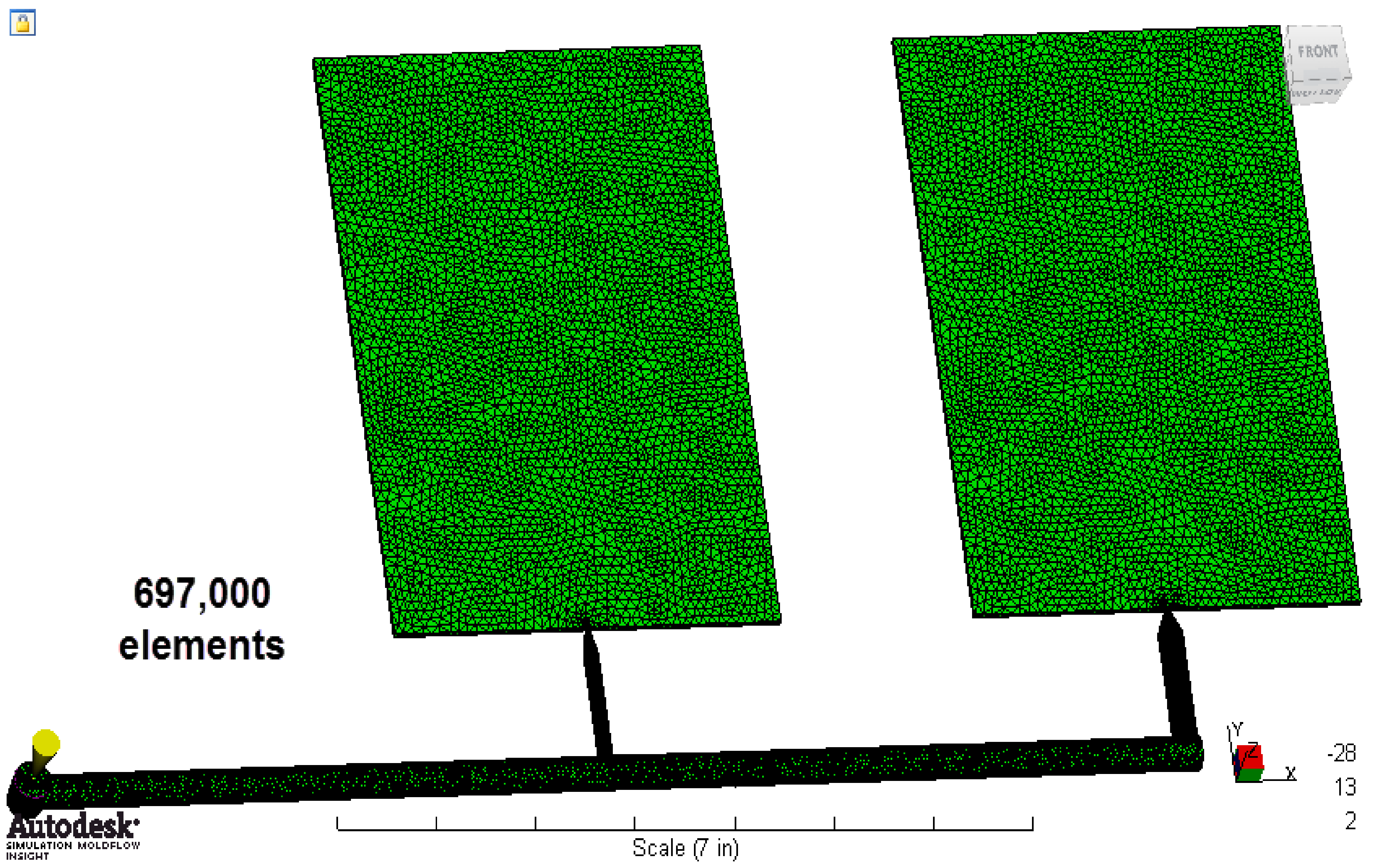


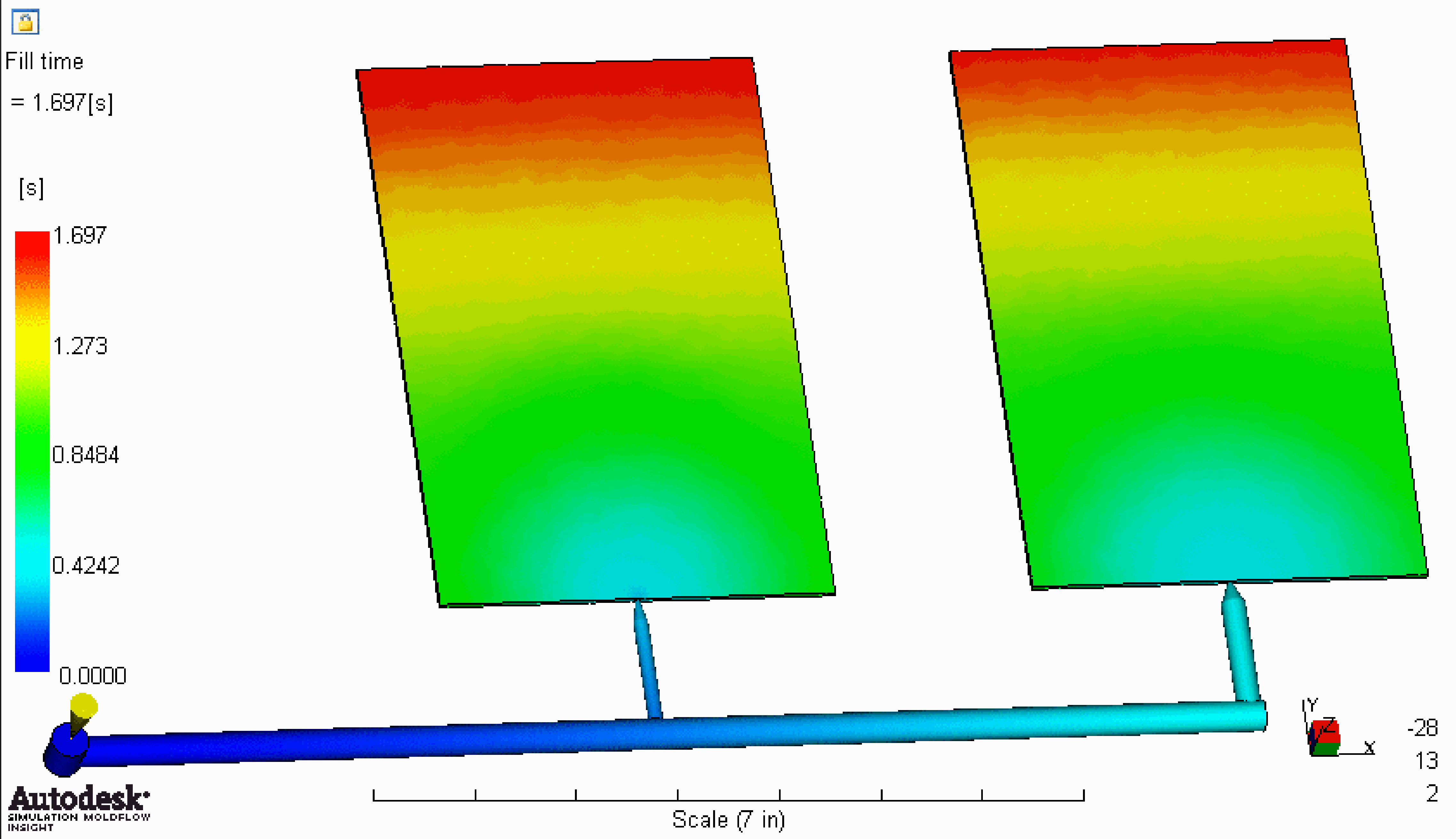


Unbalanced Layout – “Balanced”

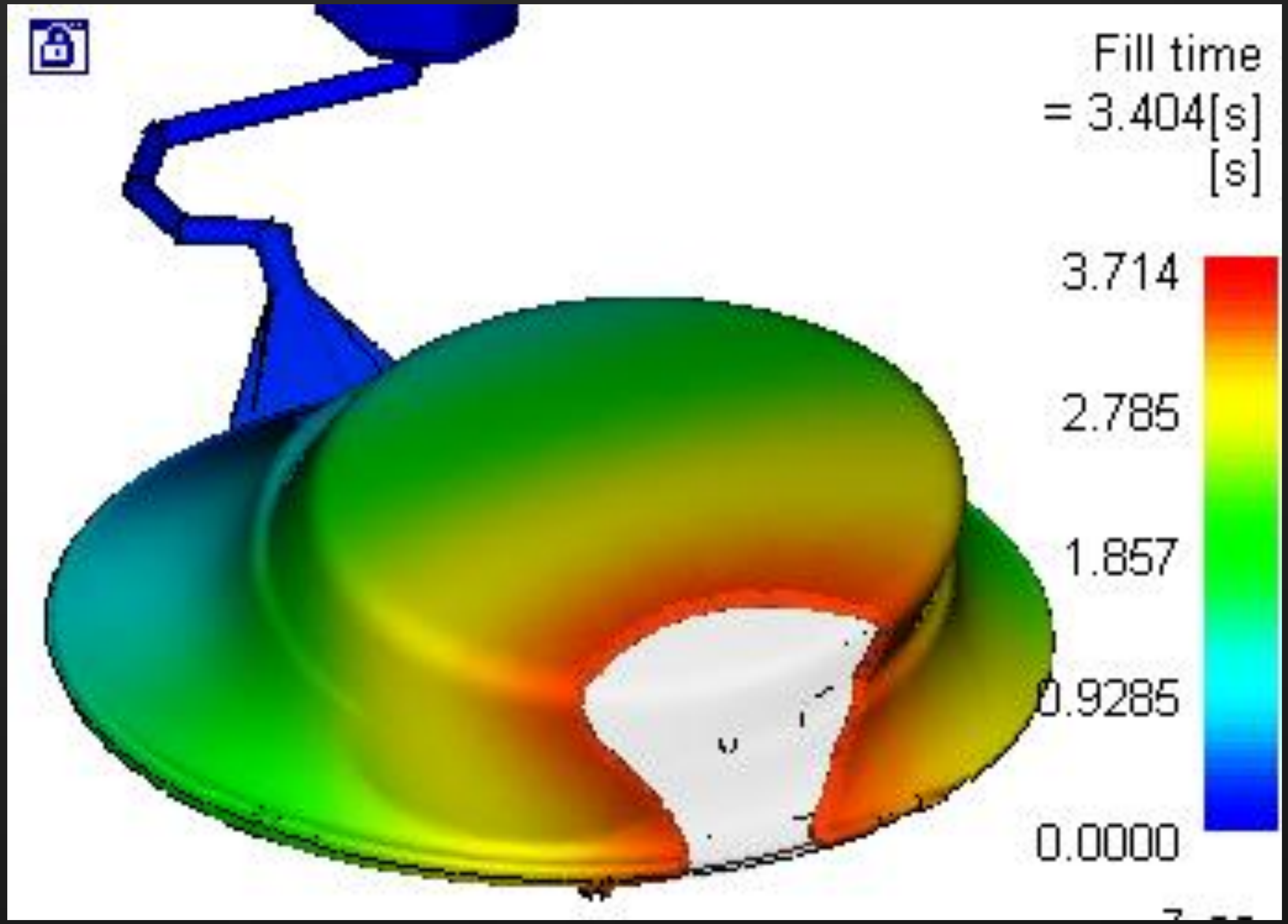
3-D Runner/3-D Part

P_{max} = 18,070 psi



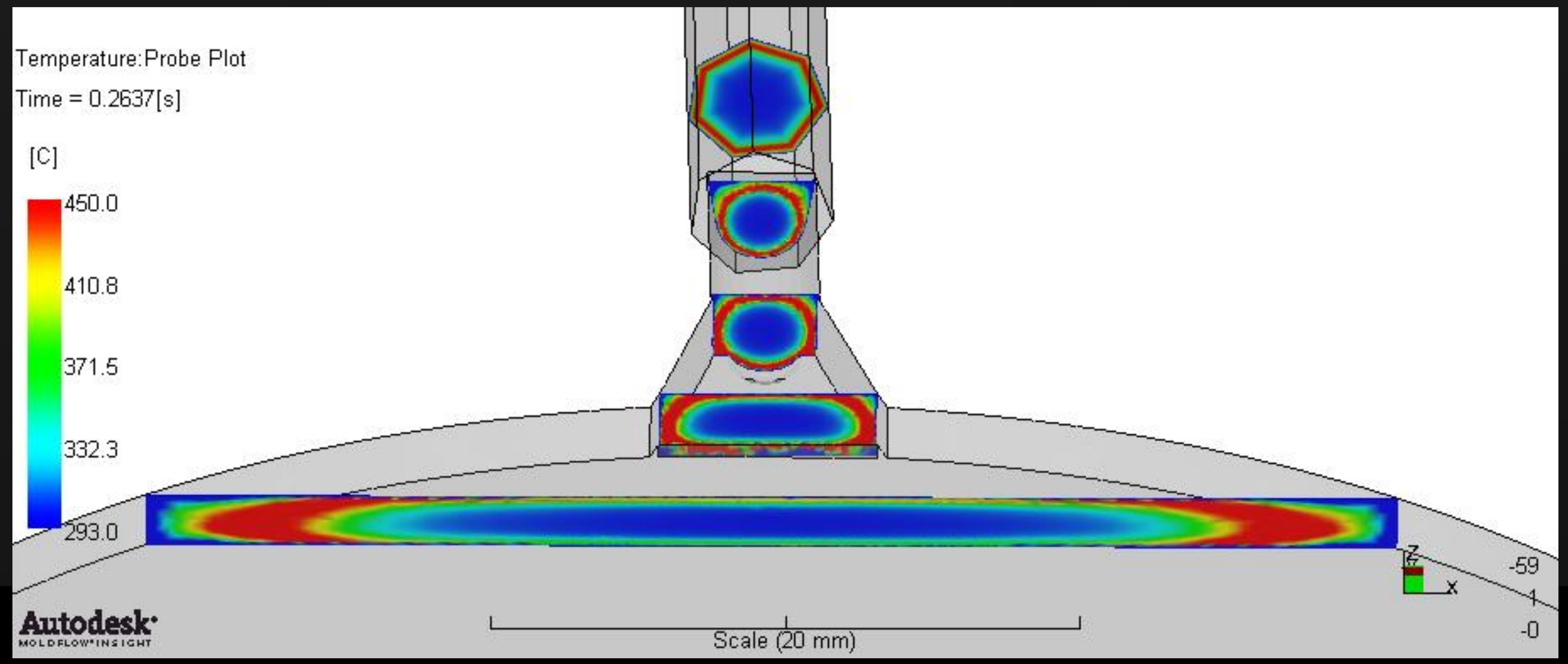


Unexpected Melt-Front Advancement
(Thanks to BTI and Autodesk for slide)



PC Lens

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



Correct Trends if Correctly Modeled

Last Year's Presentation Recommendations:

- Inertia turned ON
- Model as far upstream as practical (nozzle)
- For branching runners use 3-D elements with a minimum of 12 layers
- Fine surface mesh
- 1-D where possible and set to 20 laminate layers
- Correctly biased elements improve results
- Set Absolute Material Temp. to 1832° F/1000° C (maximum)

Mogens Papsøe e-mail

1979 Doctoral Thesis of Dr.-Ing. Schürmann at Institut fuer Kunststoffverarbeitung (IKV) at the University in Aachen, Germany

- „Zwei Verzweigungen ***dürfen*** nicht in einer Ebene liegen“

Beaumont Technologies Inc. (BTI) MeltFlipper®

Take care not to violate the following BTI patents:

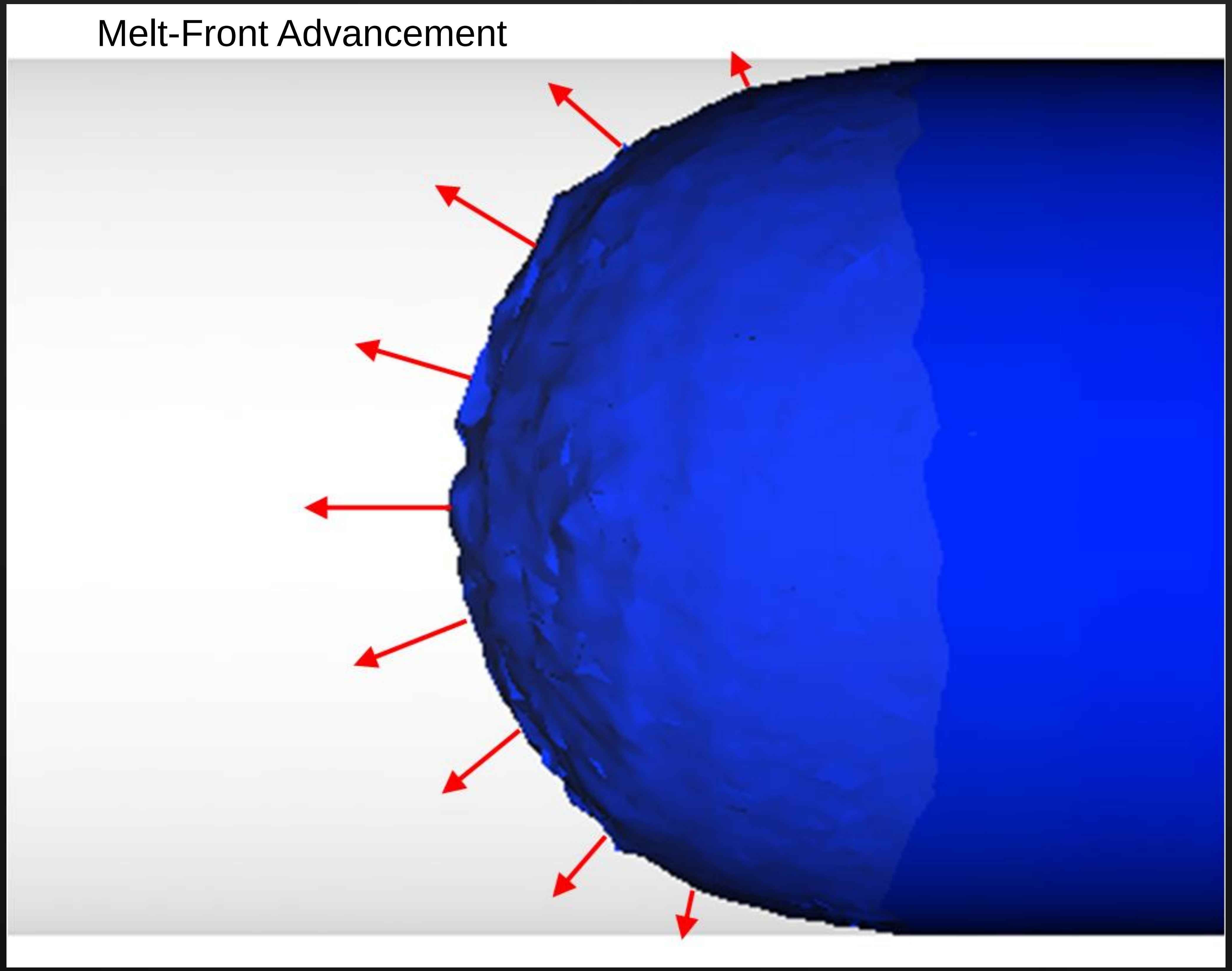
- Patent No. 6,077,470 and PCT/US98/21645
  - "Branching Runner Thermal and Flow Balancer"
- Patent No. 6,503,438 and PCT/US01/20761
  - "Method and Apparatus for Balancing Flowing Conditions of Laminar Flowing Materials"

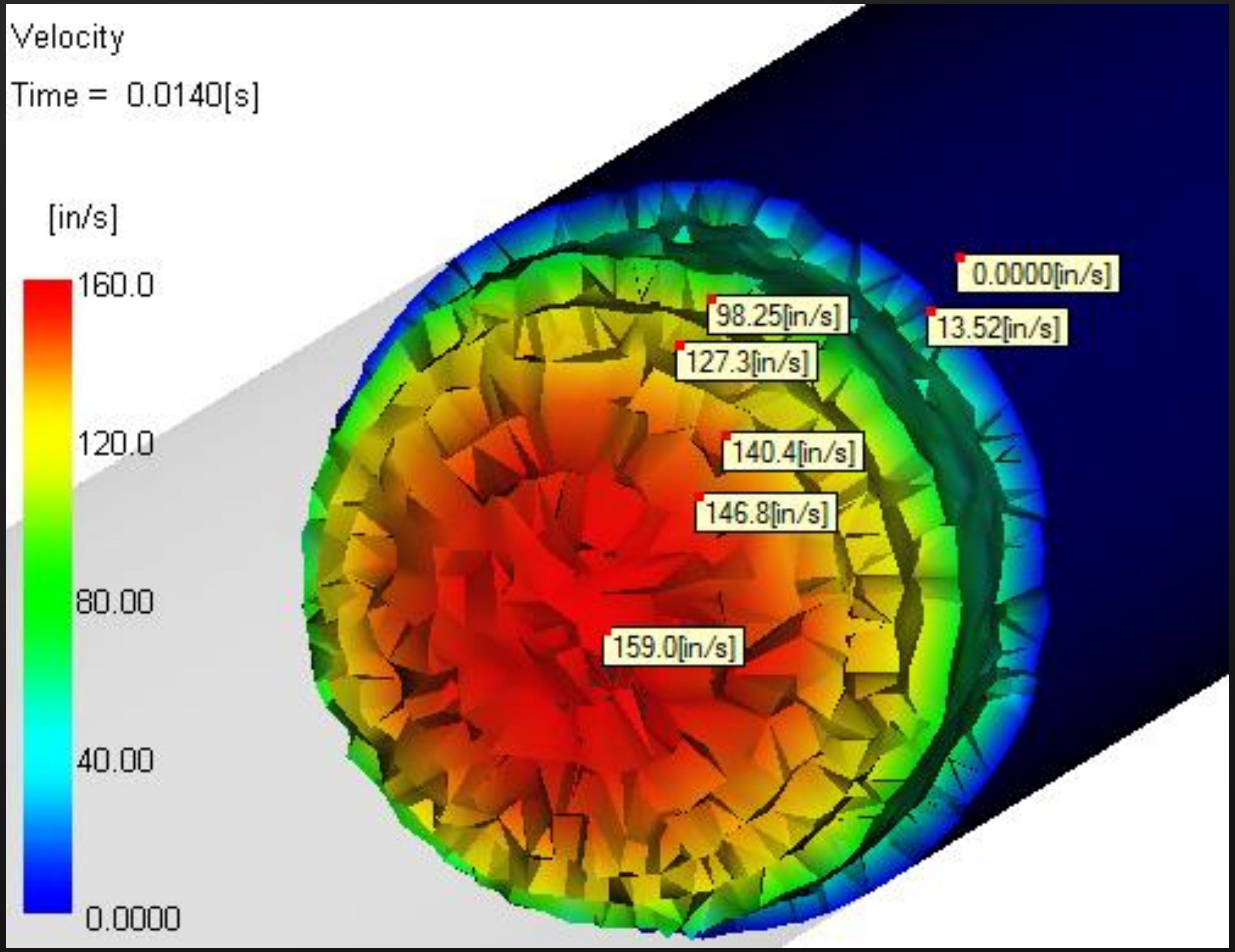
To use these you will need to complete a licensing agreement for BTI's "Melt Conditioning Technologies".

Shear Rate Concepts

All Due to Fountain Flow

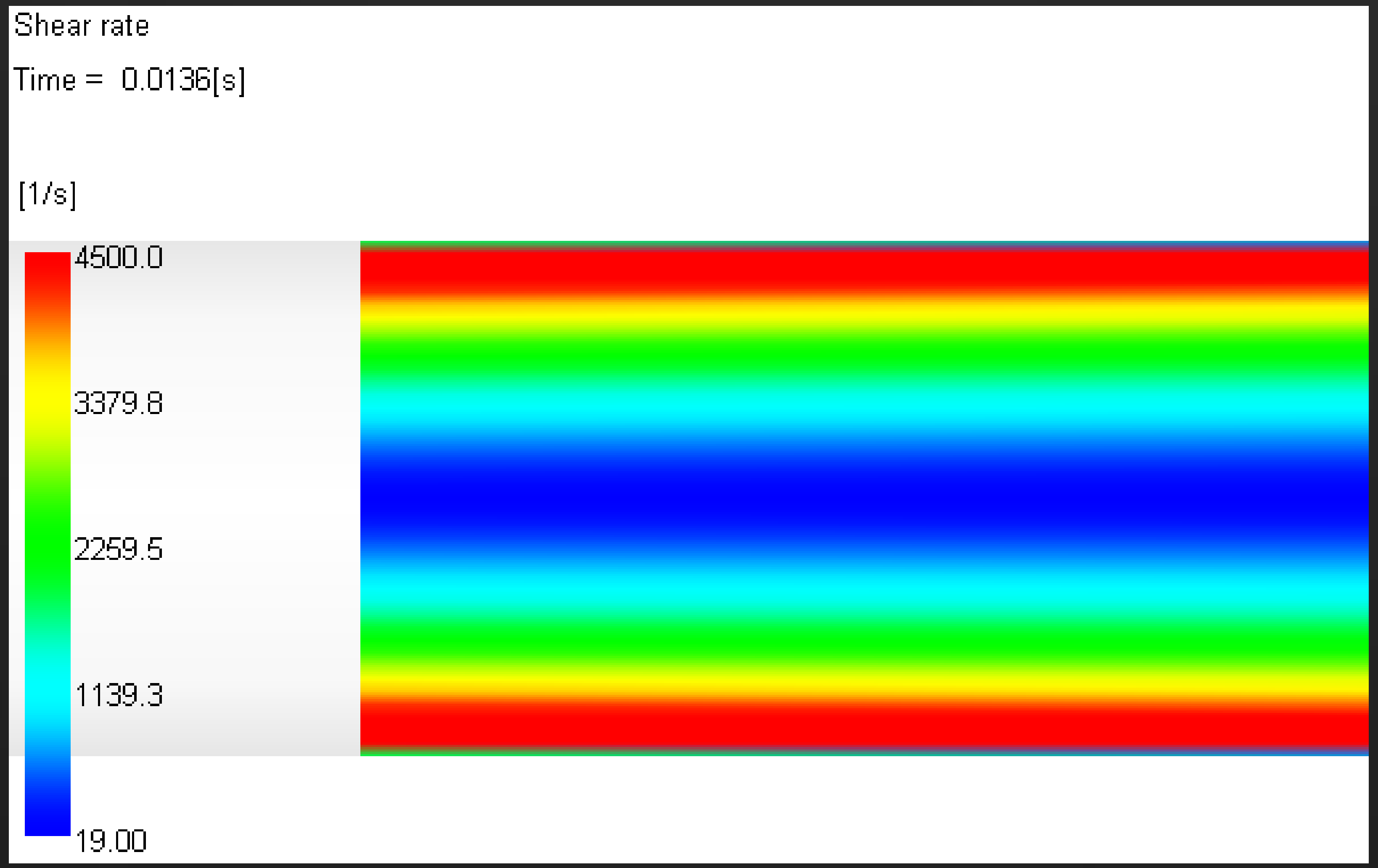
Flow of Polycarbonate in a 0.25” D runner



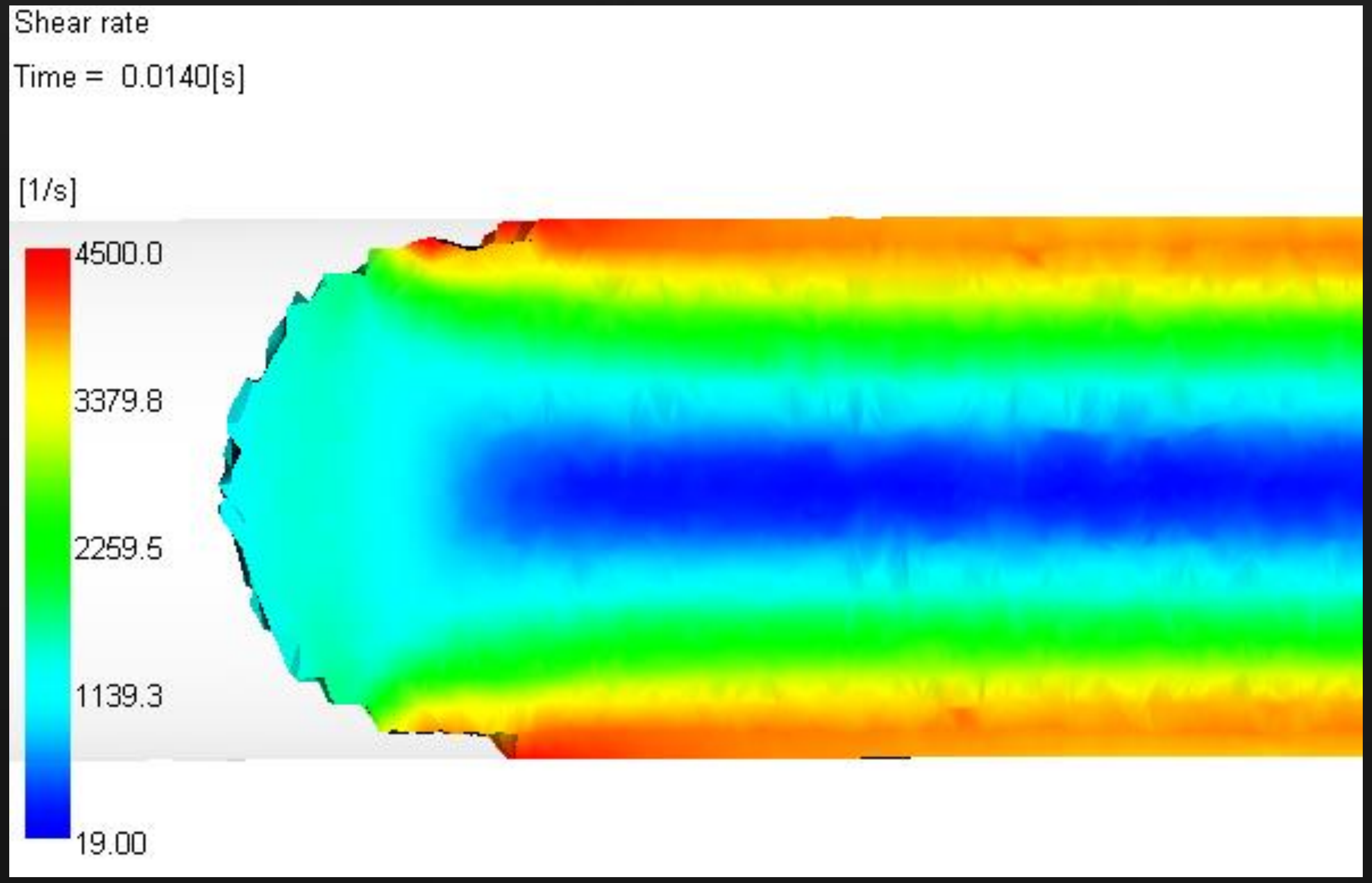


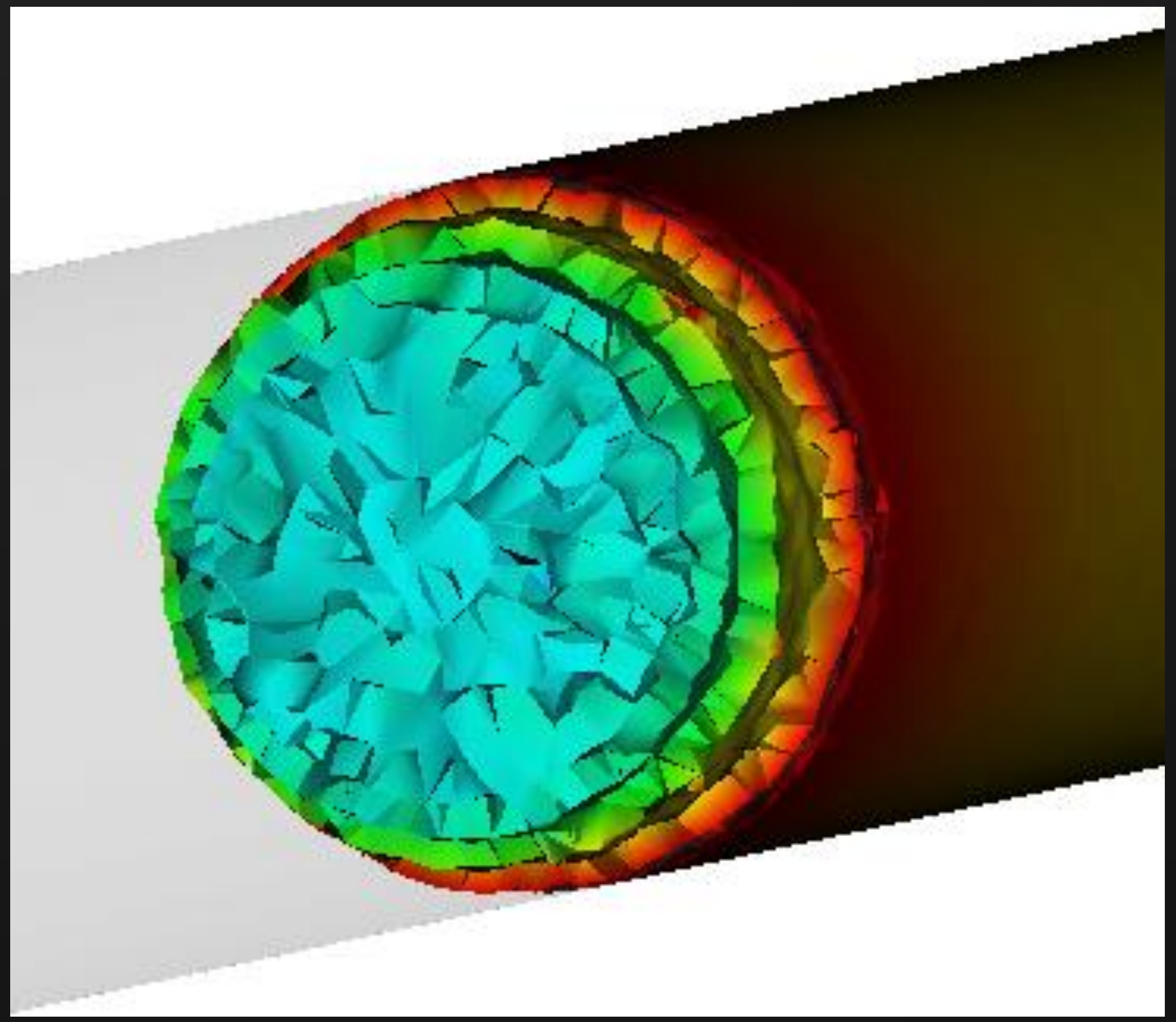
Shear Rate

1-D element



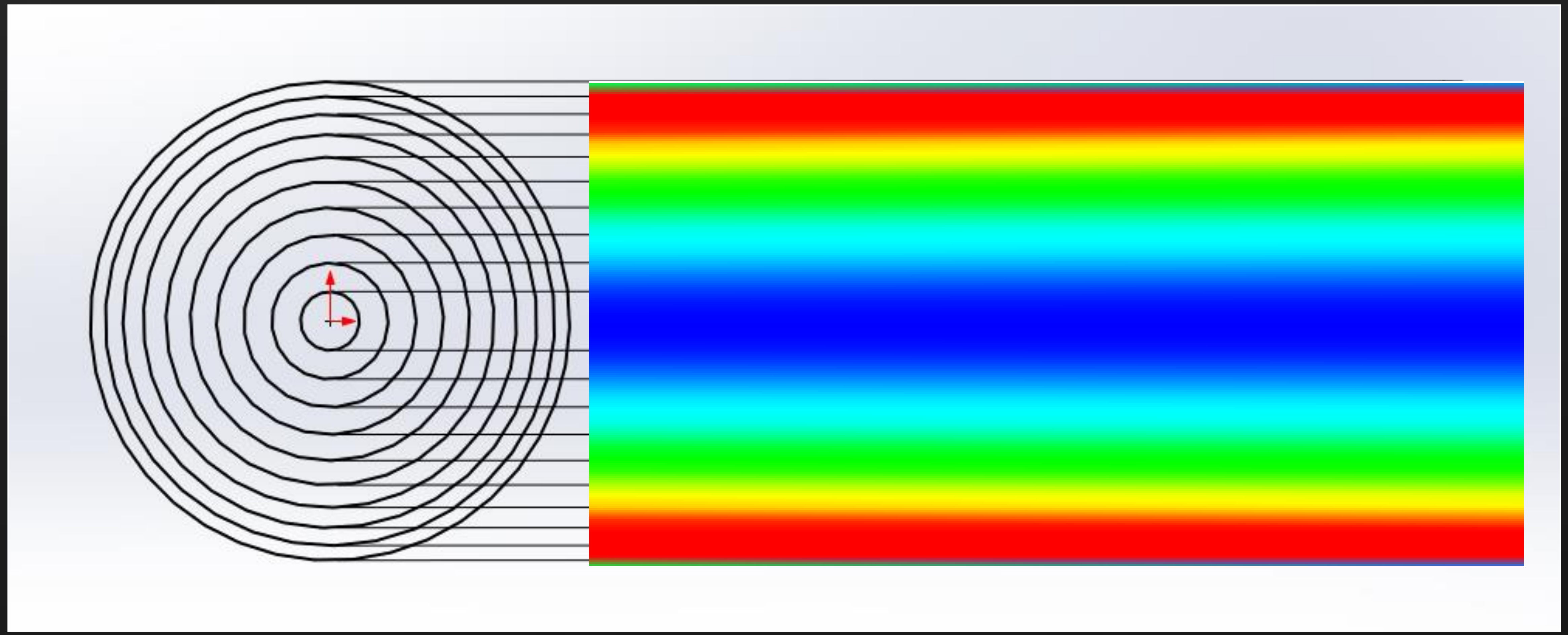
3-D elements



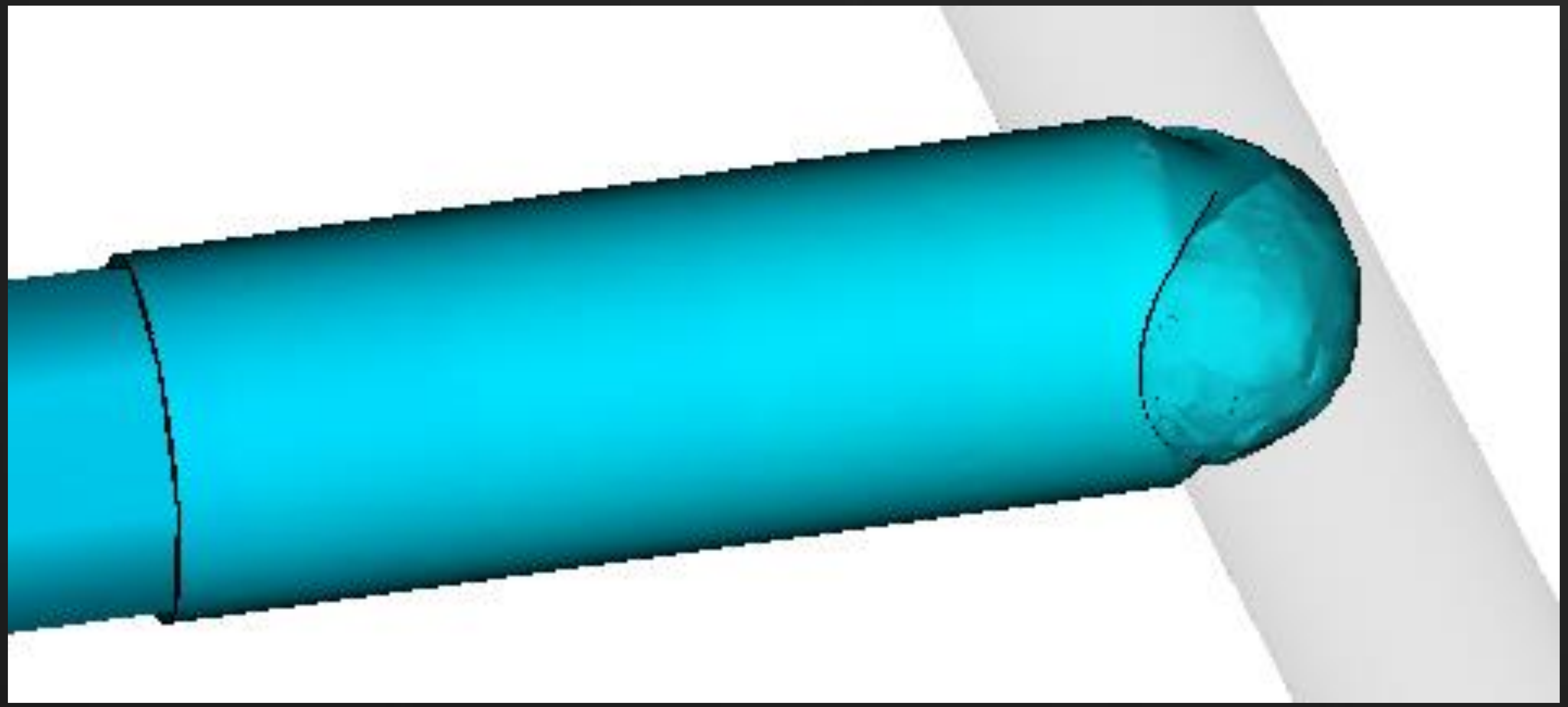


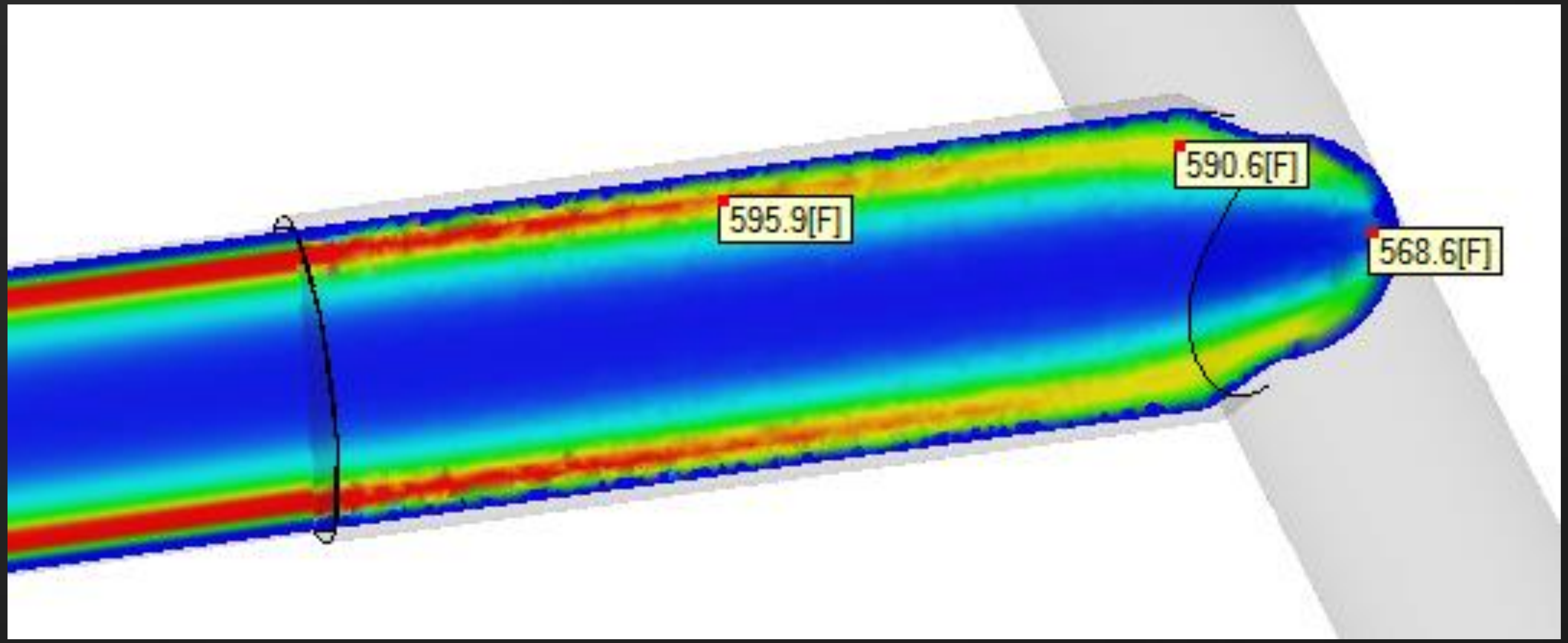
Conventional Methods - 1-D Laminates

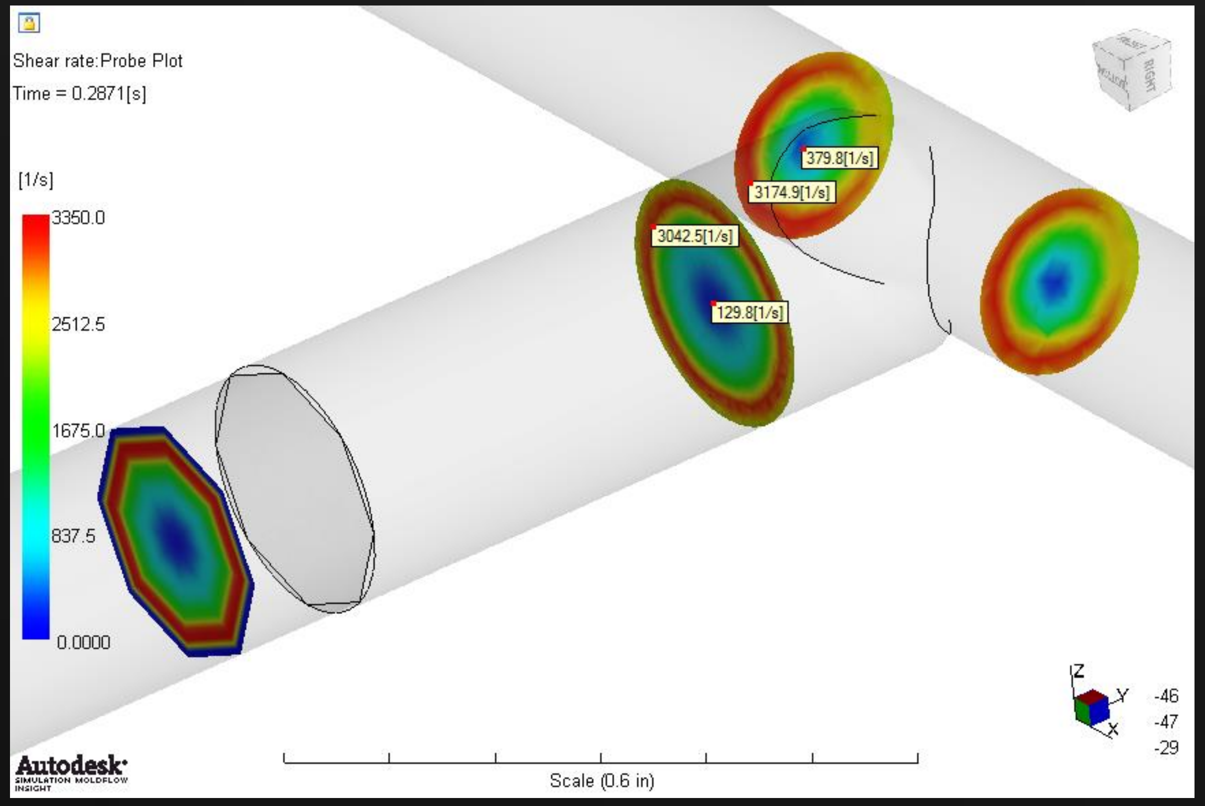
8	10	12	14	16	18	20
						1.000
					1.000	0.938
				1.000	0.926	0.864
			1.000	0.914	0.840	0.779
		1.000	0.900	0.816	0.743	0.685
	1.000	0.880	0.784	0.706	0.636	0.583
1.000	0.856	0.738	0.653	0.585	0.520	0.474
0.816	0.681	0.577	0.508	0.453	0.397	0.360
0.586	0.477	0.399	0.350	0.310	0.268	0.243
0.313	0.248	0.206	0.180	0.158	0.135	0.123
0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.313	0.248	0.206	0.180	0.158	0.135	0.123
0.586	0.477	0.399	0.350	0.310	0.268	0.243
0.816	0.681	0.577	0.508	0.453	0.397	0.360
1.000	0.856	0.738	0.653	0.585	0.520	0.474
	1.000	0.880	0.784	0.706	0.636	0.583
		1.000	0.900	0.816	0.743	0.685
			1.000	0.914	0.840	0.779
				1.000	0.926	0.864
					1.000	0.938
						1.000

