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Validation Experiment: Foaming and Filling a Complex Clear Mold

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National Nuclear Security Administration

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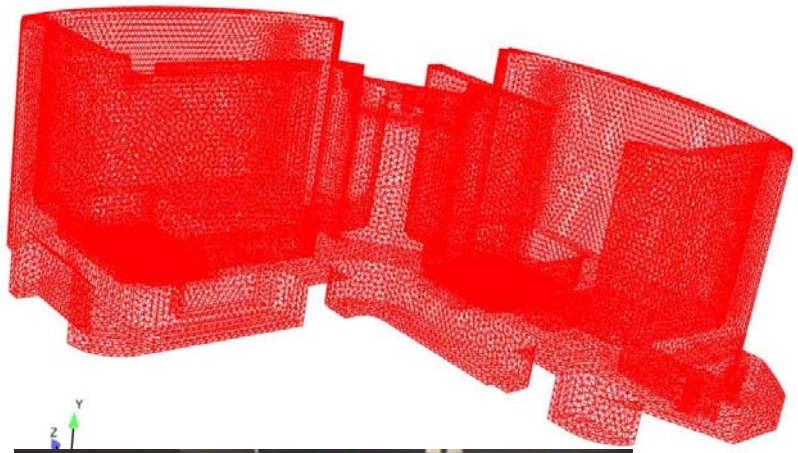
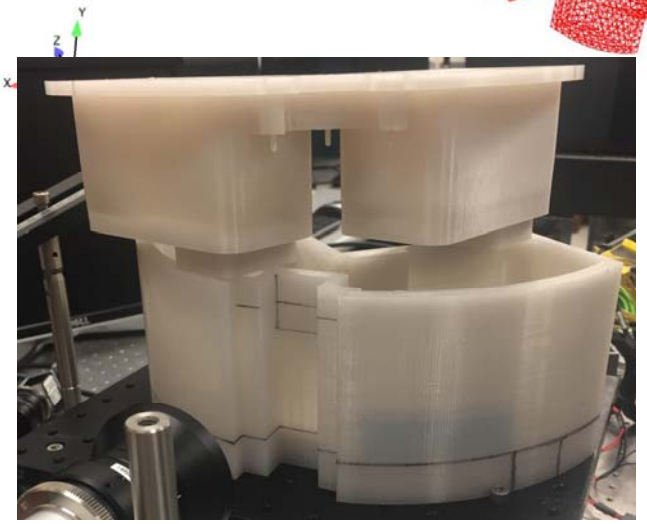
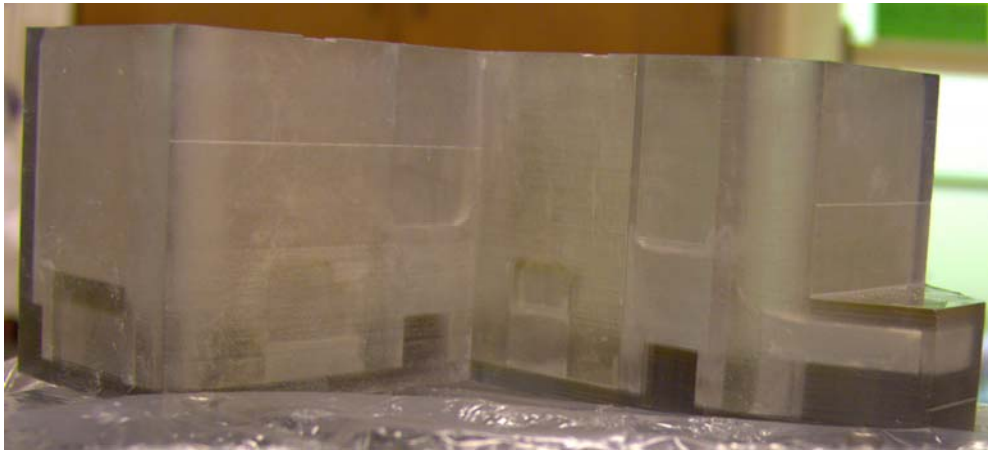
Sandia National Laboratories

Simulations & Experiments

- Simulations
  - Flat configuration
  - 5^{o} tilt
  - 20^{o} tilt
  - 20^{o} tilt toward the shelf feature
  - Study of vent locations
- Experiments
  - Flow visualization experiments
  - Additive manufacture mold

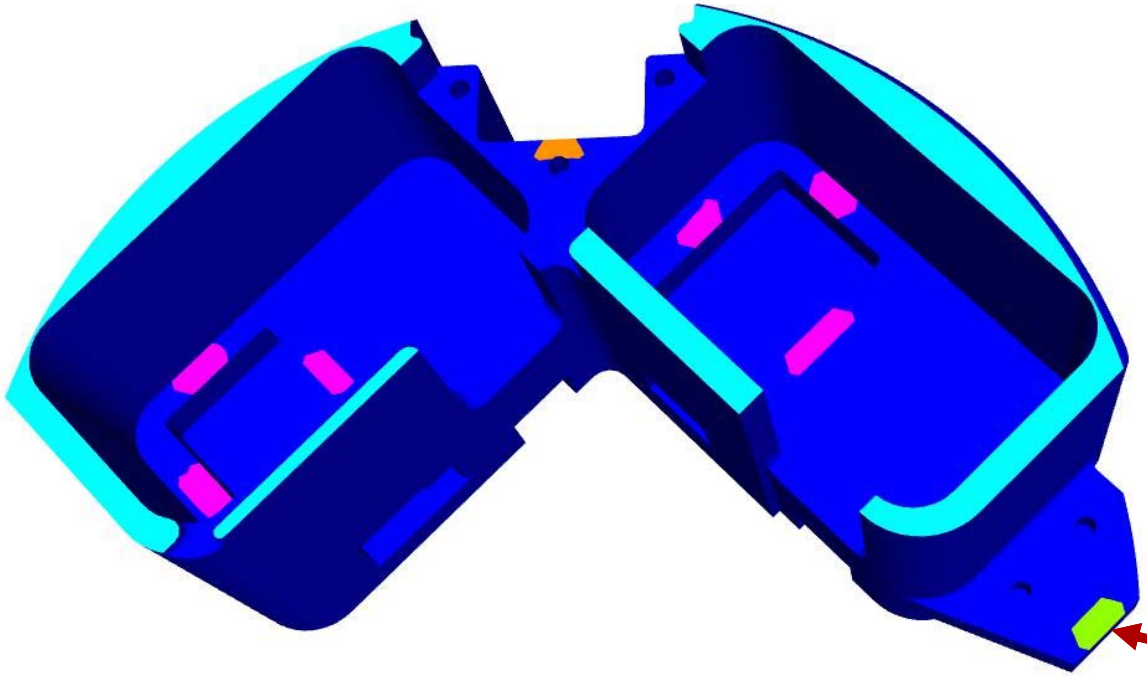






Goal: Use foaming and filling modeling and flow visualization experiments to develop confidence in foam model

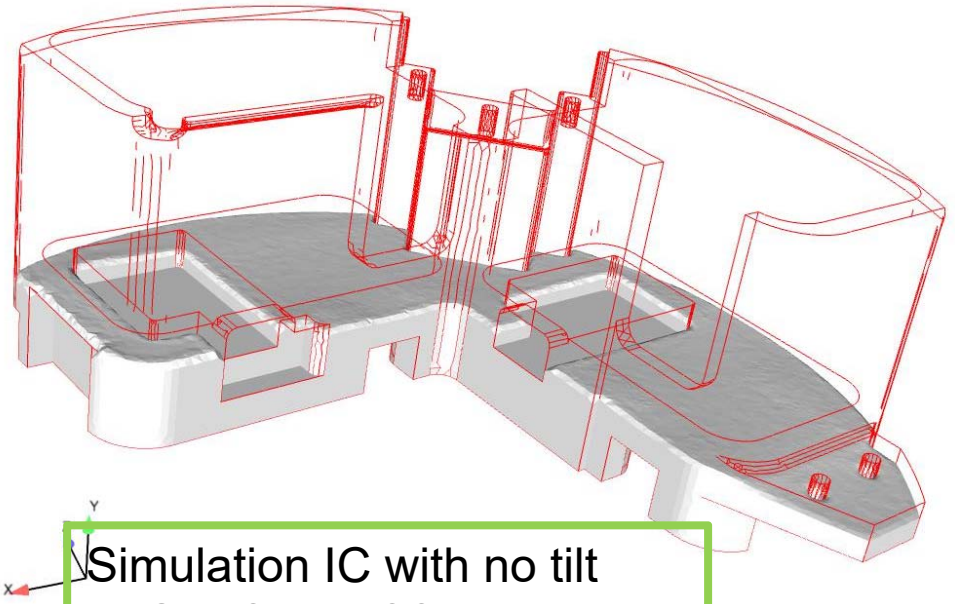
These Vent Locations Seem Representative of a Foaming Process



Simulation tests the idea of adding a vent on the shelf feature

Initial Conditions for Model: Experiments Show Shelf Starts Well-Filled

Flow visualization study using opaque mold to determine filling of shelf supports use of flat initial condition



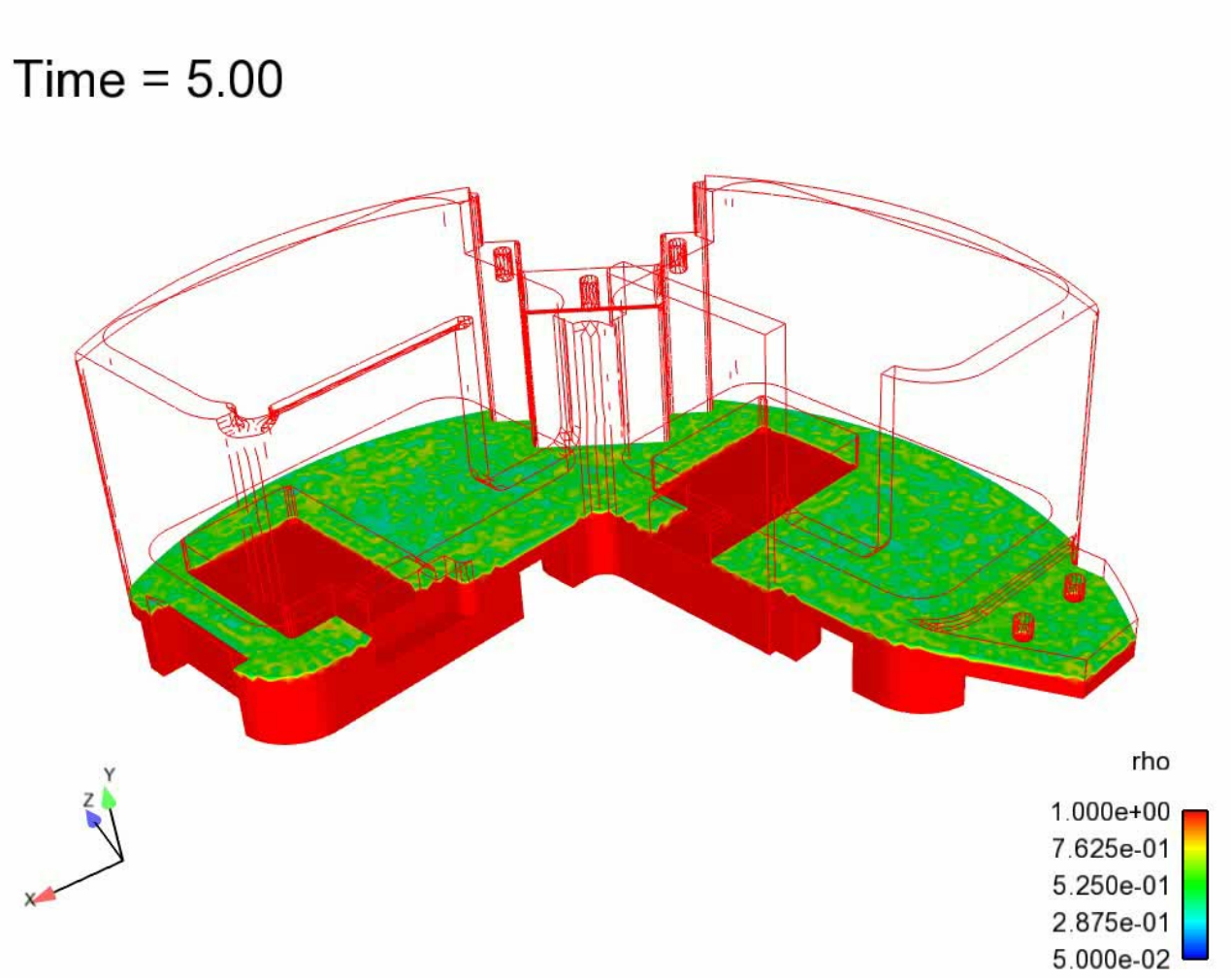
Flow visualization verifies initial condition

- *Foam levels well and flows to fill shelf area*
- *Simulation initial condition of a flat interface seems fairly accurate*

Simulation IC with no tilt

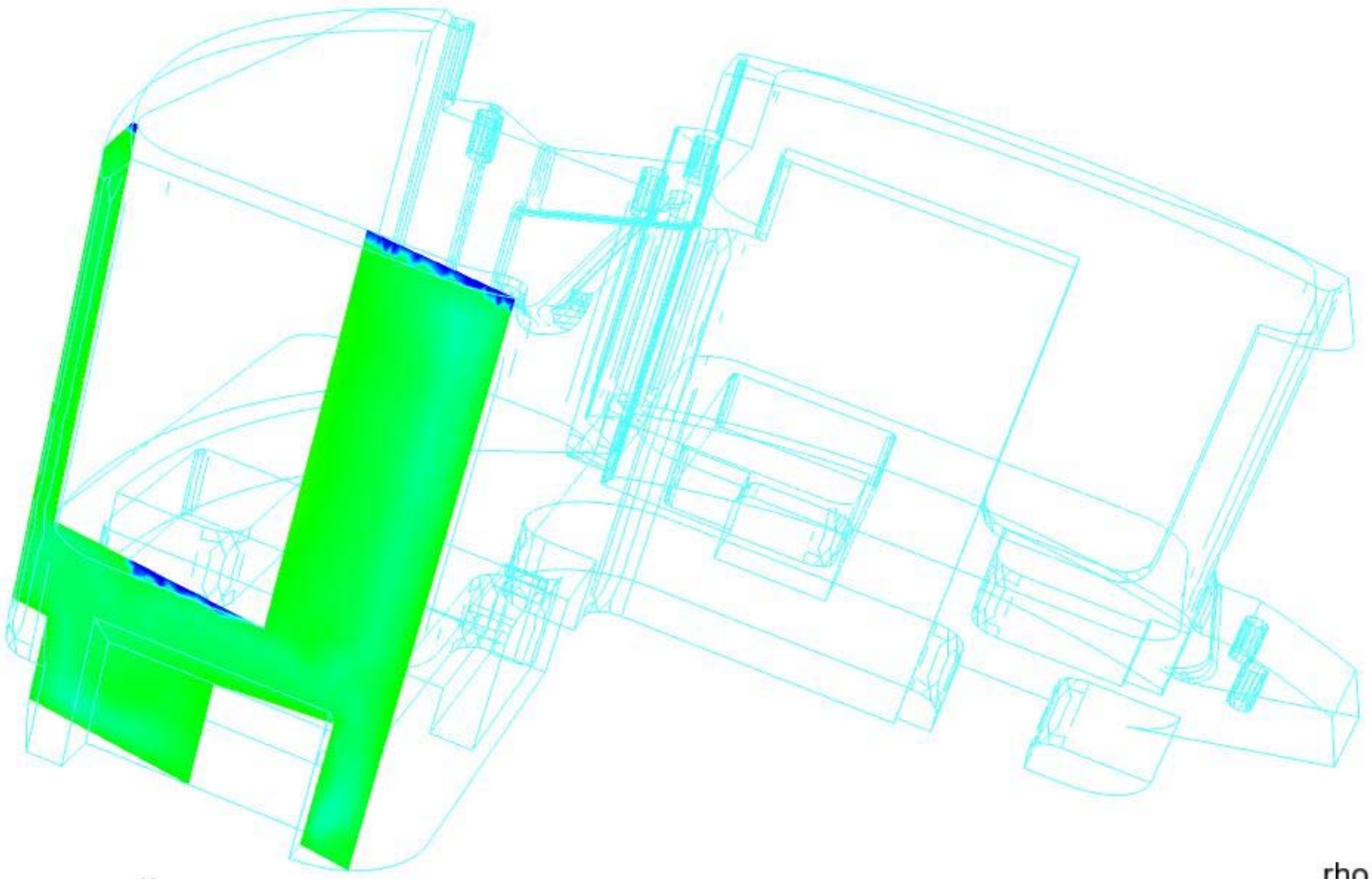
- Shelf is half-filled at start of the simulation

Foam Filling and Curing for Flat Configuration



Base Case:

- Look at issues for filling the mold when it is flat on the table
- Model shows density evolution and filling profile over time