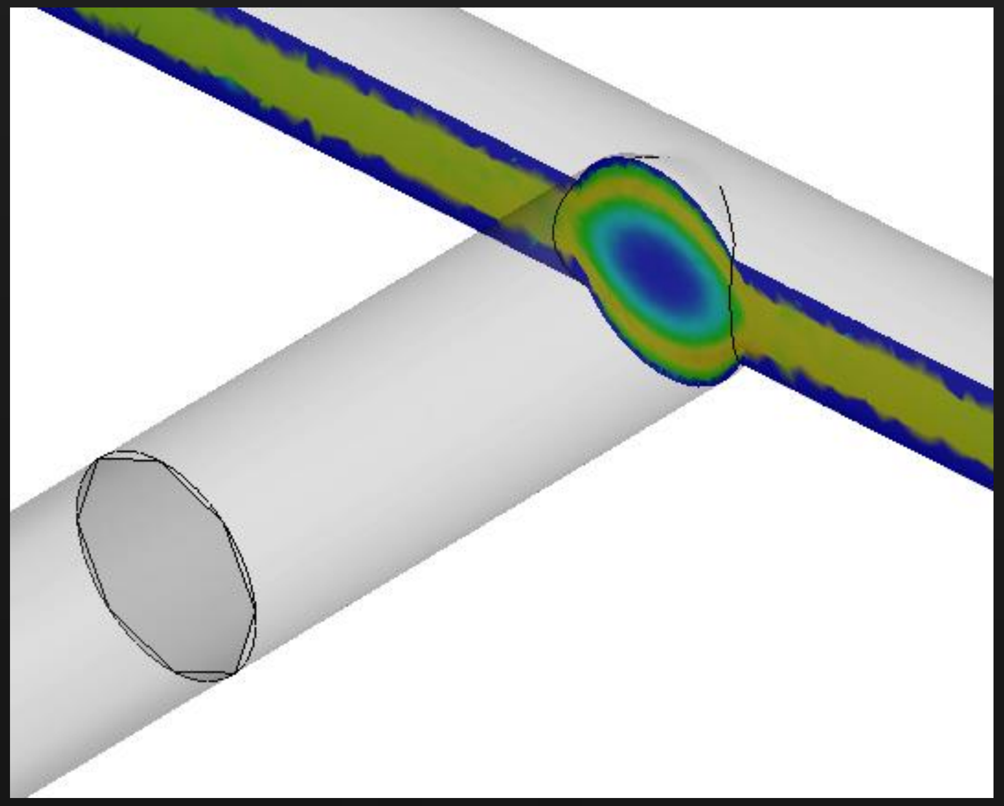


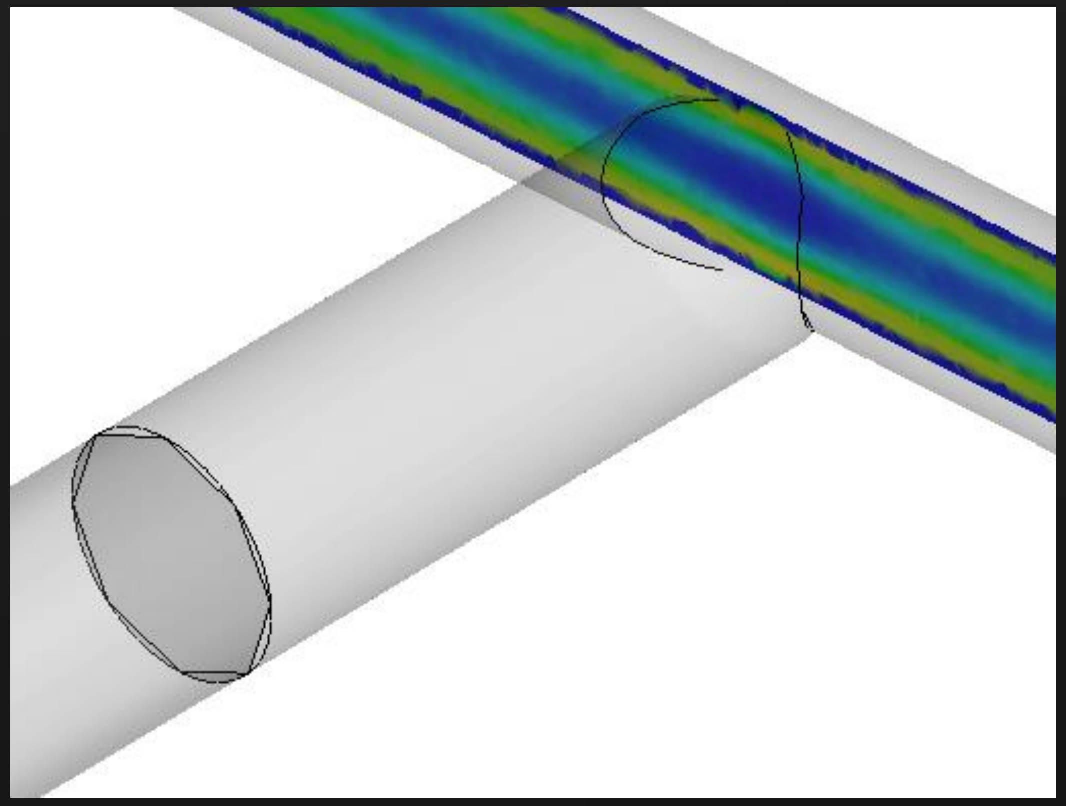
Non-Homogenious Conditions - Temperature

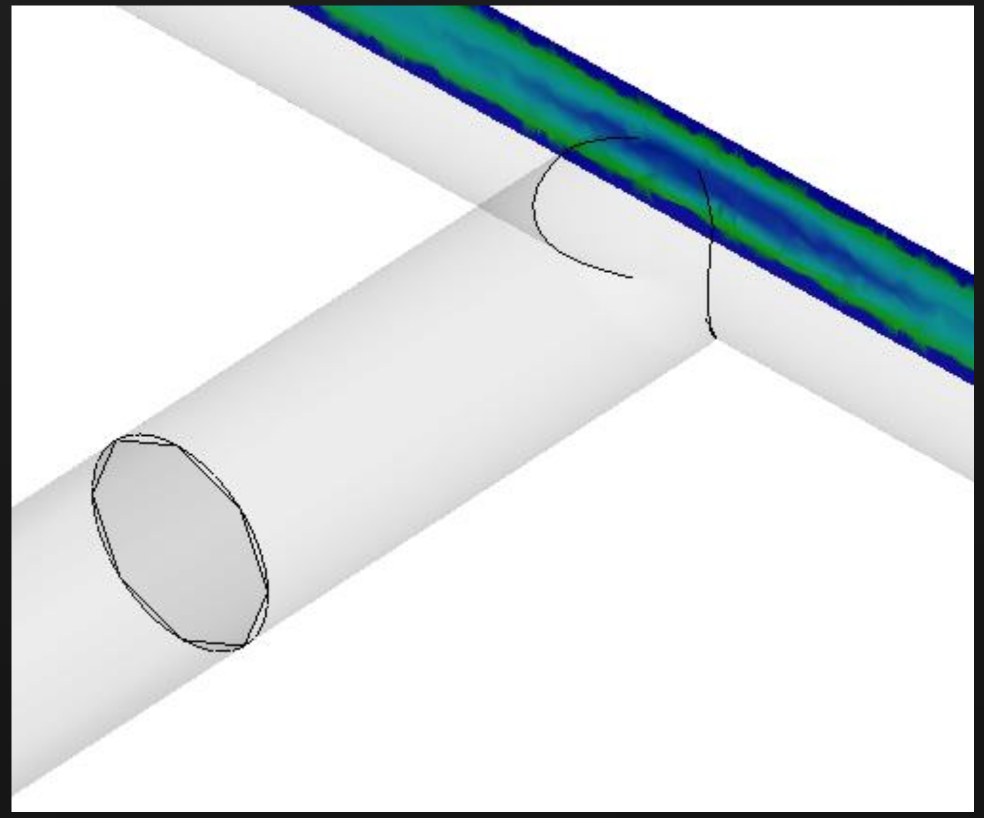




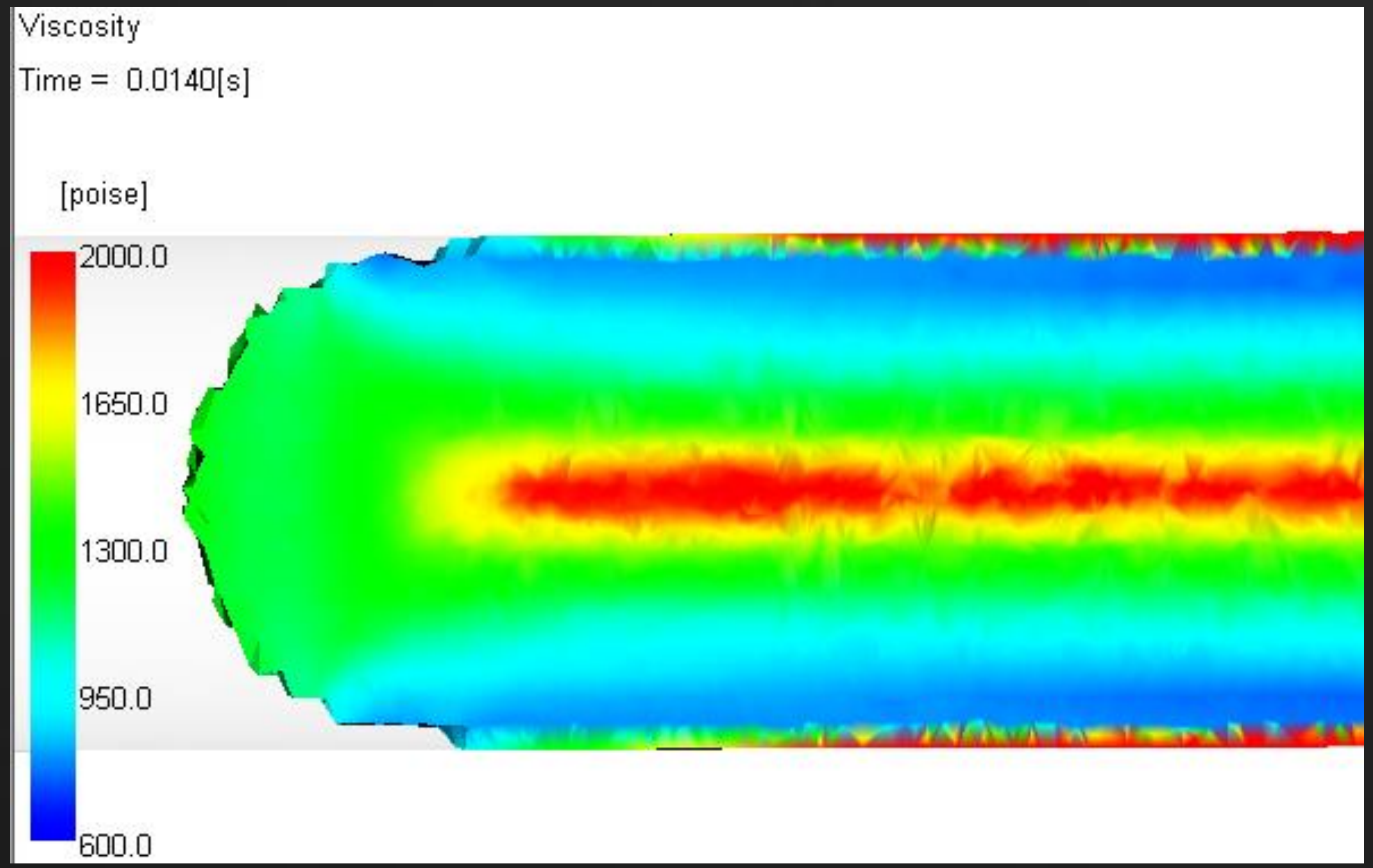


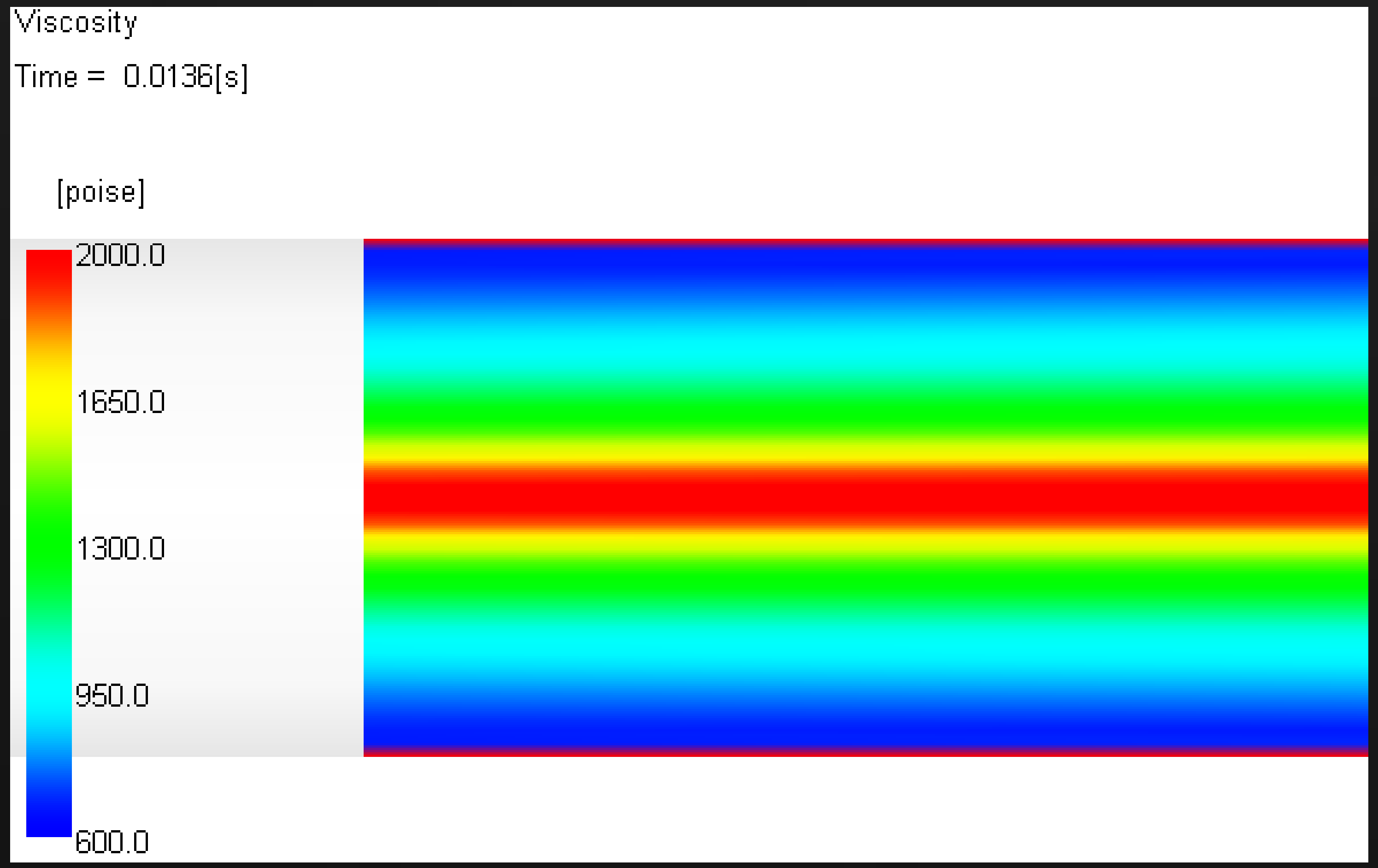


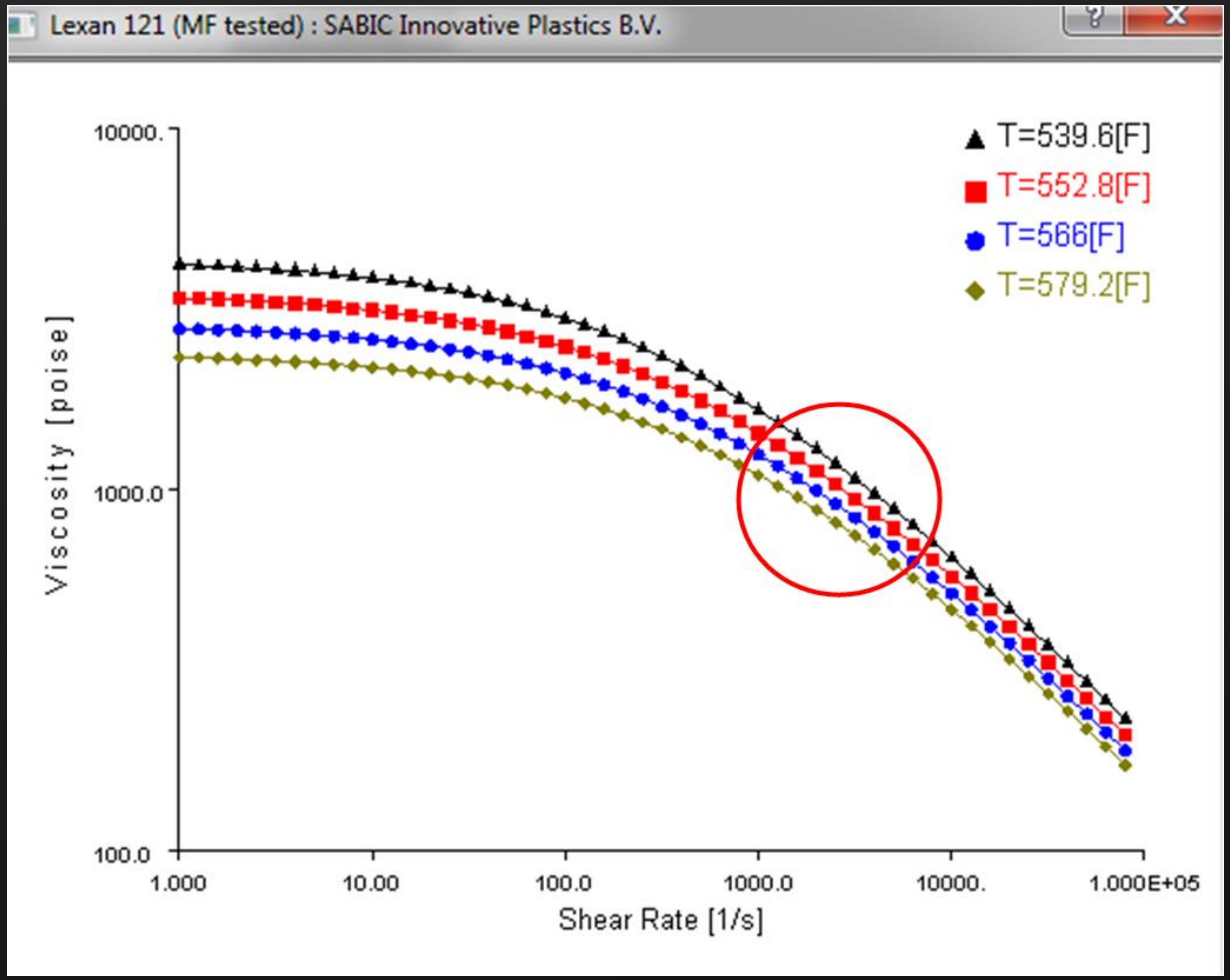




Viscosity Differences Across Channel







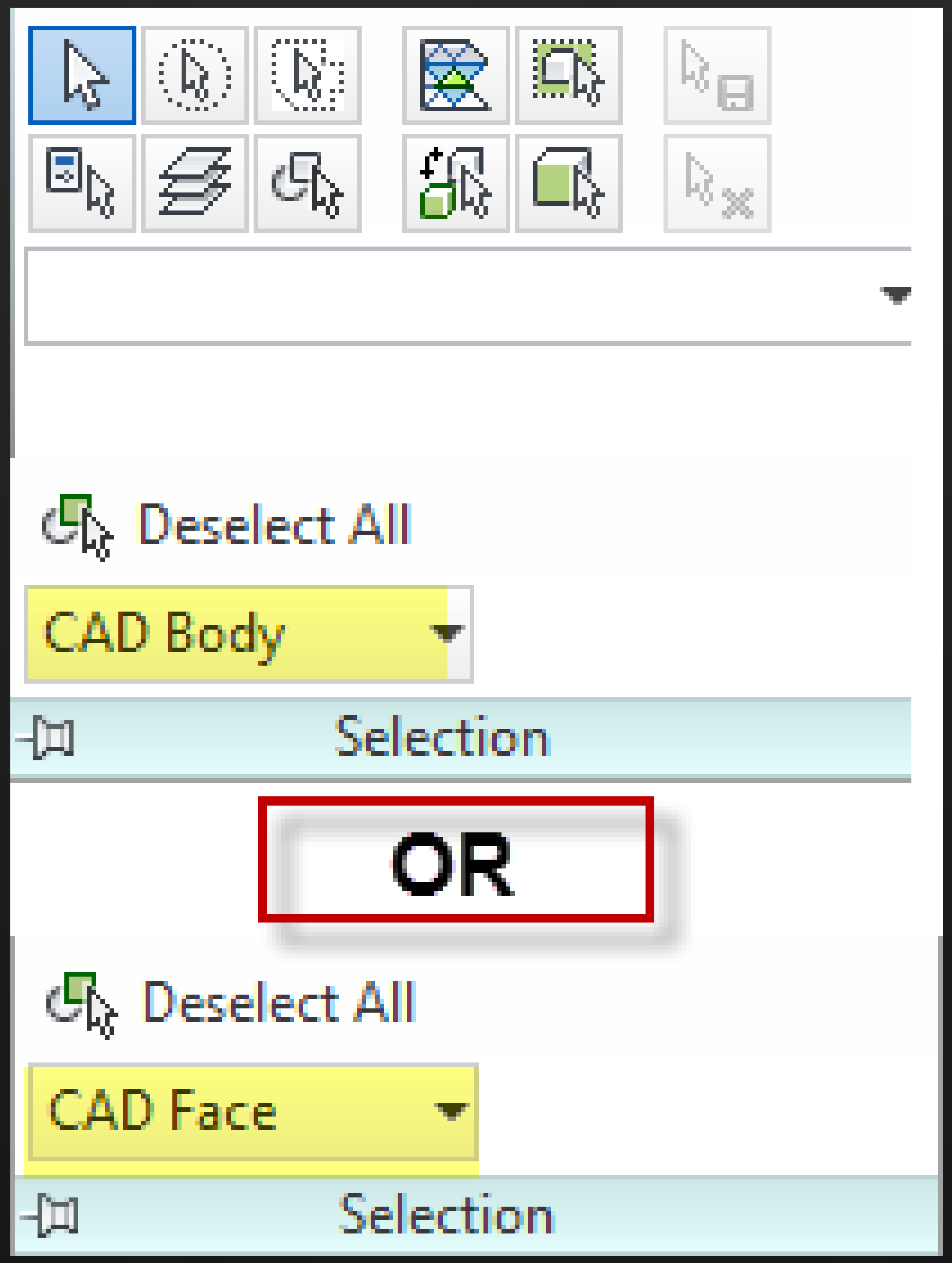
Meshing & Methodology

Correct Trends if Correctly Modeled

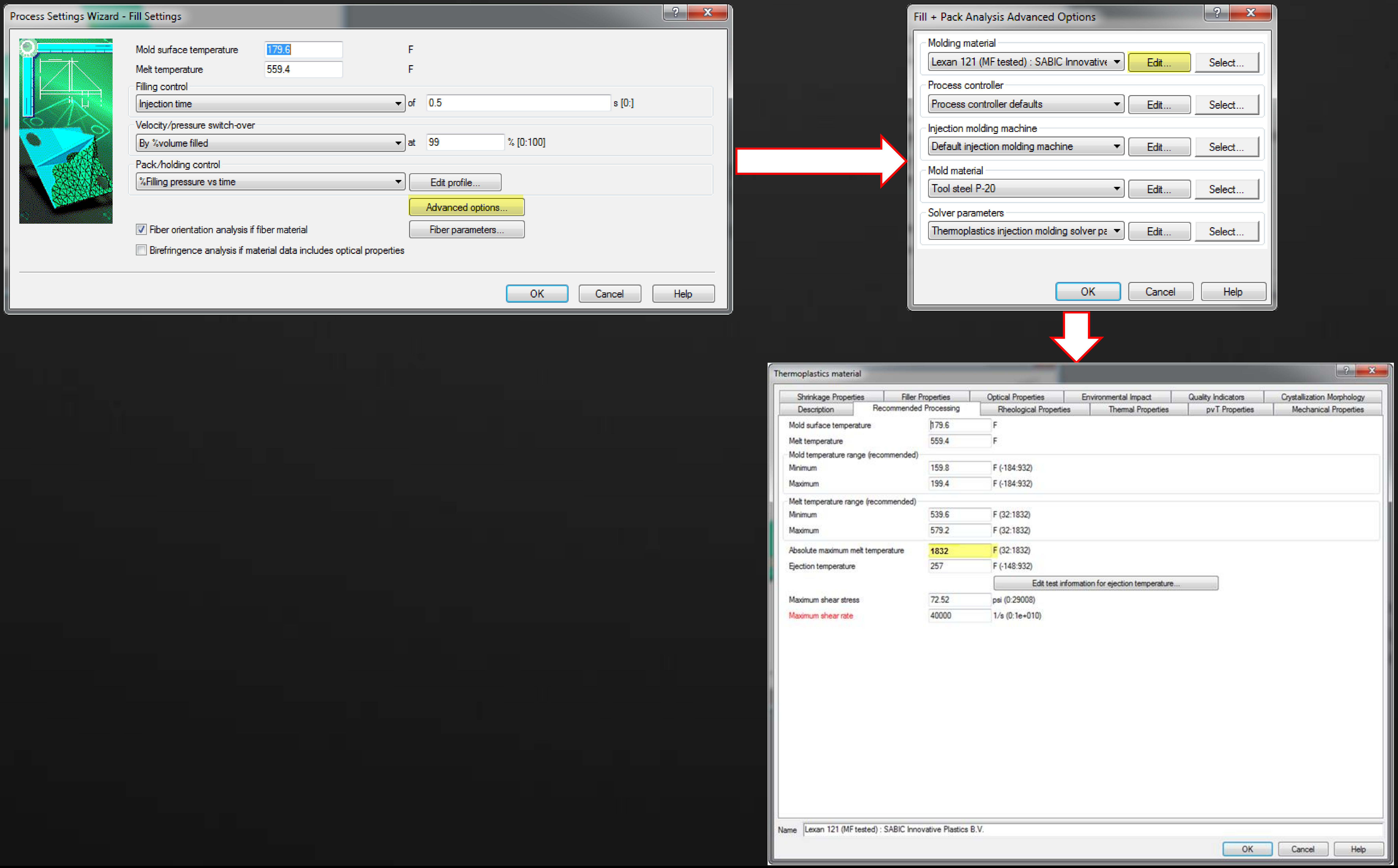
Mesh:

- Inertia turned ON Case-by-case
- Model as far upstream as practical (nozzle)
- 1-D where possible and set to 20 laminates
- For branching runners use 3-D elements with a minimum of 12 layers
- Fine surface mesh
- Correctly biased elements improve results Not recommended
- Set Absolute Maximum Melt Temp. to 1832° F/1000° C (maximum)

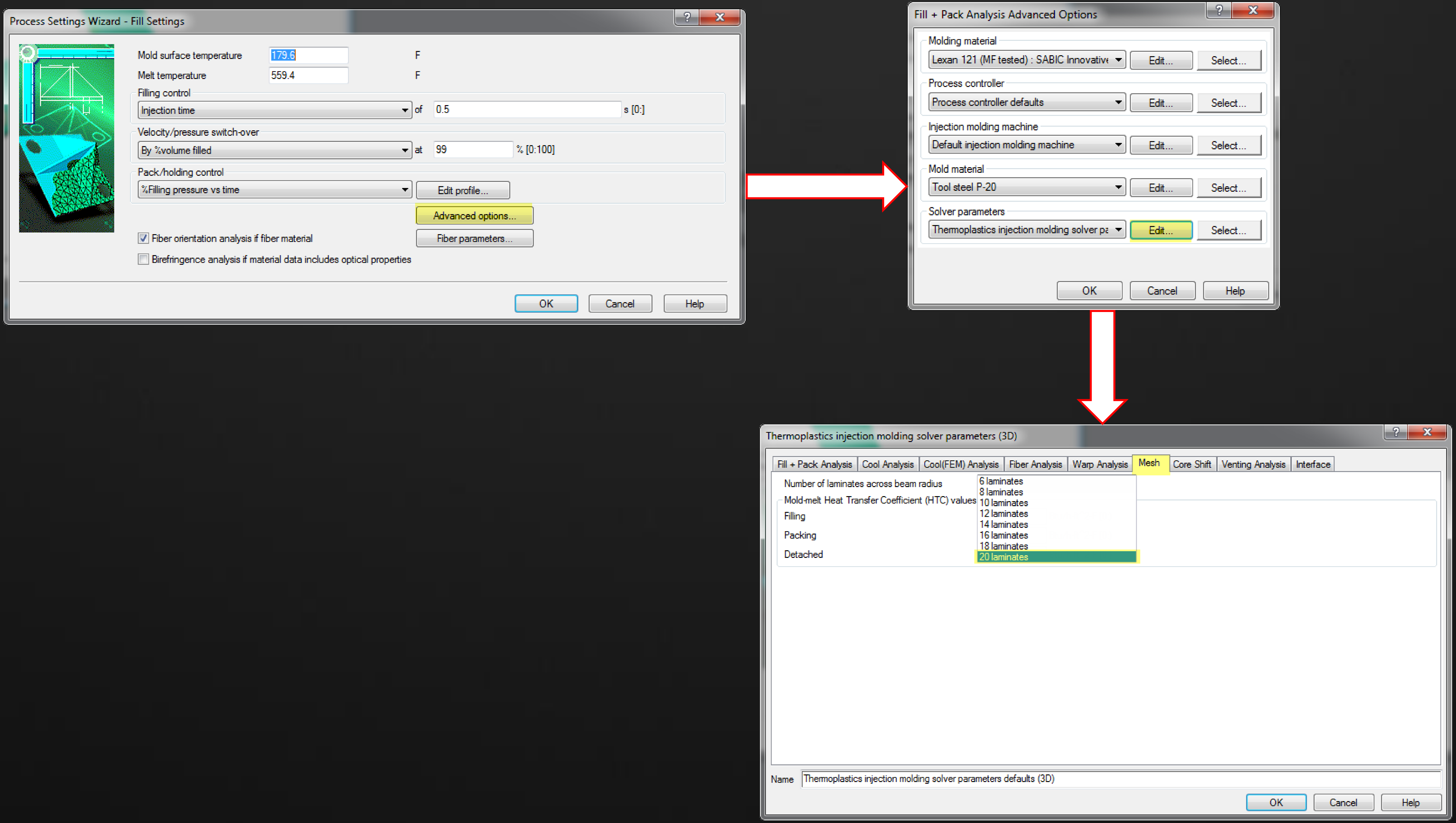
Select Solid Faces for Density



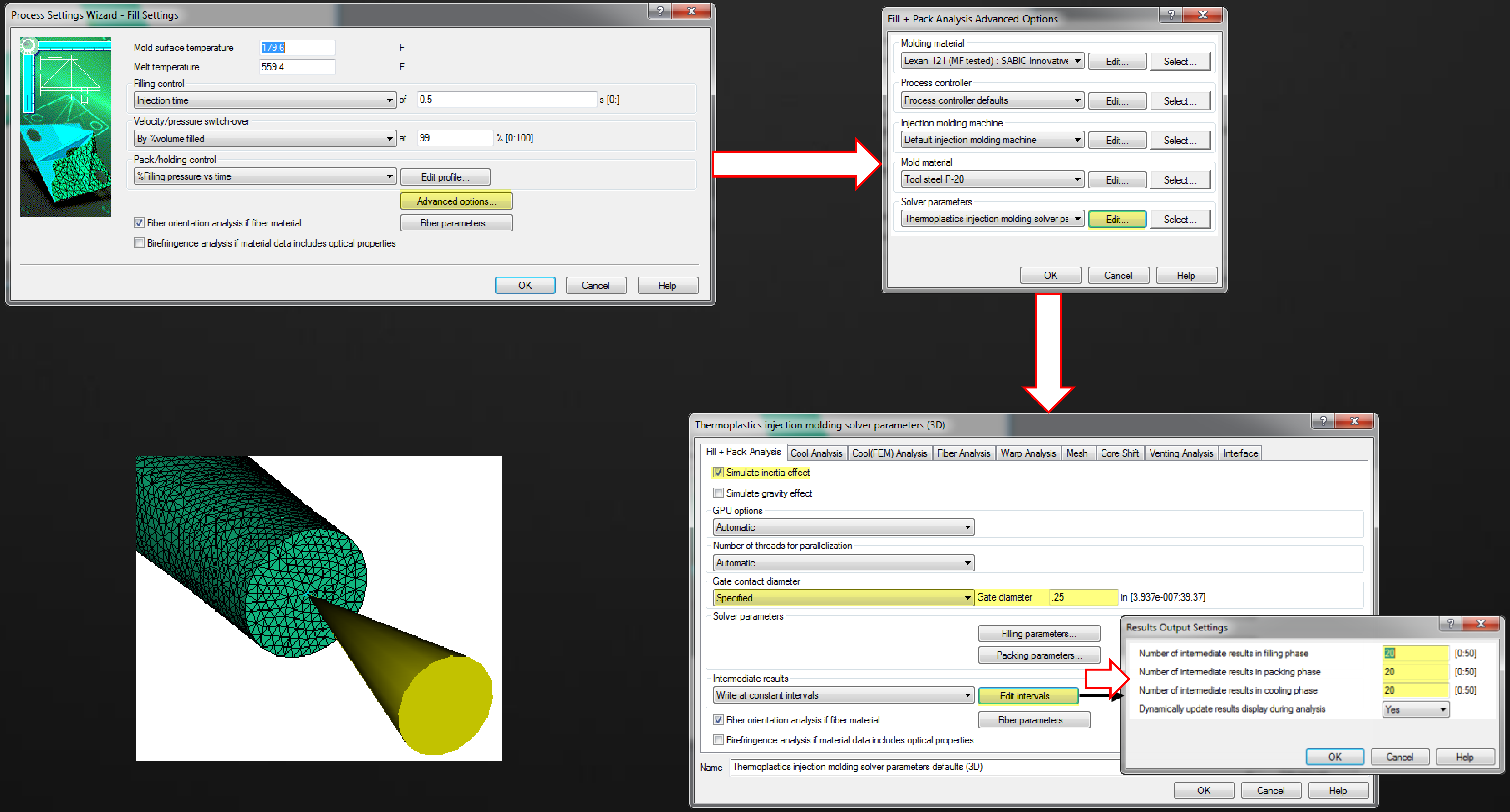
Absolute Maximum Melt Temperature



1-D Laminates



Inertia – Gate Contact - Intermediate Output



Common Sense

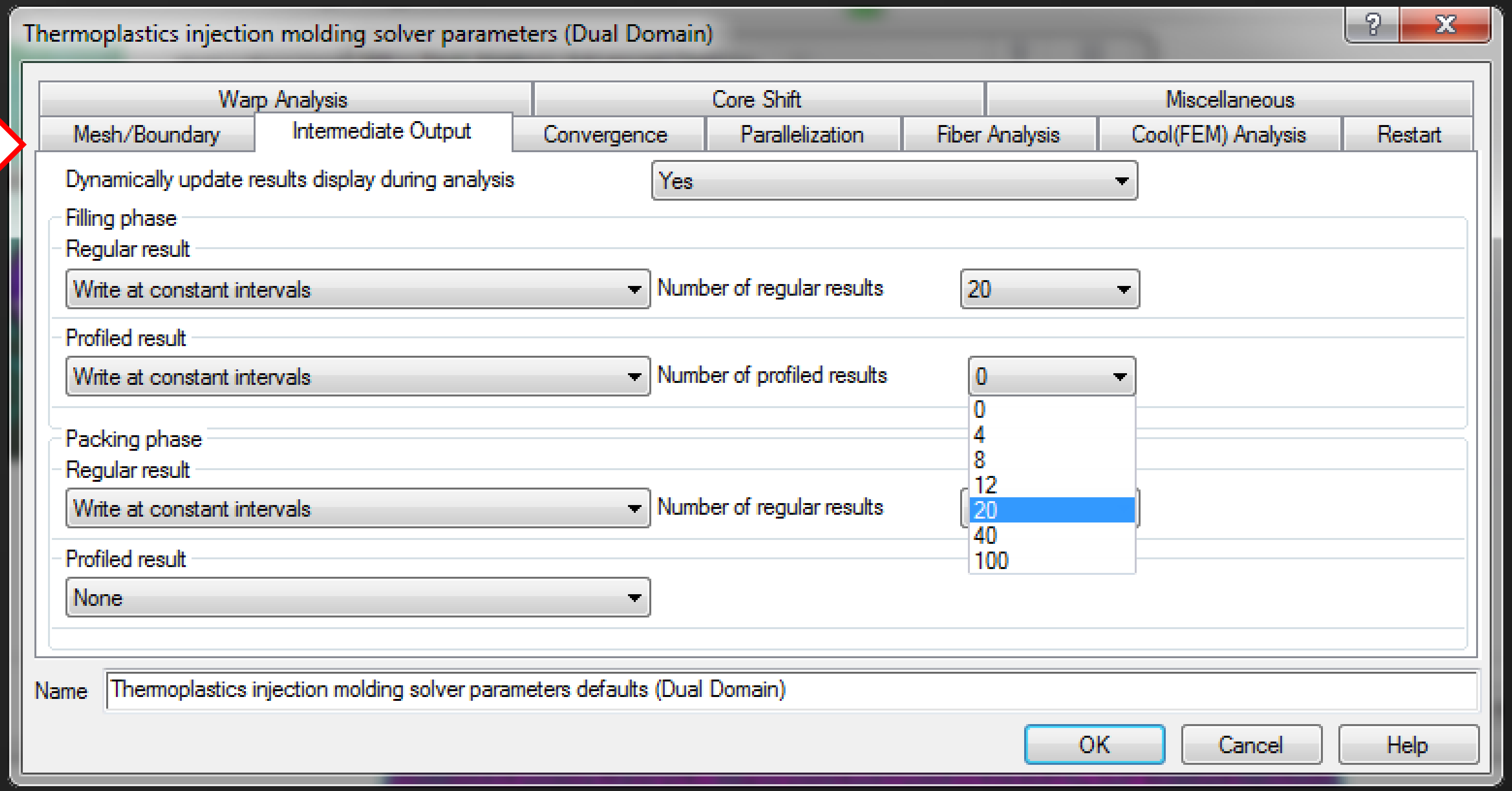
- What do we think will happen?
- Where can you use beams?
- Where should the mesh be very fine?
- Where do you need more layers?

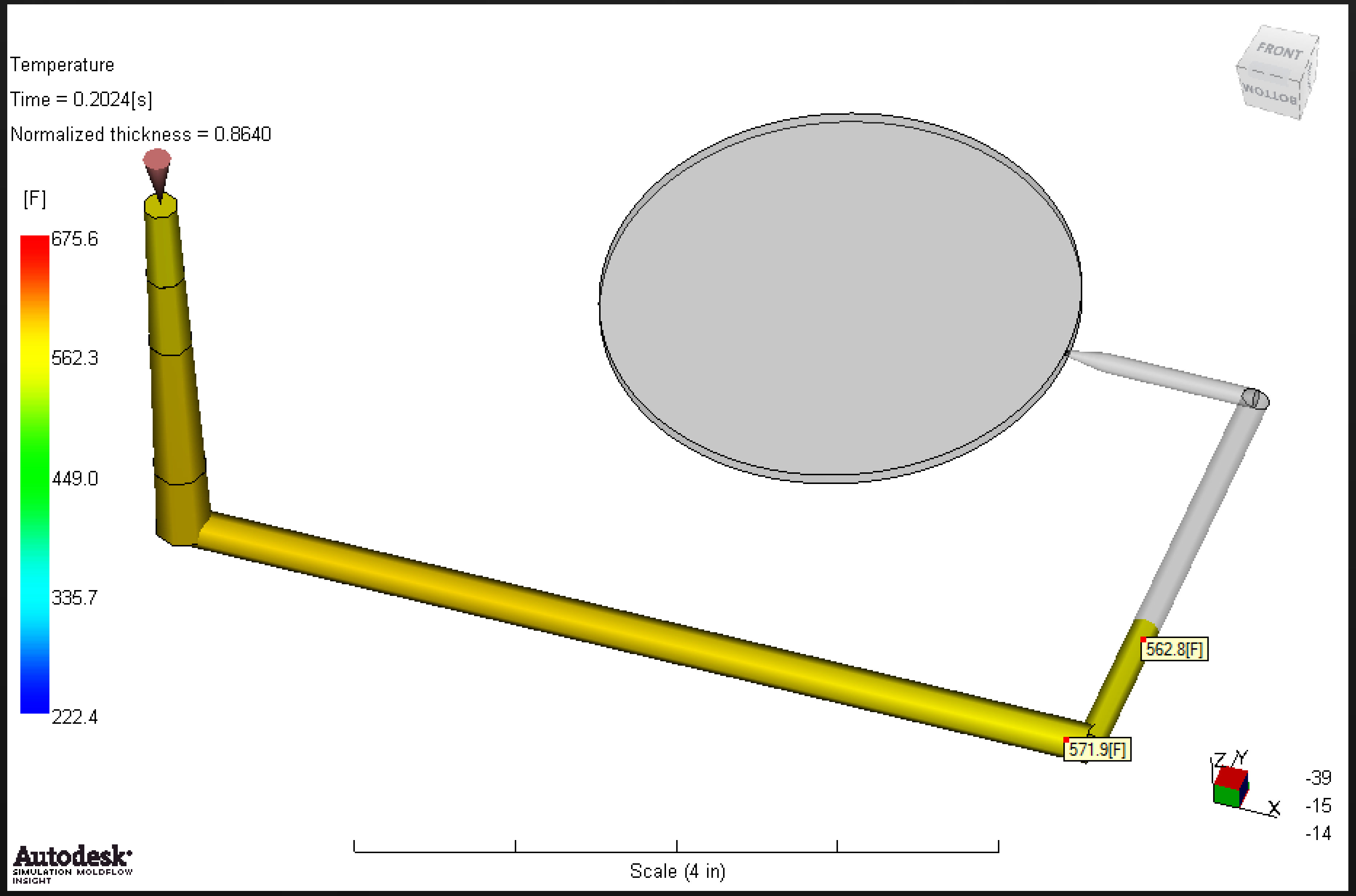
Runner Sizing Process - Do This First

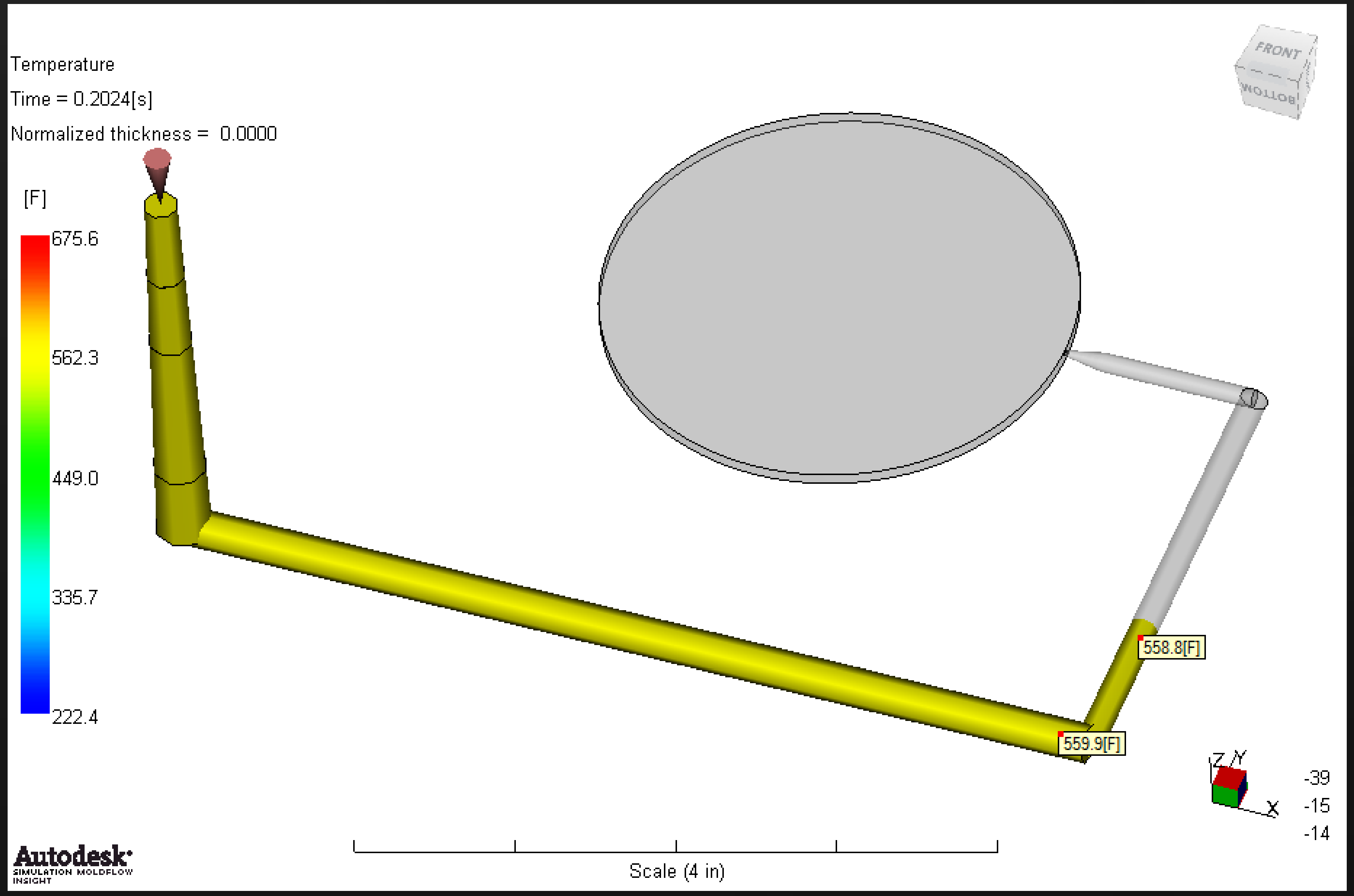
- Determine optimum fill time for part and use that flow rate
- Use this flow rate with estimated runner layout
- Preliminary sprue and runner sizing and layout based on rules of thumb
- First round evaluations using 1-D elements
- Create runner layout to allow for easy 1-D and 3-D changes
- Resize as appropriate to minimize runner, pressure drop, clamp force and get shear into an acceptable range
- NOW, look at shear imbalance
  - Pressure drop
  - Shear rate
  - Temperature rise

Is the Temperature Difference Significant?