time=82.7s
voids = 3.6%

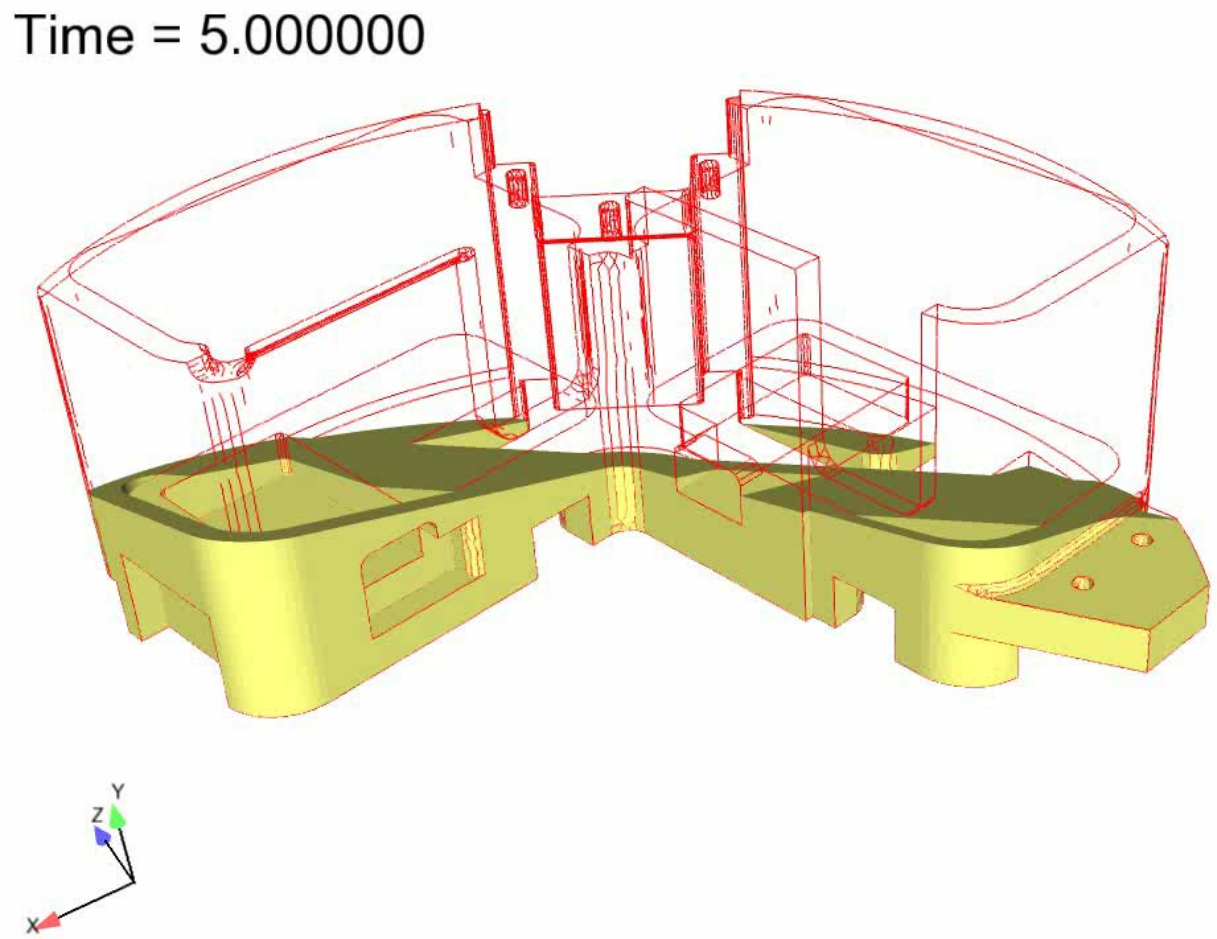
rho
4.300e-01
3.850e-01
3.400e-01
2.950e-01
2.500e-01

Density Variations at Different Locations: Flat Mold with Shelf Vent

Dynamics of Filling with 20° Tilt Angle

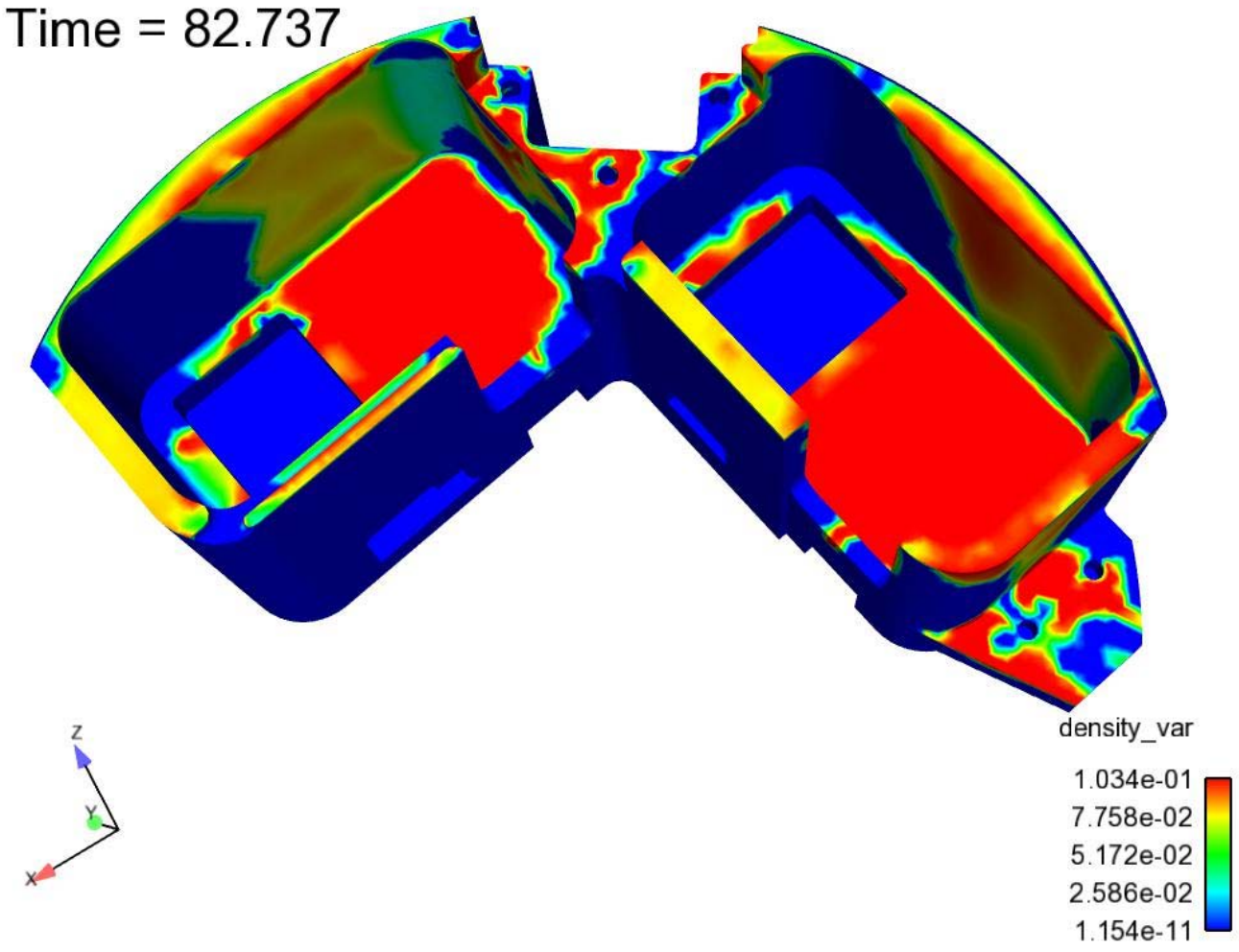
Foam Using a 20° Tilt Angle forward similar to legacy process

- Initial condition has a tilt forward for foam position and a flat interface
- Gravity vector is also tilted



Plot of Density Variation From Nominal

FLAT FILL



Density Variation:

$(\rho_{local} - \rho_{nominal})^2$

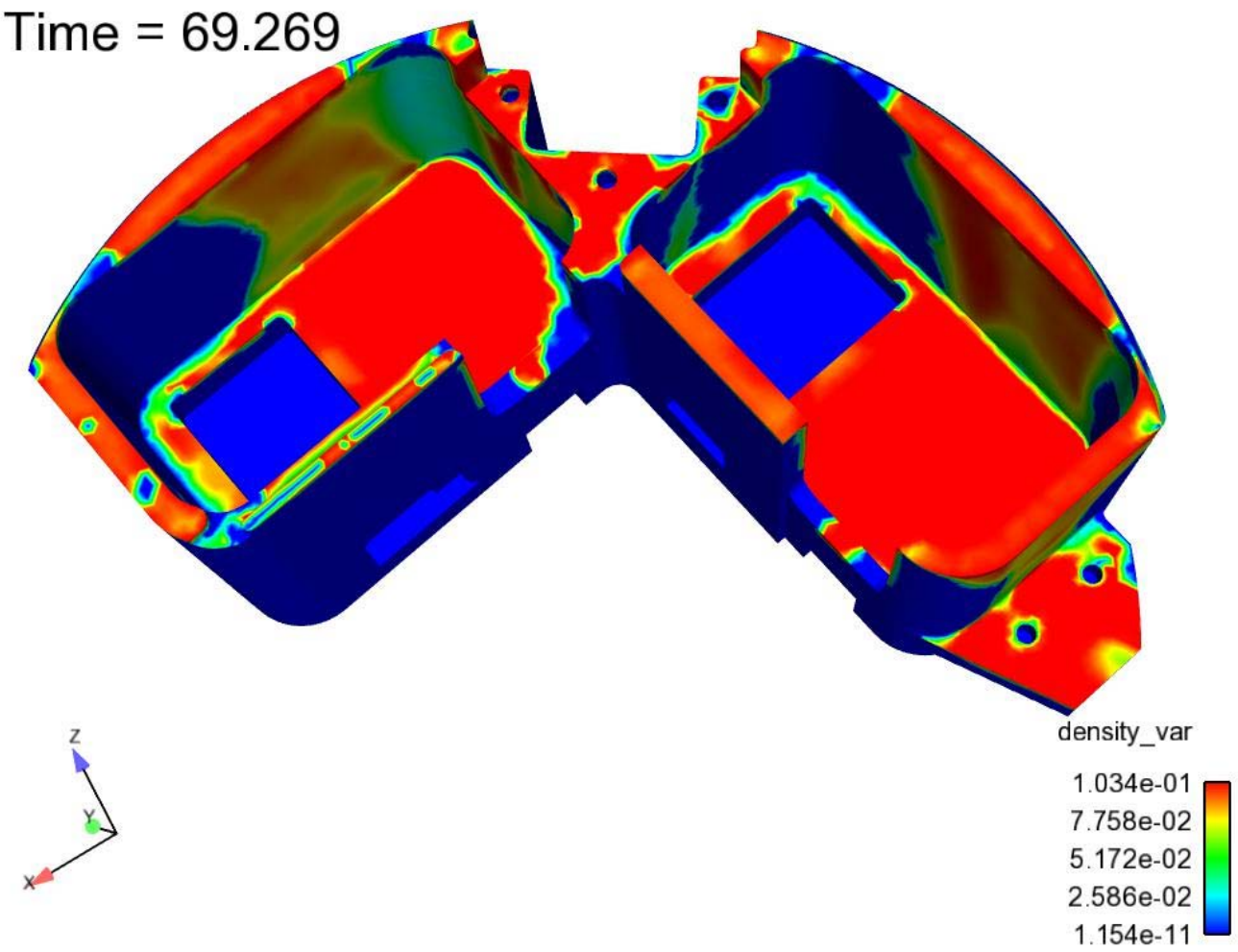
$$\int (\rho - \rho_{nom})^2 \, dV$$

$\rho_{nominal}$ = 240g/745ml
= 0.322g/ml

time=82.7s
voids = 3.6%
Int. var. = 2.81

Plot of Density Variation From Nominal

FLAT FILL HOT



Density Variation:

$(\rho_{local} - \rho_{nominal})^2$

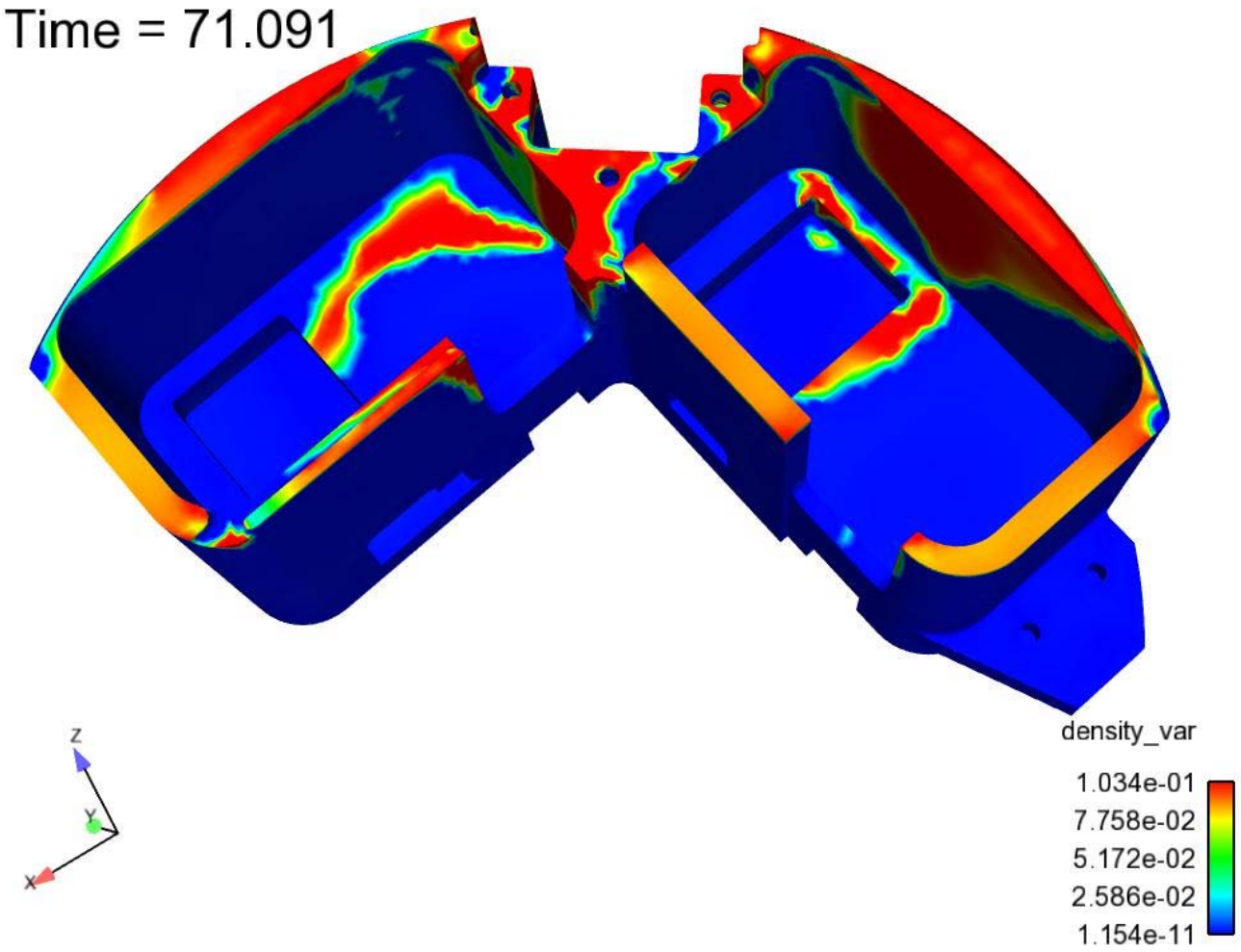
$$\int (\rho - \rho_{nom})^2 \, dV$$

$\rho_{nominal}$ = 240g/745ml
= 0.322g/ml

time=69.3s
voids = 4.5%
Int. var. = 3.56

Plot of Density Variation From Nominal

TILT 20 DEGREES FILL



Density Variation:

$(\rho_{local} - \rho_{nominal})^2$

$$\int (\rho - \rho_{nom})^2 \, dV$$

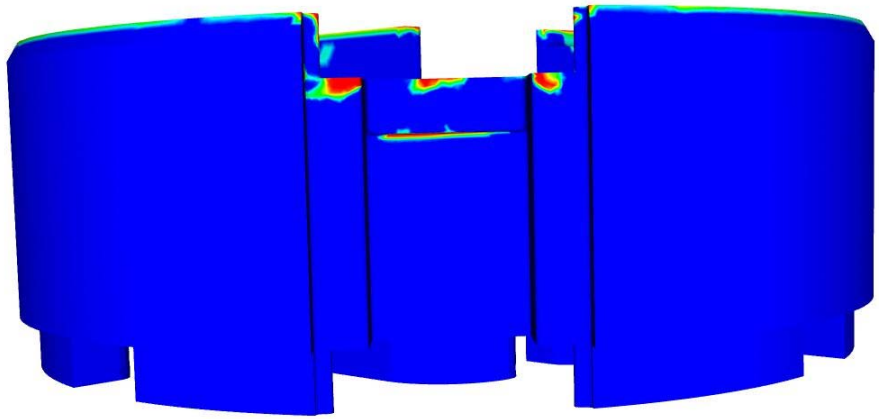
$\rho_{nominal}$ = 240g/745ml
= 0.322g/ml