- Branching runner system, can use 1-D's with profiled output for vital information with low computational overhead
- Can measure temperature difference between high and low shear areas – in this case only about 4° F
- Small amount of artificial balancing will provide very good parts all around



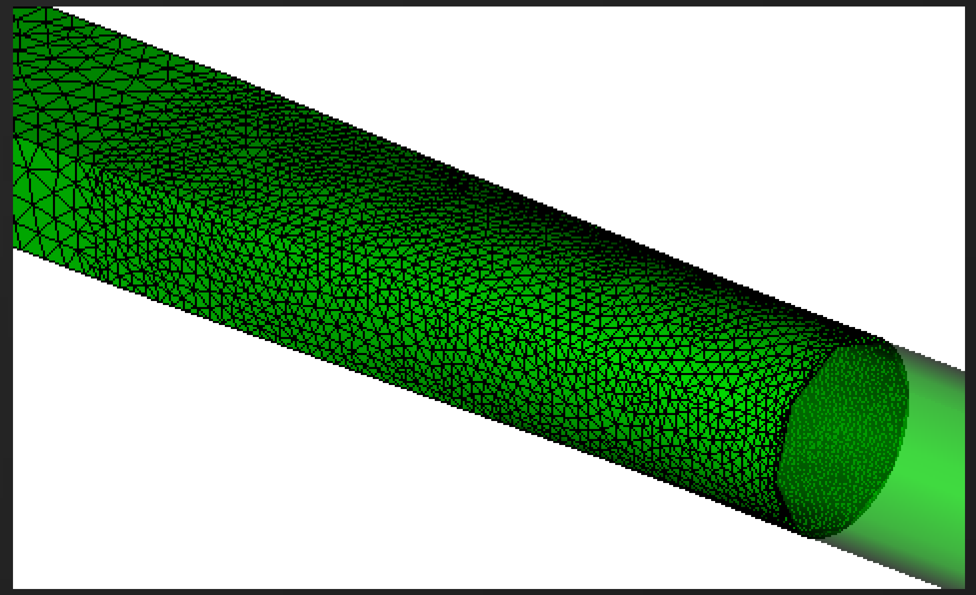




Meshing Tips

- Only mesh runners as equivalent diameters
- Mesh Match where possible
- Do NOT decrease number of layers with remesh
- If there is no branching, use beam elements
- Create an orderly 1-D to 3-D transition
- Use simplified parts with equivalent pressure drop and volume

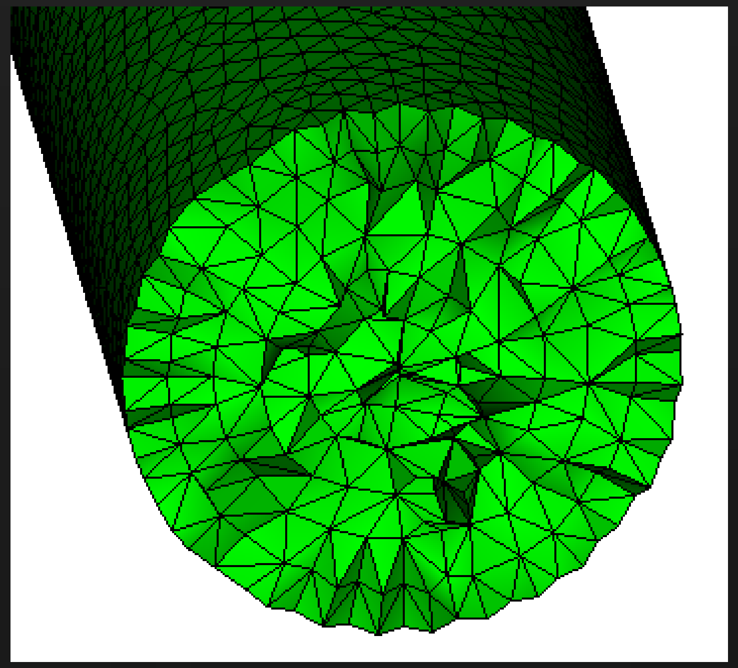
Minimum Requirements

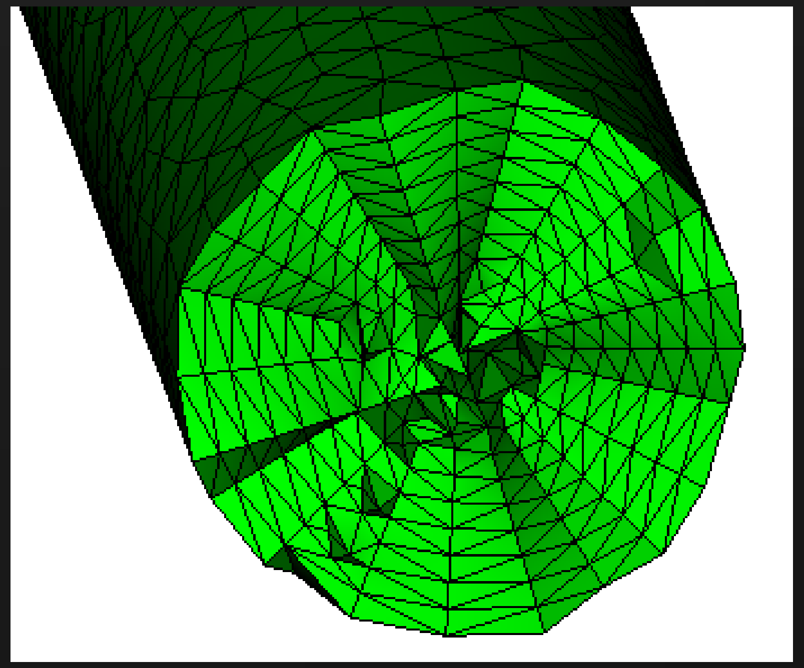


- If there is different shape close to the cavities then blend a 3-D section onto the part to match runner
- Maximum surface mesh size in critical areas of shear:

DIA / NUMBER OF LAYERS * 2

- Minimum number of layers: 12 (Goal = 20)

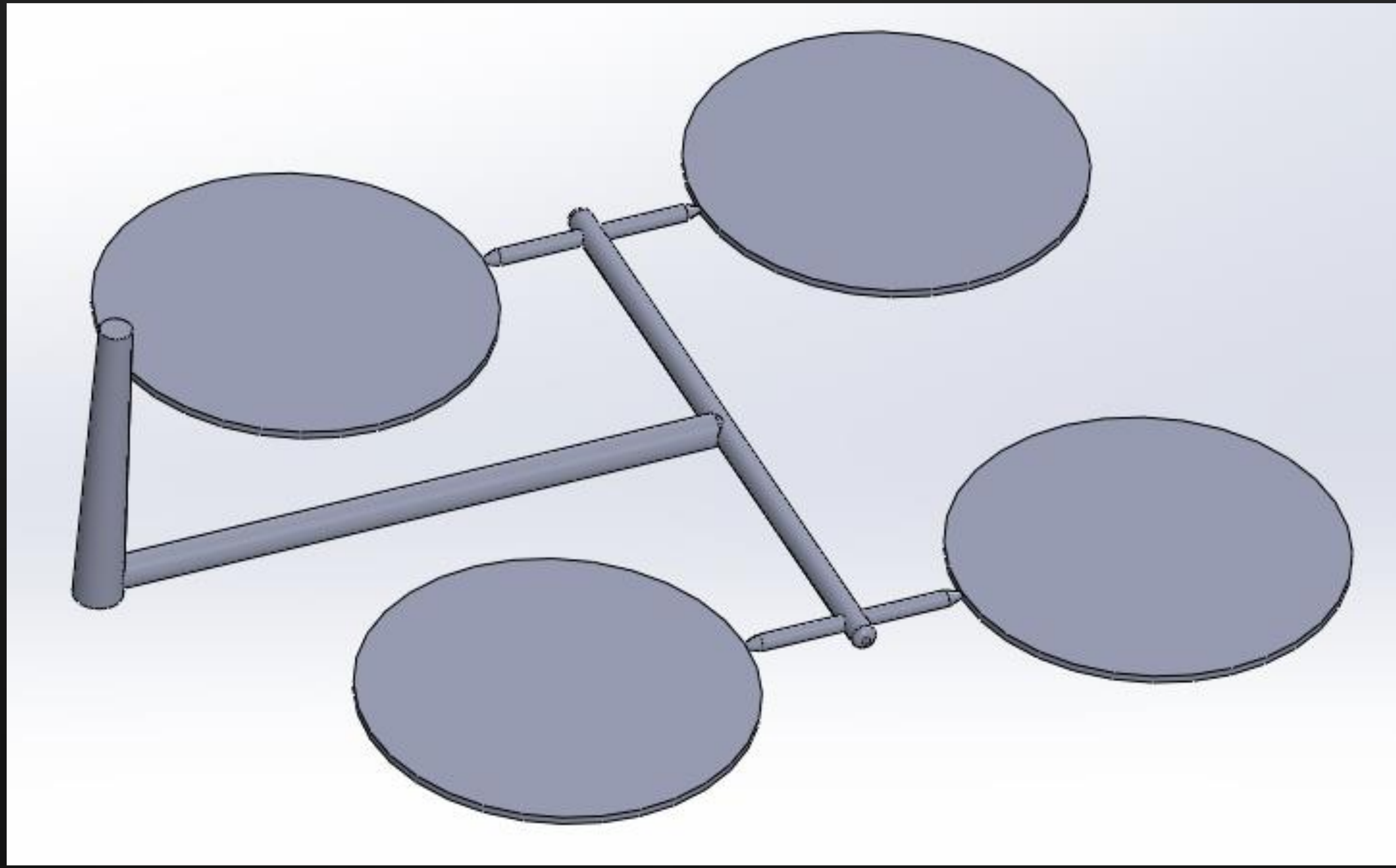


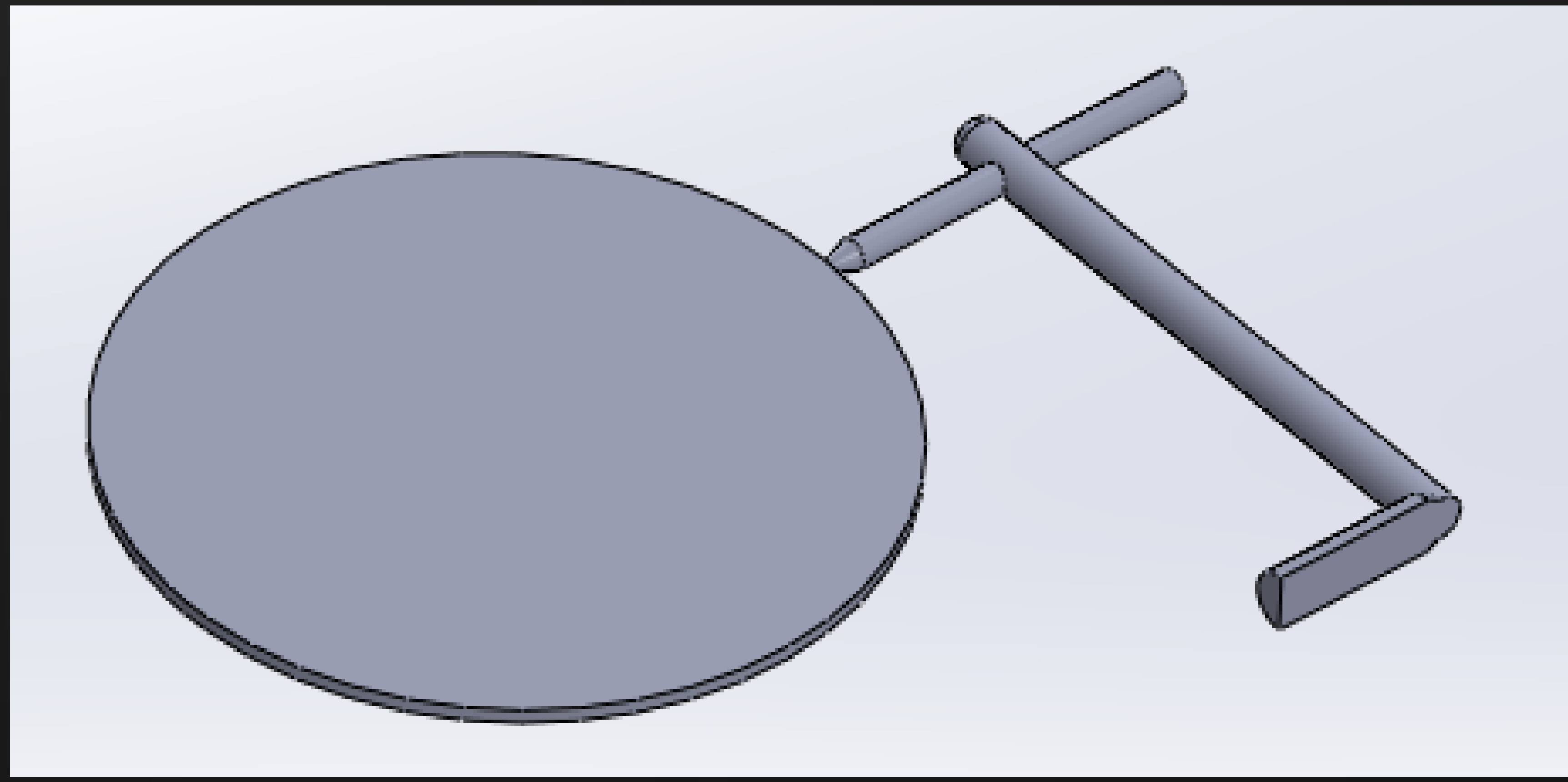


- Part surface mesh and layers as coarse as practical. Will depend on number of cavities.

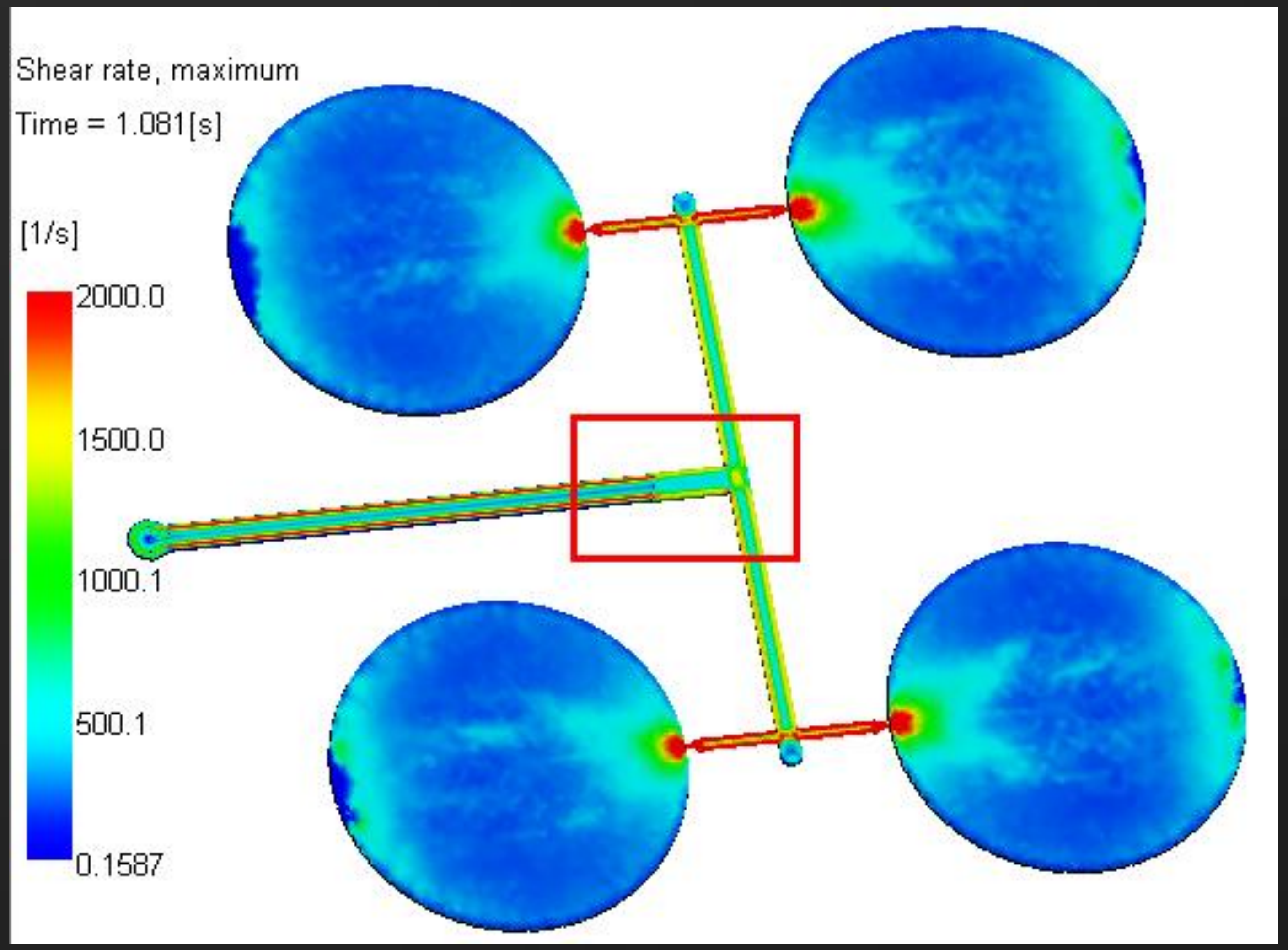
Surface Mesh Takes a Long Time to Generate

- Use symmetry if possible
- Assign density to faces



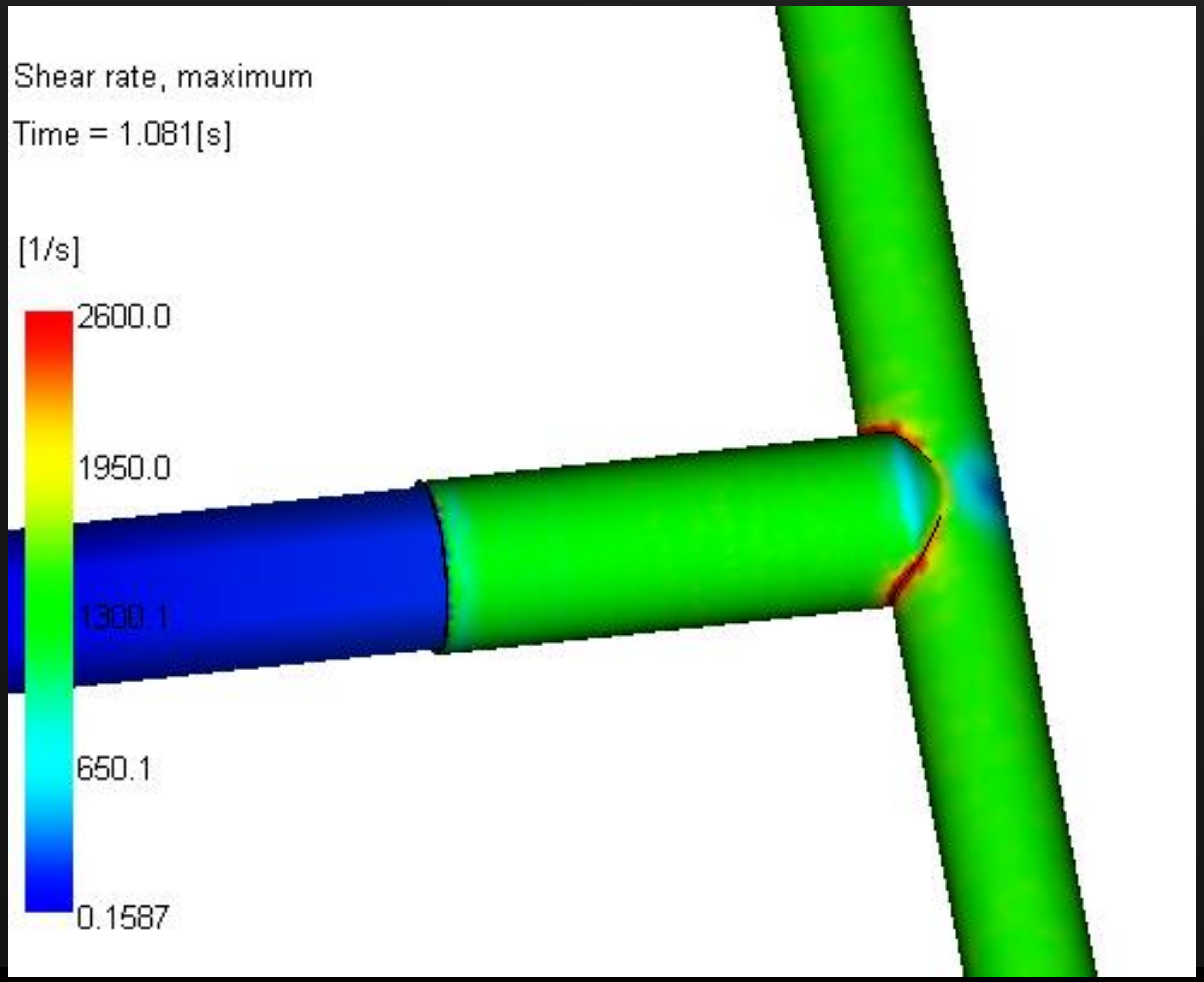


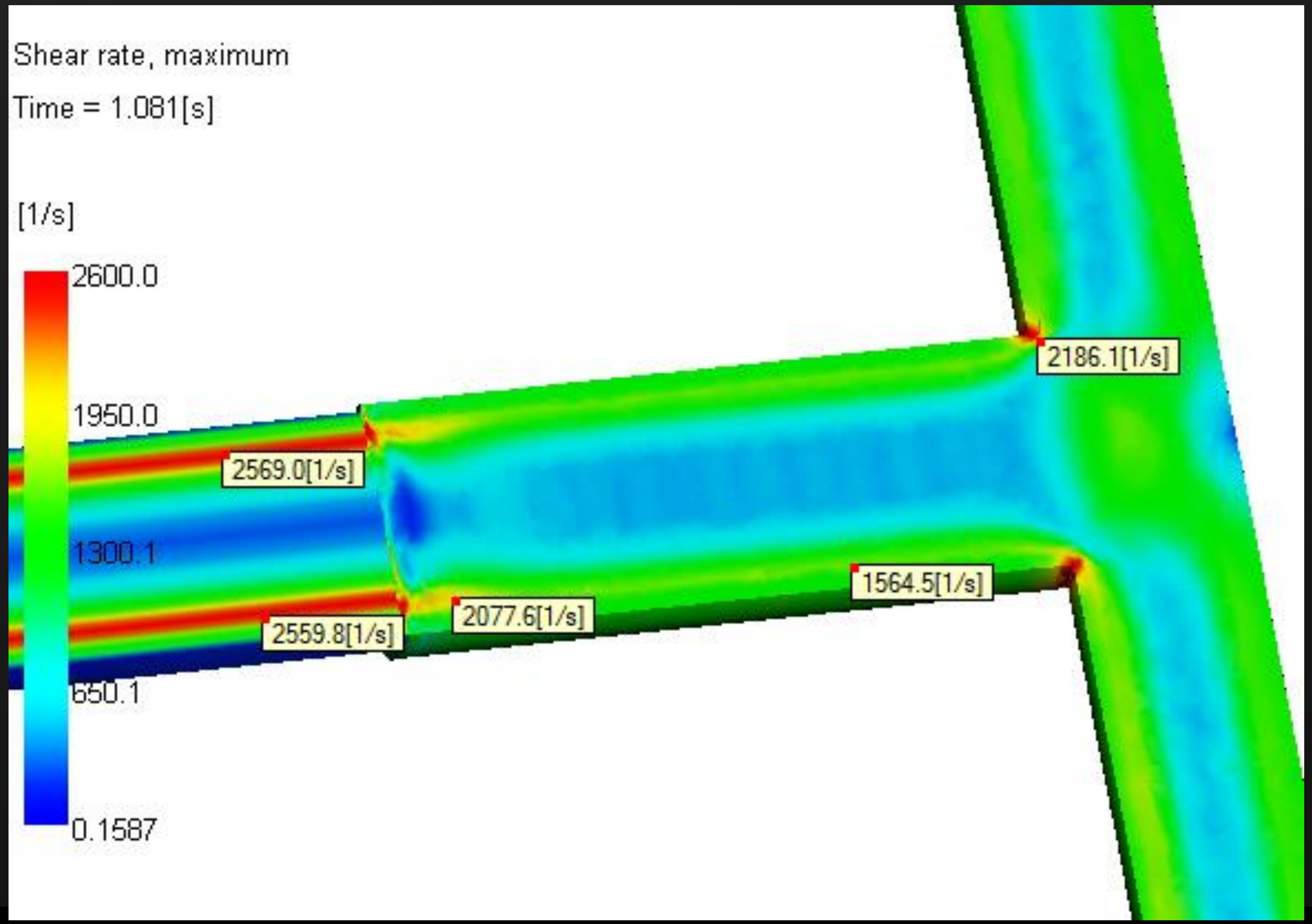
1-D to 3-D Transition



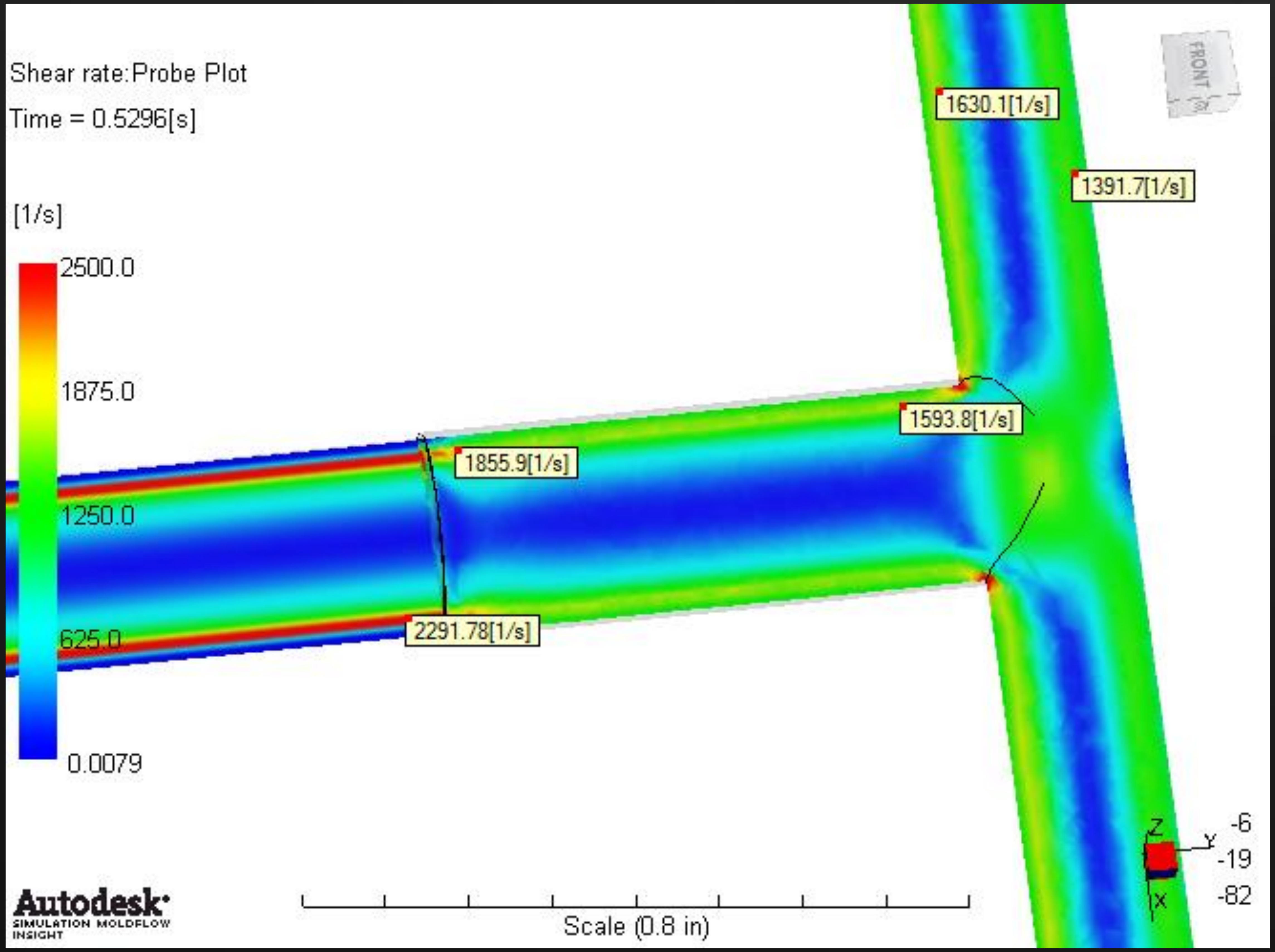
What's going on here?:

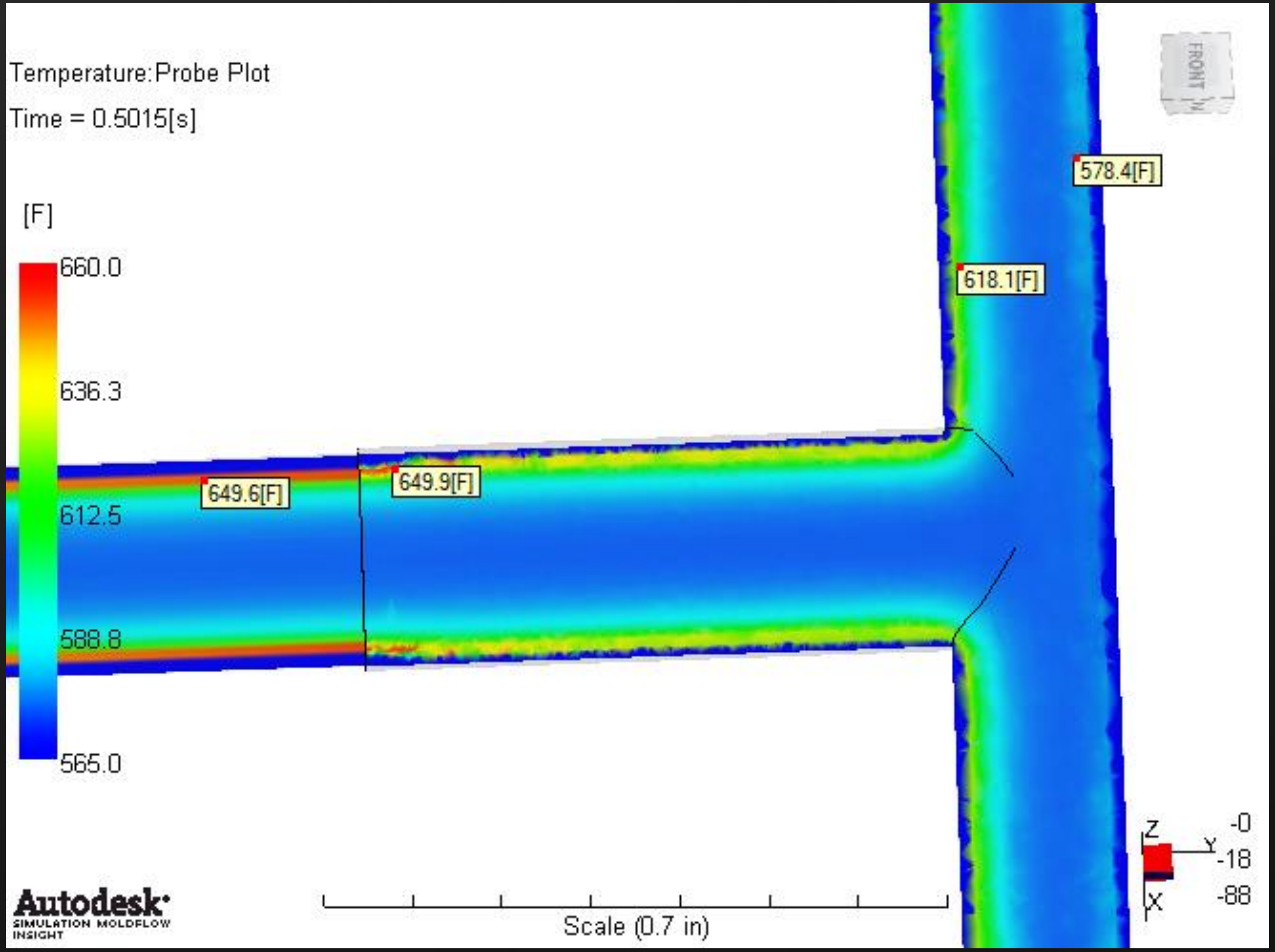
- Wall is treated differently
- Smearing
- Notice there *is* an effect at the corner





1-D to 3-D Transition





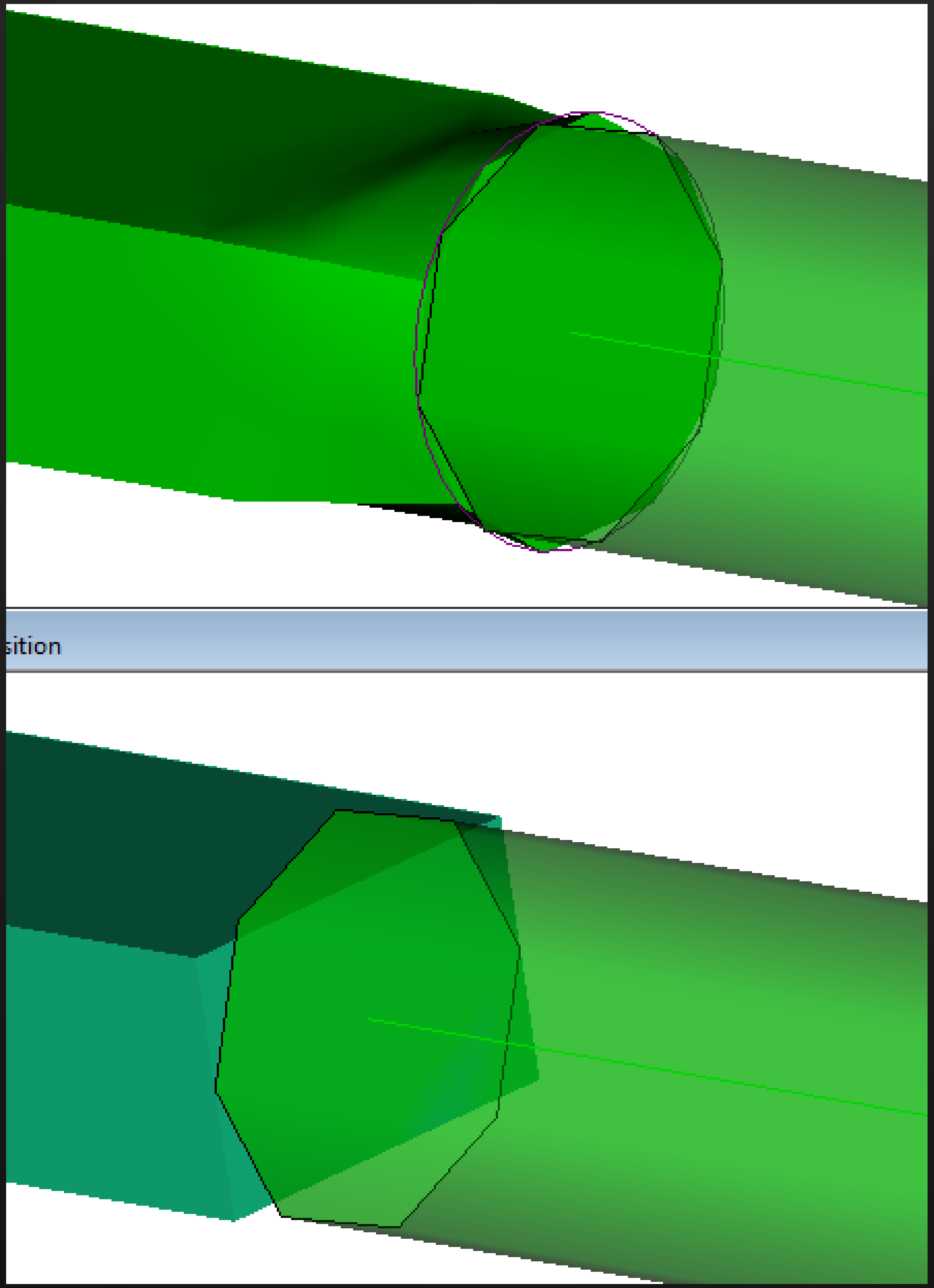
1-D to 3-D Transitions (Franco Costa)

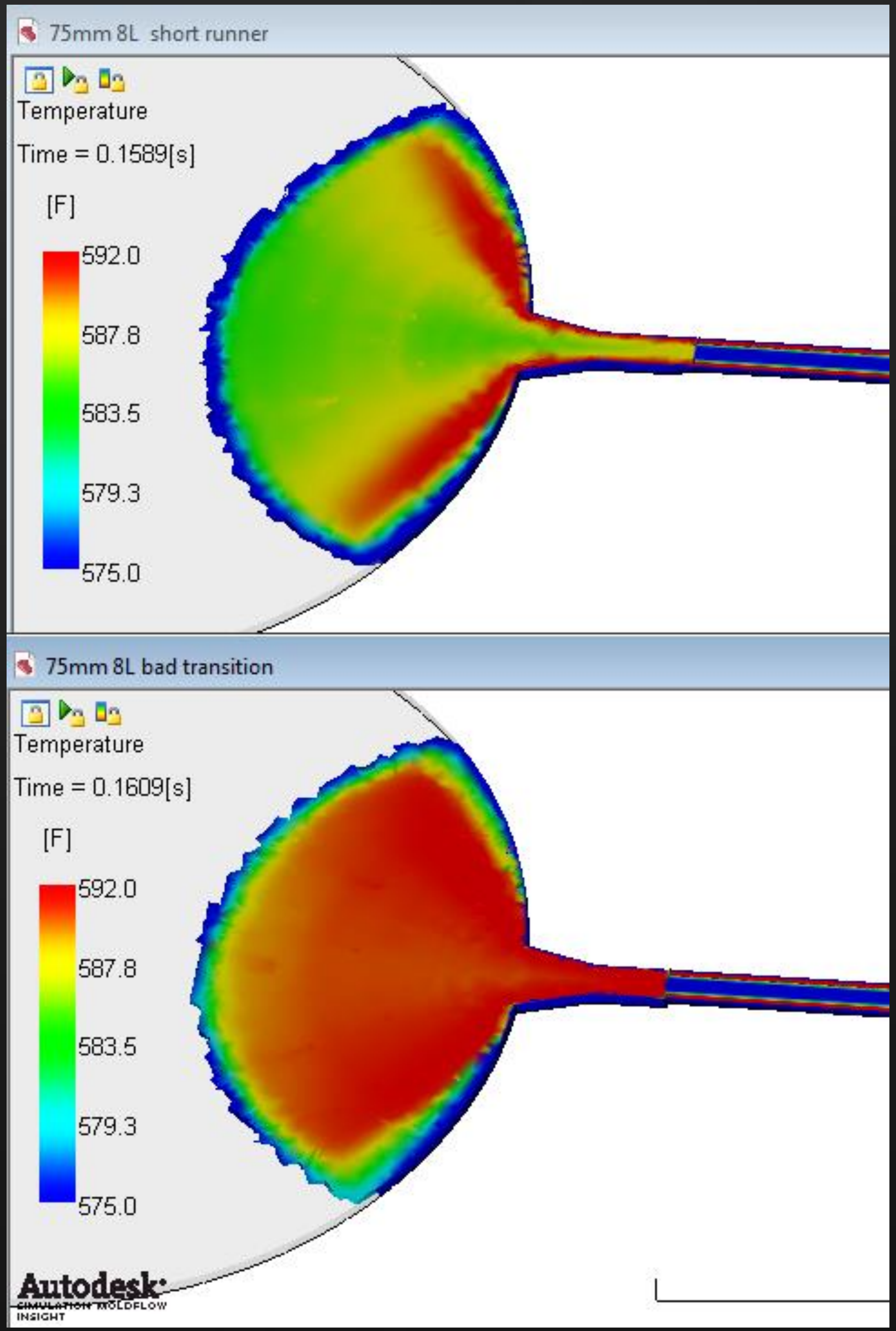
- Beam elements assume that pressure is uniform across the diameter
- Beam elements DO evaluate the profile of shear rates, viscosities, velocities, temperatures, densities, etc. calculated at each laminate across the diameter
- Beam to 3-D interface: all nodes that lie in that contact circle will have the same pressure, but their shear rates, viscosities, velocities, temperatures, densities, etc. will be unique for each node.
- Beam to 3-D -> temperature profile preserved

Upstream Convection (Franco Costa)

- Convection is an upstream process, meaning that 3D nodes will look upstream, following the local velocity vectors, to see what temperature is coming to them from the flow. This upstream convection process identifies which laminates on the beam radius are closest to the upstream location and interpolates based on that radial position. It is by this process that the temperature process will be preserved.

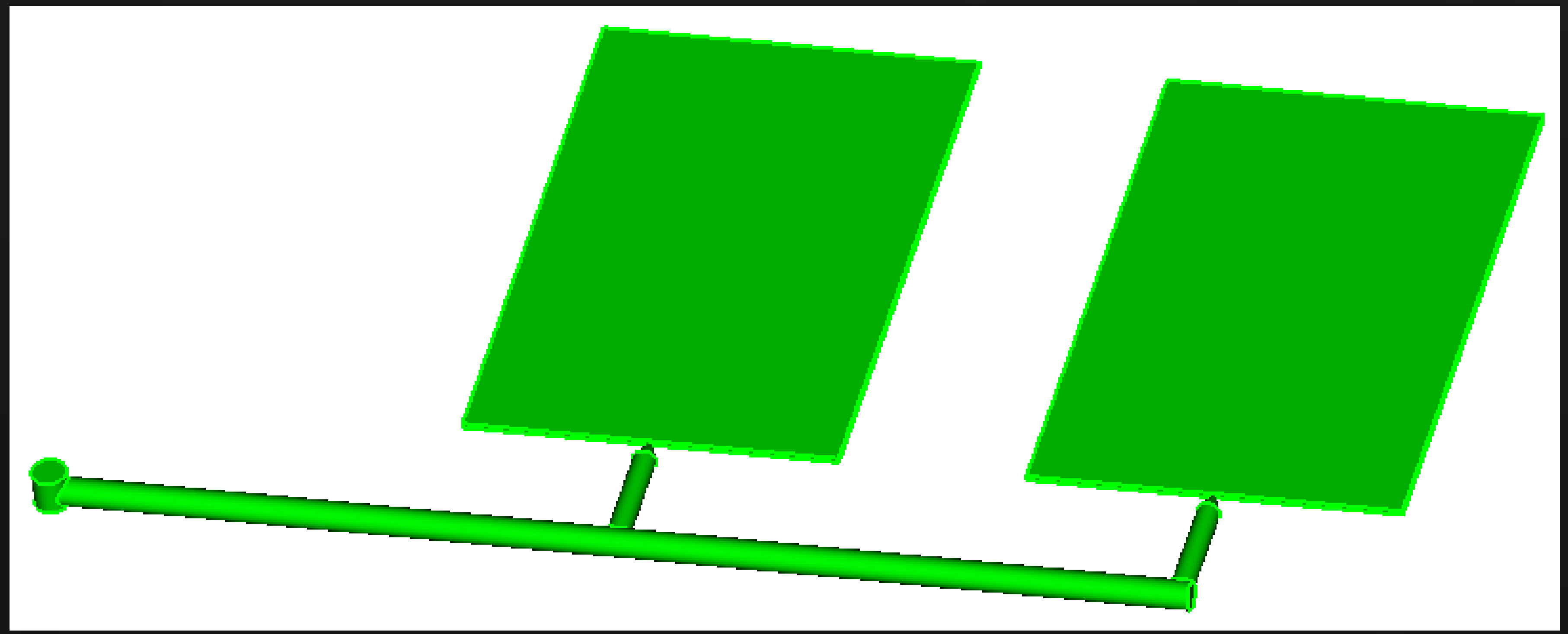
Improper 1-D to 3-D Interface

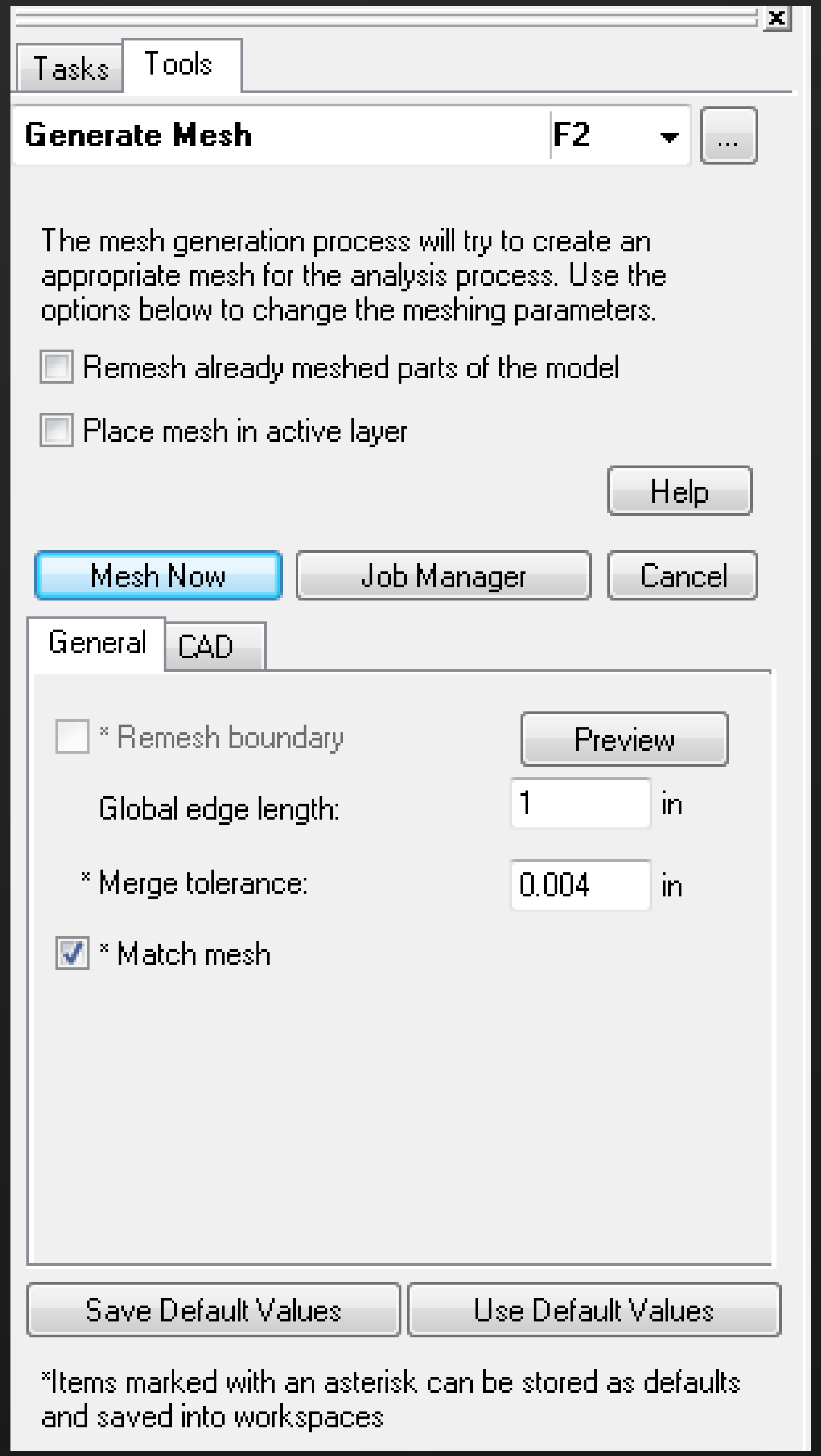


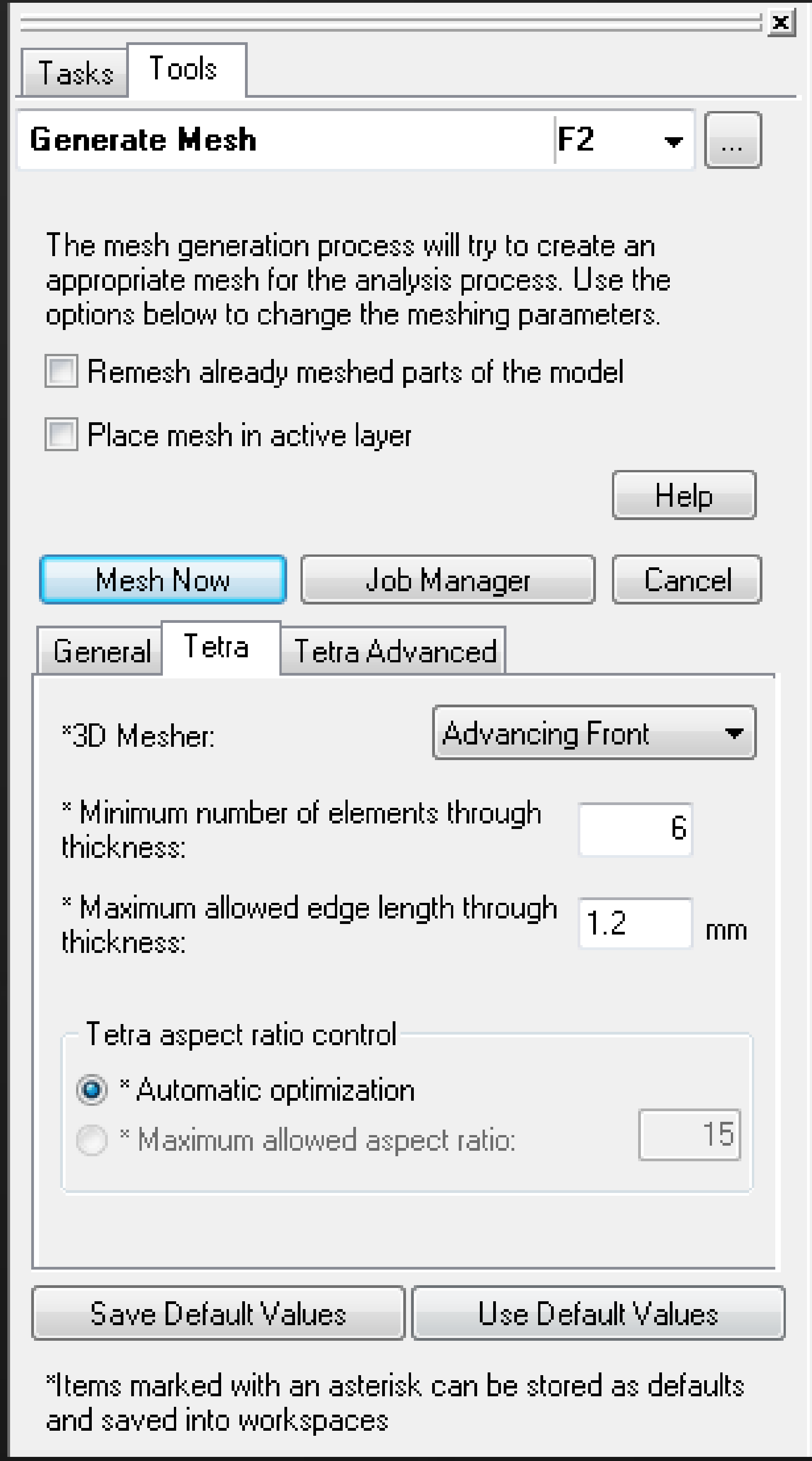


Meshing Limitations

- Cannot specify Mesh Match and non-Mesh Match on DD meshing
- Would be nice to be able to specify different number of layers from initial meshing
- Remesh doesn't allow bias







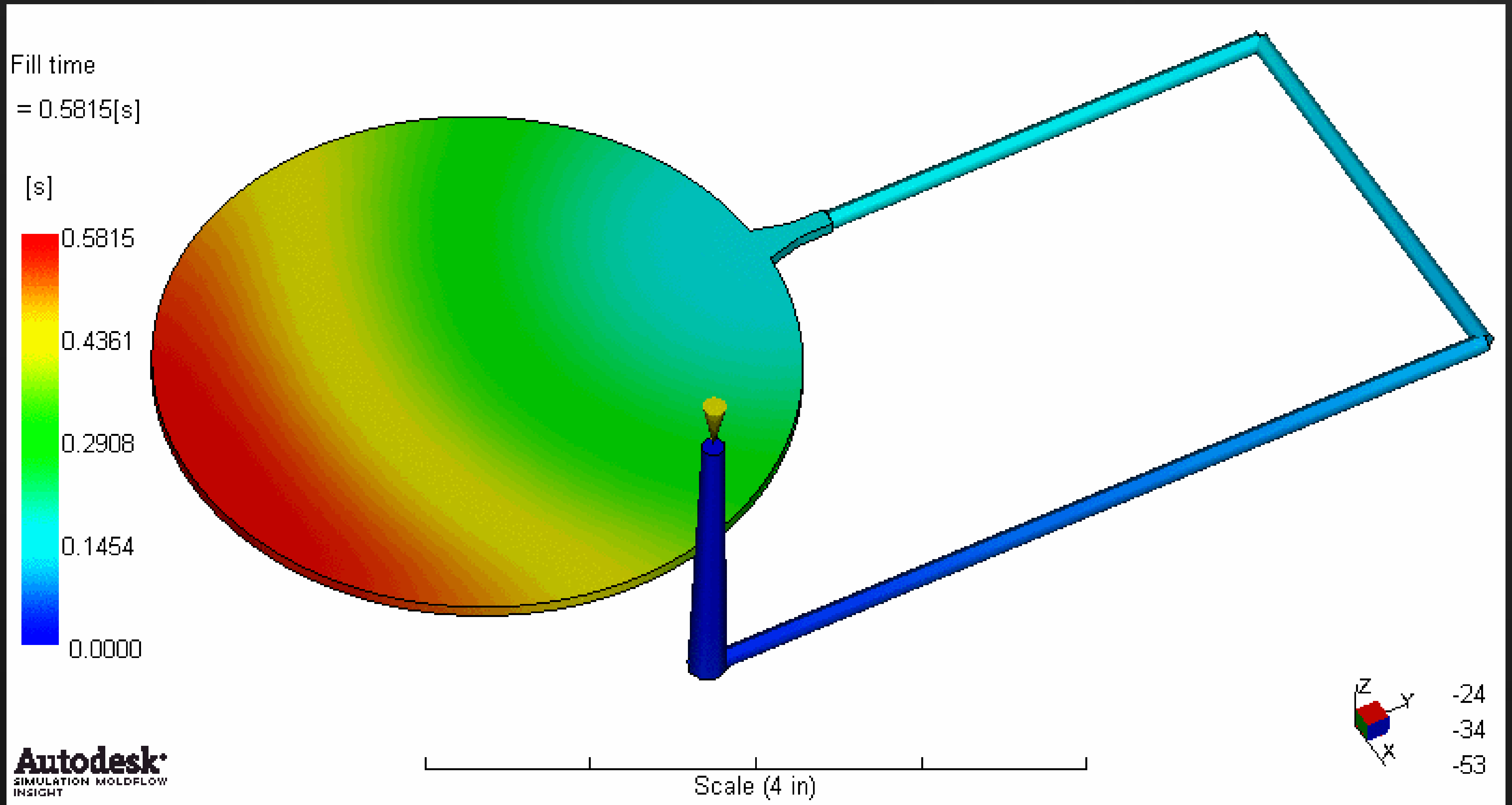
Sensitivities

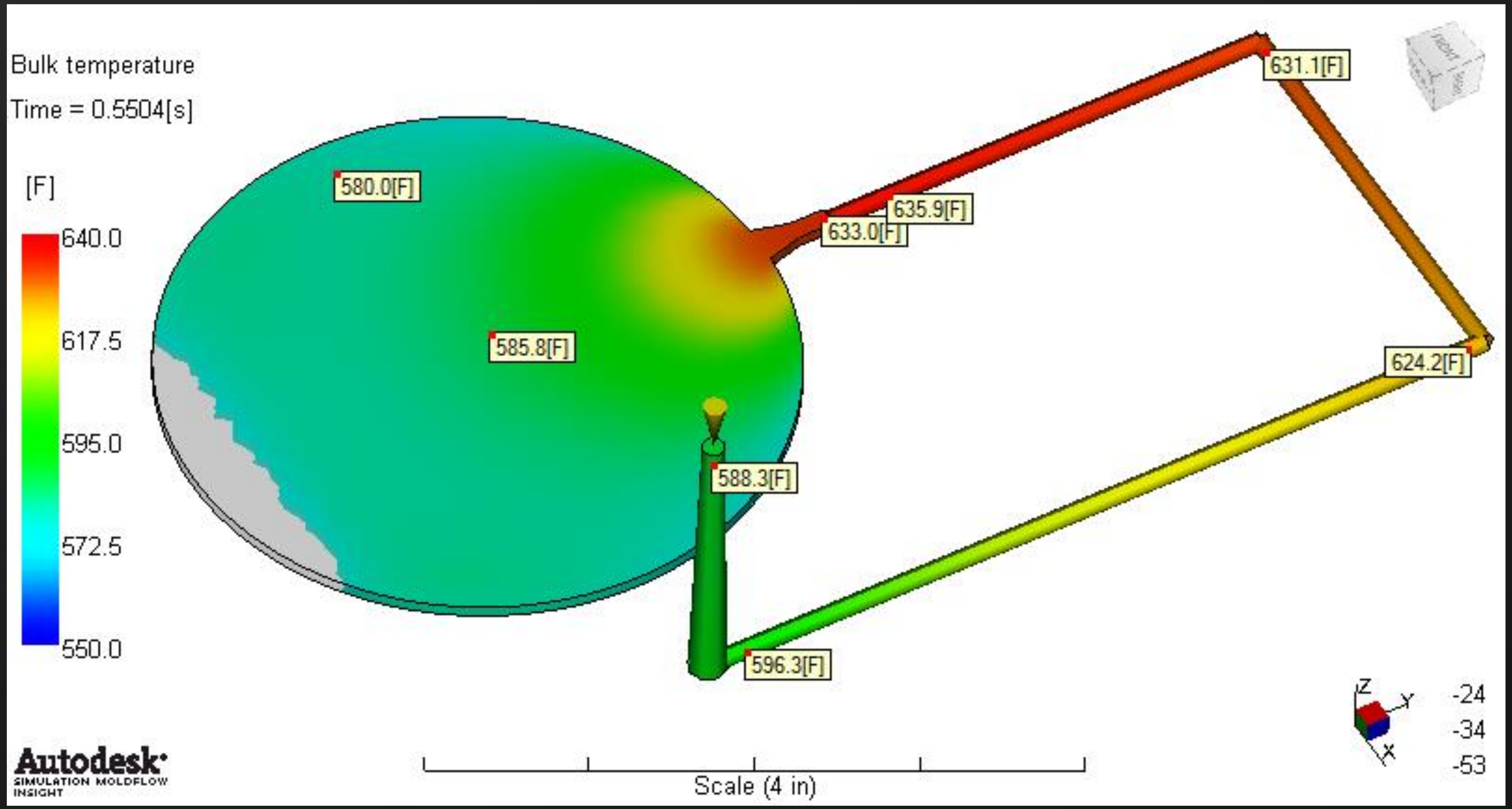
What is Affecting Results?

Getting the most accurate results with lowest overhead:

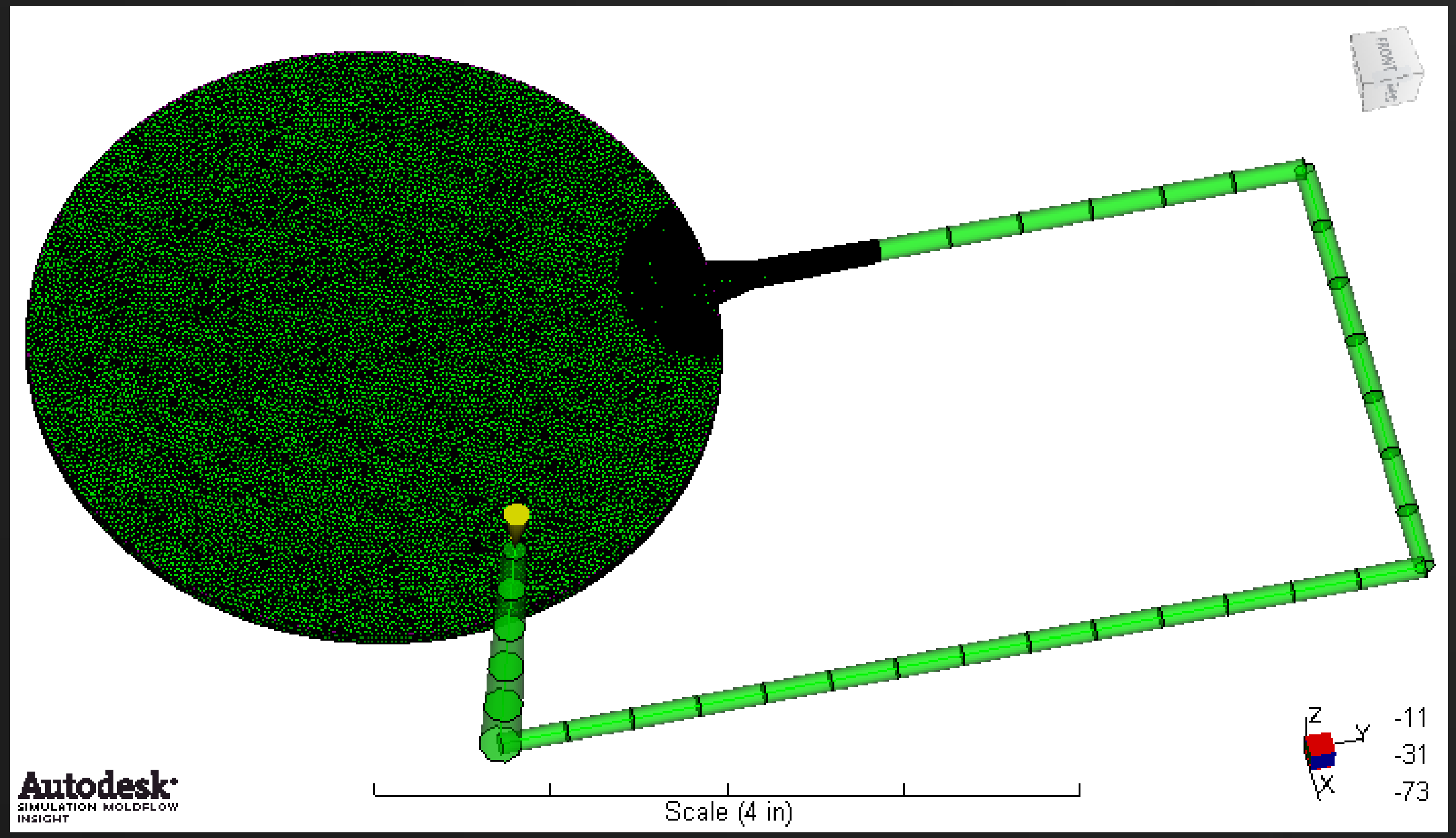
- Inertia ON or OFF
- Absolute material melt temp. 608° F or 1832° F
- Surface mesh
- Number of layers