time=71.1s
voids = 2.9%
int. var. = 2.87

Density Variations: Back View

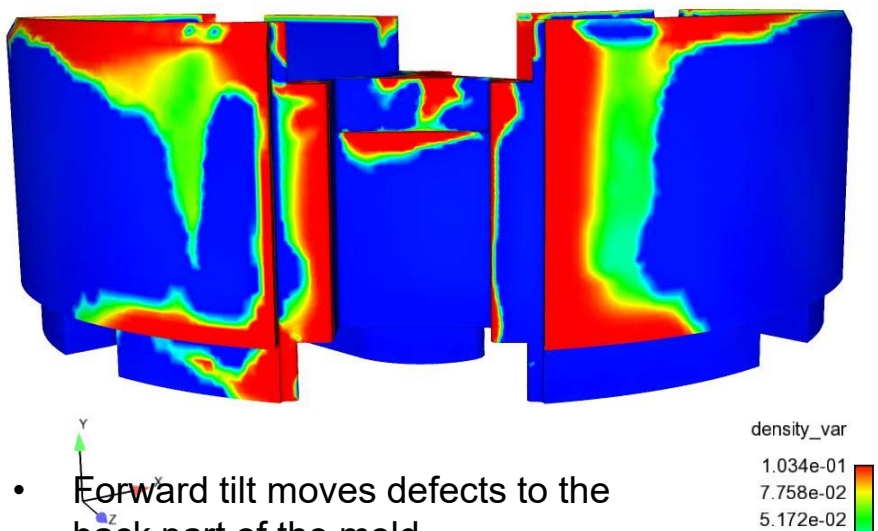
Time = 82.737

FLAT FILL

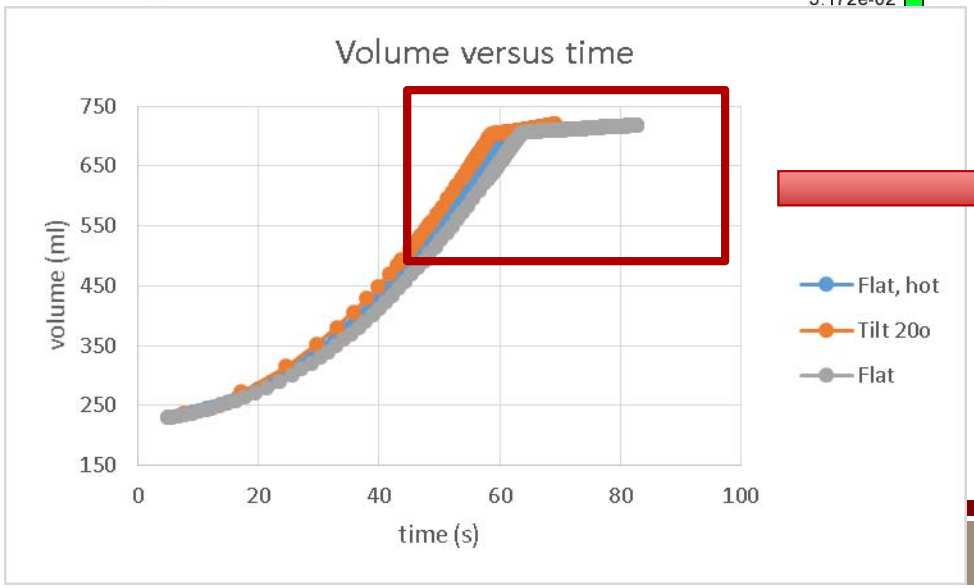


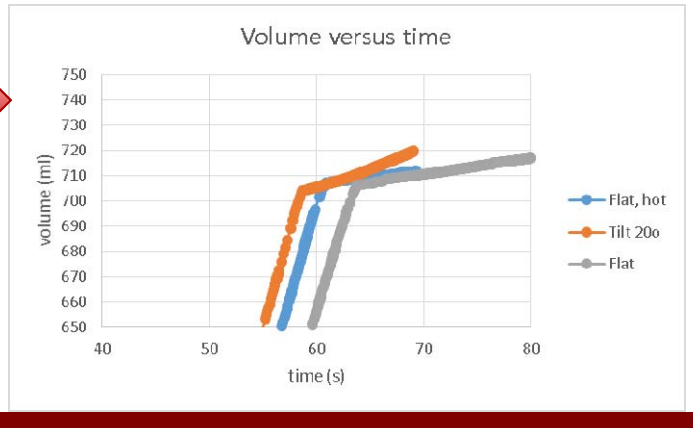
Time = 71.091

TILT 20 DEGREES FILL

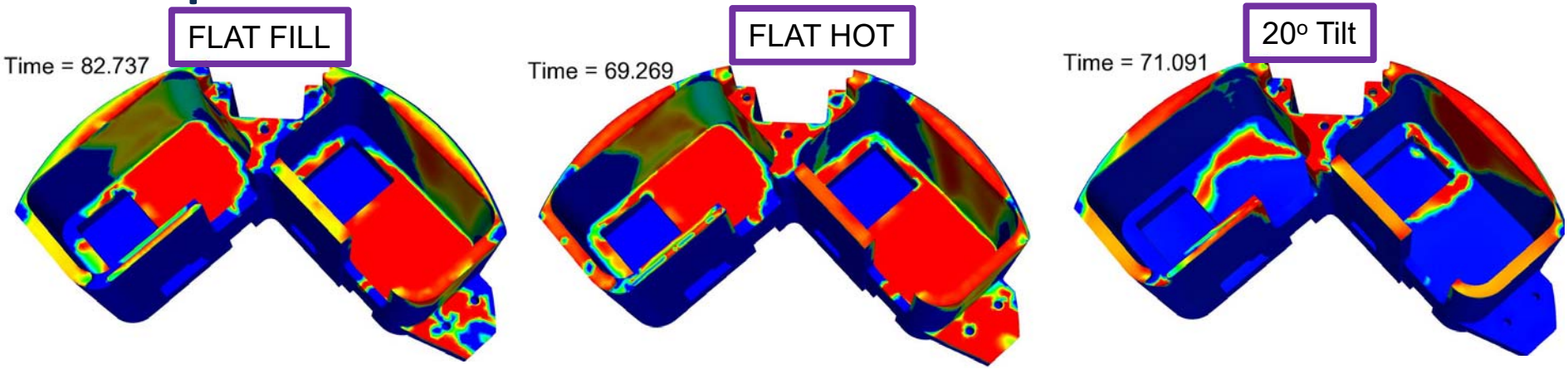


- Forward tilt moves defects to the back part of the mold
- Tilt fills faster than flat

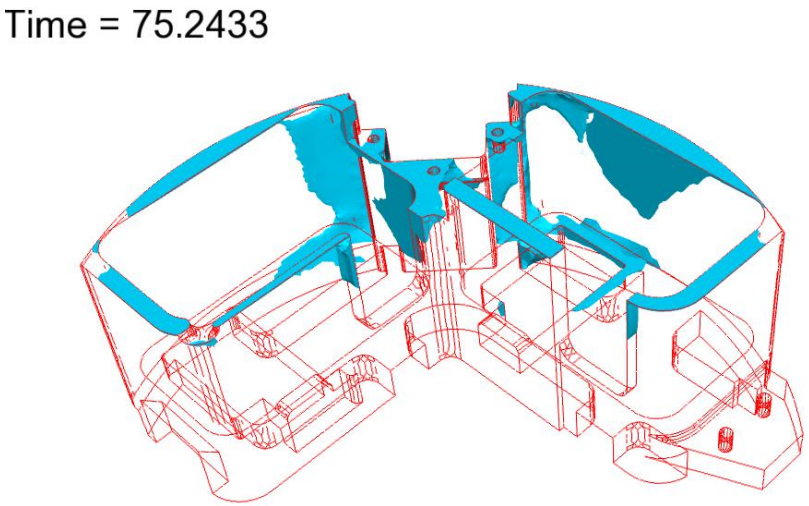




Computational Models of Foam



Density variations for three cases of interest



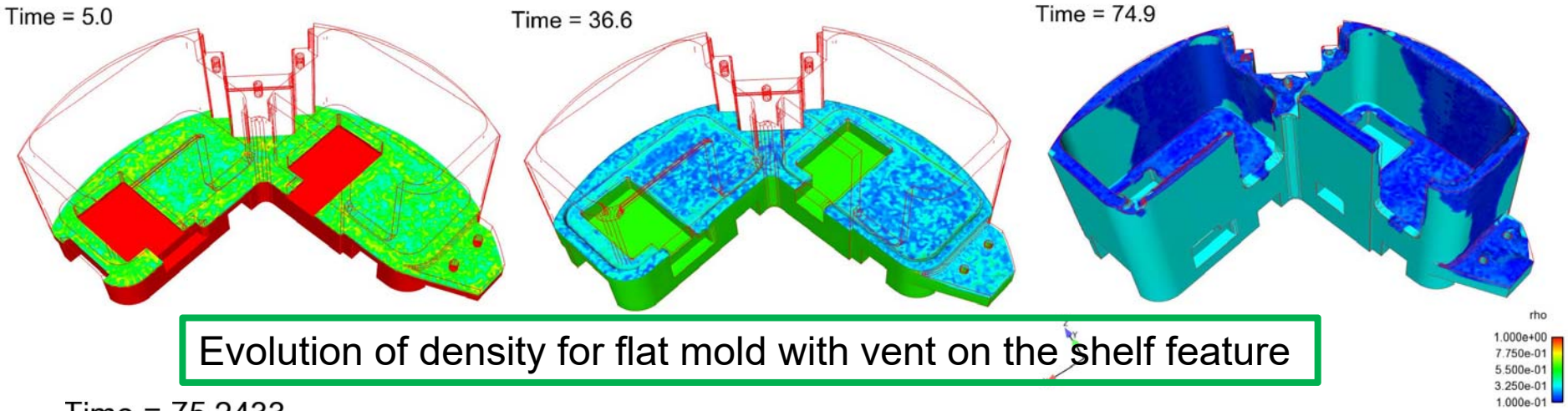
Foam filling for 20° tilt: the angled fill reduces voids on the new shelf

Case	Flat	Flat Hot	20° Tilt
Max. Time (s)	83s	70s	71s
Voids	3.6%	4.4%	2.9%
Density variation	2.8	2.9	3.6

All cases fill well!

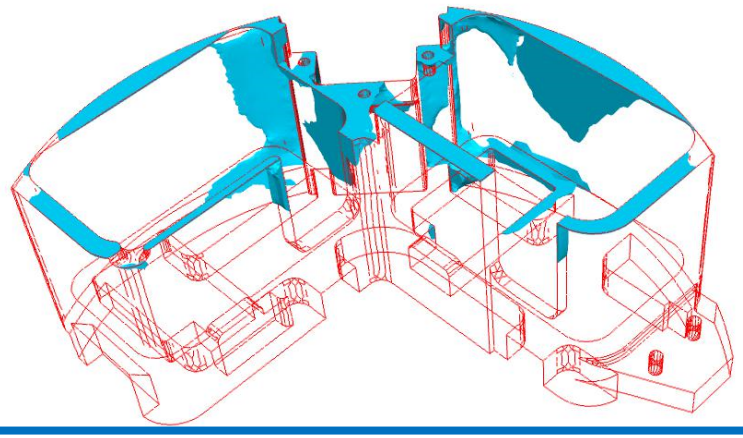
- Model over-predicts voids, but predictions are small
- Density variation greater with tilt

Computational Models of Foam



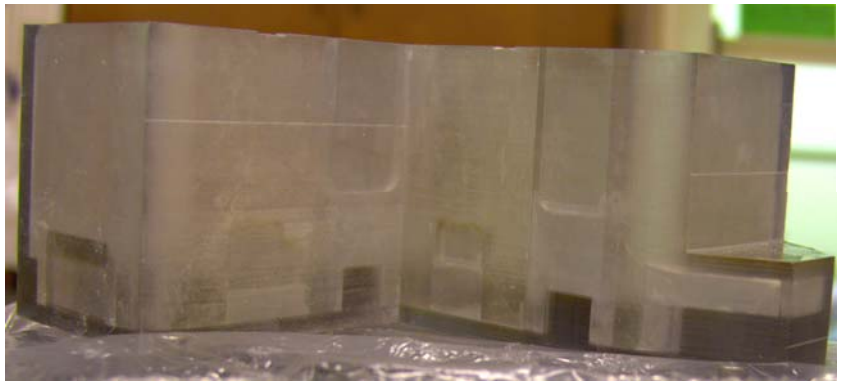
Evolution of density for flat mold with vent on the shelf feature

Time = 75.2433

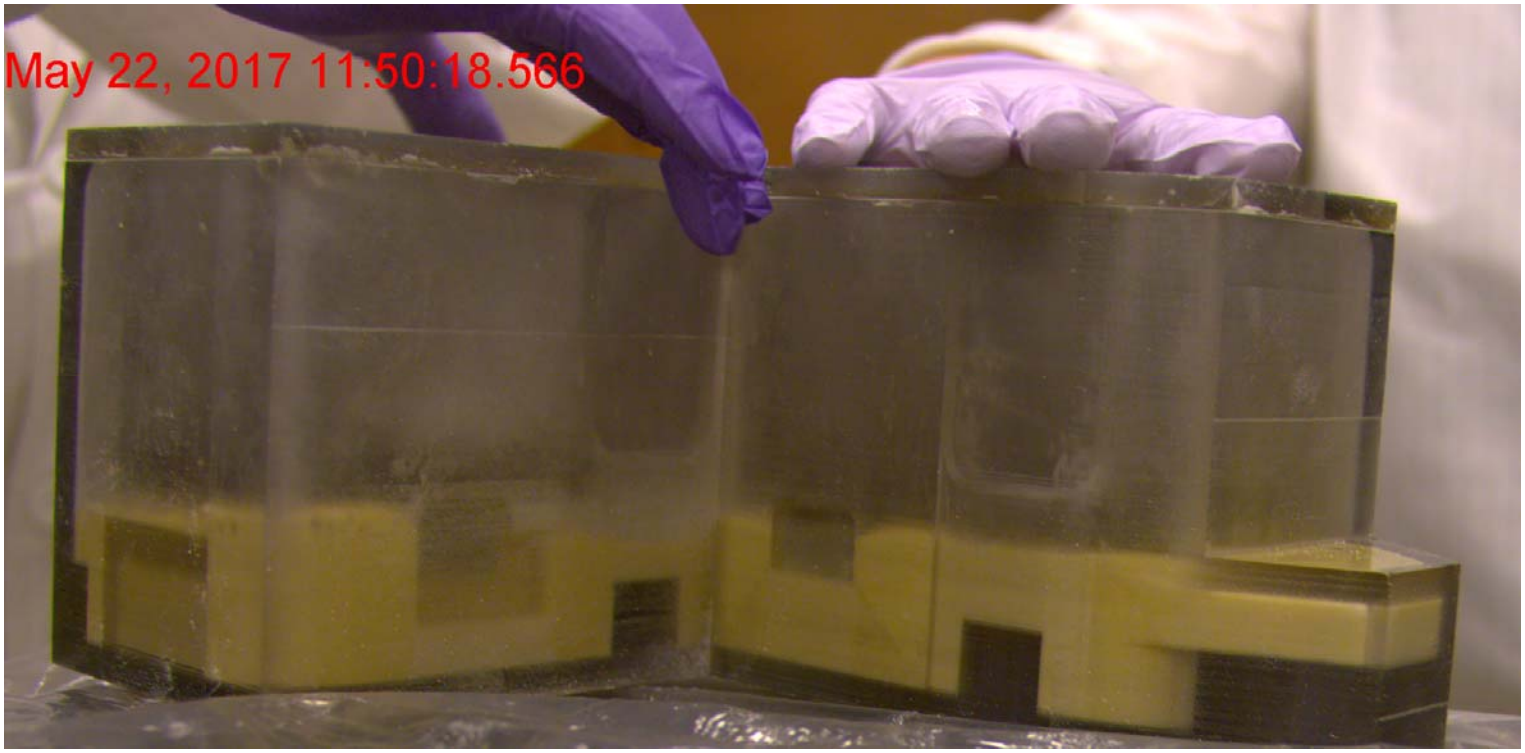


Foam filling for 20° tilt: the angled fill reduces voids on the new shelf

Flow visualization study supports computational conclusions



Validation Experiment: 5 Degree Tilt: Foam Fills Shelf and Levels Quickly

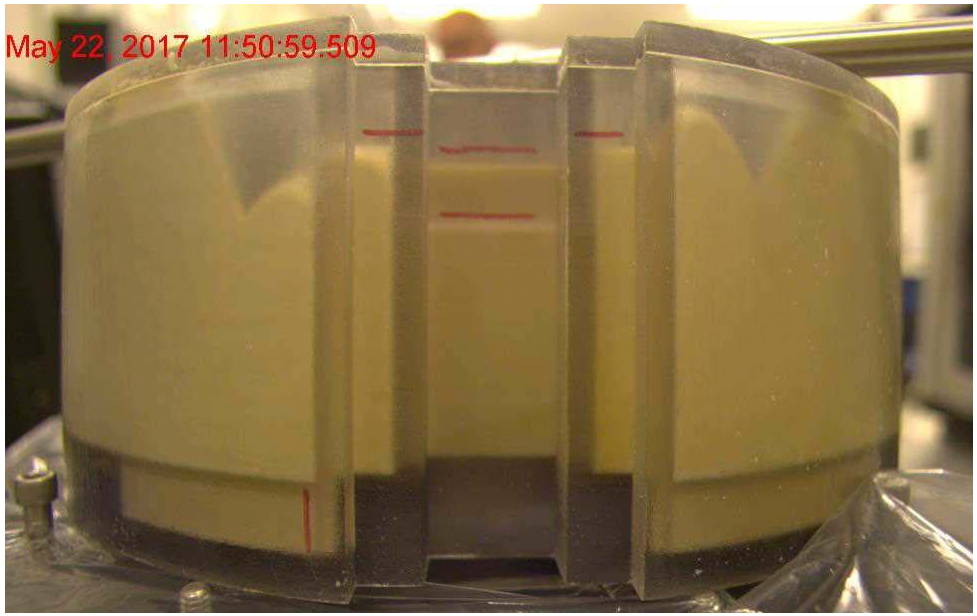


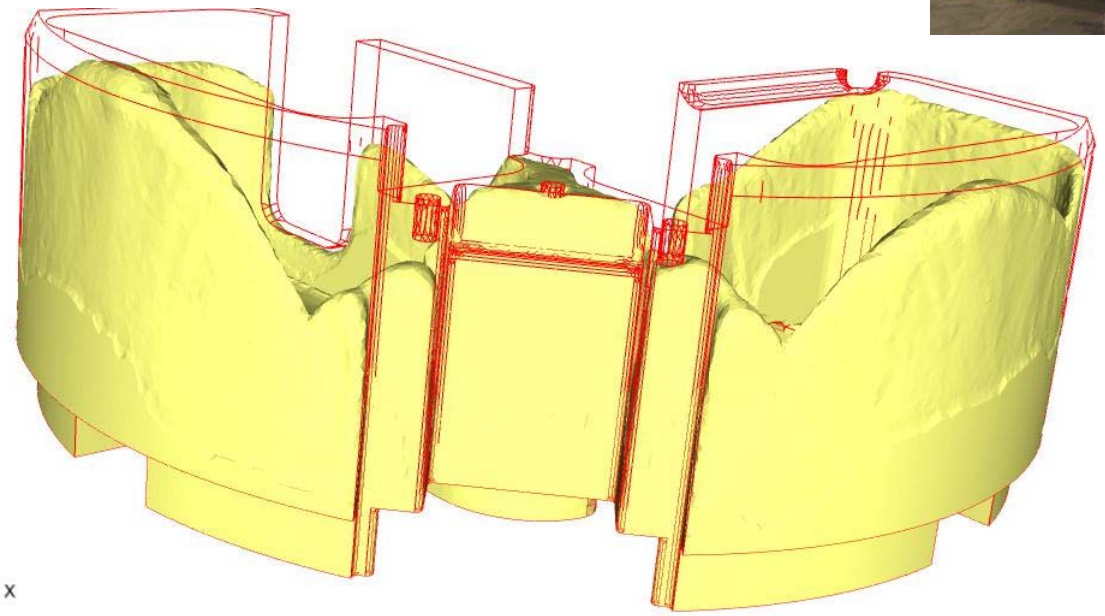
- New experiment using clear mold
- Room temperature mix of foam, which heats up to 24°C
- Mold stays roughly 22°C
- 5 degree tilt towards the front of the mold