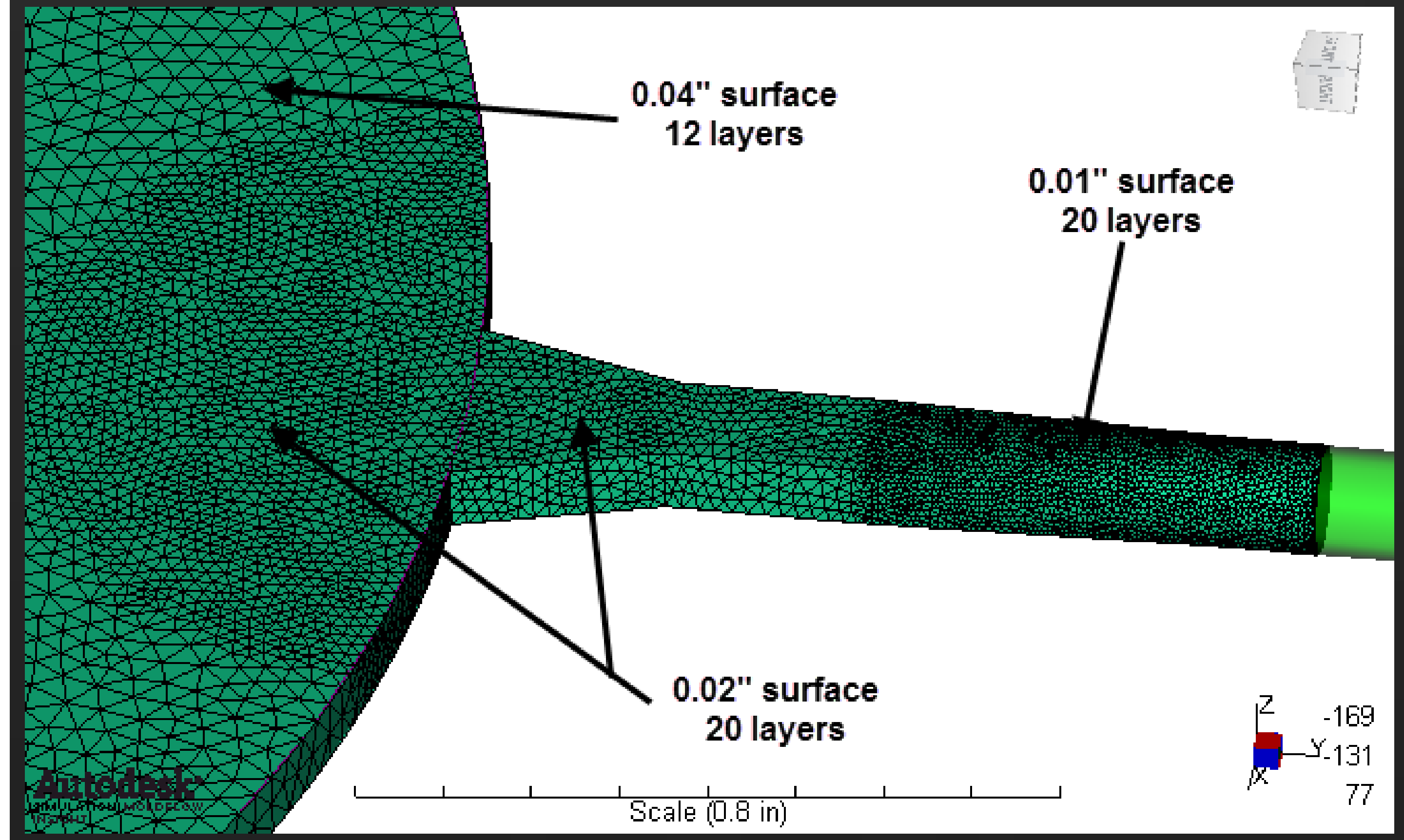
100 mm Disk – Dual Domain

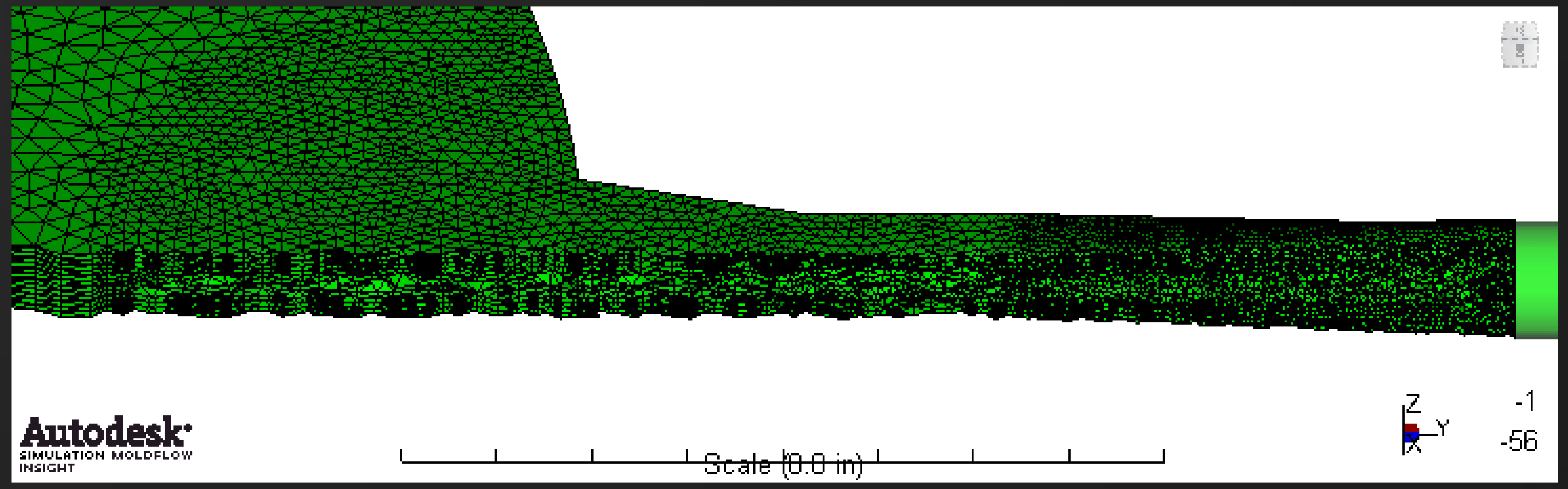


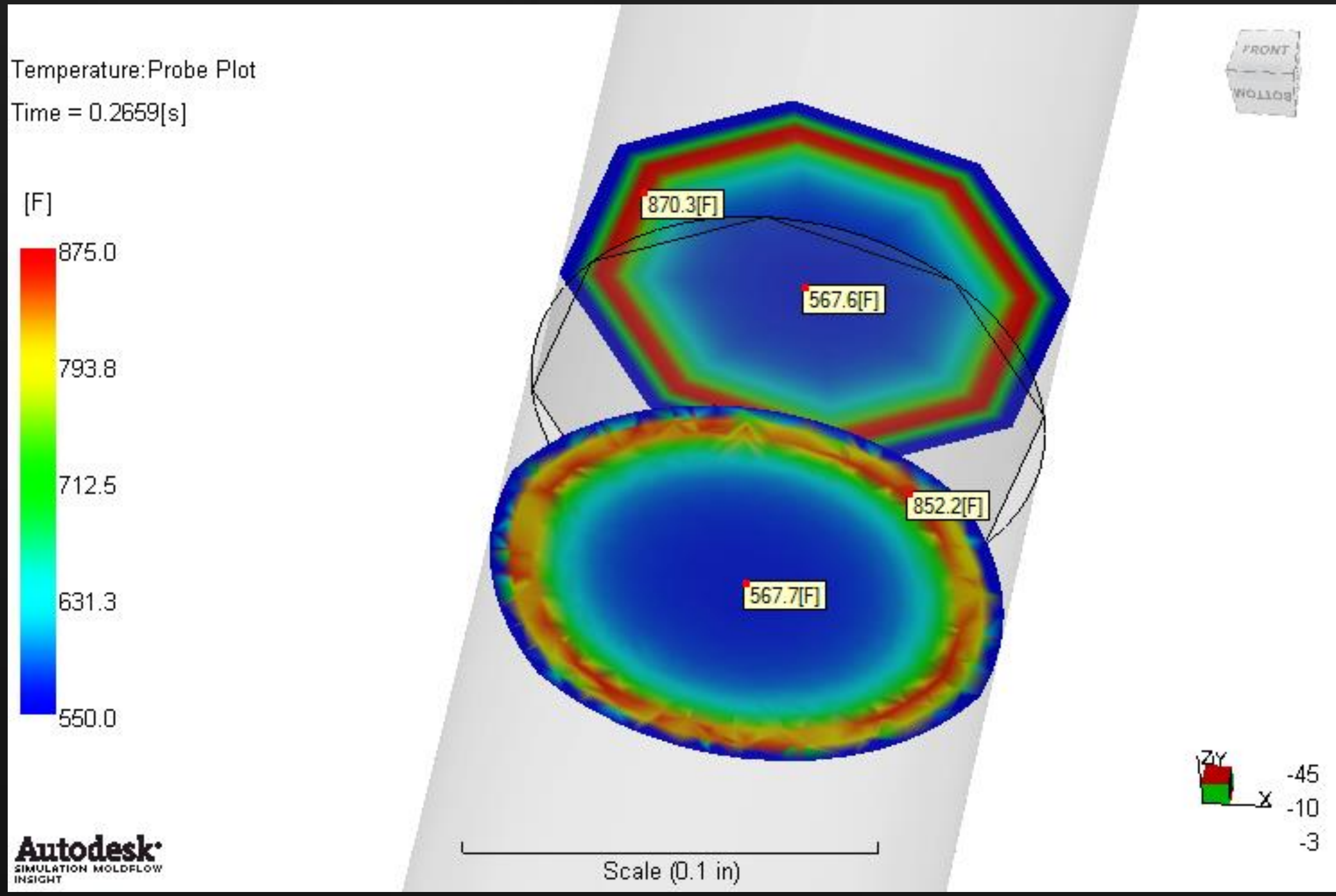


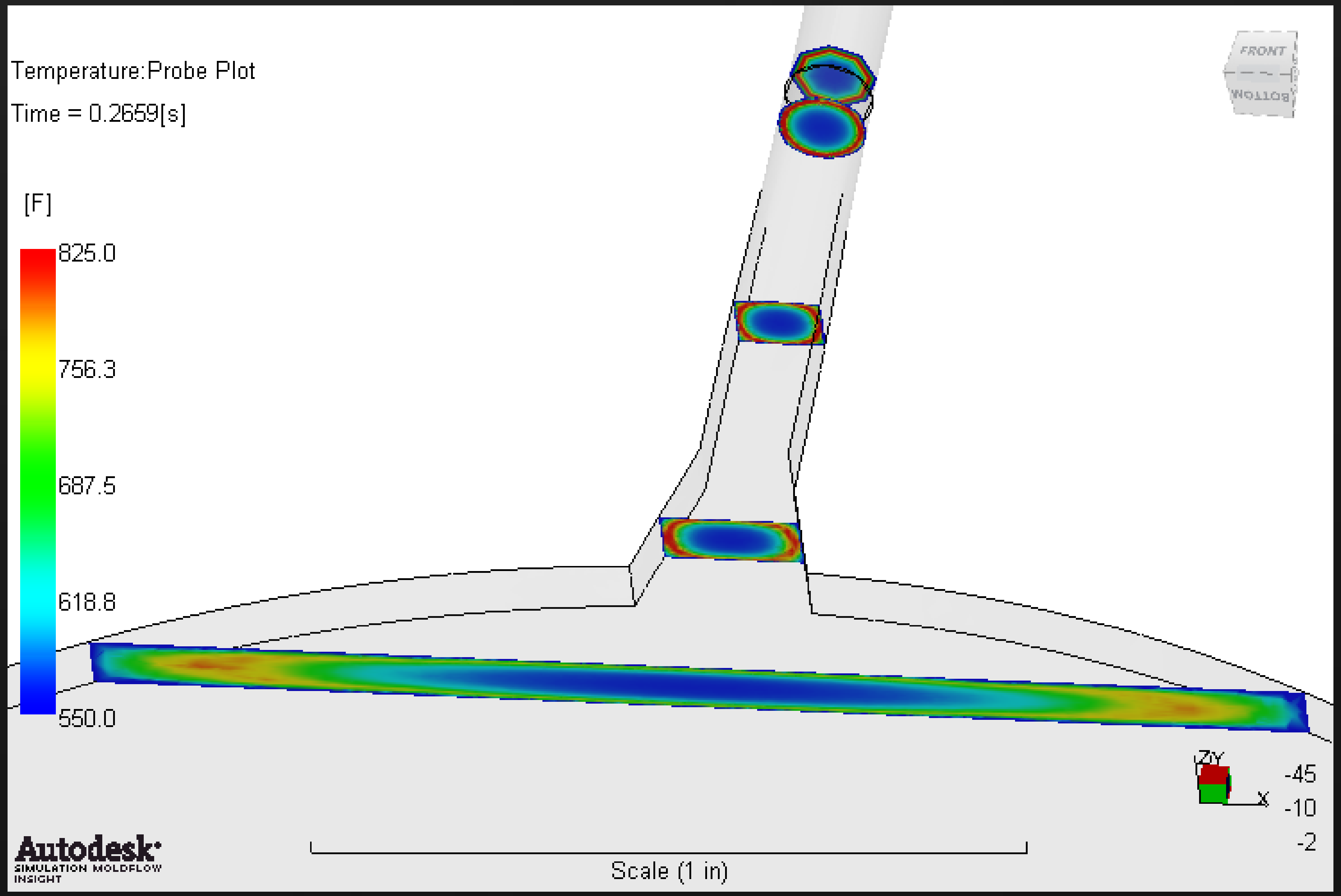
100 mm Disk – Very Good Mesh



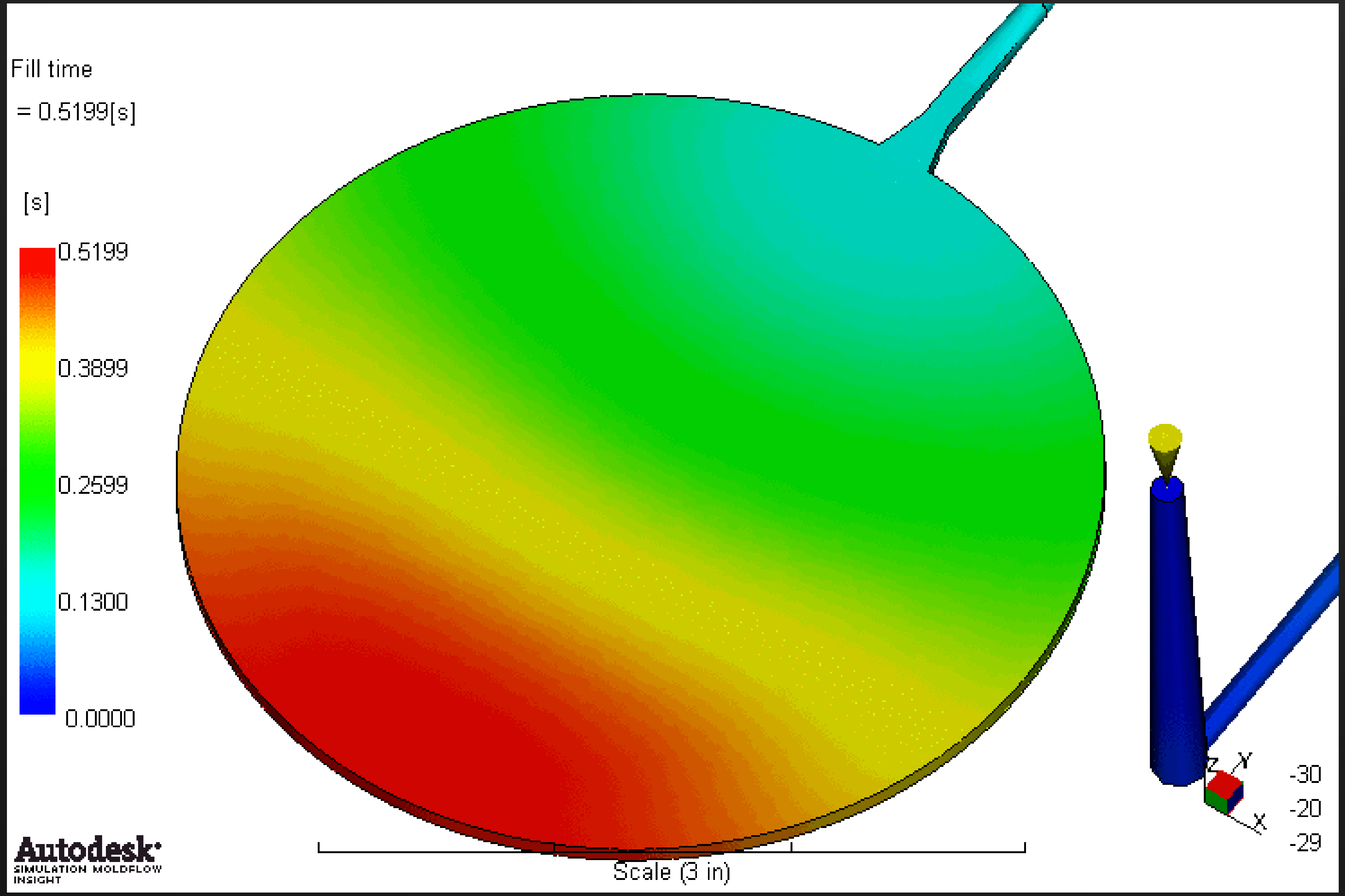


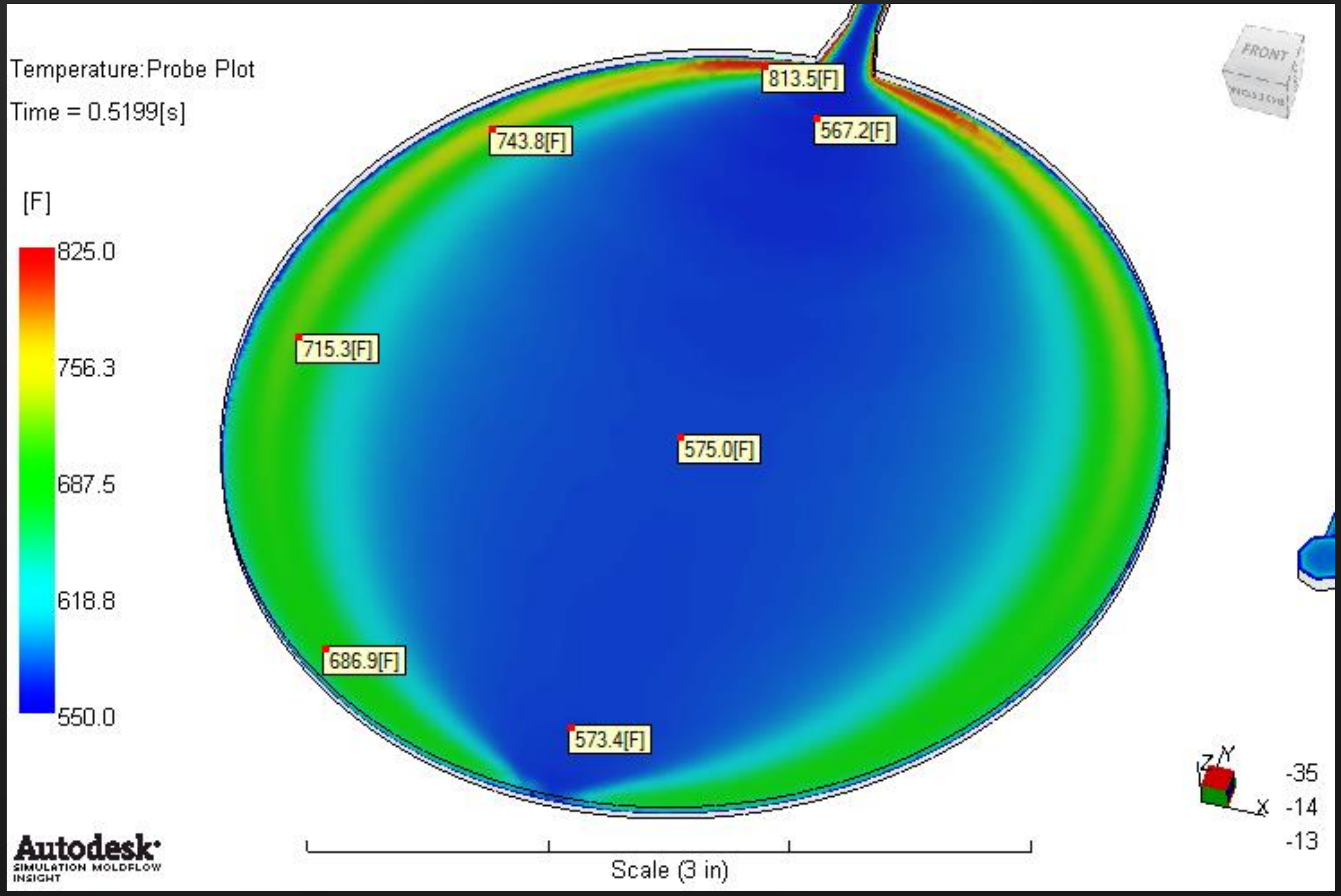






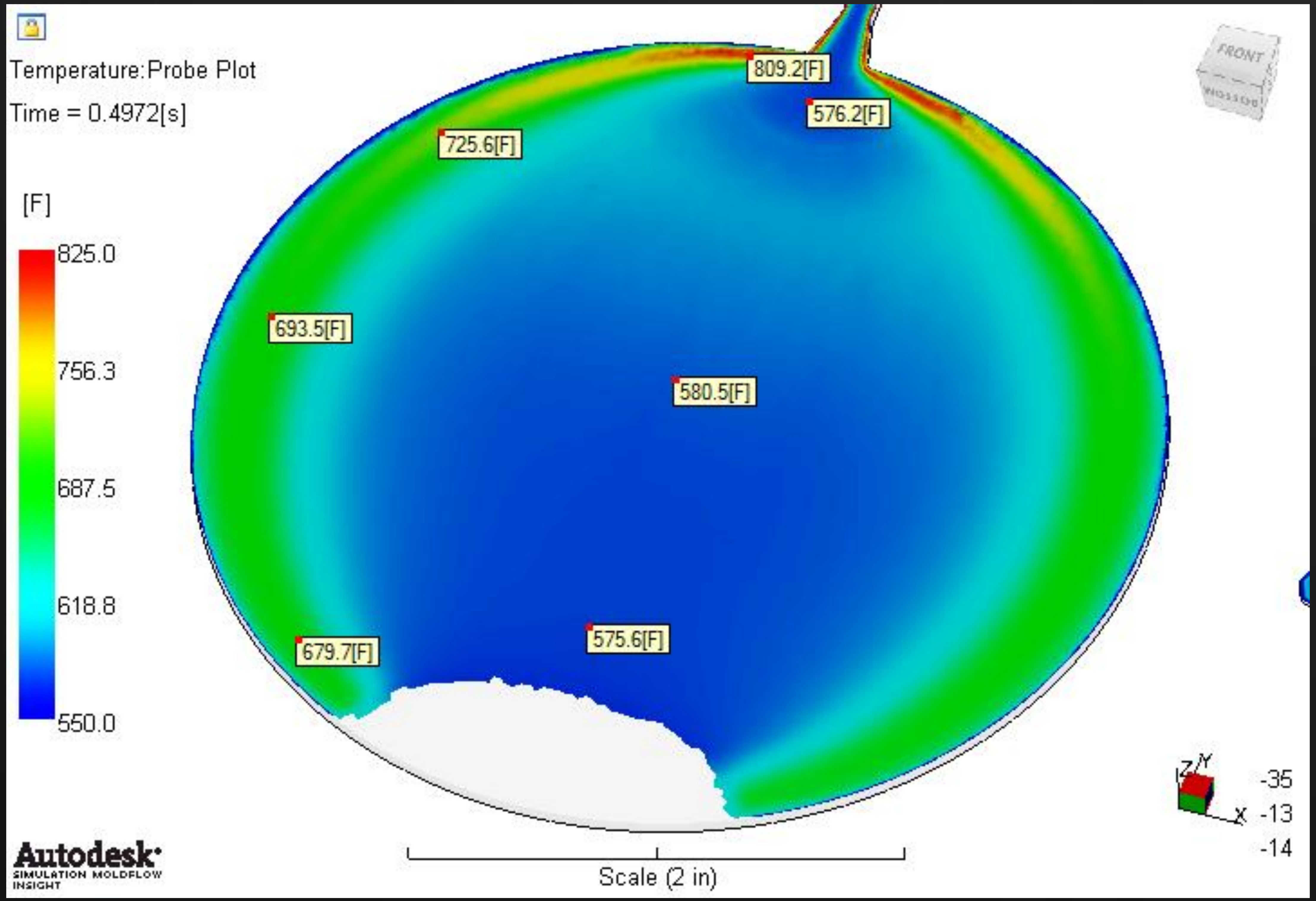
100 mm Disk - Optimal



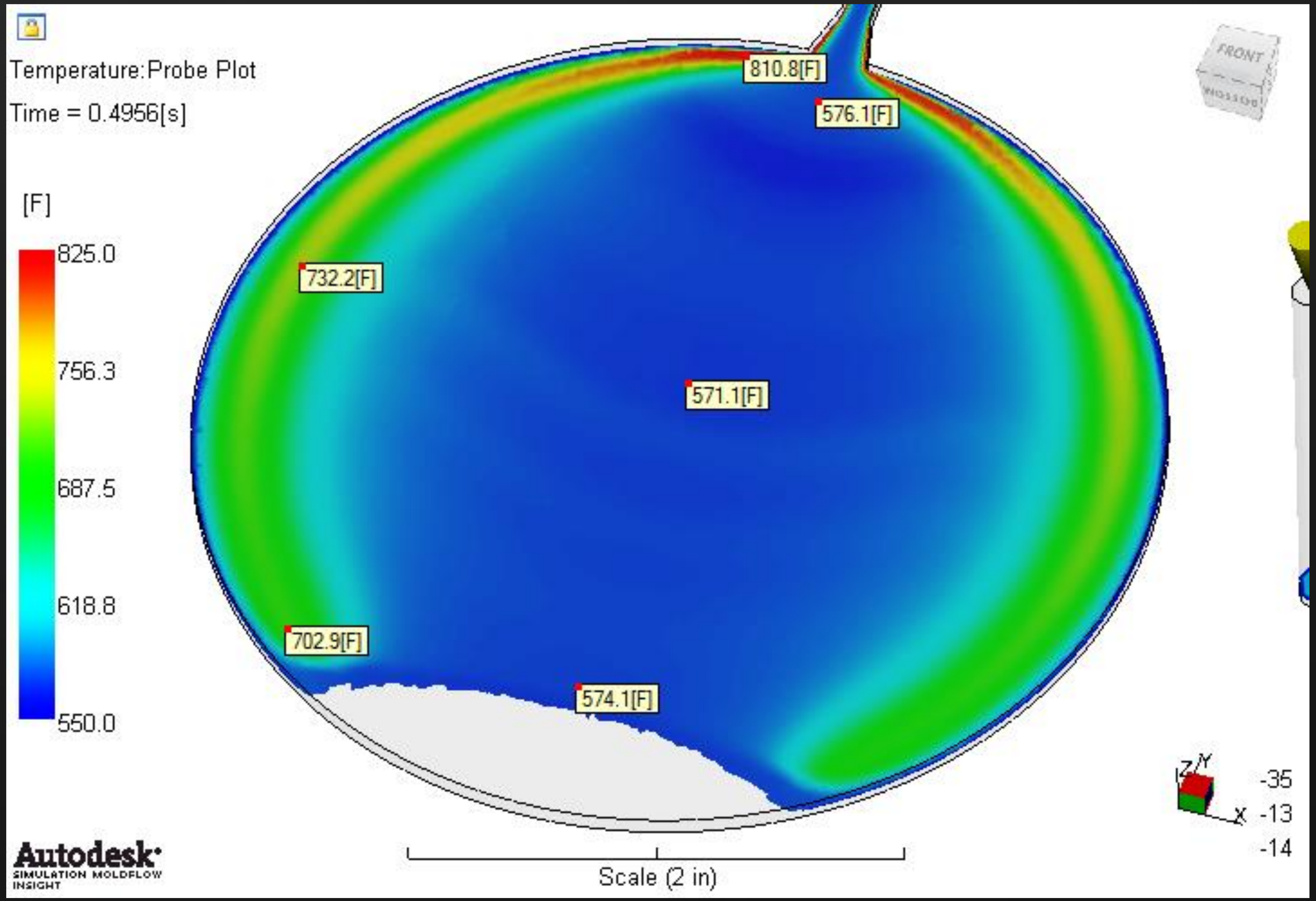


100 mm Disk

Inertia ON



Inertia OFF

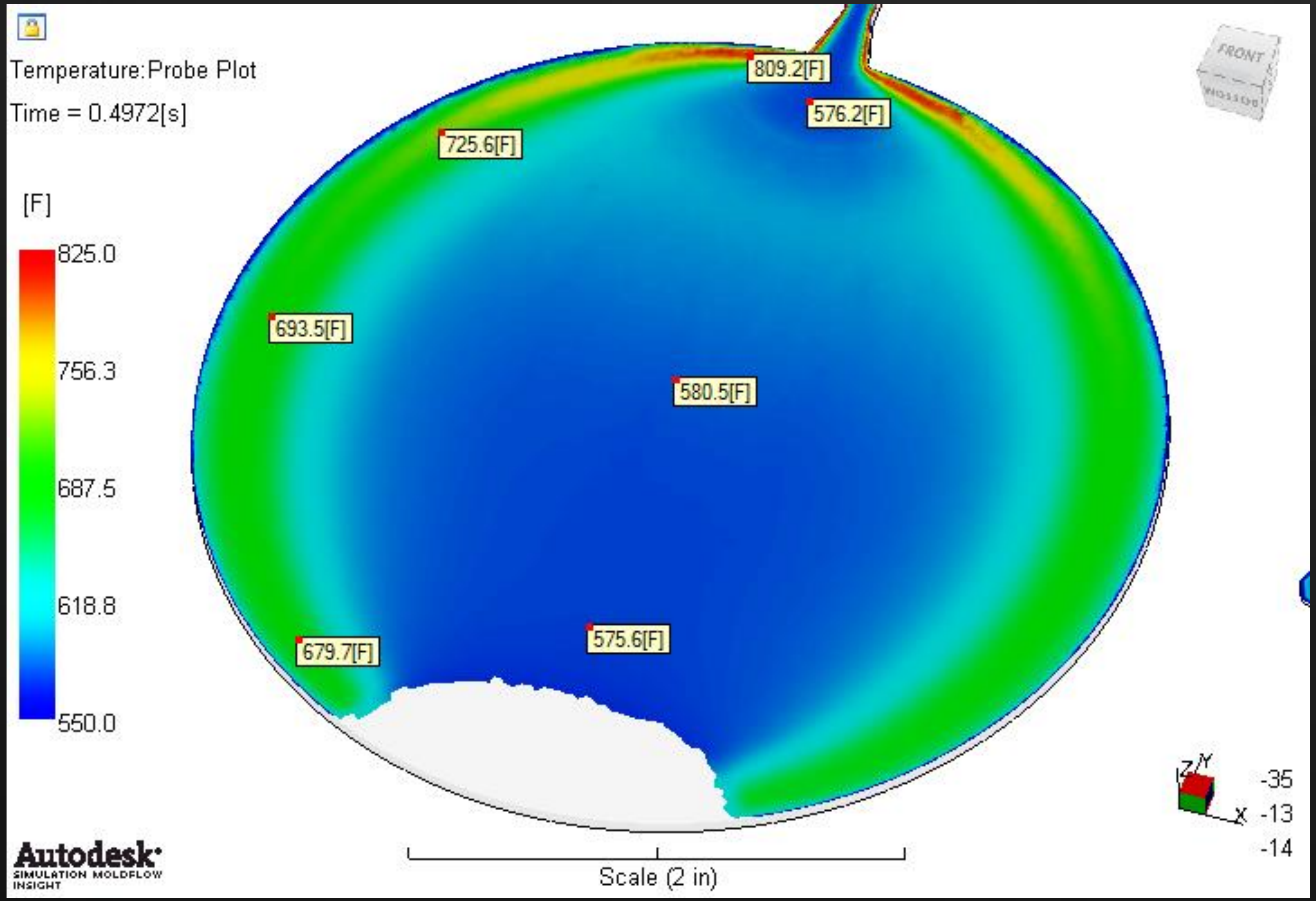


1.34 ME (MegaElement)/8hr 34min (CPU)

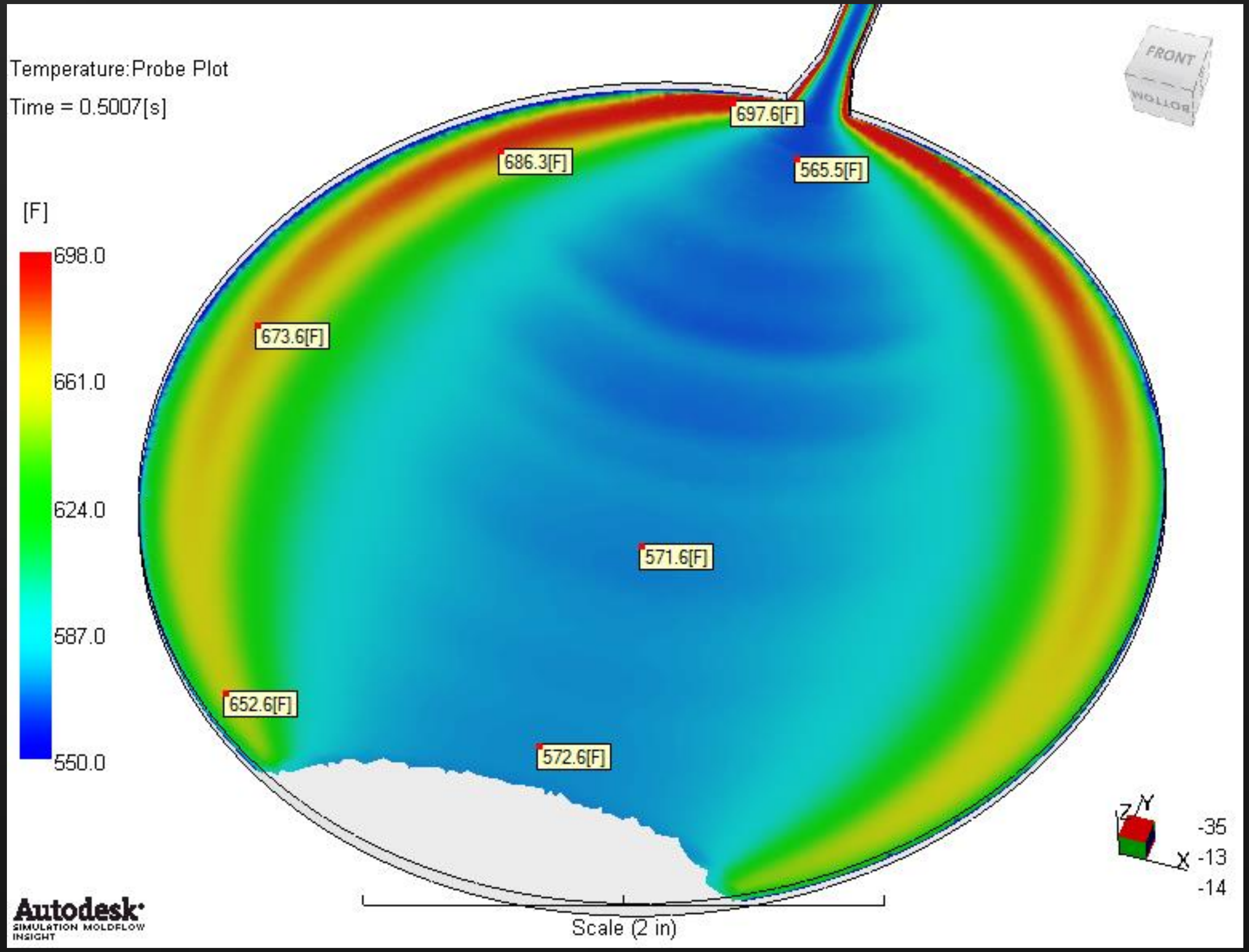
Dell Precision M6500 I7 Q820@1.73GHz 16GB

100 mm Disk – Inertia ON

Max. Temp. = 1832° F



Max. Temp. = 608° F

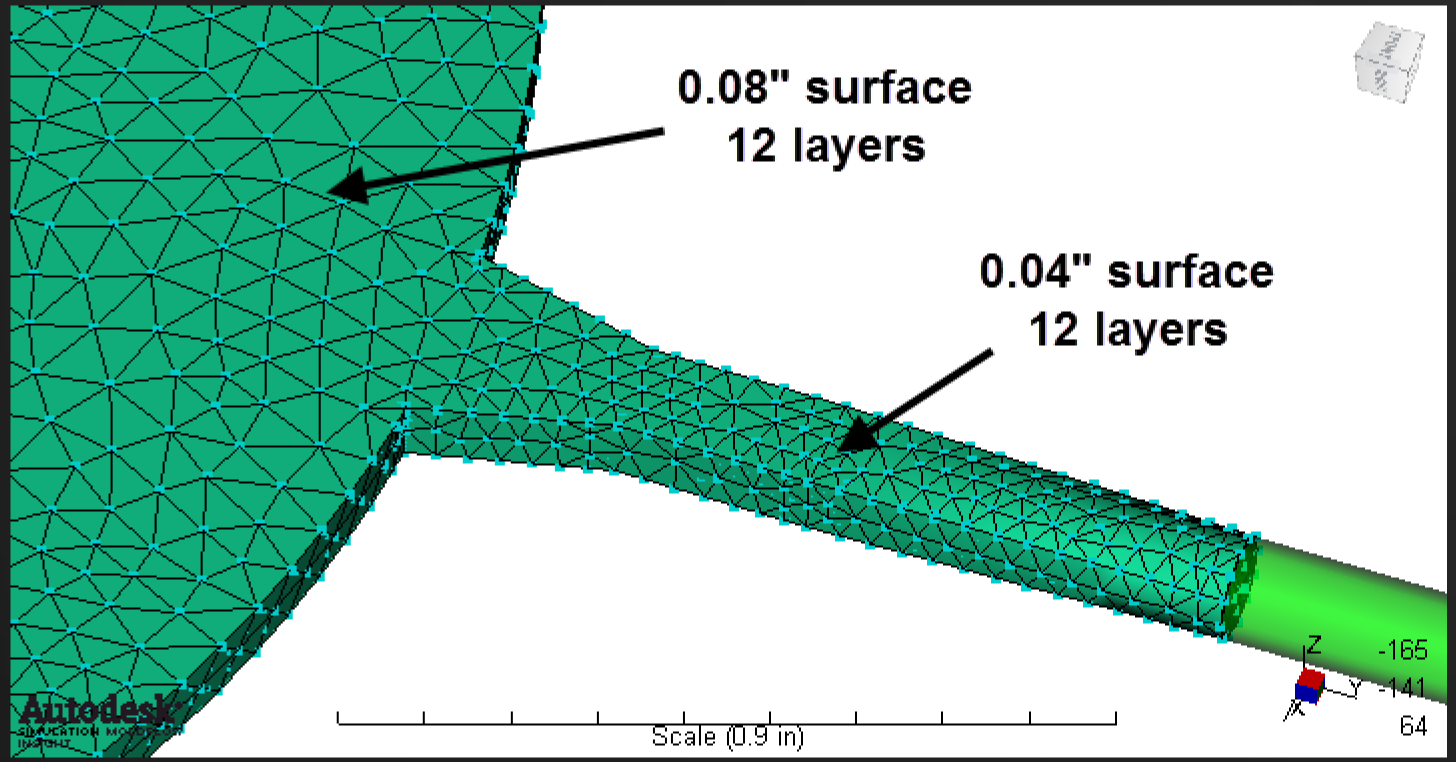


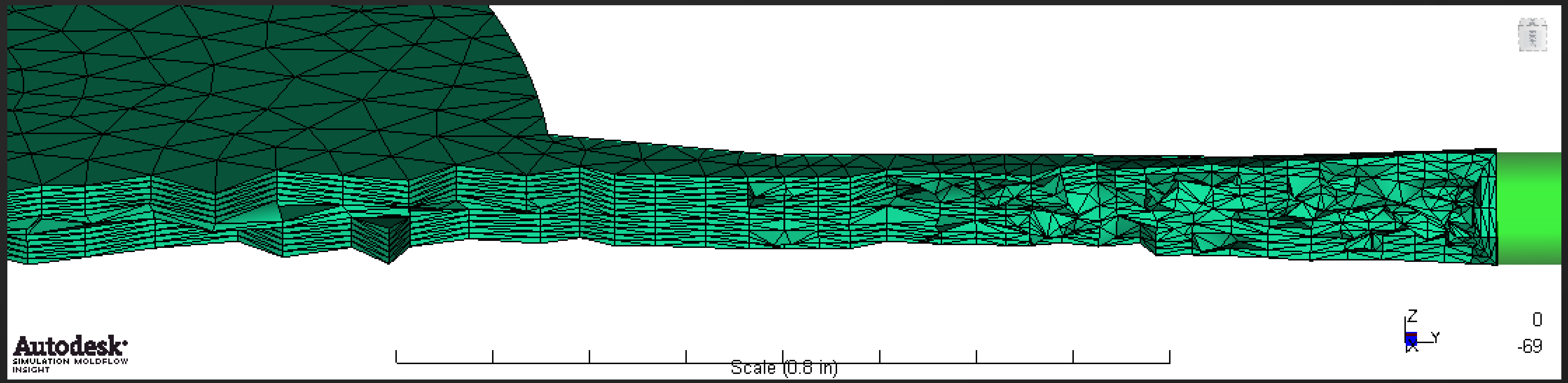
1.34 ME (MegaElement)/8hr 11min (CPU)

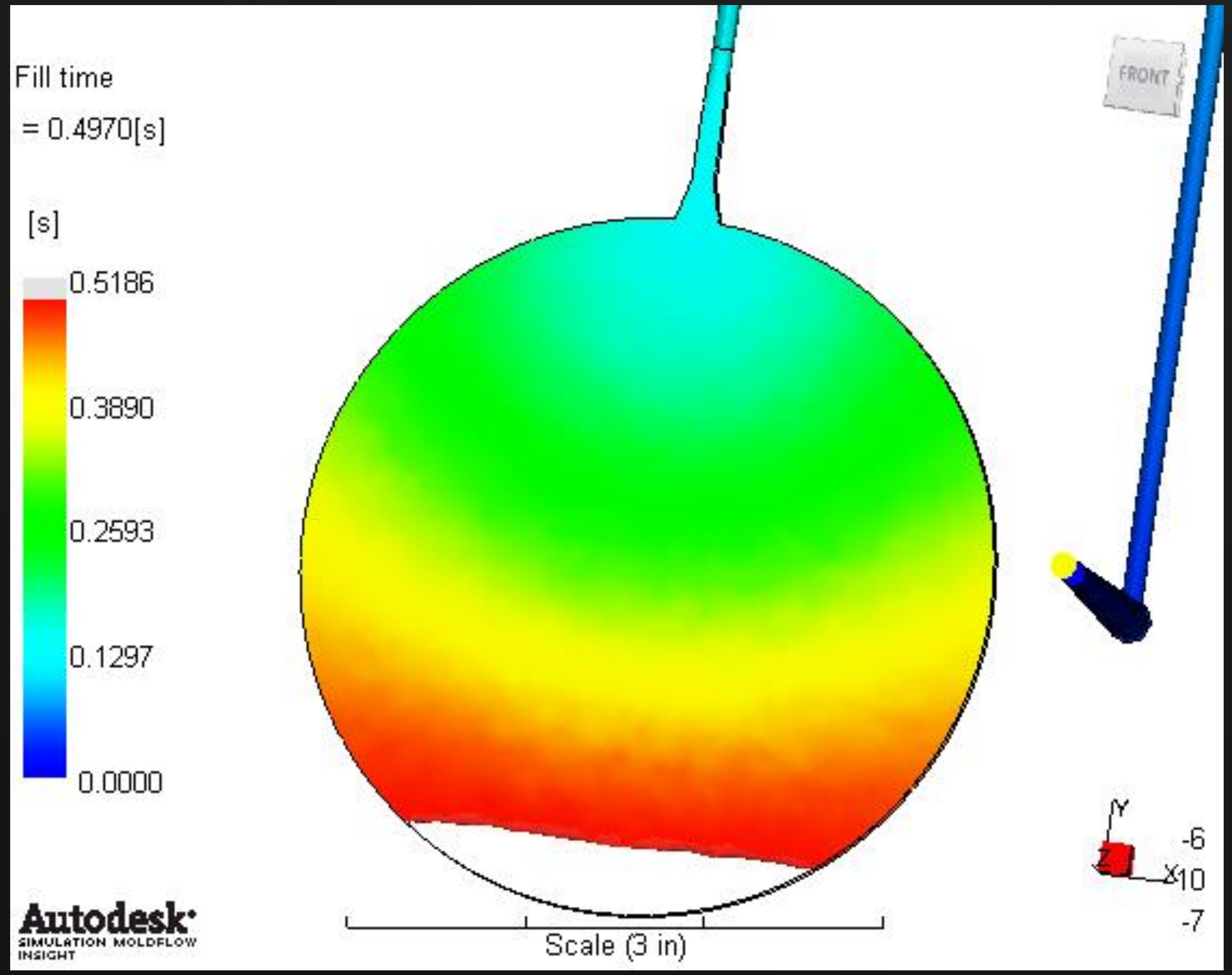
Dell Precision M6500 I7 Q820@1.73GHz 16GB

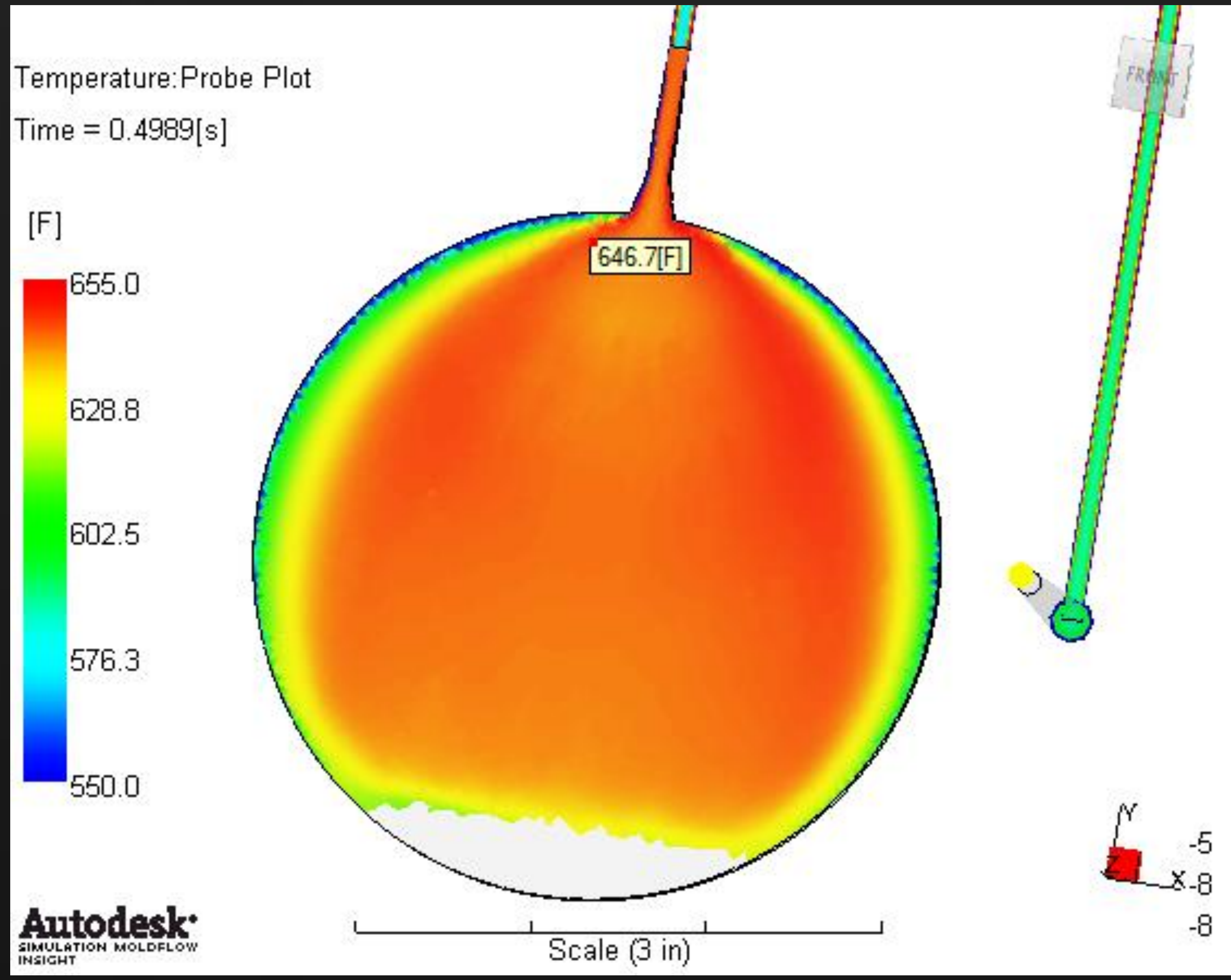
100 mm Disk – 0.04” Surface Refinement

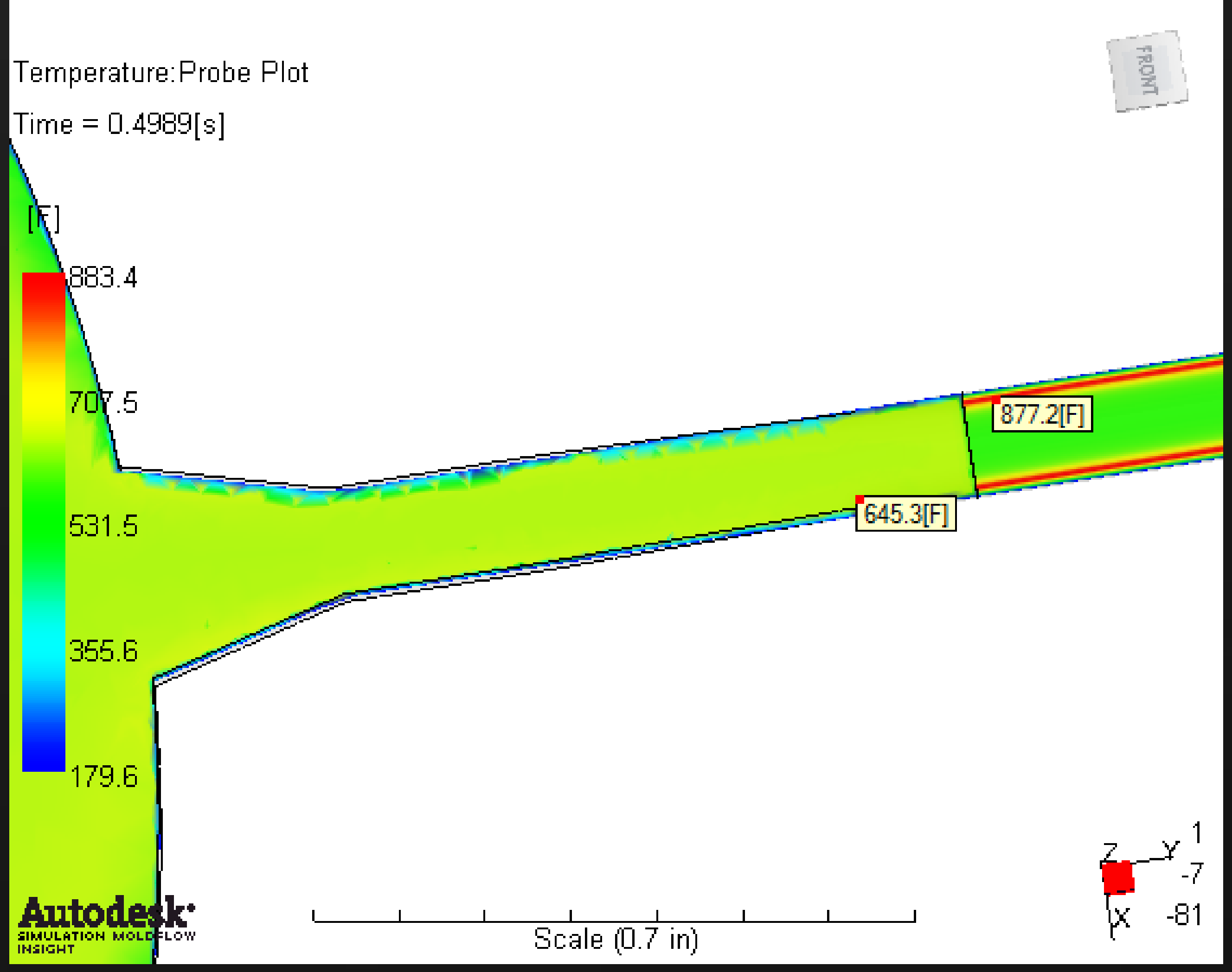
Inertia=ON, Absolute=1832° F, 20 laminates









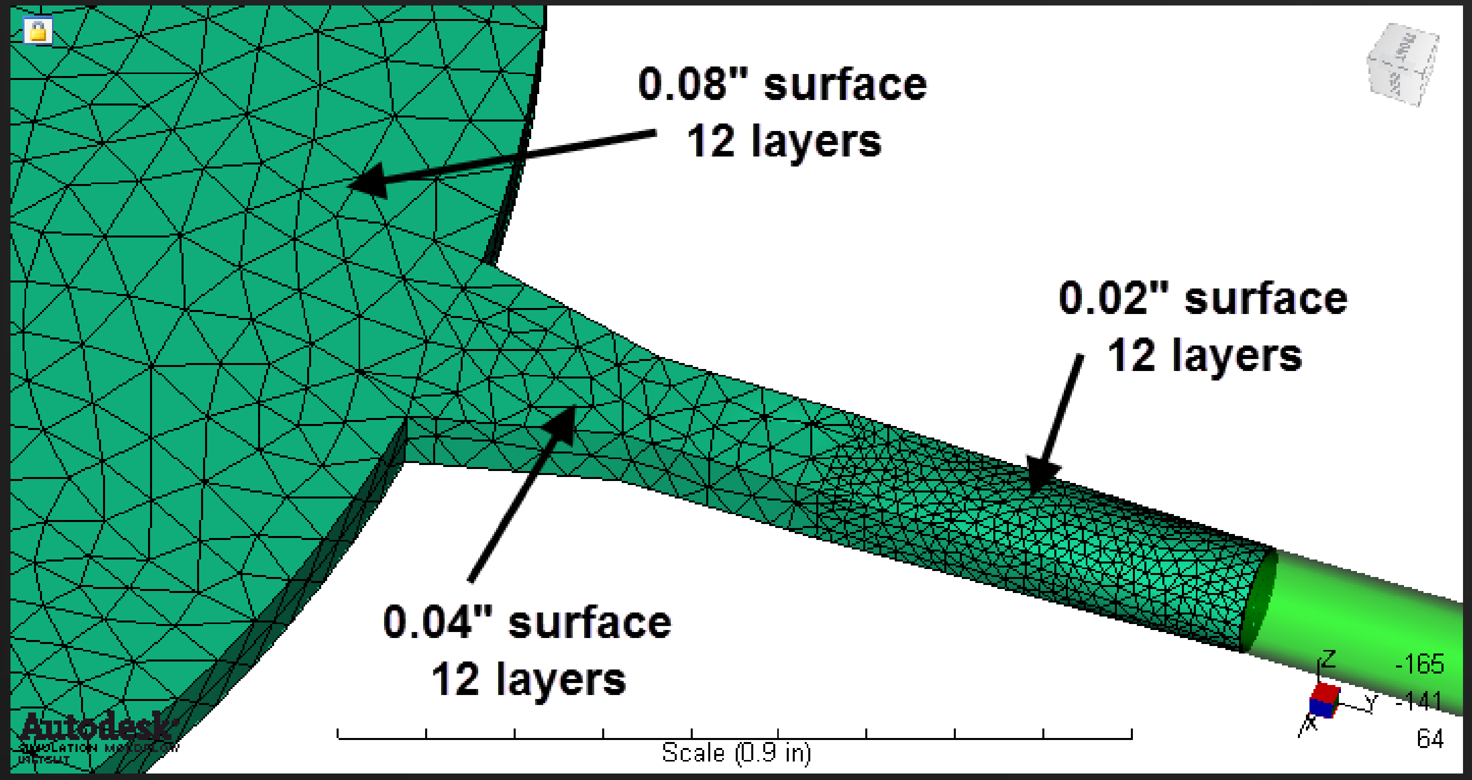


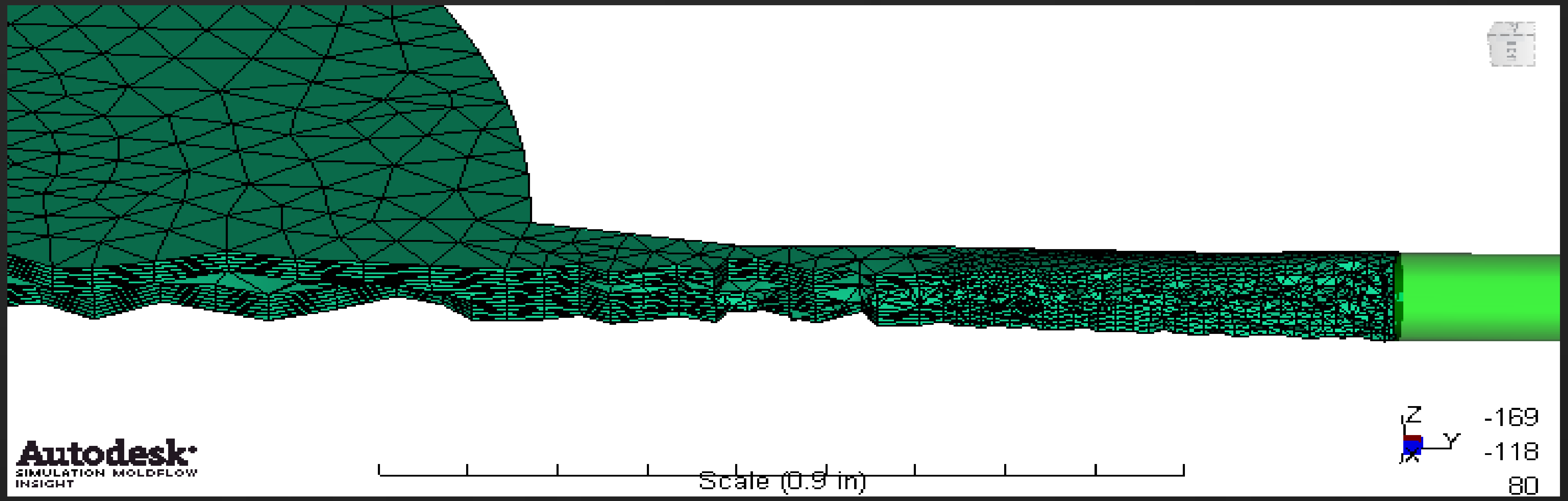
0.22 ME (MegaElement)/0hr 30min (CPU)

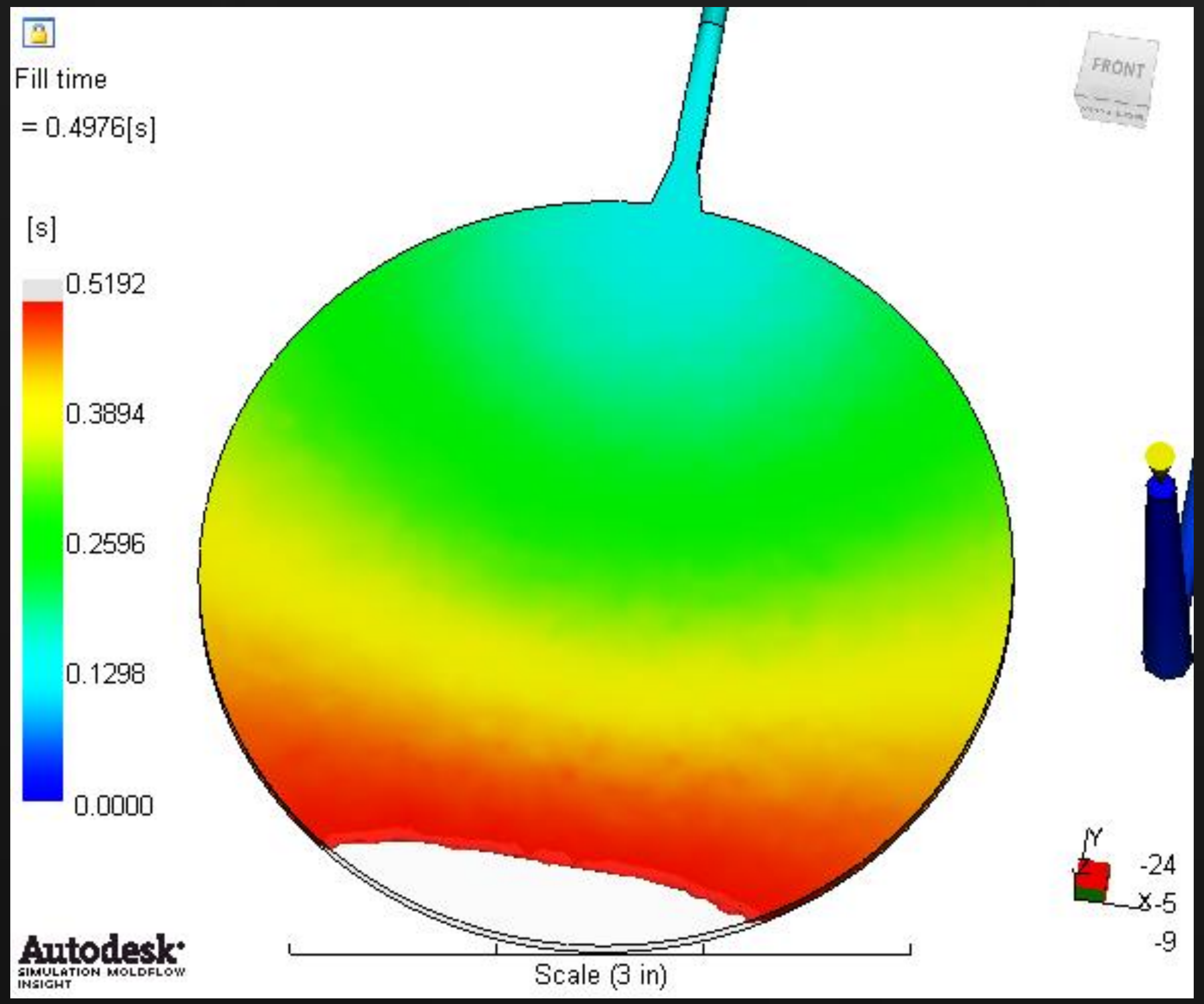
Dell Precision M6500 I7 Q820@1.73GHz 16GB

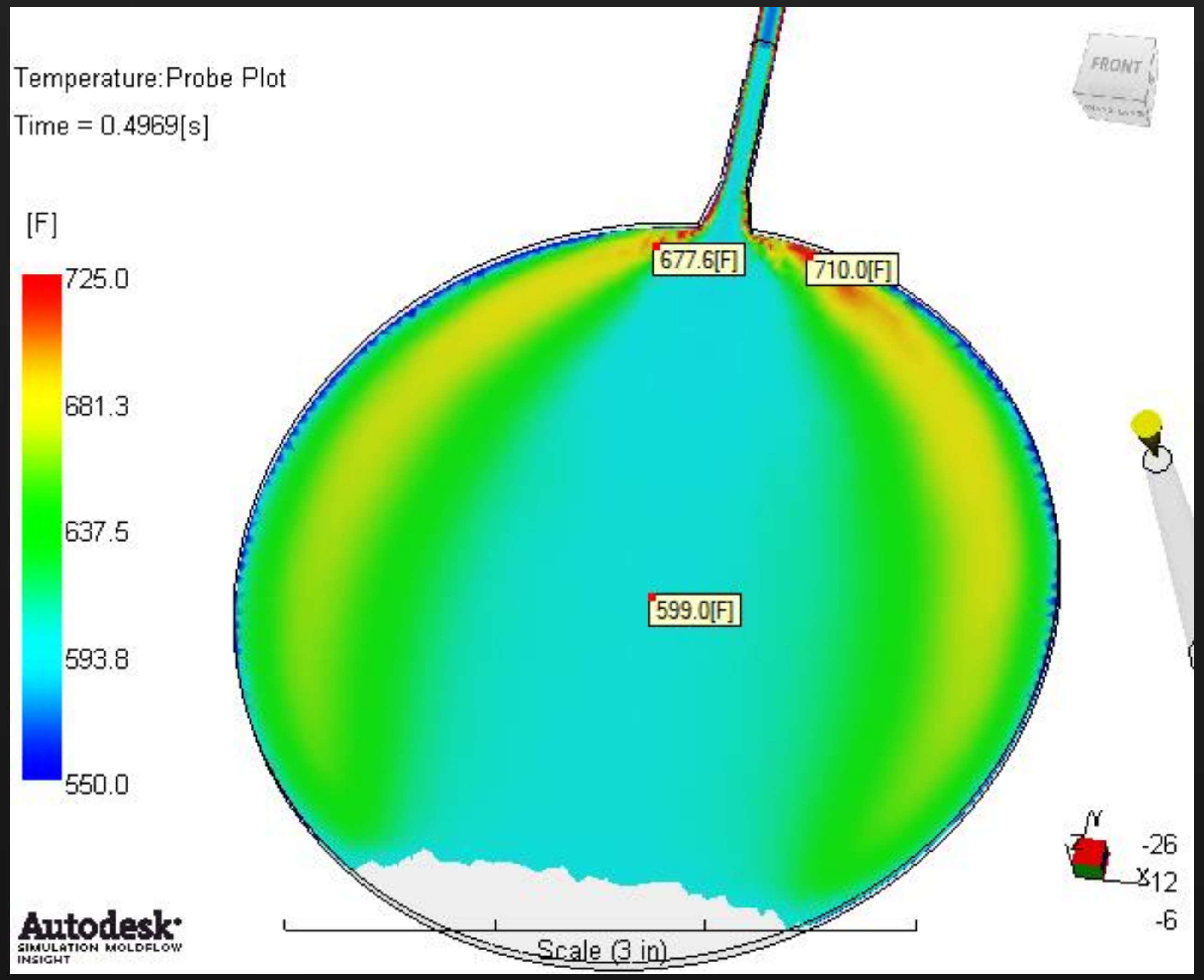
100 mm Disk – 0.02” Surface

Inertia=ON, Absolute=1832° F, 20 laminates





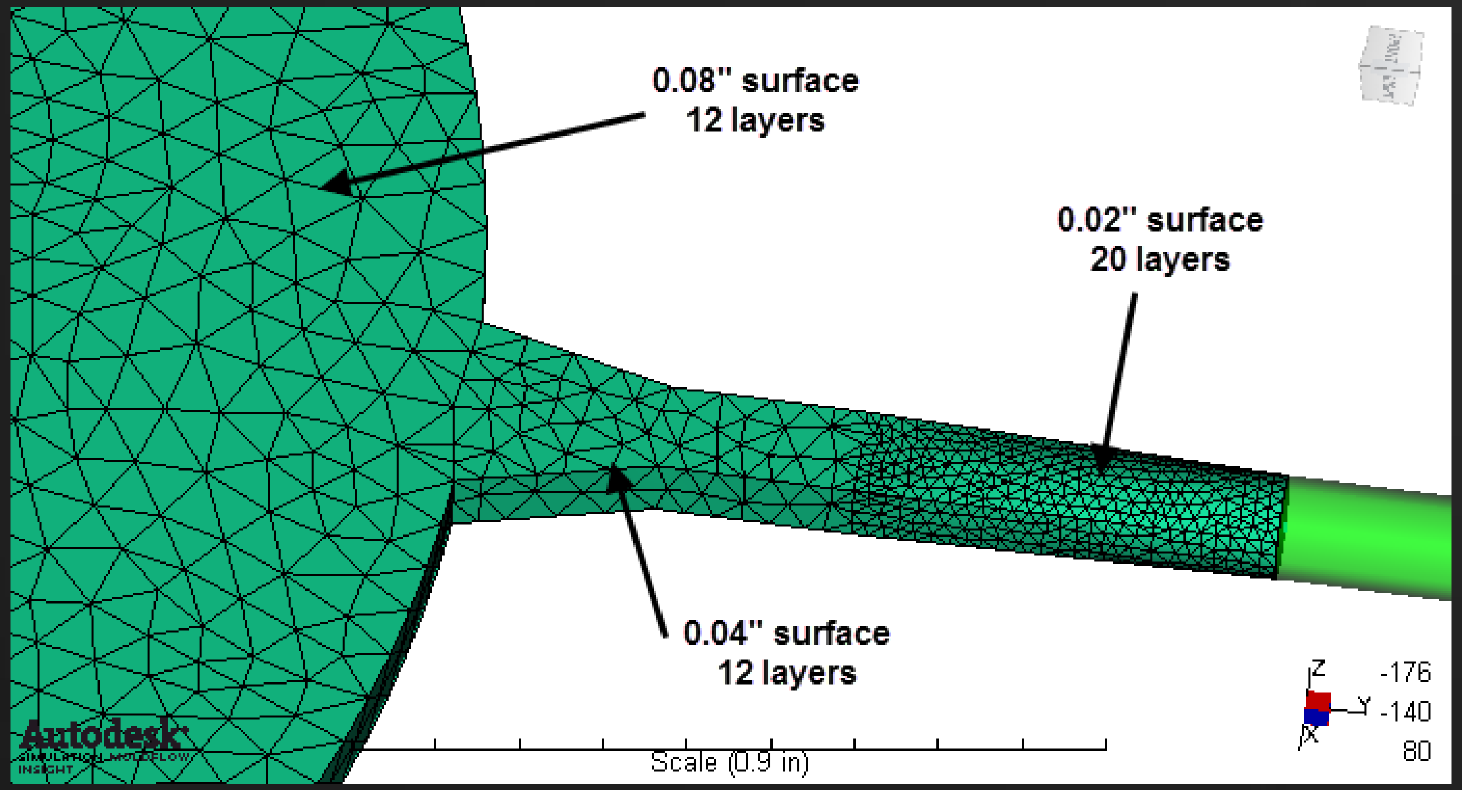




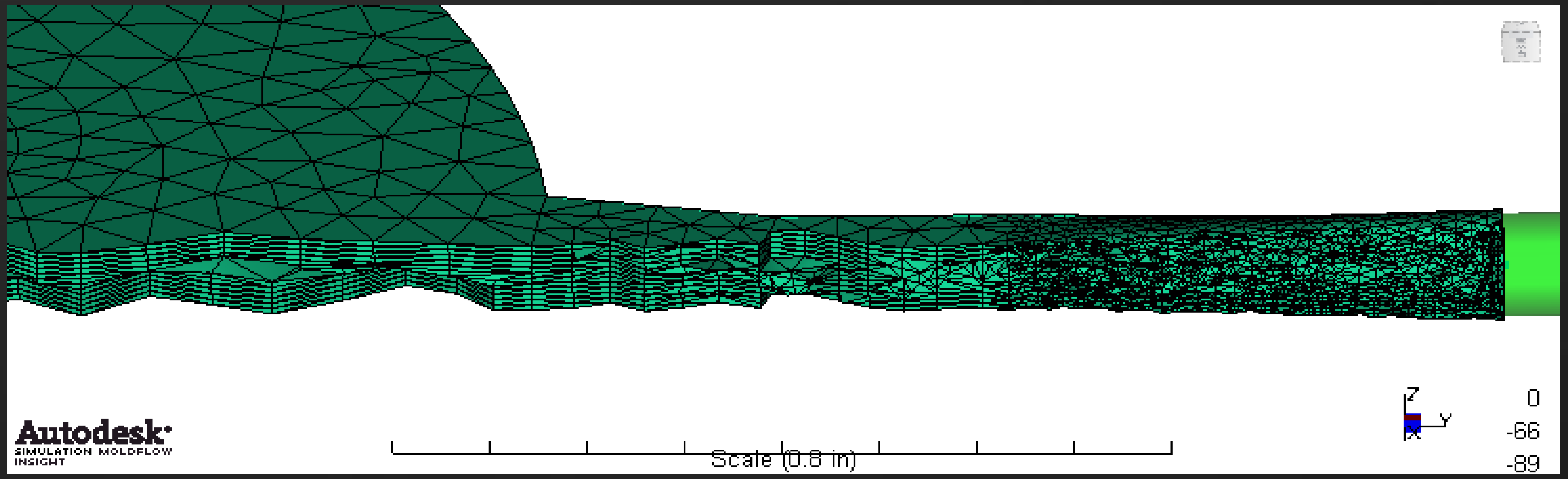
0.23 ME/0hr 34min

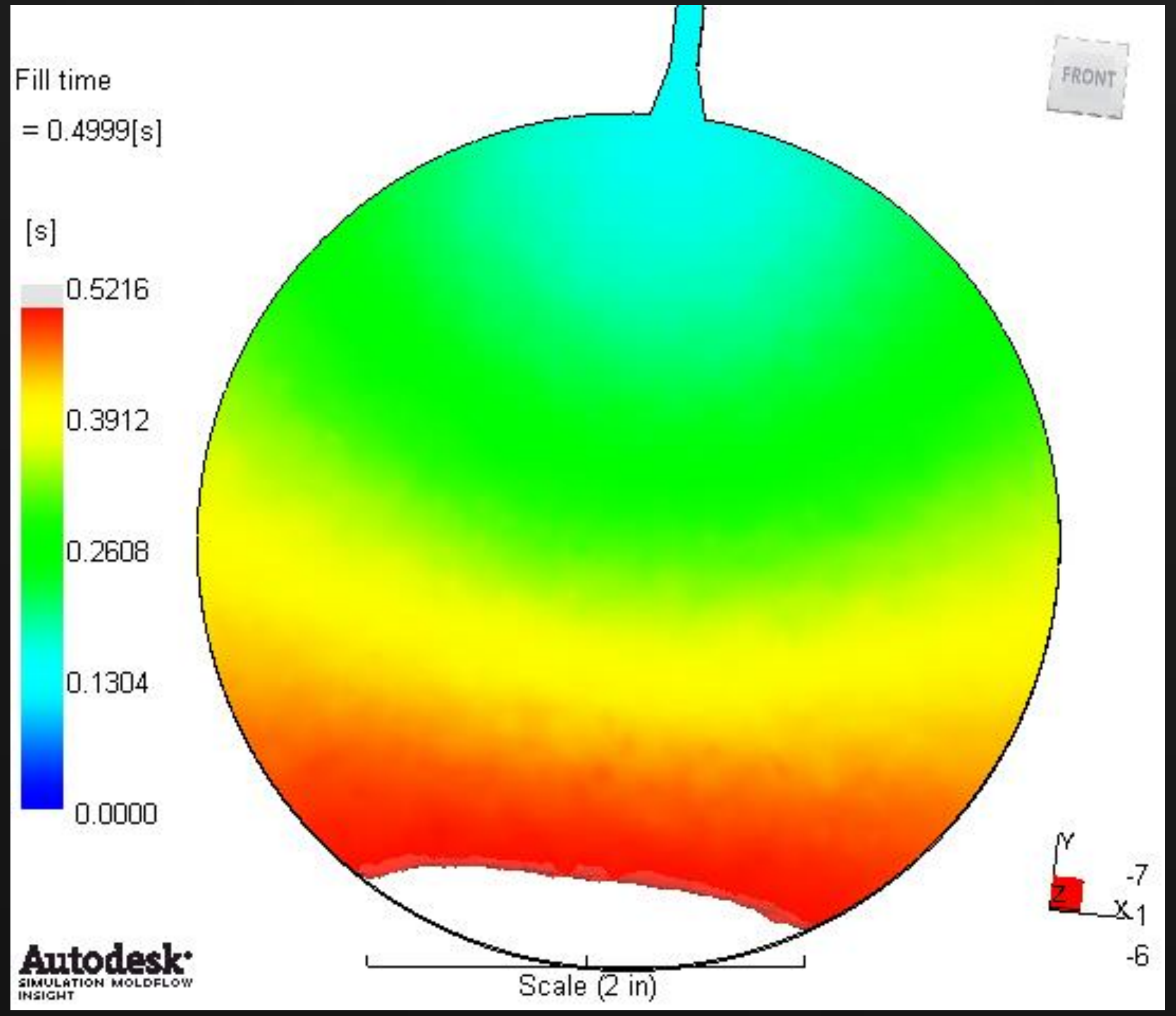
Dell Precision M6500 I7 Q820@1.73GHz 16GB