Experimental Conditions: Back of Mold

Run model with similar initial conditions:

- 240g material
- 4 degree tilt
- Room temperature mold and foam

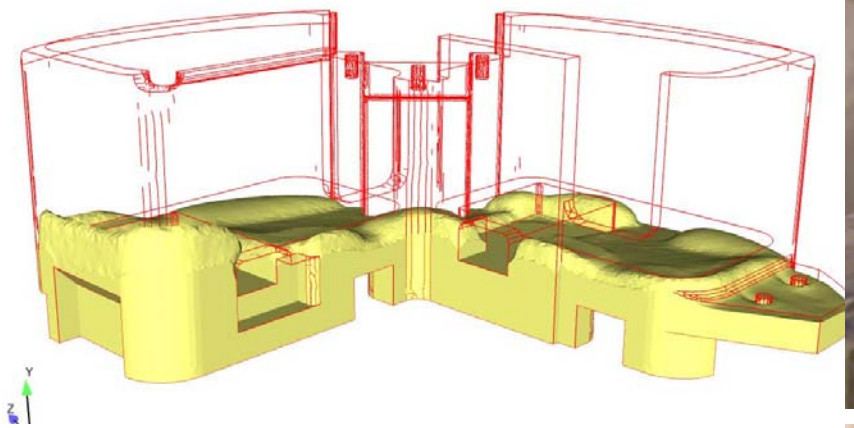


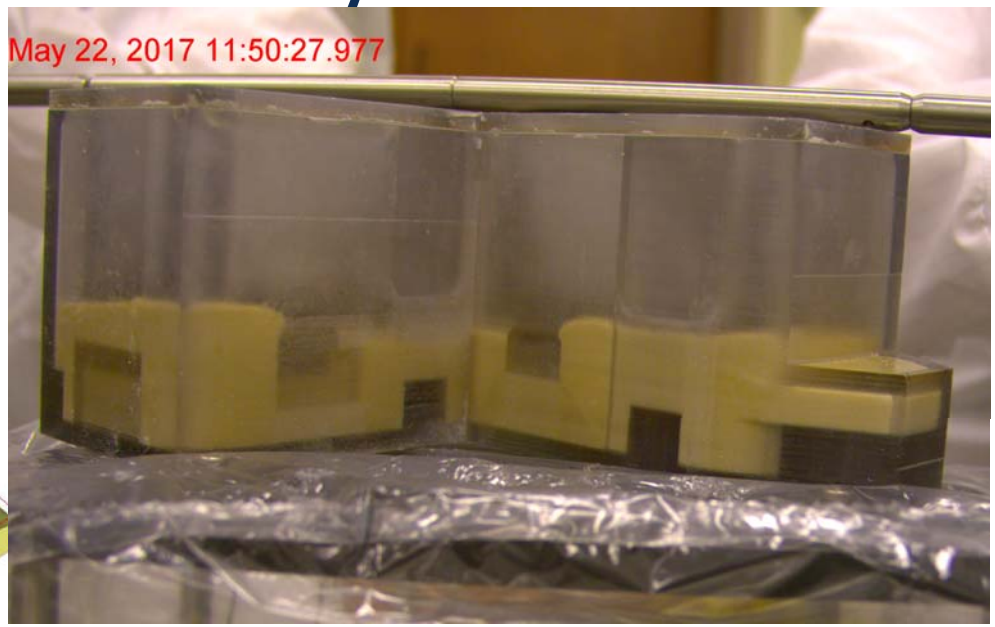


Shape of the model interface matches well with shape of experiment thought model fills back feature faster