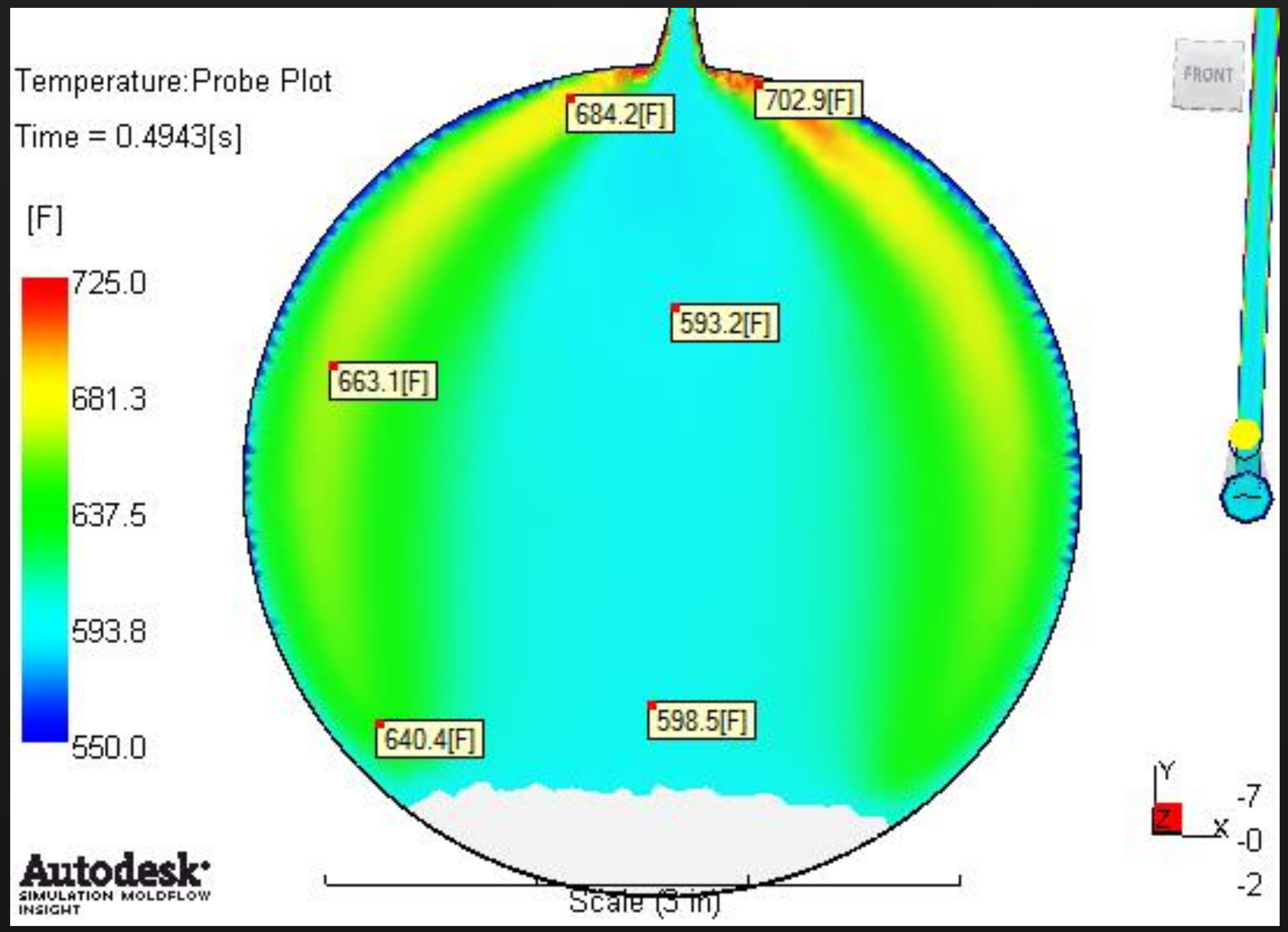
100 mm Disk – 0.02" Surface/20 layers

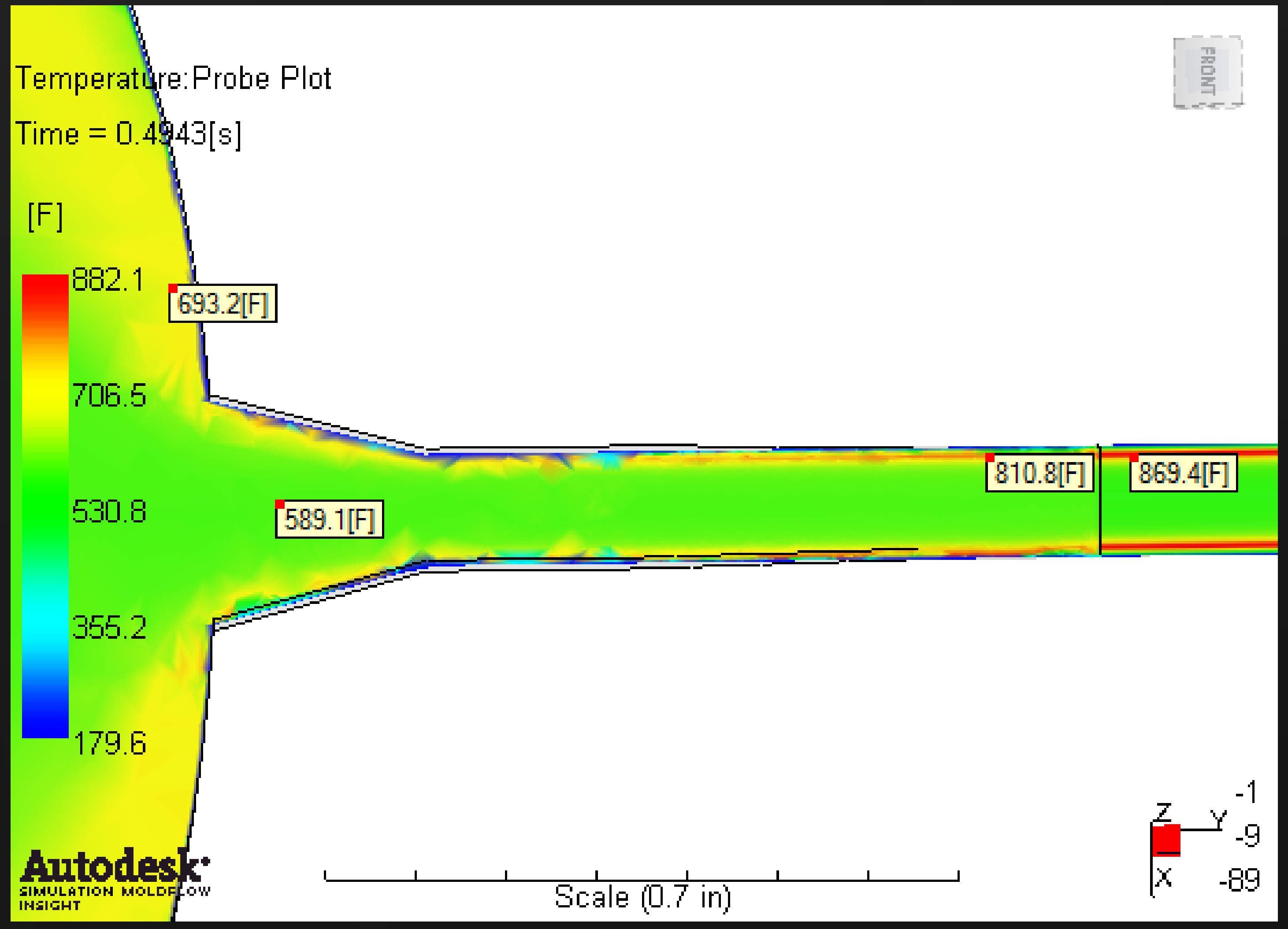


Inertia=ON, Absolute=1832° F, 20 laminates





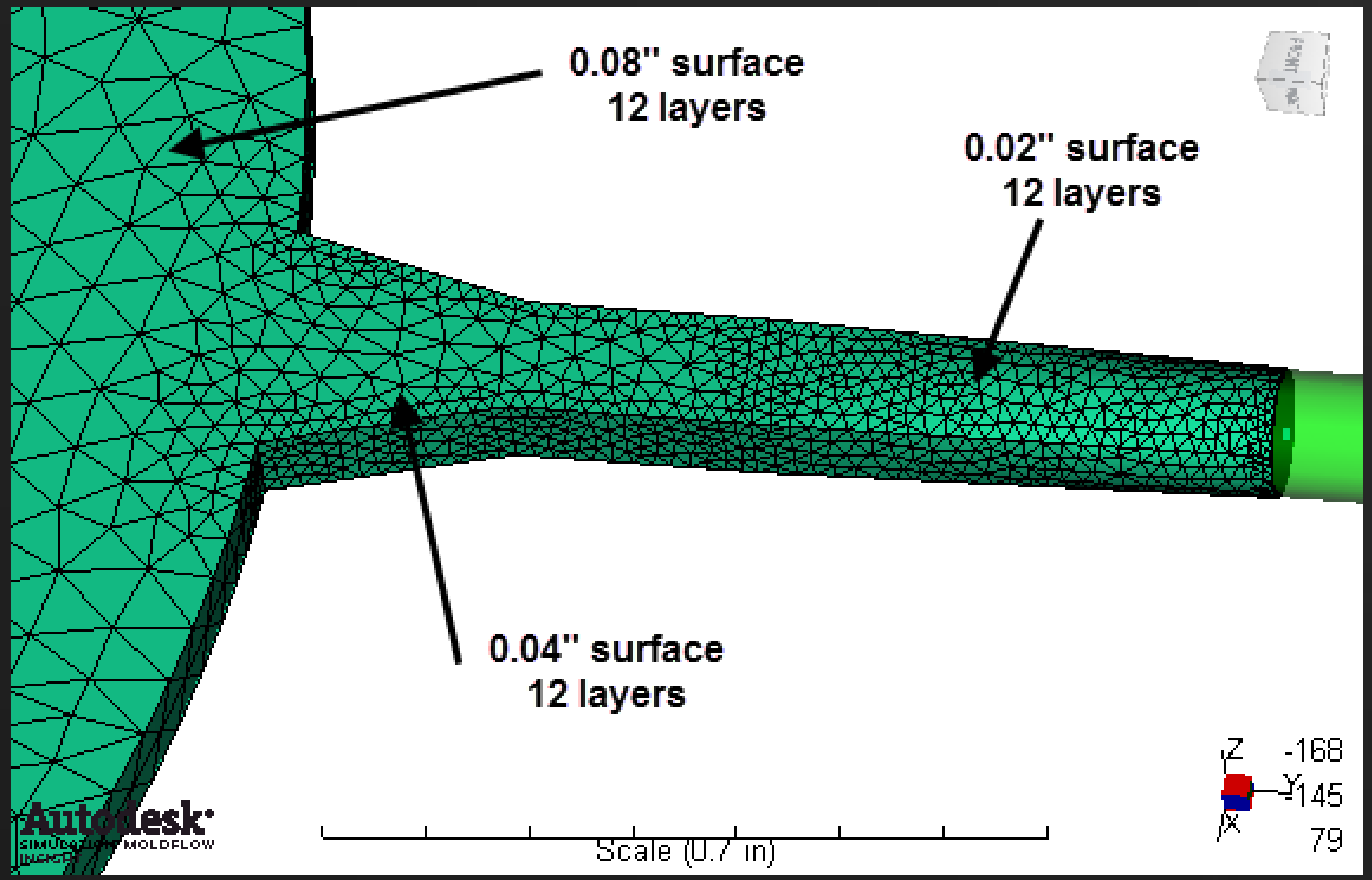


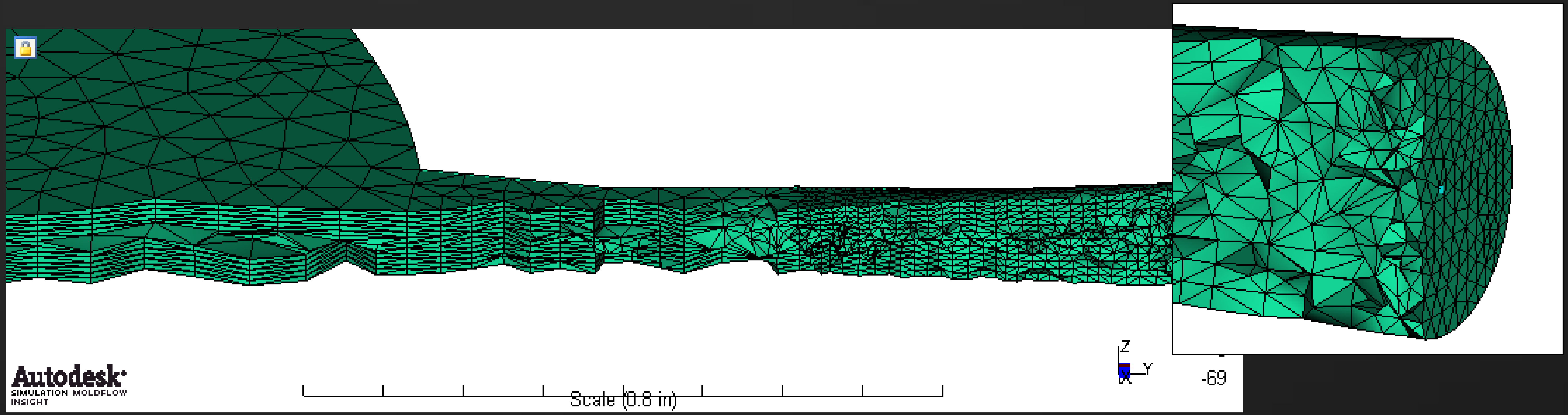


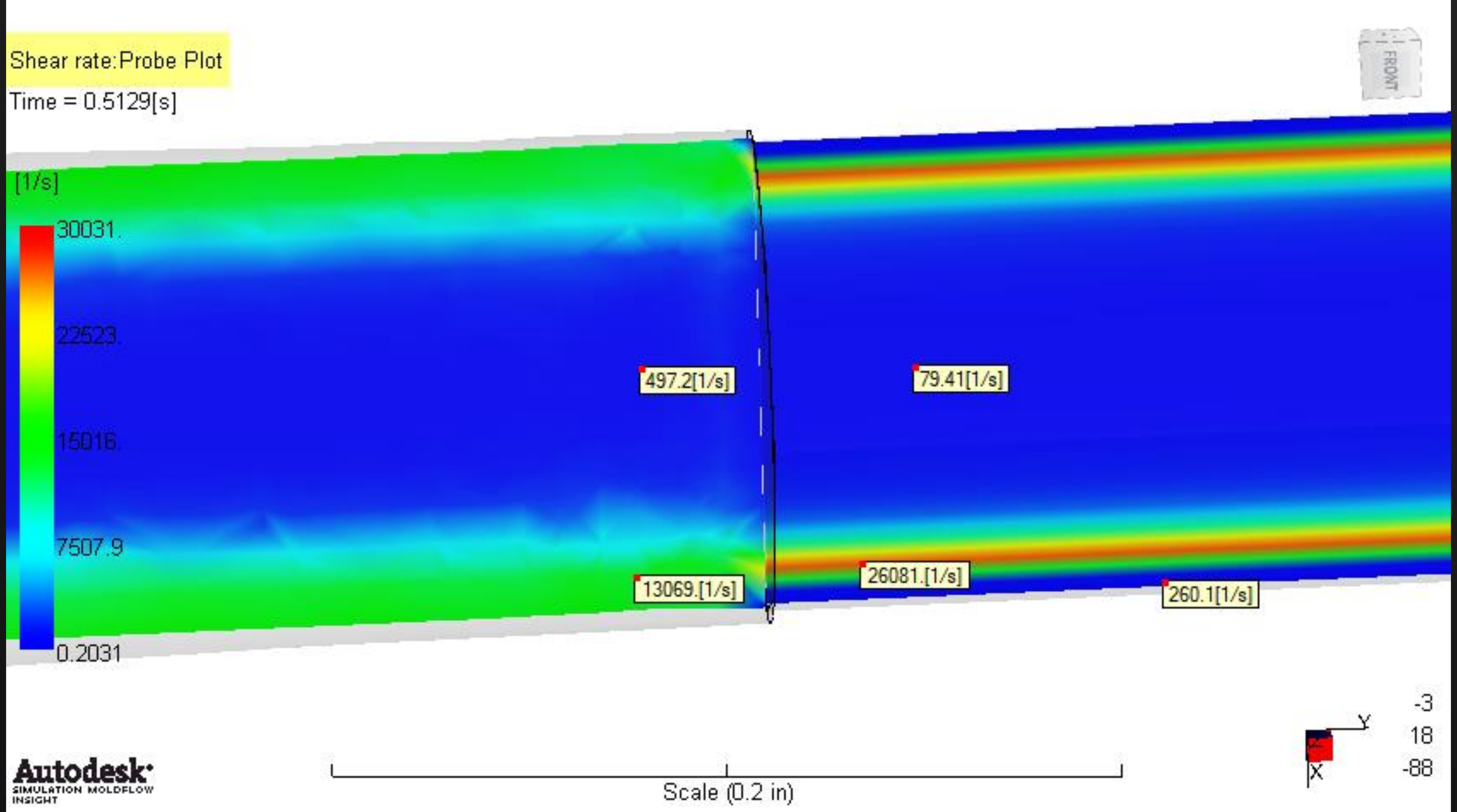
0.28 ME/0hr 56min

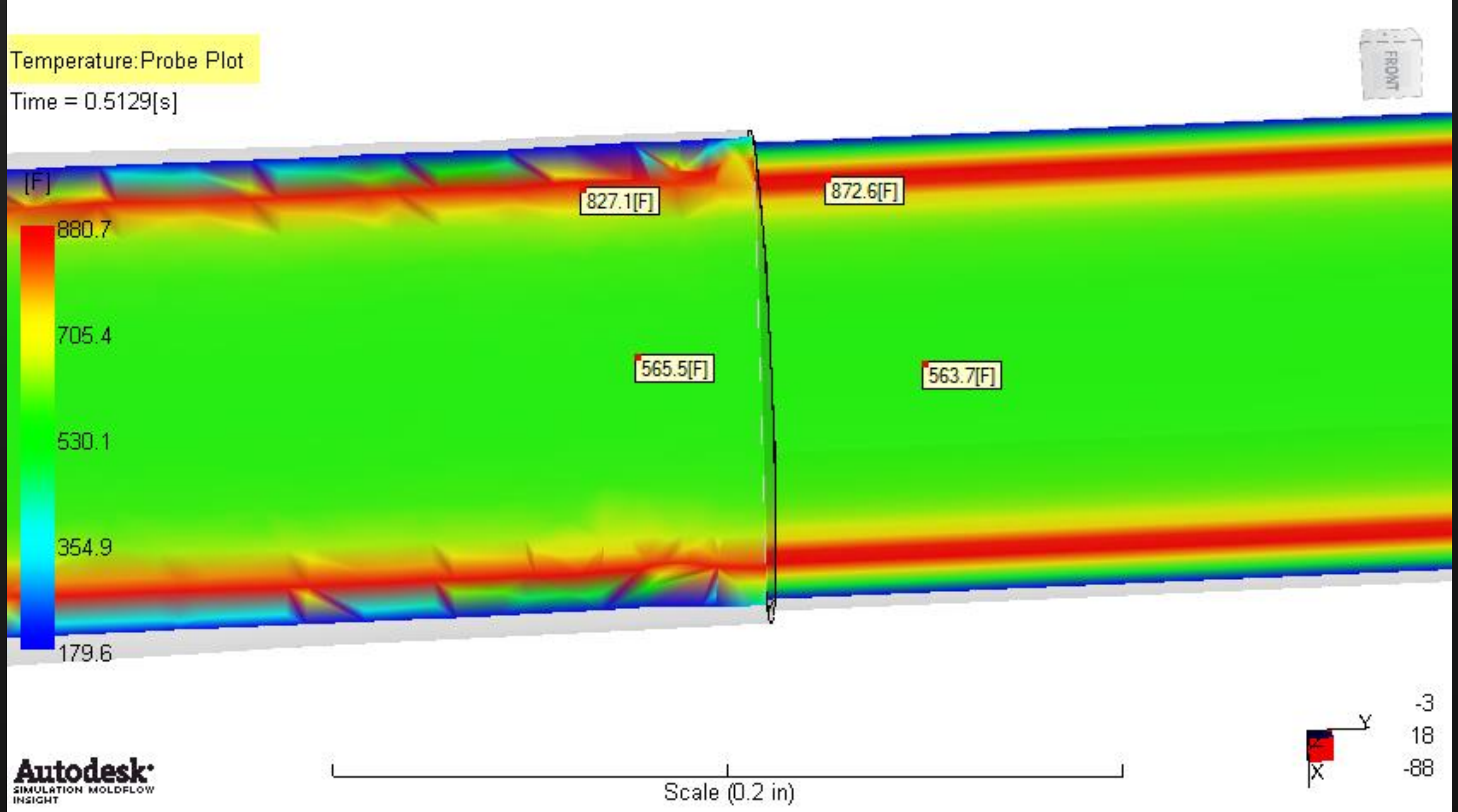
Dell Precision M6500 I7 Q820@1.73GHz 16GB

100 mm Disk – 1-D to 3-D Refined at End



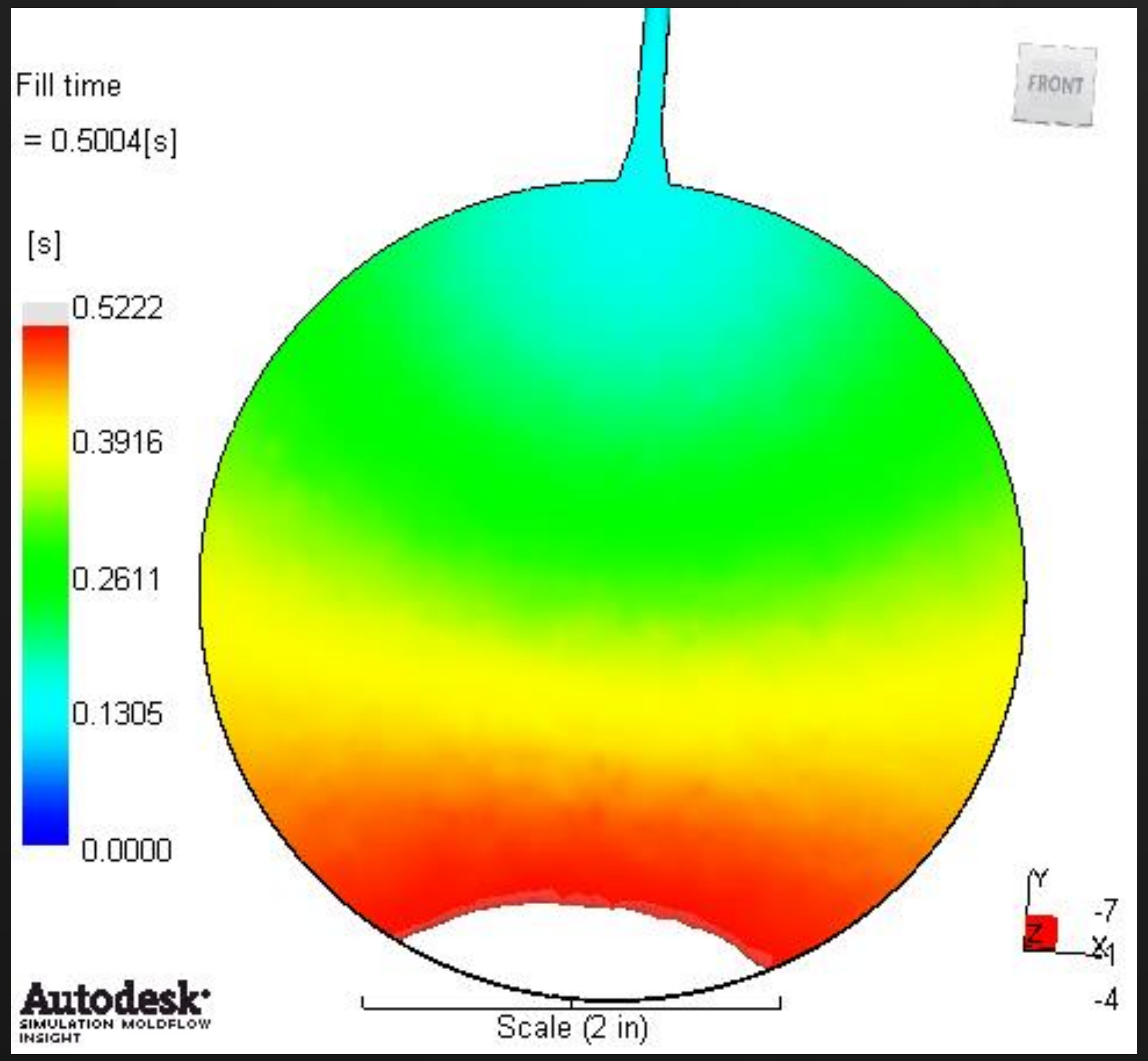


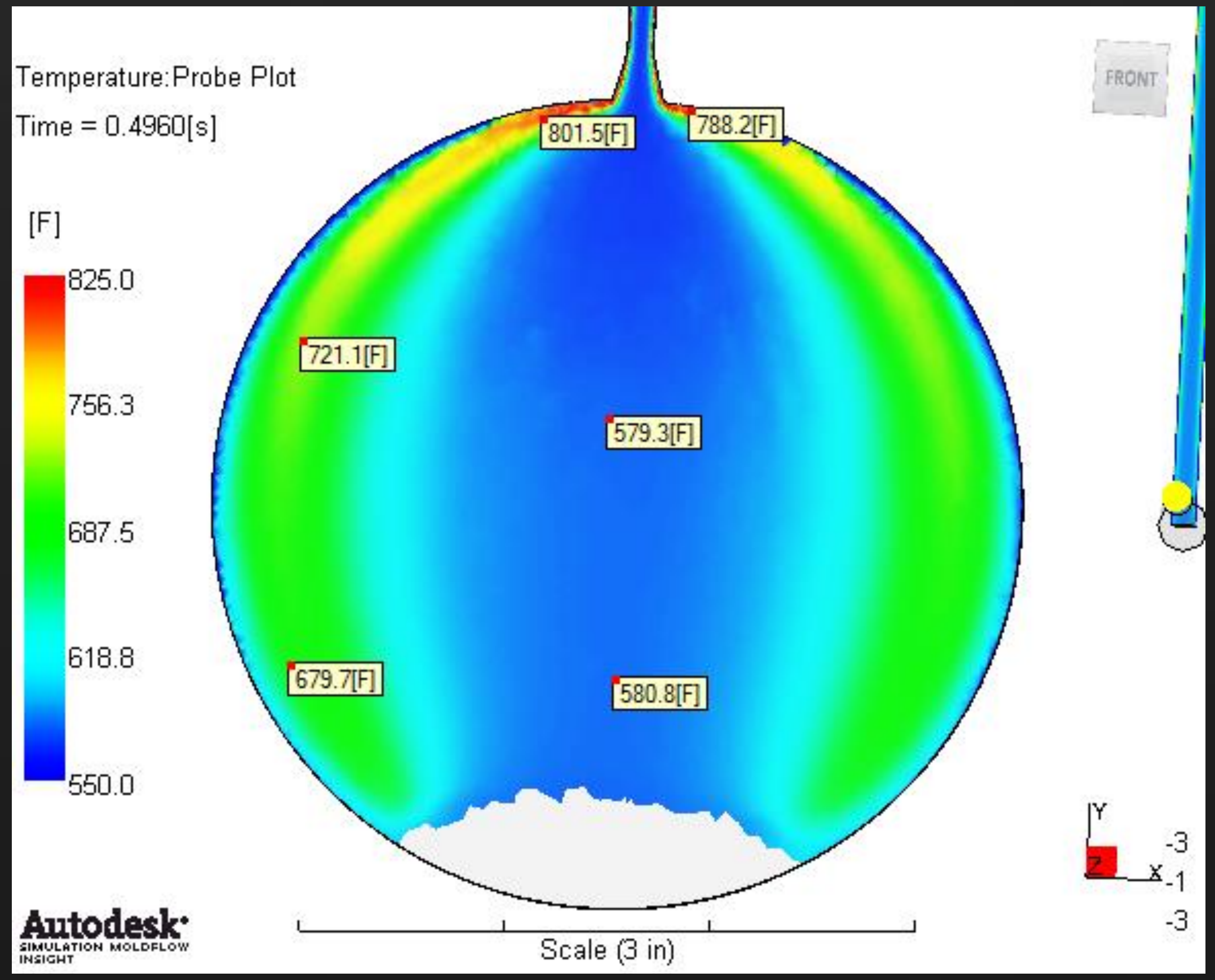


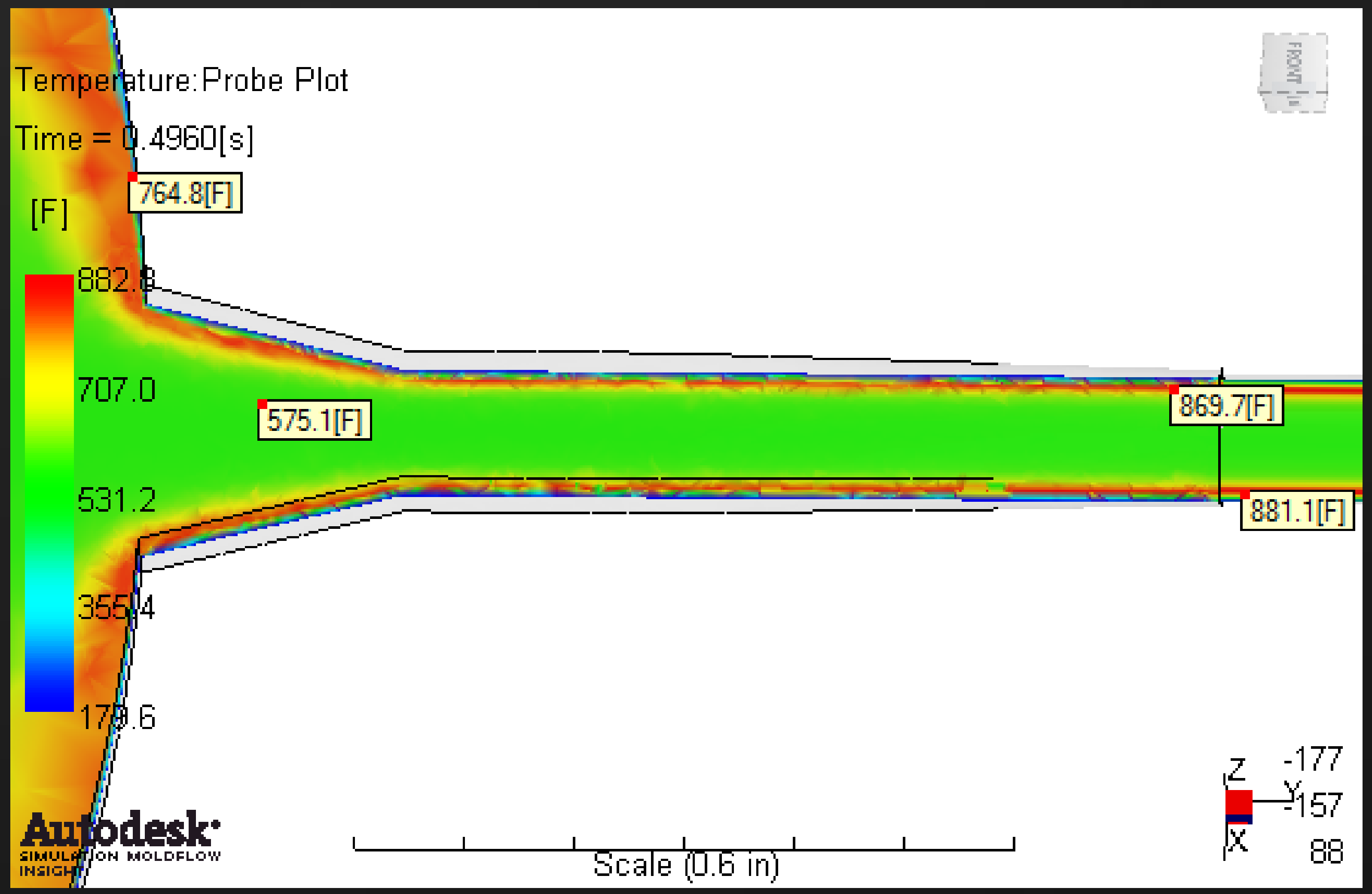


100 mm Disk – 1-D to 3-D Refined at End

Inertia=ON, Absolute=1832° F, 20 laminates





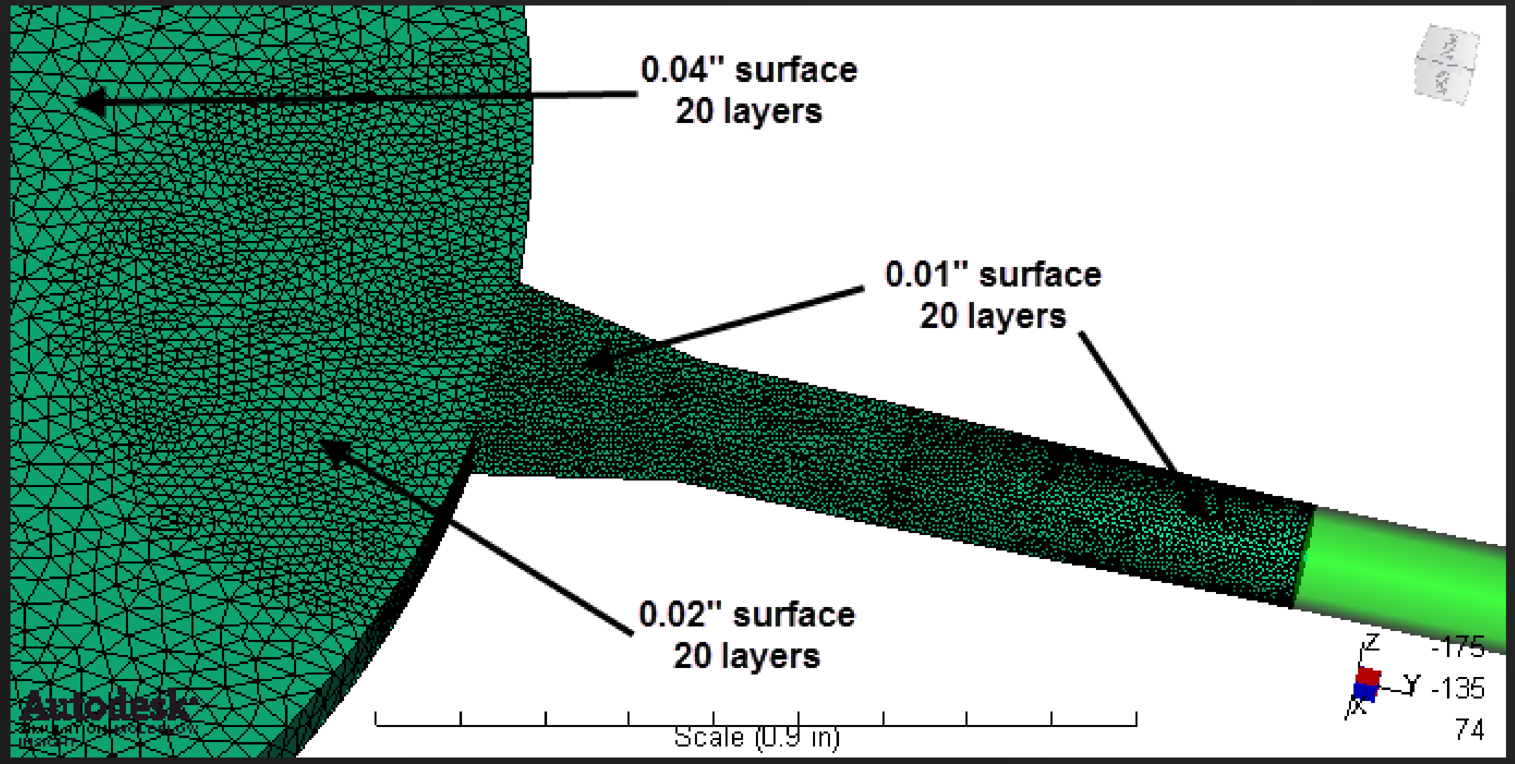


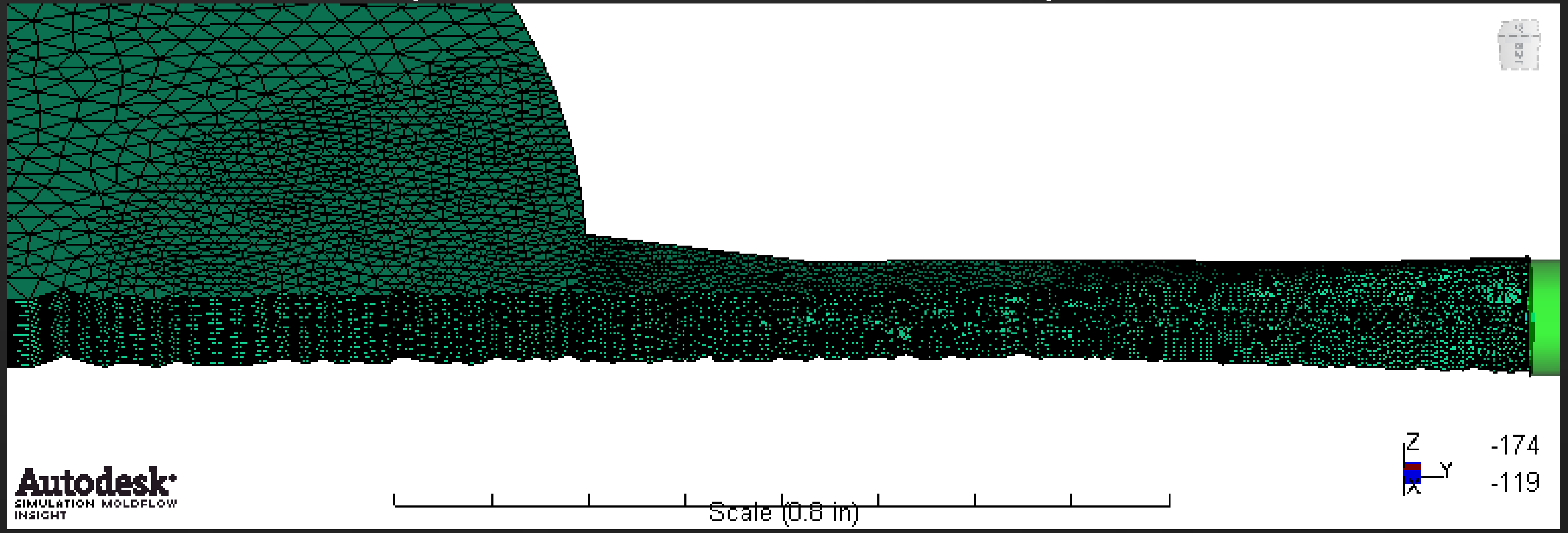
0.48 ME/0hr 26min

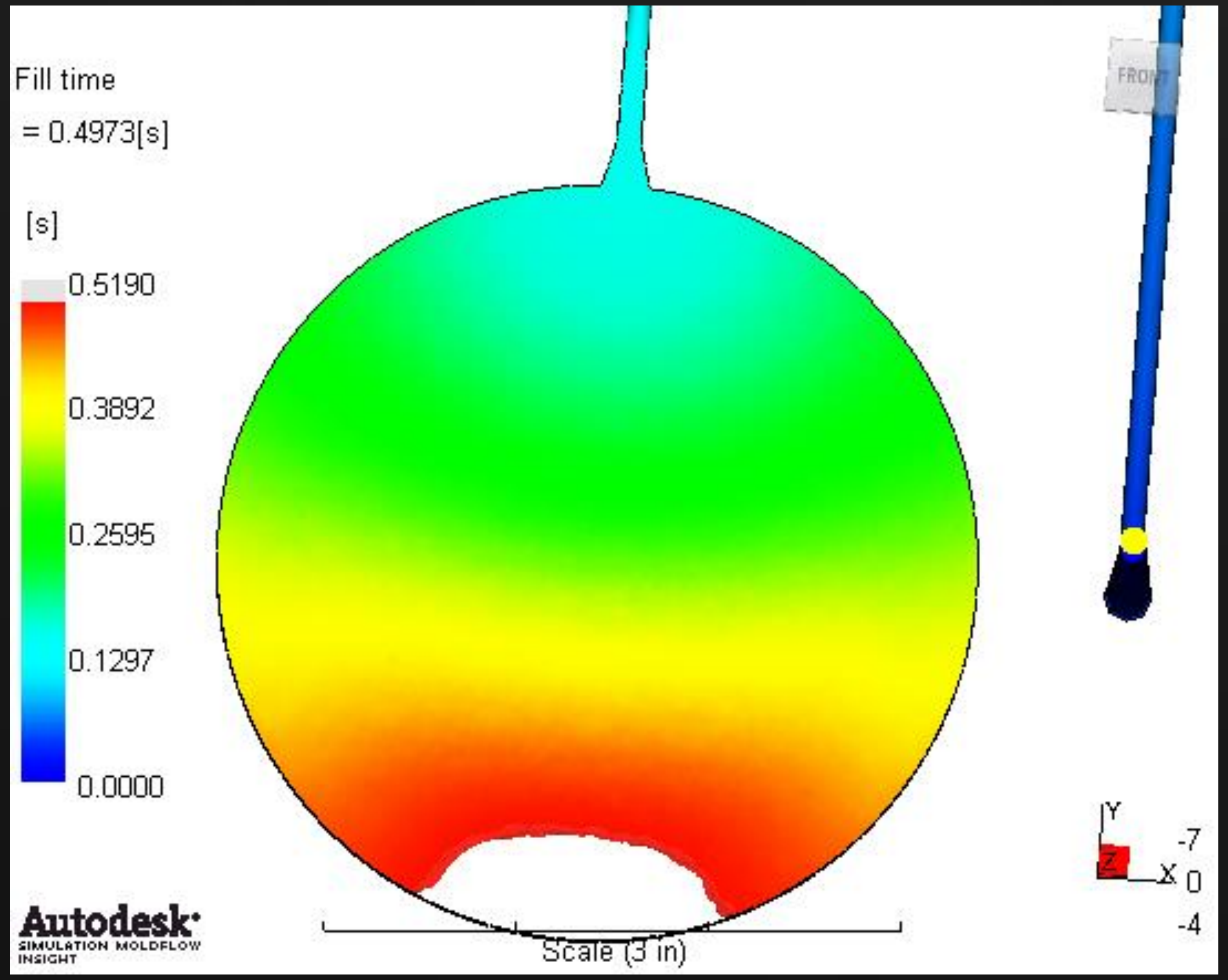
Dell Precision M6500 I7 Q820@1.73GHz 16GB

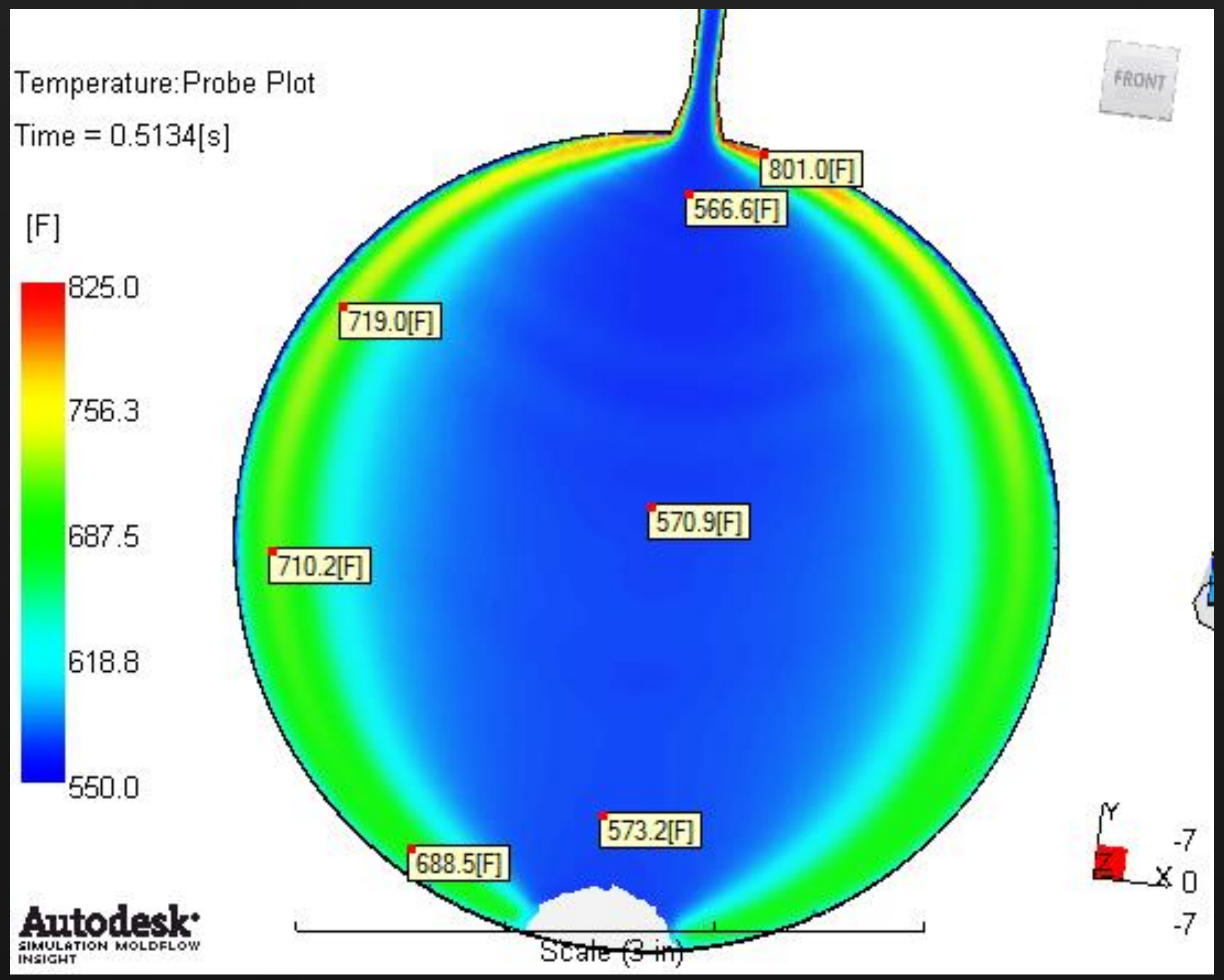
100 mm Disk – 0.04” part/20 layers throughout

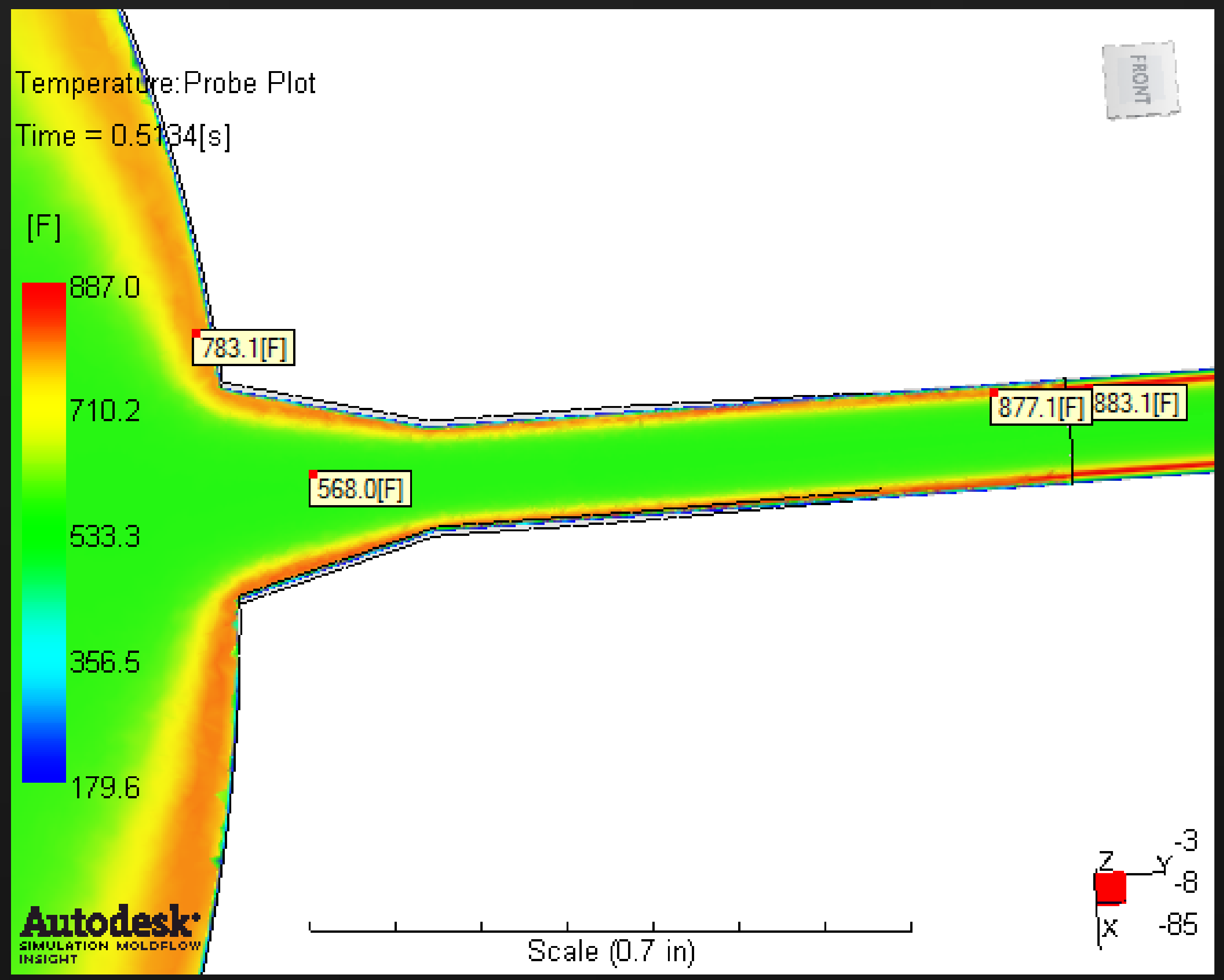
Inertia=ON, Absolute=1832° F, 20 laminates







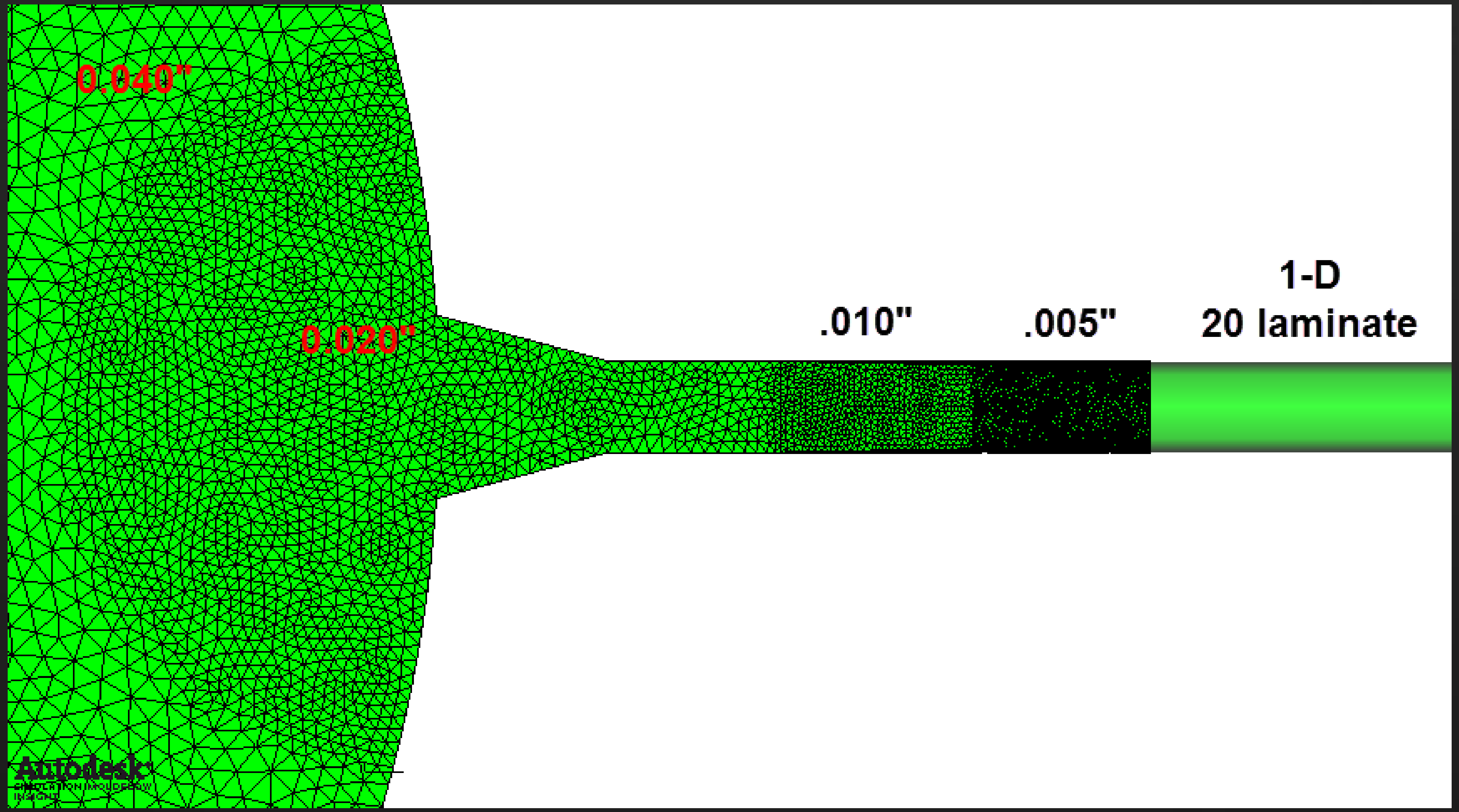


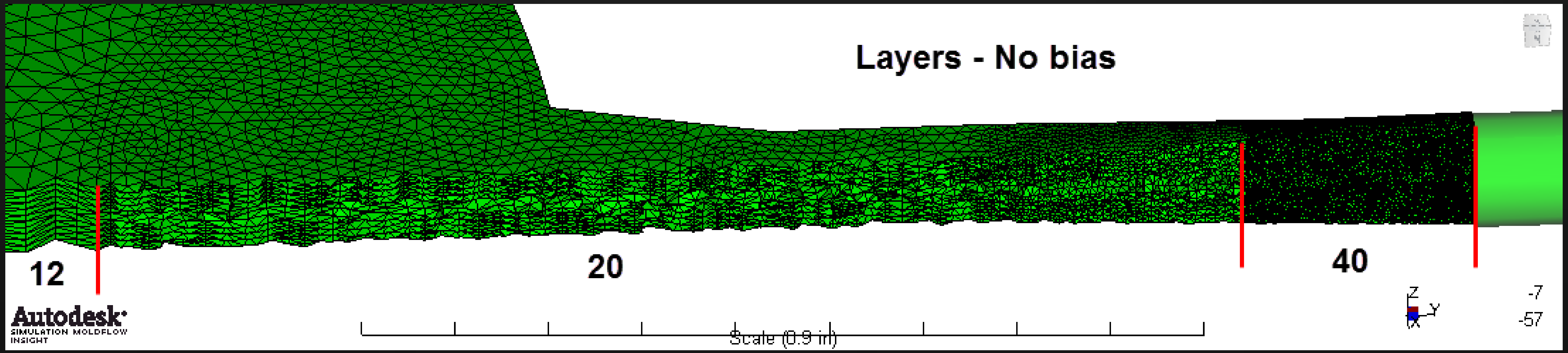


1.75 ME/15hr 12min

Dell Precision M6500 I7 Q820@1.73GHz 16GB

100 mm Disk – 2x the solution time





Inertia Option from Moldflow Help Files

- The classical, complete Navier-Stokes equations (including inertia) for non-Newtonian viscosity are the slowest but most complete solver option. Inertia is the mass-velocity term in the momentum equations. This means that if fluid has a velocity, it will tend to keep that velocity, unless some other force acts upon it. Other forces can include the viscous forces (stresses) which come from shear deformation. In the particular case of injection molding of polymers, the viscous stresses are very large compared to the inertia terms. This is because of the relatively high viscosity of polymer melt (compared to other fluids such as air) and the narrow cavities through which polymers are injected. This is equivalent to saying: In injection molding, the Reynolds number of the flow is usually much less than one and so inertia terms are not significant.
- Generally, use the inertia option when the Reynolds number is expected to be greater than 1. Even then, consider whether your analysis needs to have this accuracy. There might be high velocities in a small gate region, but if the gate is only a small contribution to the total injection pressure, there may be little difference in results with or without inertia.
- If the inertia term is removed from the momentum equations, the calculations are simplified and so make some analysis speed improvement. Since in most cases, the dropping of the inertia term will make no difference to injection molding predictions, this option is a good choice for most users. A Navier-Stokes analysis without inertia terms is sometimes called a Stokes analysis. The speed saving is about 10% to 30%.
- By default, the inertia option is turned off.

Inertia – On or Off?

- No hard, fast rule – dependent on the problem
- May be able to use Extension Result to help assess need
- Always on will not hurt solution but will hurt solution time

  10% to 30% penalty
- Always off will sometimes give you inaccurate melt-front results

Extension Rate Result
Only Applies to 3-D Elements

Extension Rate from Moldflow Help Files:

Extension rate represents the amount of elongation the polymer undergoes as it passes through a change in thickness. Typically this is strongest at gate regions where the flow rate is high and the thickness changes can be large. A contraction is a reduction in thickness along the flow direction, and results in a positive extension (elongation) of the melt. Such extension occurs at the entrance to a gate. Inversely, a negative extension (compression in the flow direction) is experienced by the melt as it passes through an expansion (increase in thickness) such expansion occurs where a narrow gate connects to a thick part of the cavity. Fiber filled materials undergo significant orientation in regions of strong extension flow.

The Extension rate result can be used to see where the flow is undergoing a significant elongation deformation. This will have implications for understanding the additional pressure drop which occurs at gates (sometimes called the entrance pressure loss). The extension rate result is only available on tetrahedral elements. It is not available on beam elements.

When the Extension rate (3D) result is displayed, scale the result using Results tab > Properties panel > Plot Properties and the Scaling tab.

The extension rate is equal to zero in a part with uniform thicknesses. When material flows through a contraction in the part, extension rate is positive, and when material flows through an expansion, extension rate is negative.

An extension rate of 200 or less is acceptable. If the extension rate is higher than 200, the effects of extensional viscosity need to be considered, as the extensional viscosity may significantly increase the injection pressure required to fill the part. If the material you have selected has juncture loss coefficients data, the effect of extensional viscosity has been incorporated in the result.

Local thickening at the end of flow or in thin sections can be used to reduce extension rate.

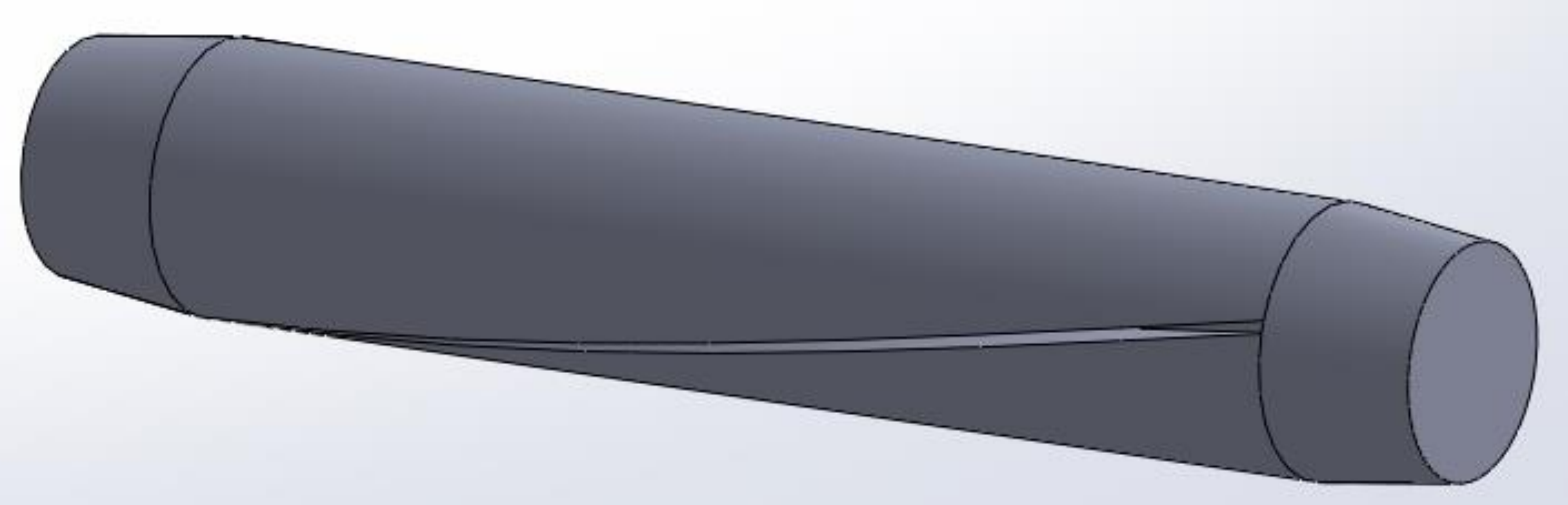
Extension rate is related to flow kinematics and geometry. In injection molding sense, extension rate is more dependent on flow rate and geometry. The material property may influence the extension rate, but not dependent upon it. It is more like that the viscosity is influenced by extension rate.

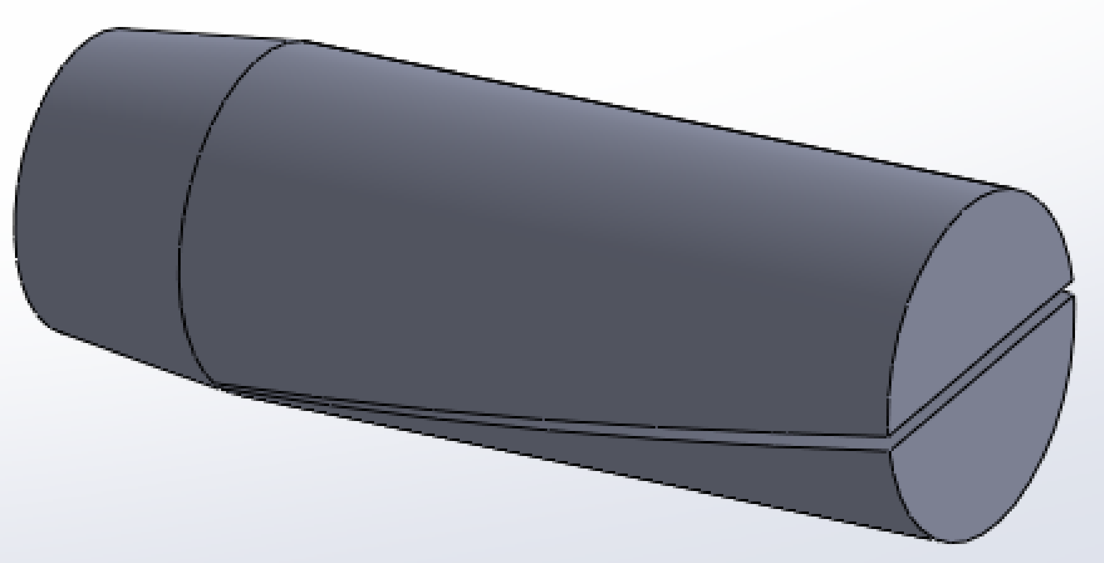
Other Ways to Affect Shear Rate

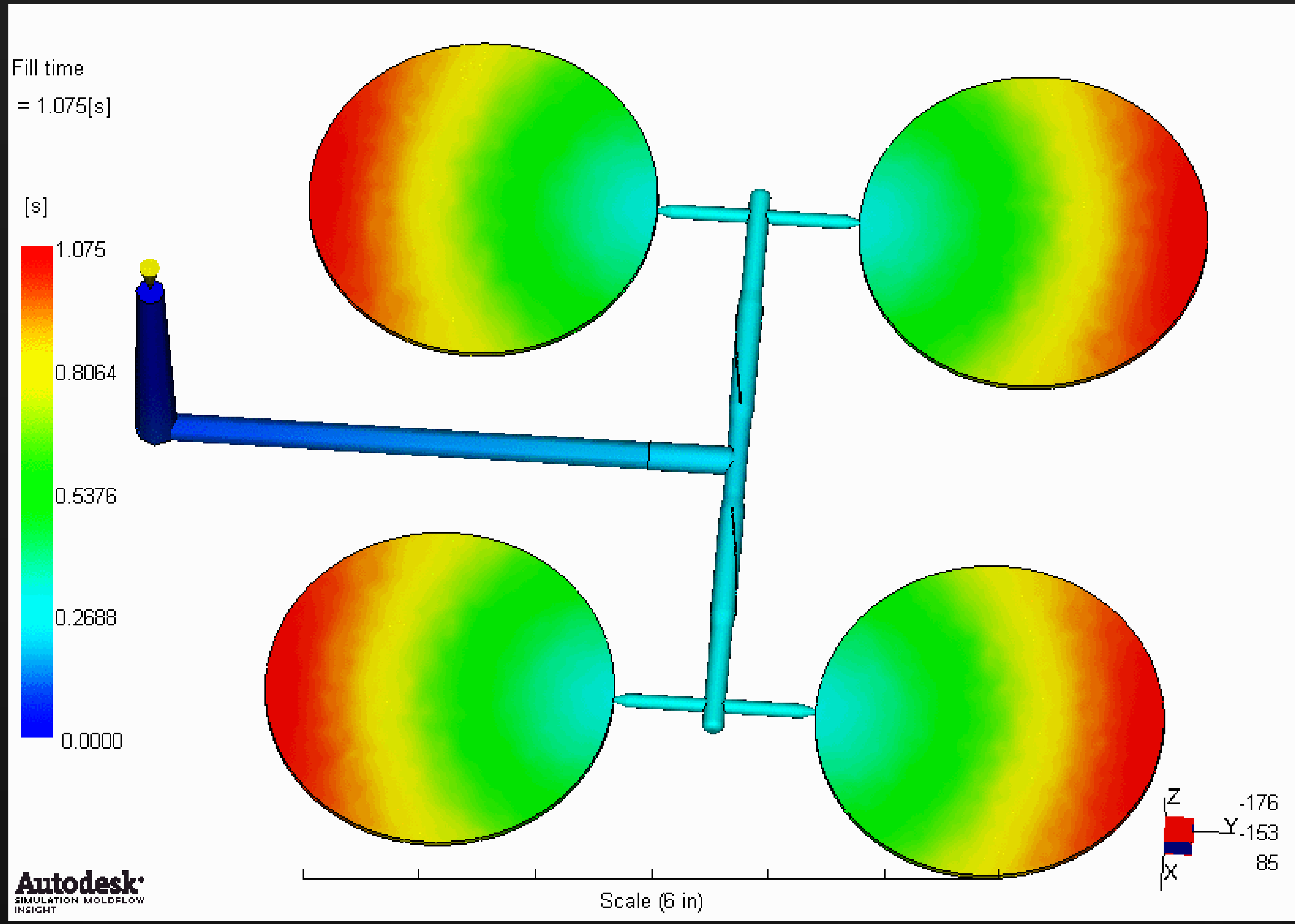
Other Ways to Affect Shear Rate

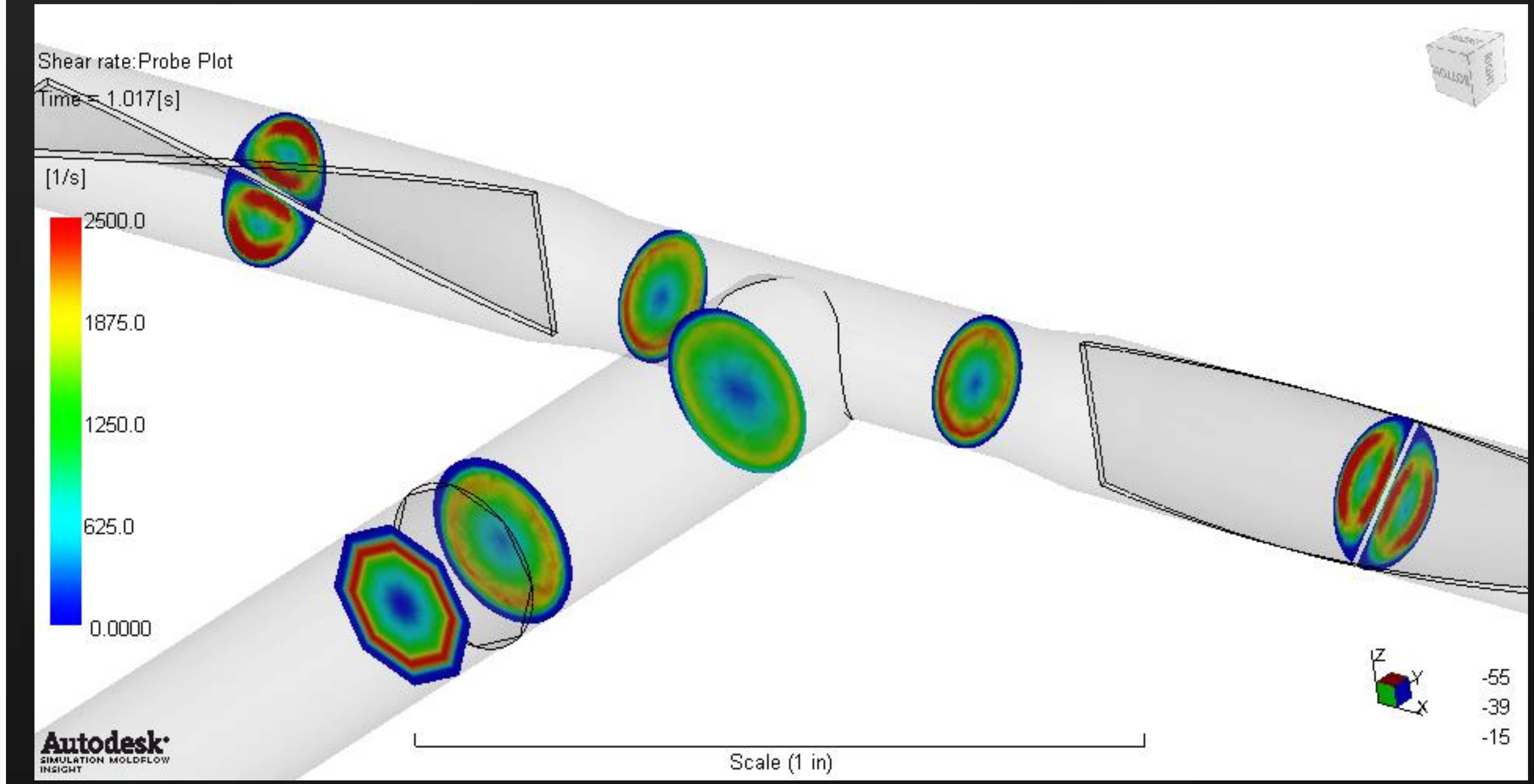
- Virtual solutions that may not be legal
- Process conditions
- Layout, Diameter, Gate style & size
- Material