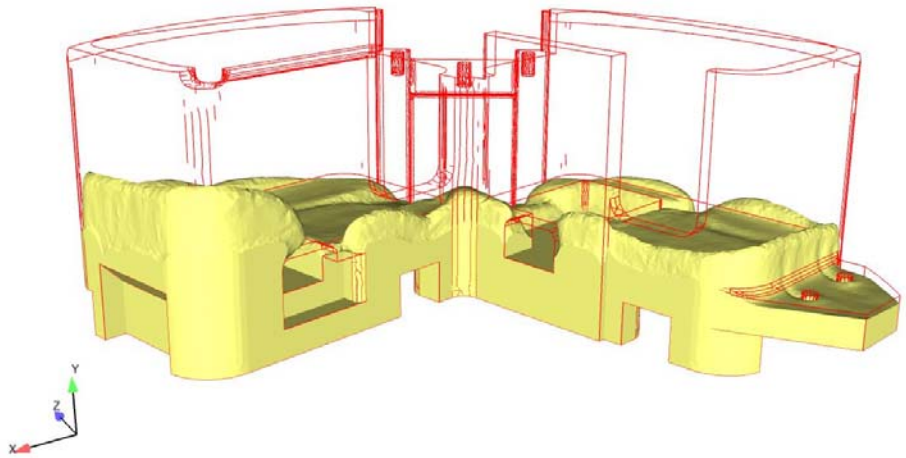
Compare Mold Front: Early Times

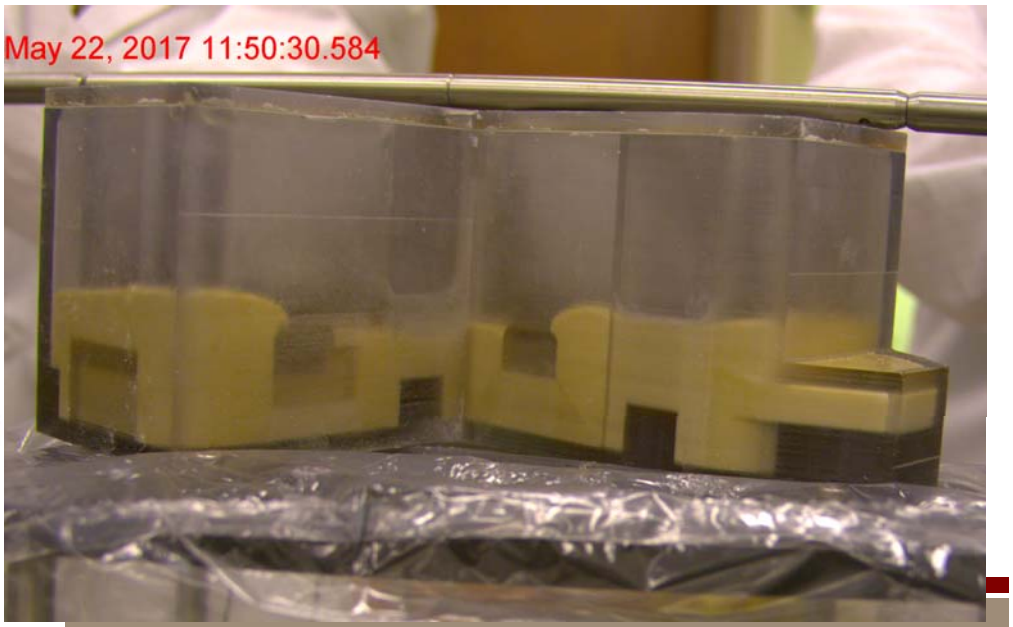
Time = 34.184





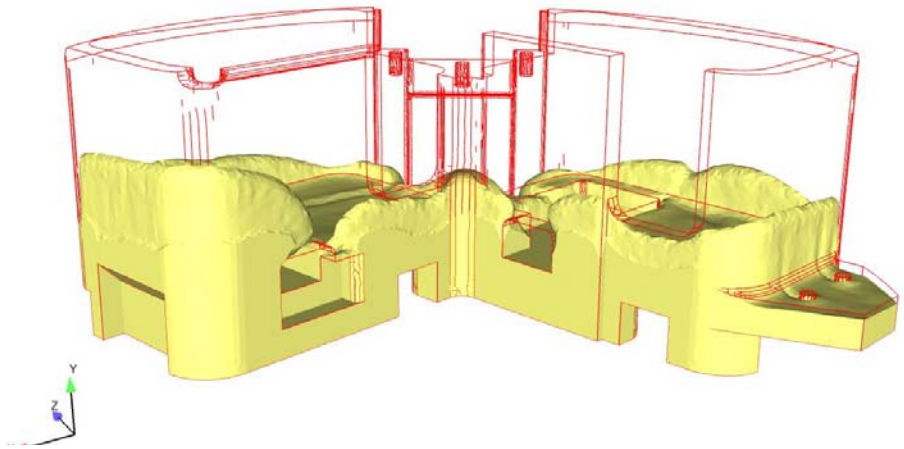
Time = 44.617



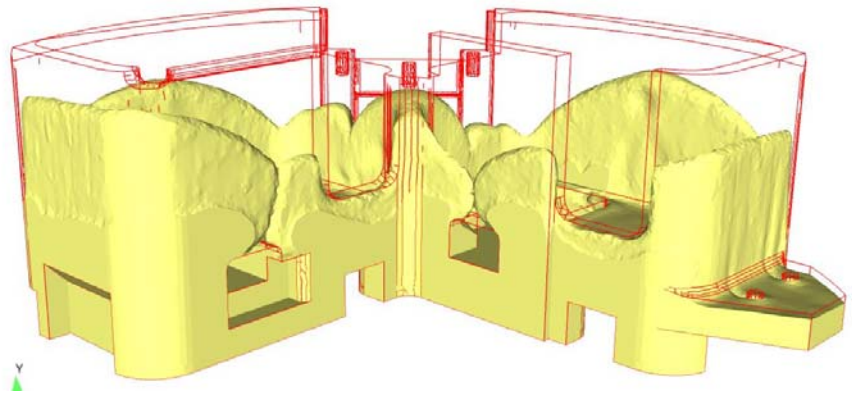


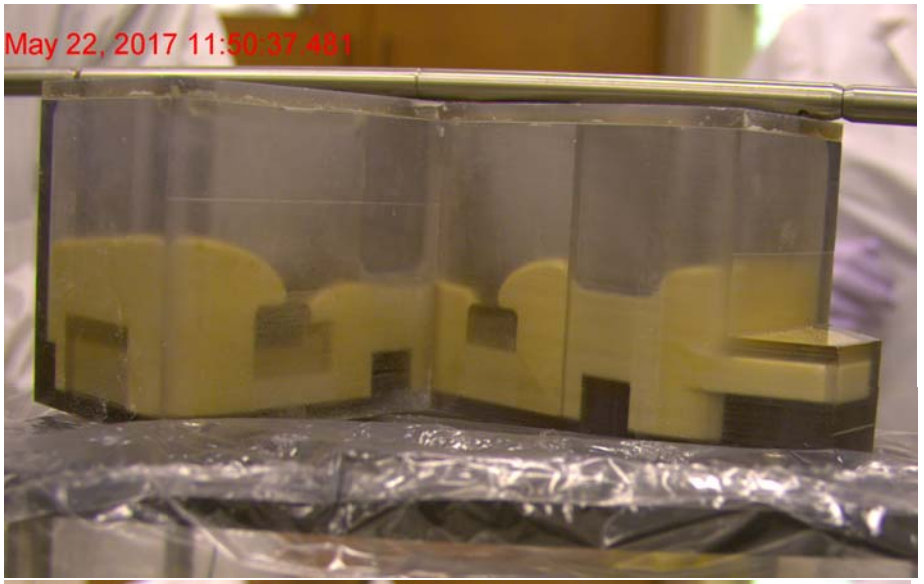
Compare Mold Front: Moderate Time

Time = 49.913

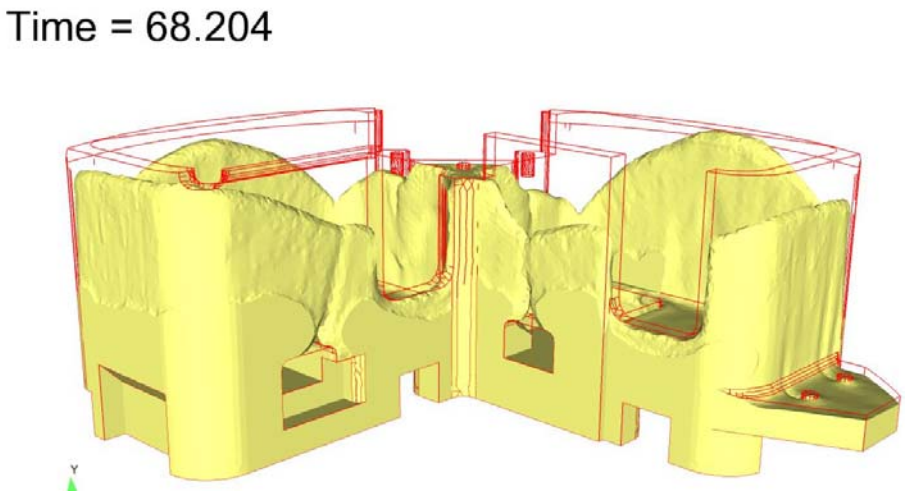


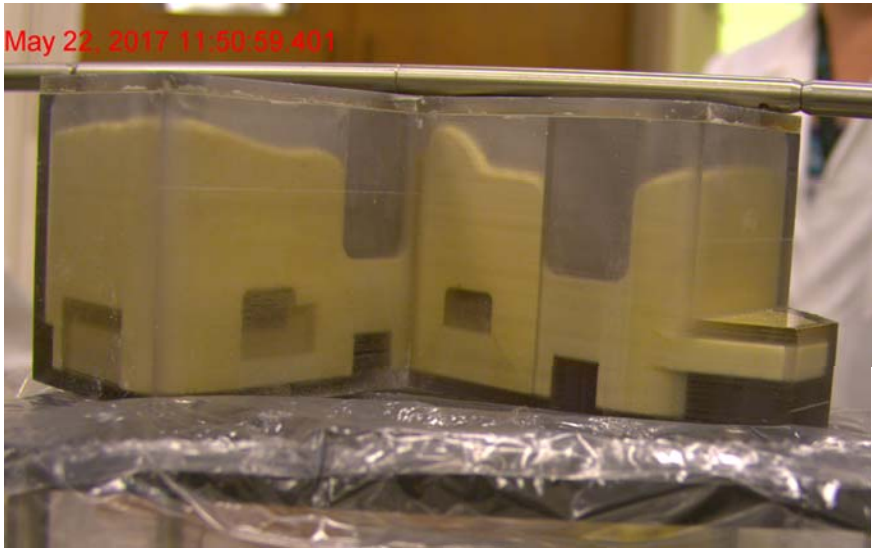
Time = 62.538





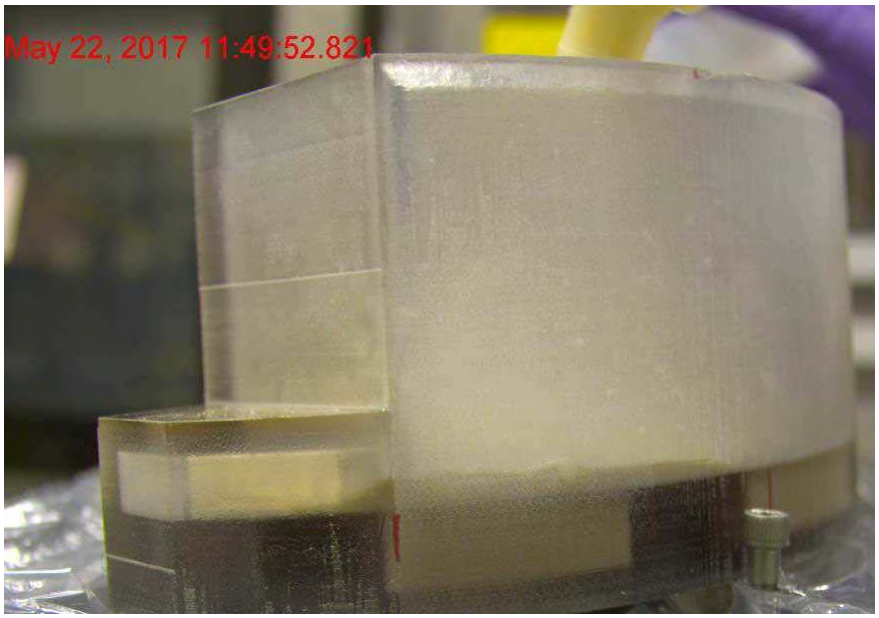
Compare Mold Front: Late Time

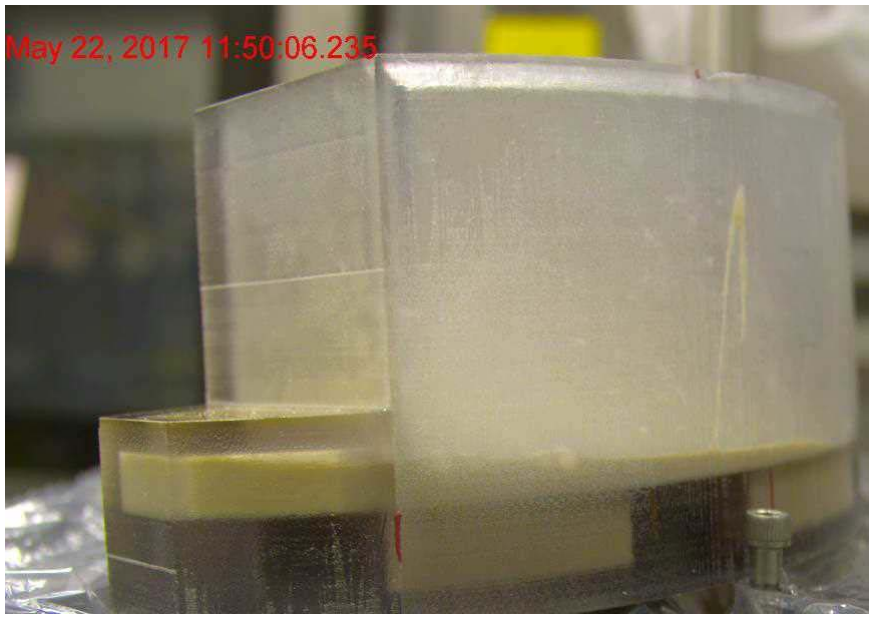




Shape of the model interface matches well with shape of experiment and the time-scale is similar

Shelf Feature Fills Well in Clear Mold





Experiment shows good filling of the shelf feature even at early times giving confidence in the foam model