Static Mixer

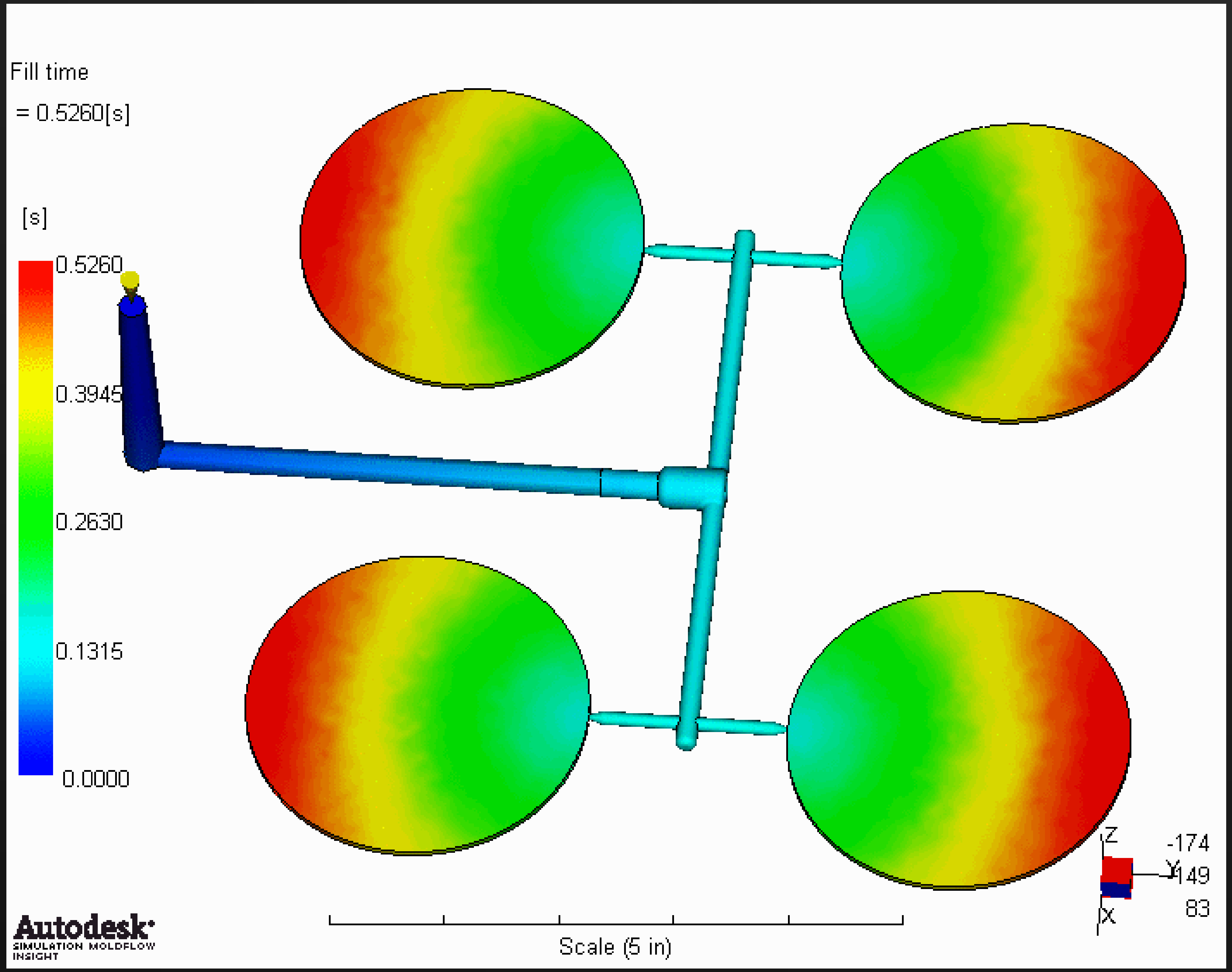


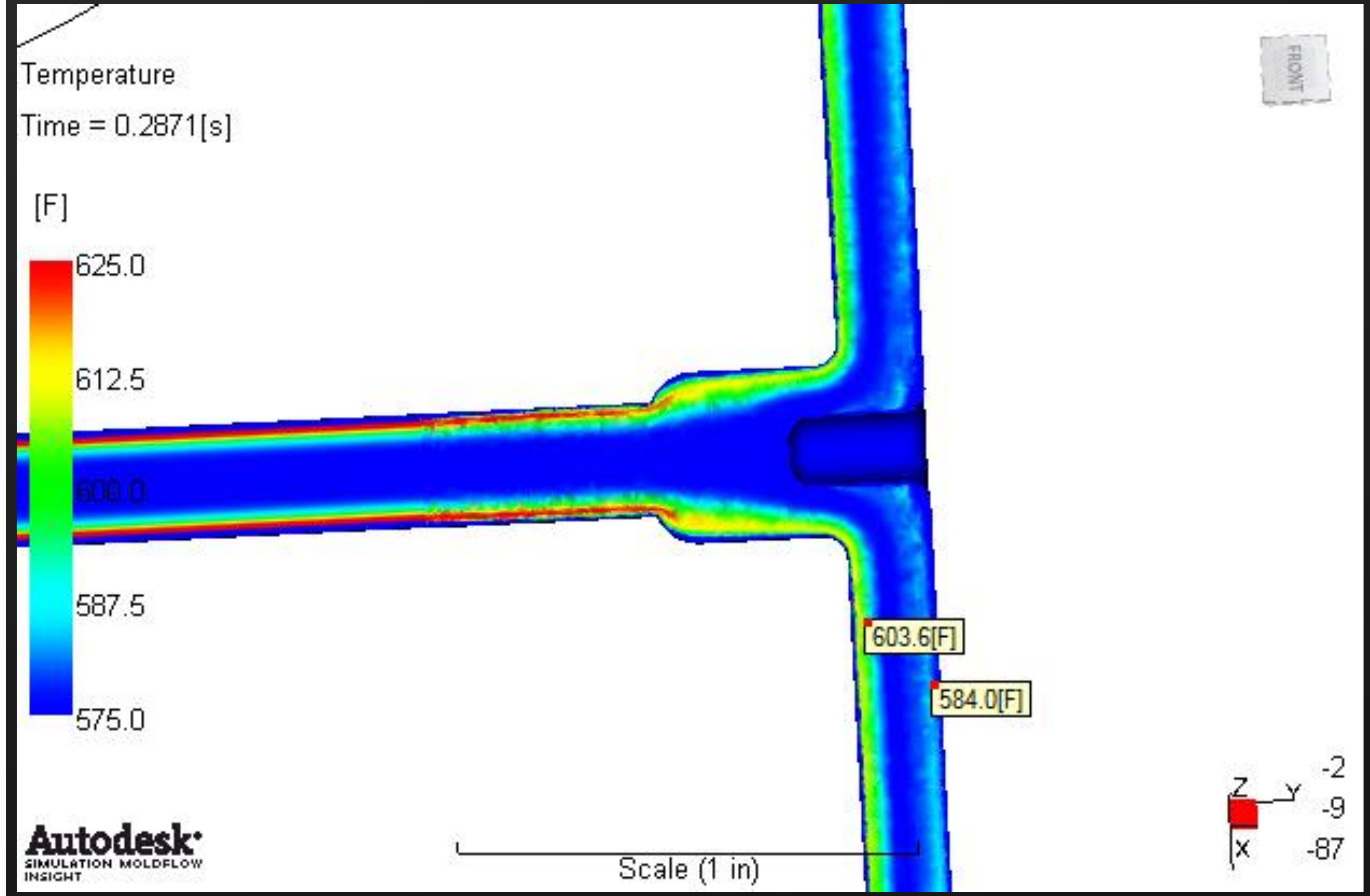




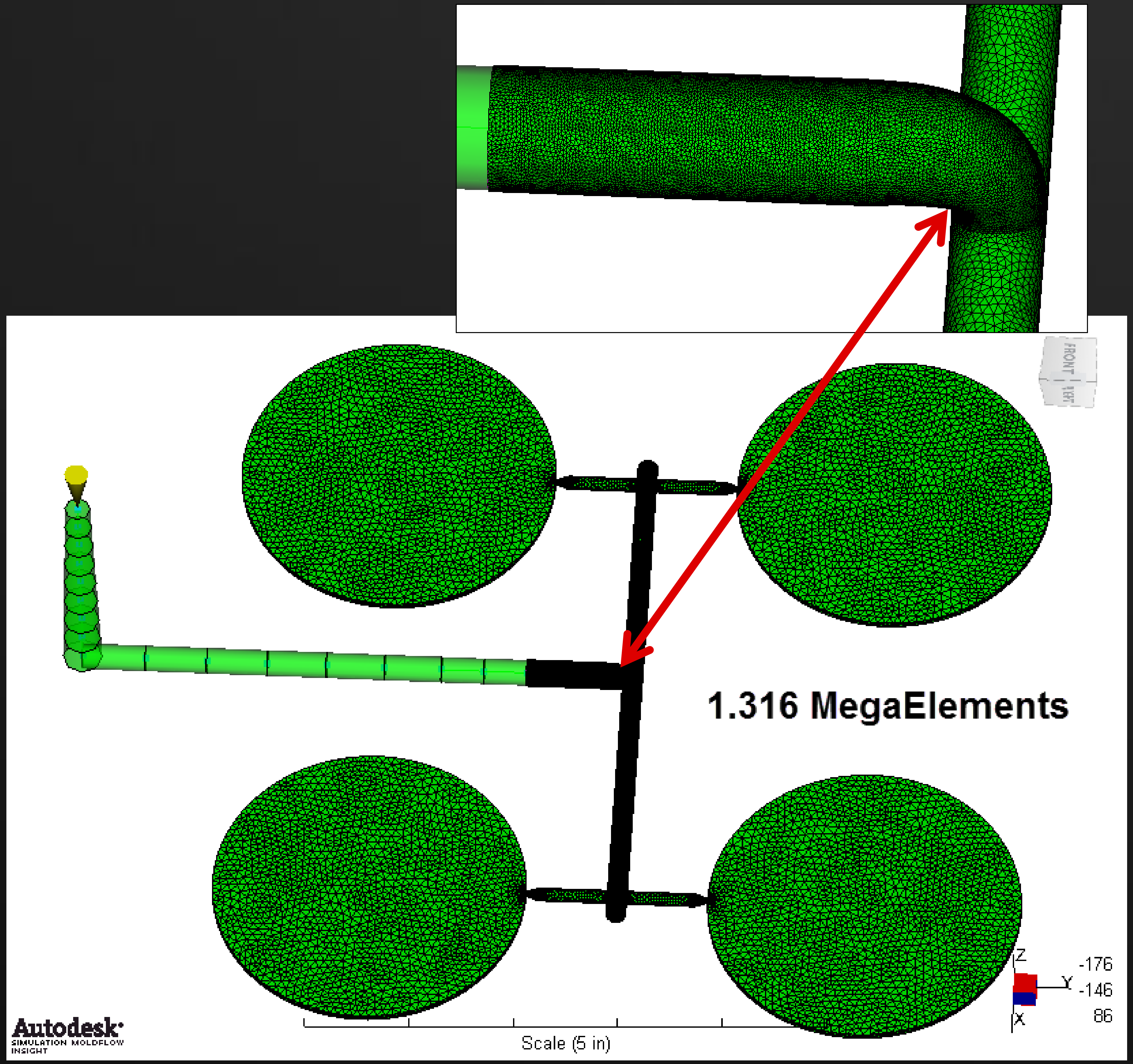


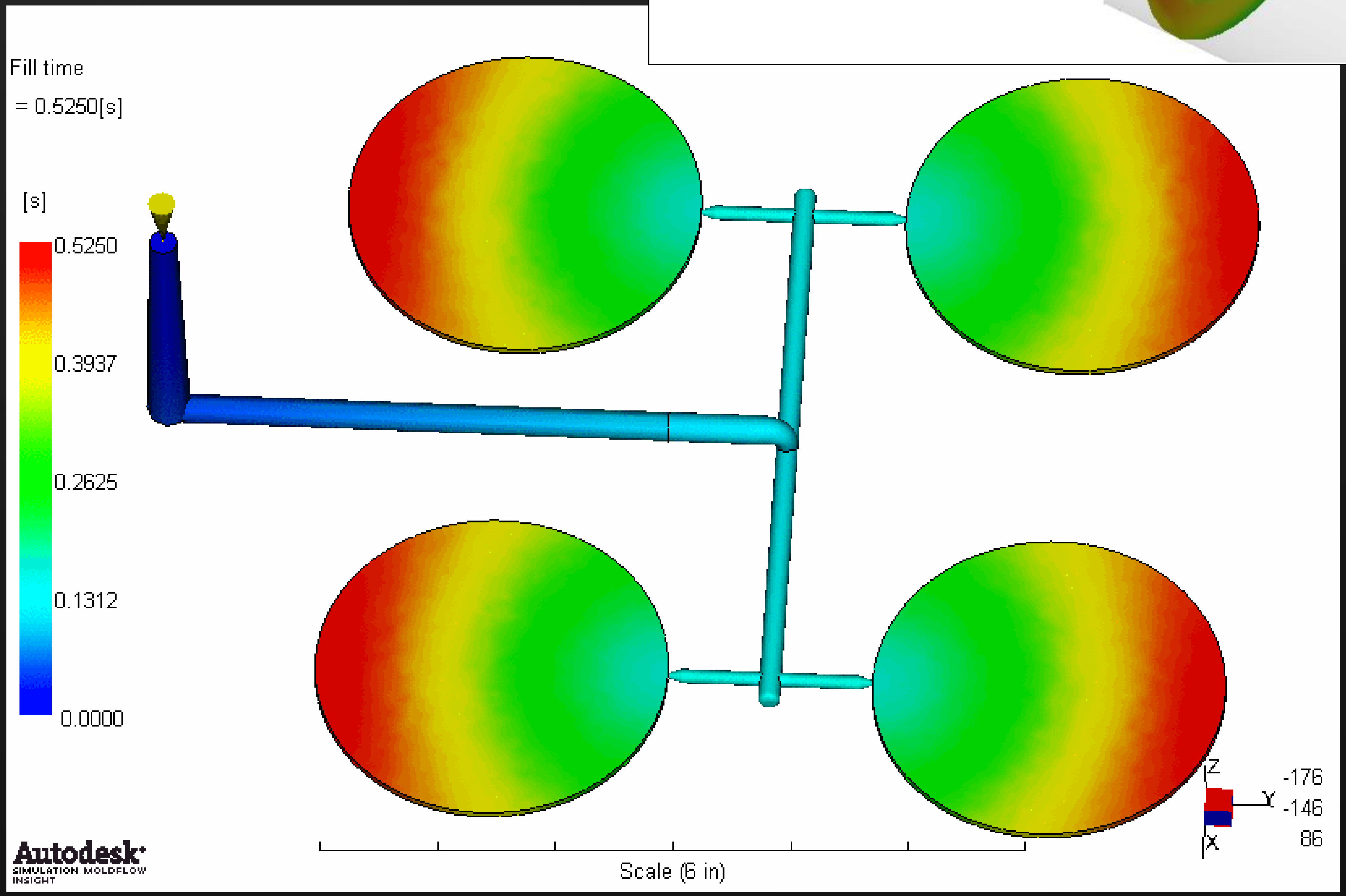
Expansion Area

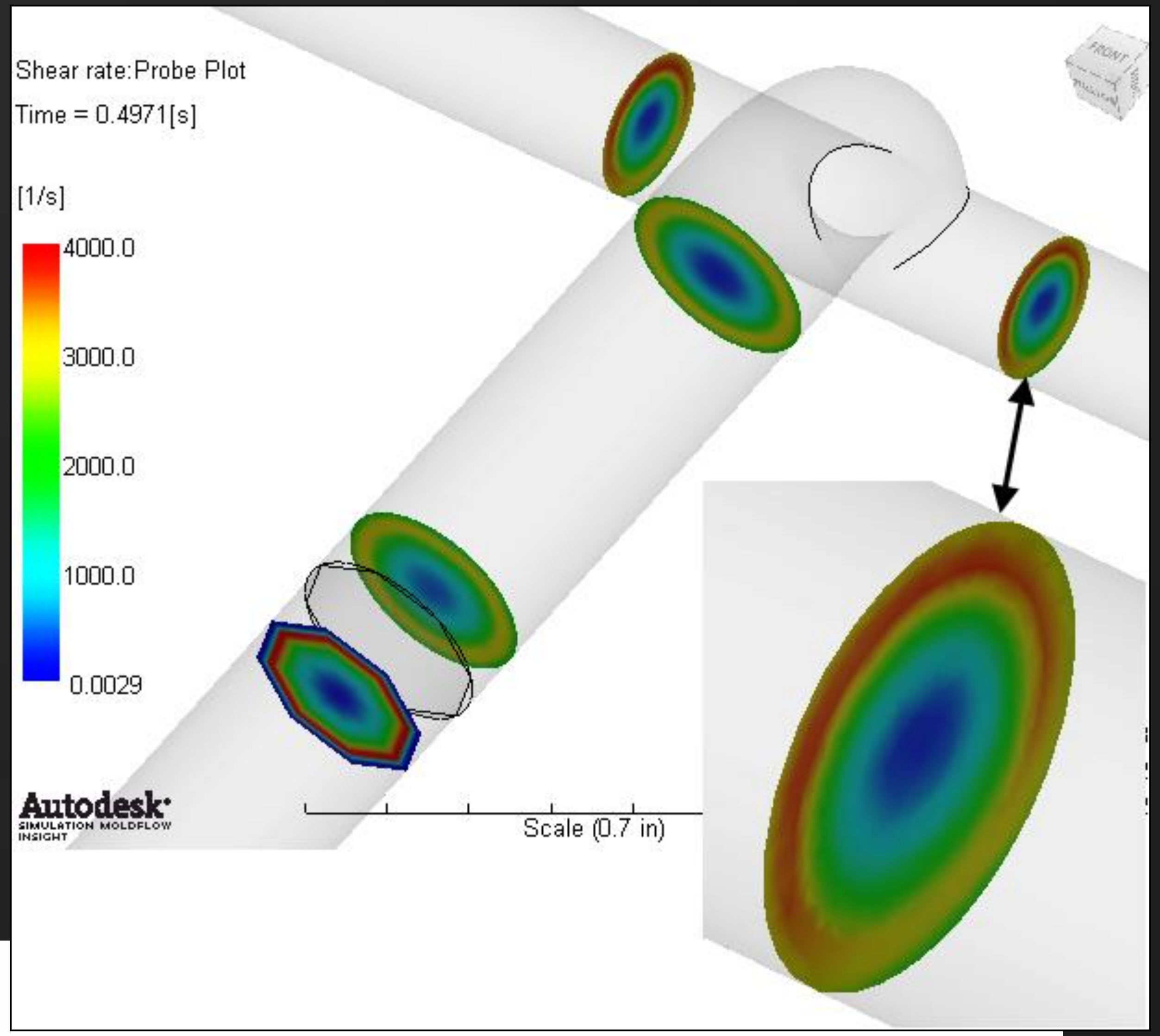




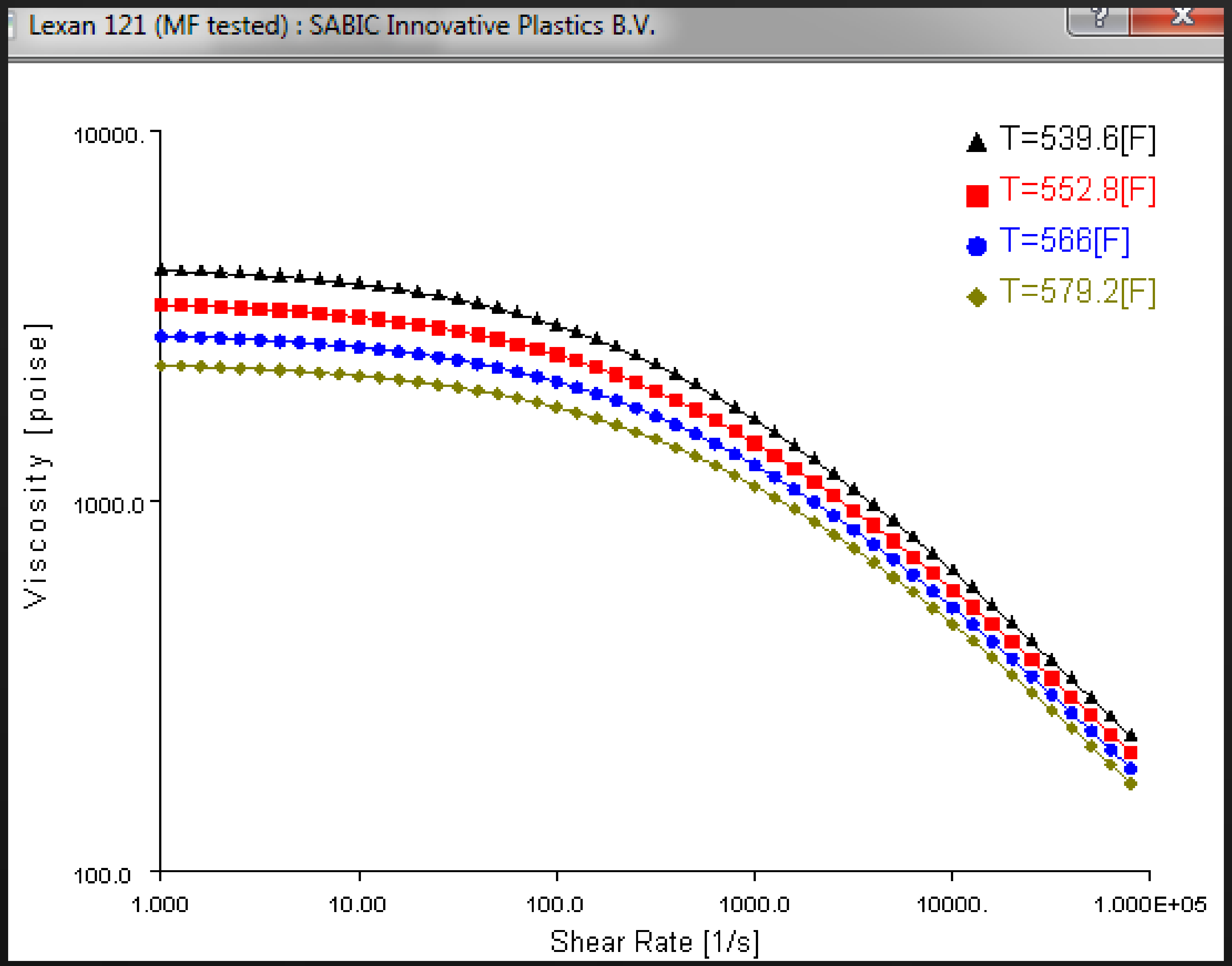
Two consecutive branches must not be in the same plane

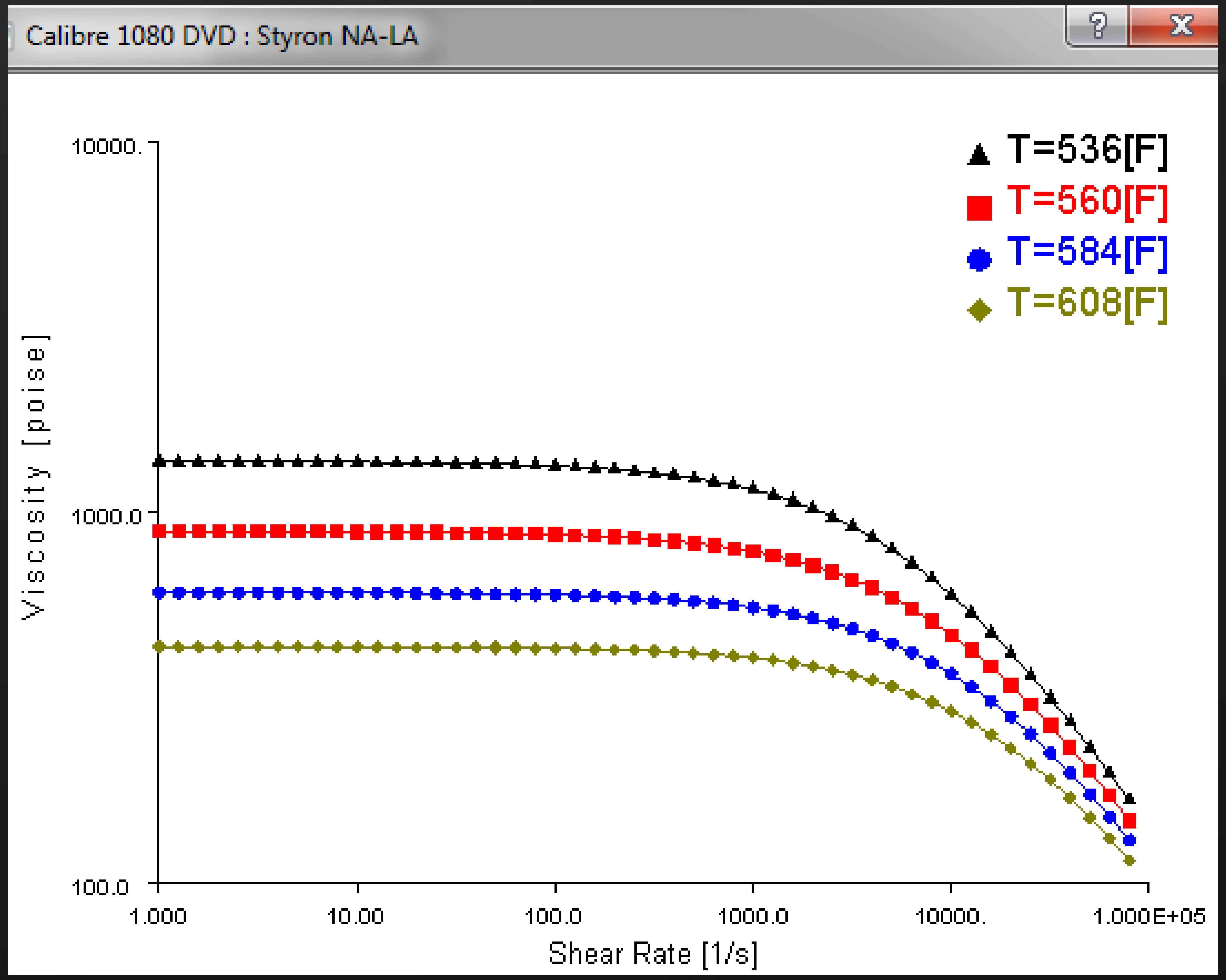




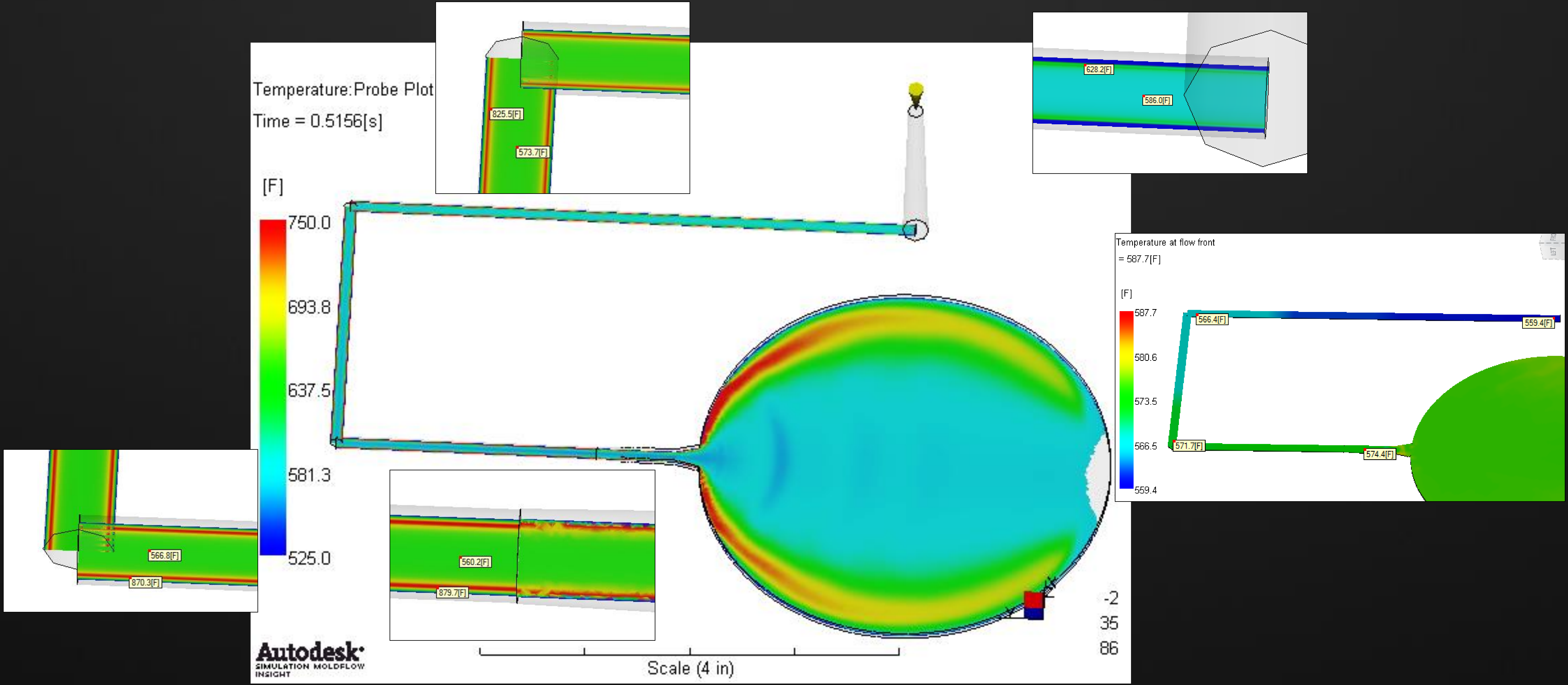


Material – Shear Rate vs. Viscosity

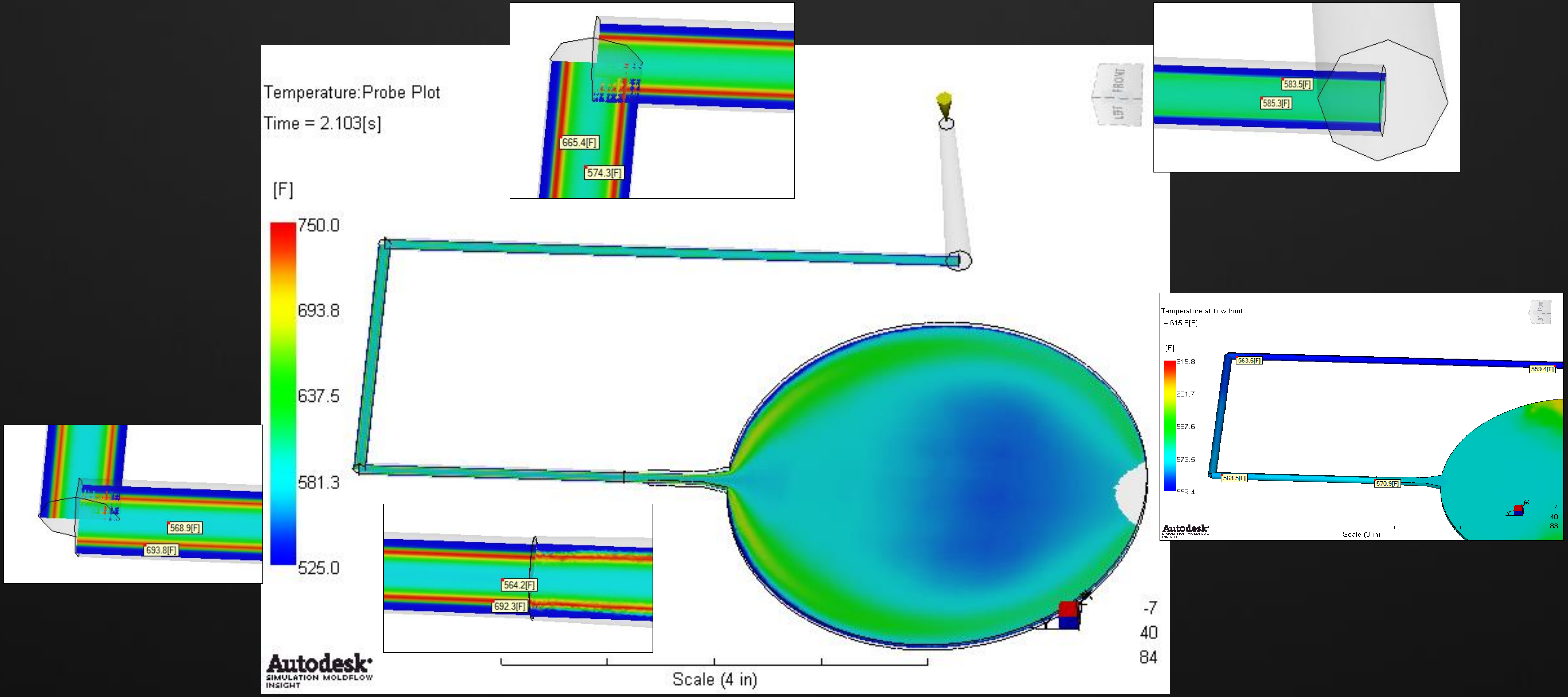




Reduce Flow Rate – 0.5 s fill time

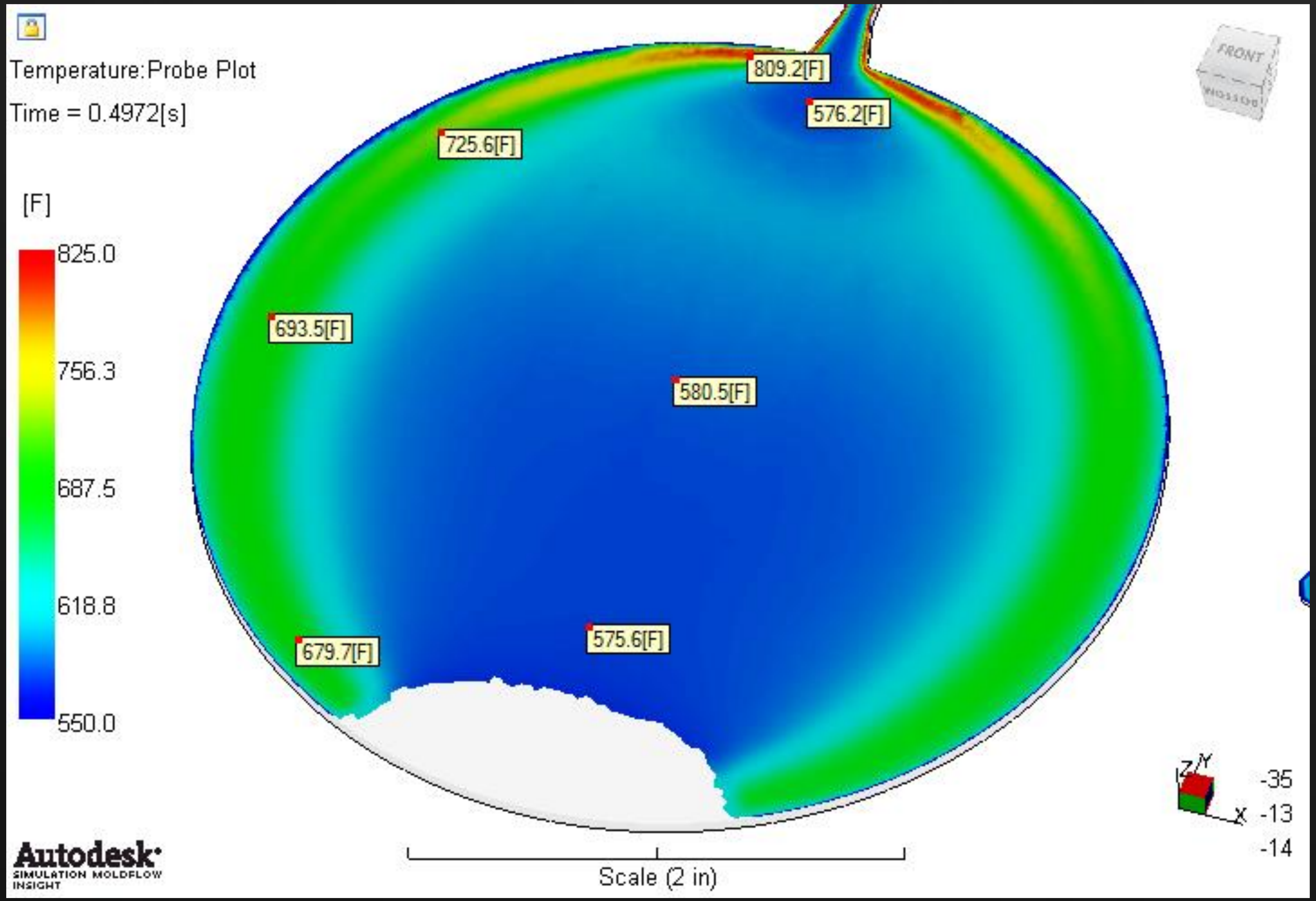


Reduce Flow Rate – 2.0 s fill time

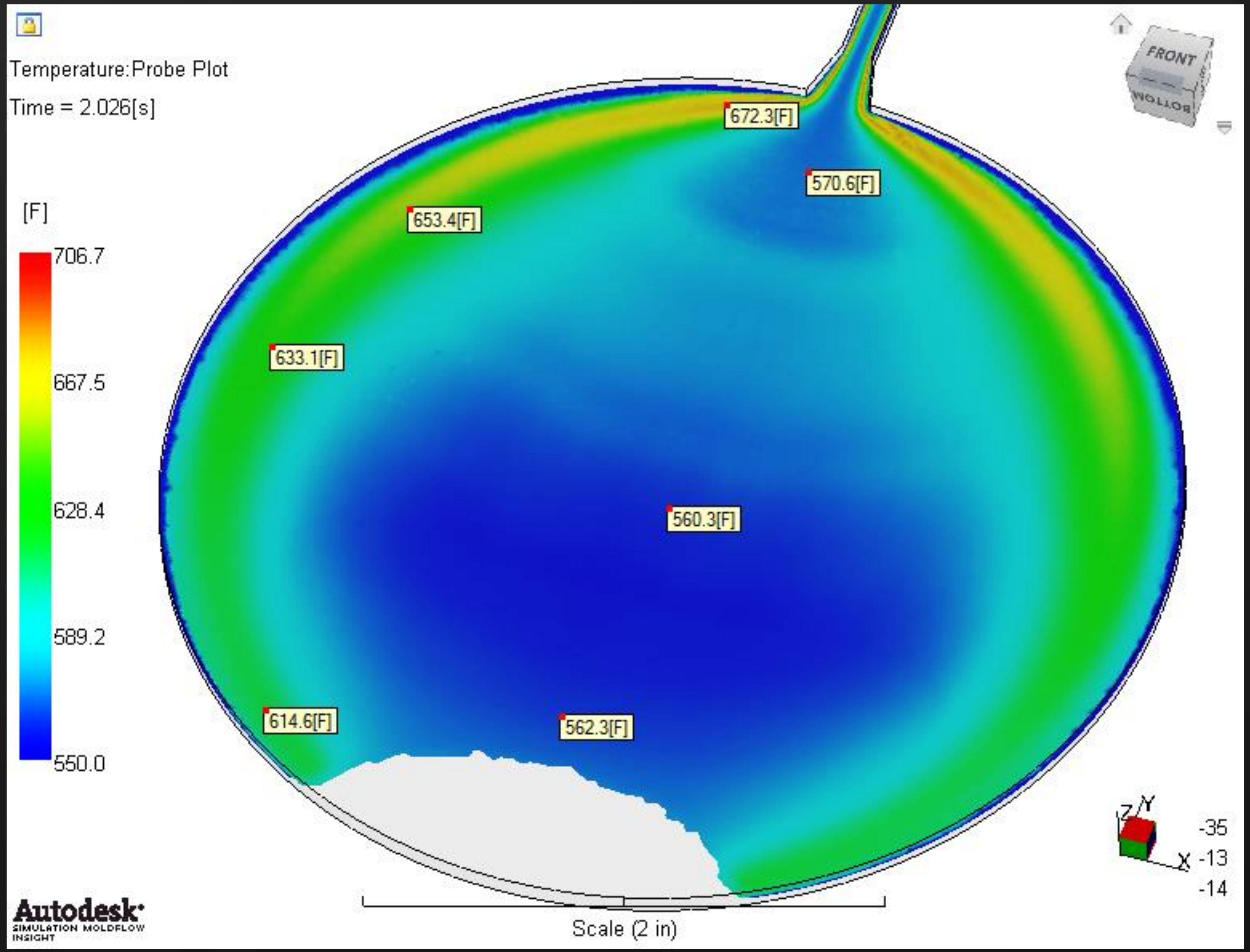


100 mm Disk

Optimal

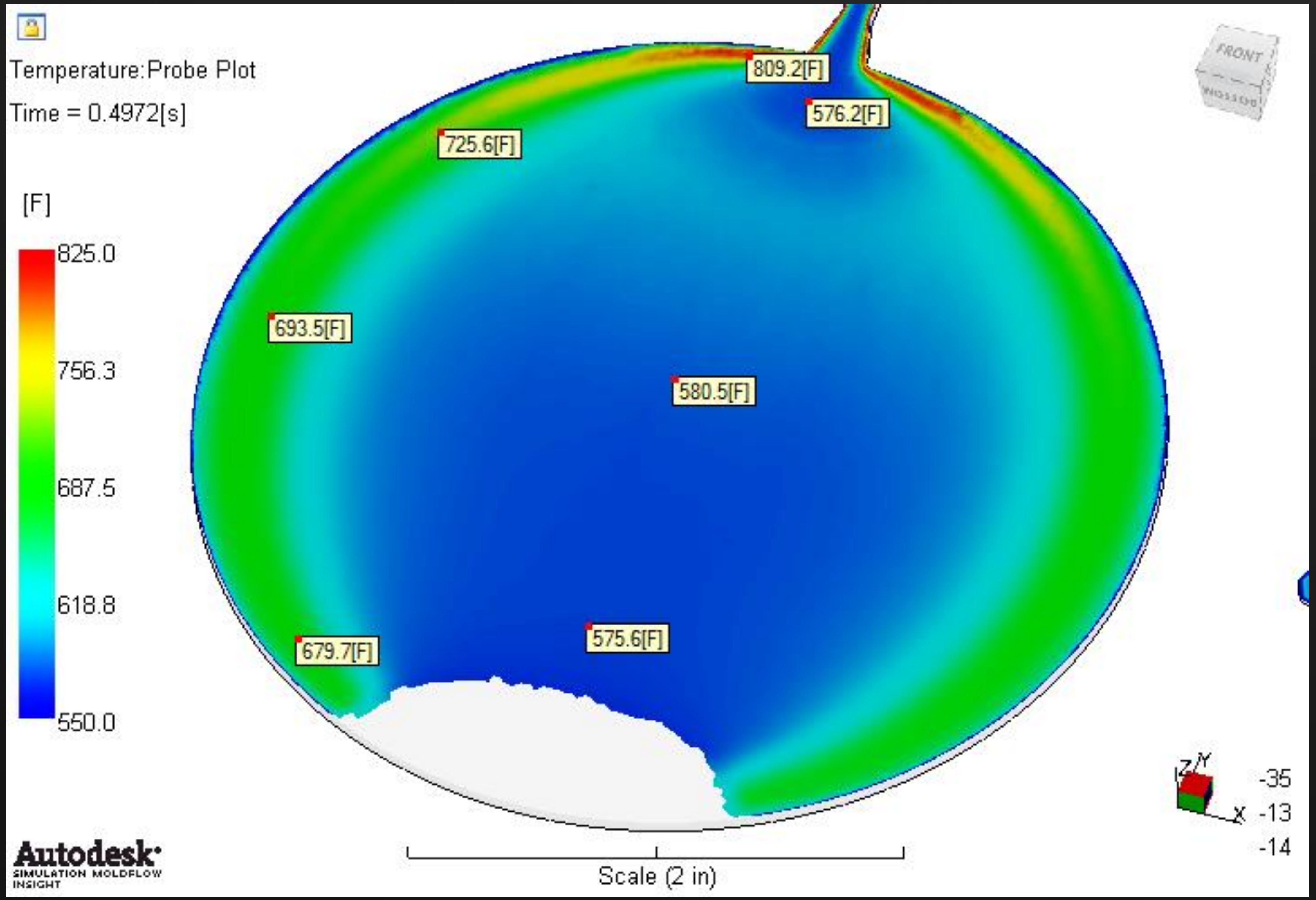


2 s Fill Time

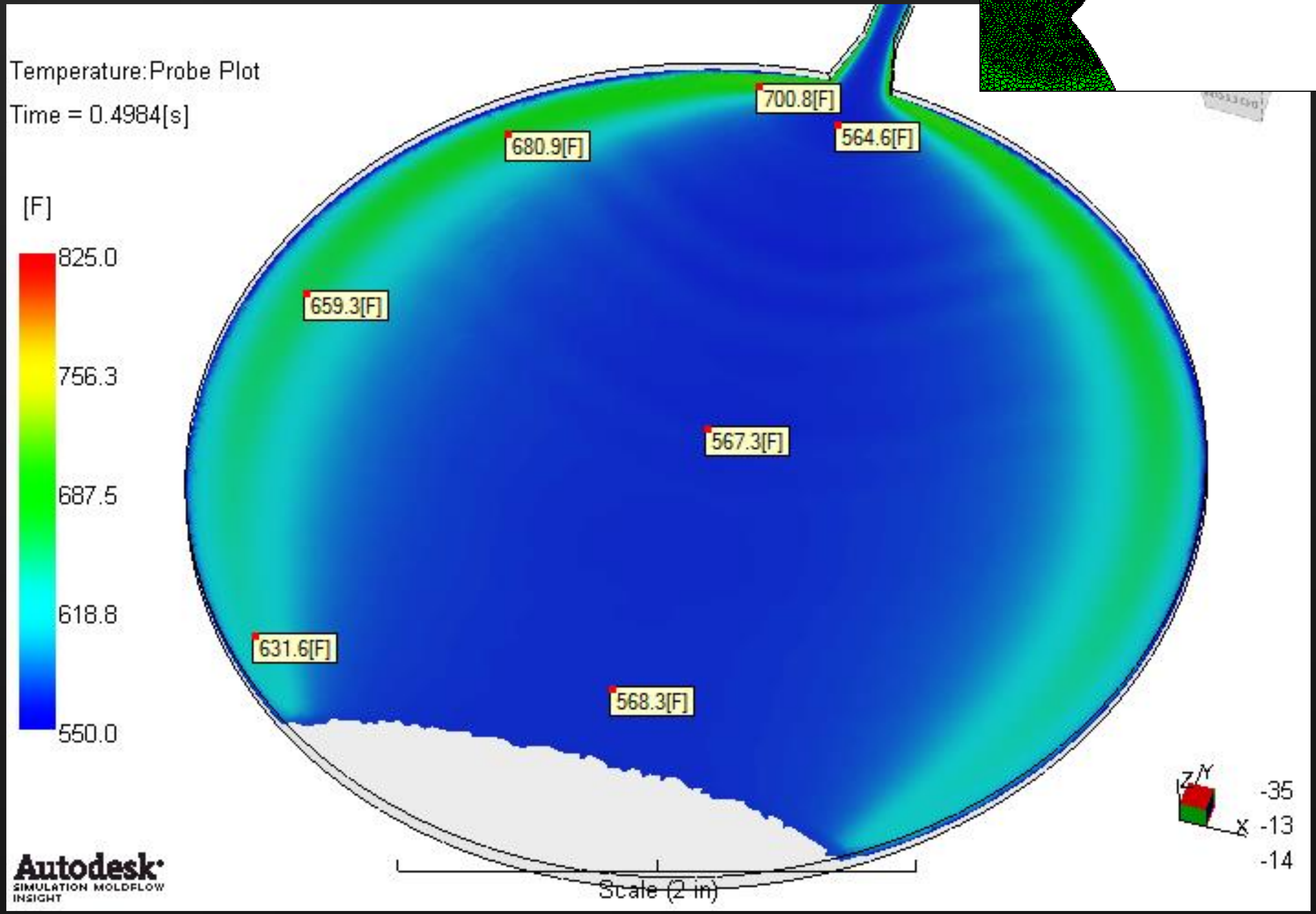


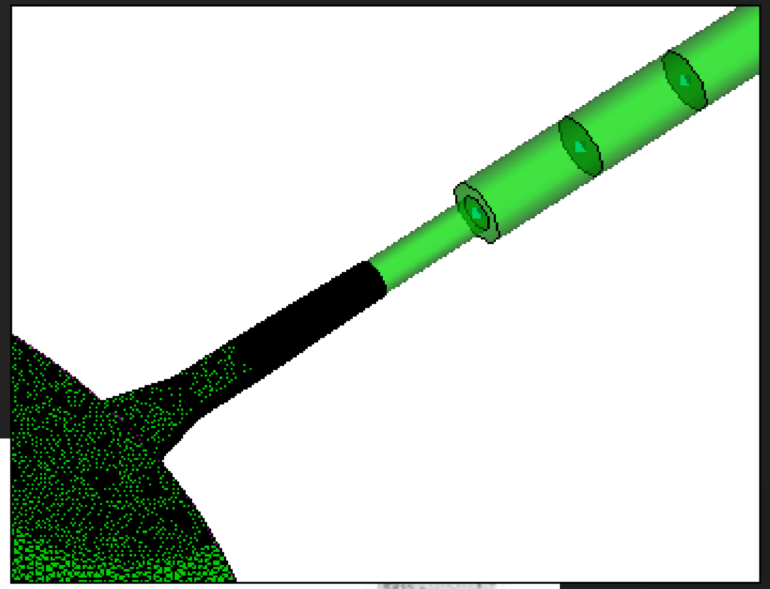
100 mm Disk

Optimal



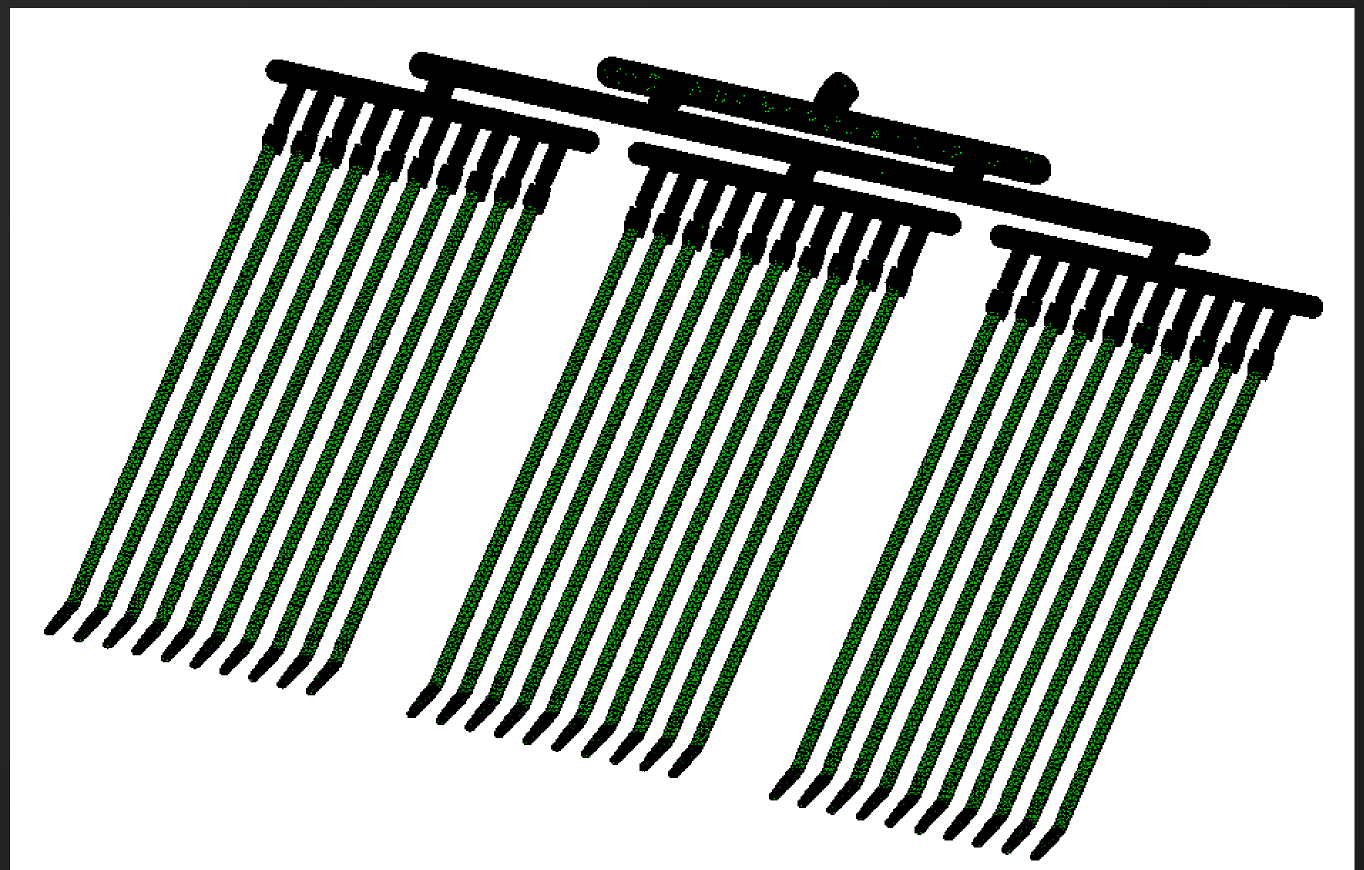
Bigger Runner (0.219”D vs. 0.125”D)

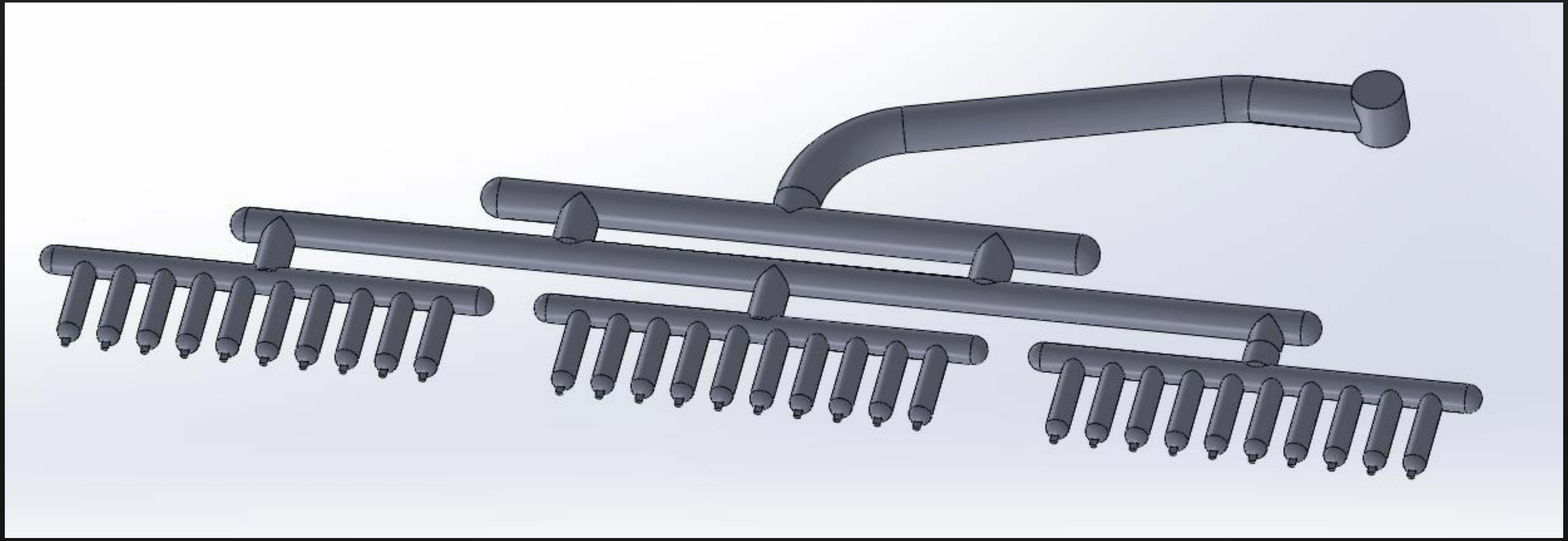




Comparative ΔP (Runner Flooding)

Smaller the pressure drop in the runner compared to the pressure drop in the parts, the less likely shear imbalance will be a problem.





Juncture Loss/Bagley Correction
Only Applies to Midplane & Dual Domain (Sort of)

- Material Database
  - **2055 of 8816 have the correction**
  - **523 are amorphous**
  - **498 materials: coefficient 1 is greater than 2**

Juncture Loss from Moldflow Help Files:
A large pressure drop is often observed when the melt passes through contractions in the feed system, such as between the sprue, runners and gates, at the entrance of the die. Typically 85% of the pressure loss occurs at the entrance of the die, and 15% at the exit.

If juncture loss data is not available for the material that you selected, you can evaluate whether juncture loss is significant to your application by running Fill analyses with and without juncture loss coefficients. For this purpose, you can use typical values for the juncture loss coefficients, and enter these into the material data. There is an inverse relationship between the coefficients, so as increases, decreases. values range from 0.00001 to 10 (typically 0.0001), while values range from 2.5 to 1 (typically 2). If analysis results show that juncture loss is significant to your application, it is strongly recommended that you have the material characterized by Autodesk Moldflow Plastics Labs for juncture loss coefficients.

Extension Viscosity Model
Only Applies to 3-D Elements

- Material Database
  - **1687 of 8816 have the data**
  - **348 are amorphous**

Extension Viscosity Model from Moldflow Help Files:
The extension viscosity model describes the dependence of the viscosity on the shear rate, temperature, pressure, and extension rate in 3D flow. The extension viscosity coefficients are determined by using the shear viscosity model and experimental pressure measurements in convergent flow.

Note: The extension viscosity model is used only in tetrahedral regions of a 3D Fill+Pack analysis (if this option is selected in the Rheological Properties tab of the Thermoplastics Material dialog). In the case of Midplane and Dual Domain Fill+Pack analyses, and for beam elements in a 3D Fill+Pack analyses, pressure loss due to extension stresses are calculated by using a juncture loss model.

Summary (3 Slides!)

Summary

- Be aware of potential for shear rate issues
- Use common sense to understand implications of part & tool design
- Use Moldflow to help you figure out the risks and make changes
- AMI will accurately pick up the trends if modeled correctly

Summary

Tips for Most Accurate Solutions with Less Compute Time:

- Inertia ON gives the most accurate melt-front advancement
  but doesn’t affect shear rate or temperatures
- 1-D elements provide the greatest shear rate and temperature increase
- 1832° F is required in all cases
- More nodes at 1-D to 3-D interface provides most bang for the Euro
- Most important to have small surface mesh with 20 layers
  at the 1-D to 3-D interface

Summary

Checklist:

- 1-D set to 20 laminar layers
- Maximum absolute temperature to at least 1832° F
- Runners 12-20 layers of 3-D elements
- Increase number of results output to 20
- Turn on inertia
- Use gate diameter setting
- Always look at cross-sections of mesh