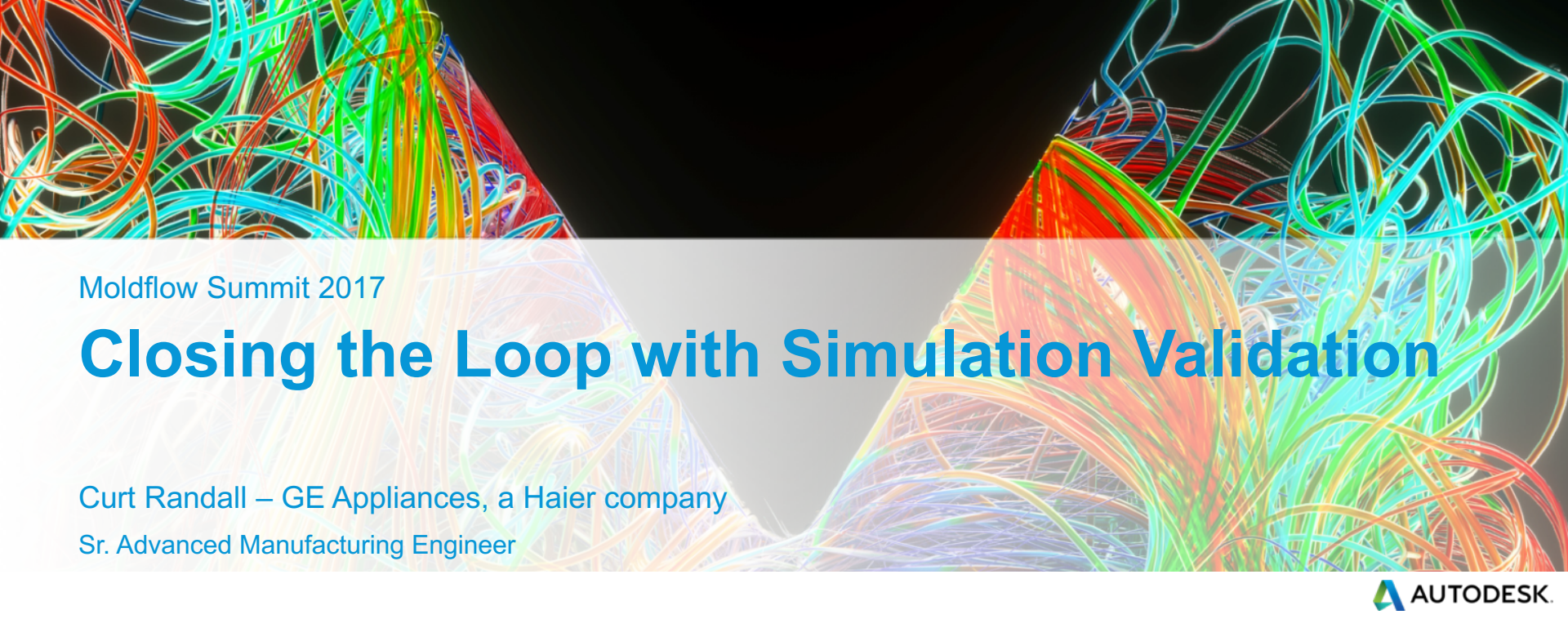


Moldflow Summit 2017

Closing the Loop with Simulation Validation

Curt Randall – GE Appliances, a Haier company

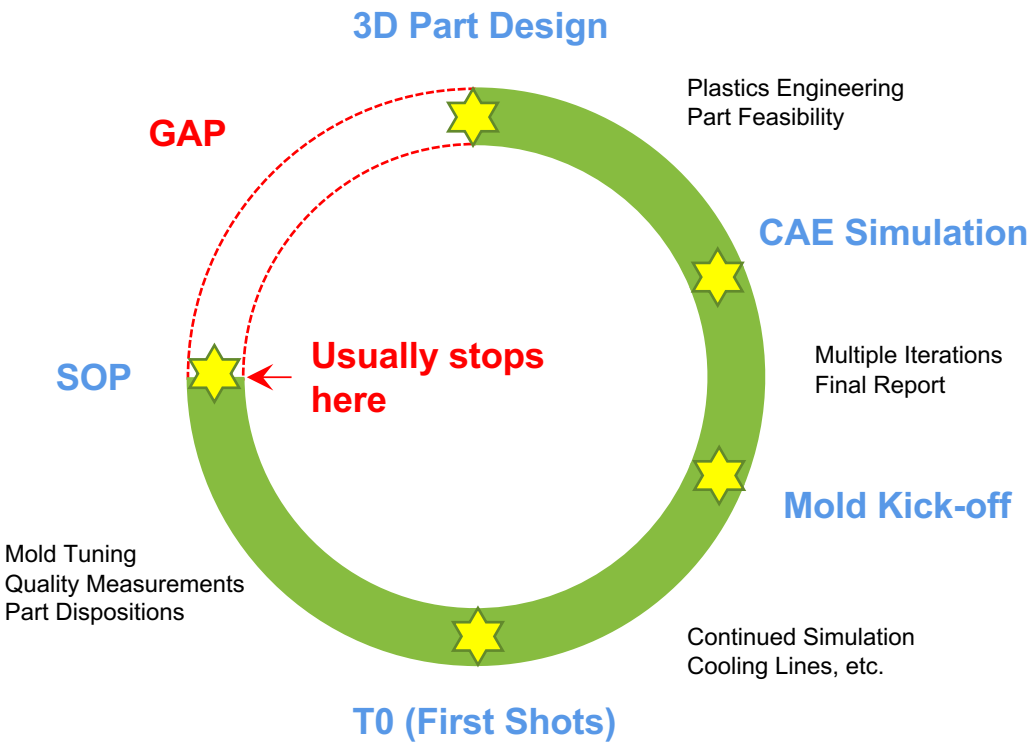
Sr. Advanced Manufacturing Engineer

AUTODESK.

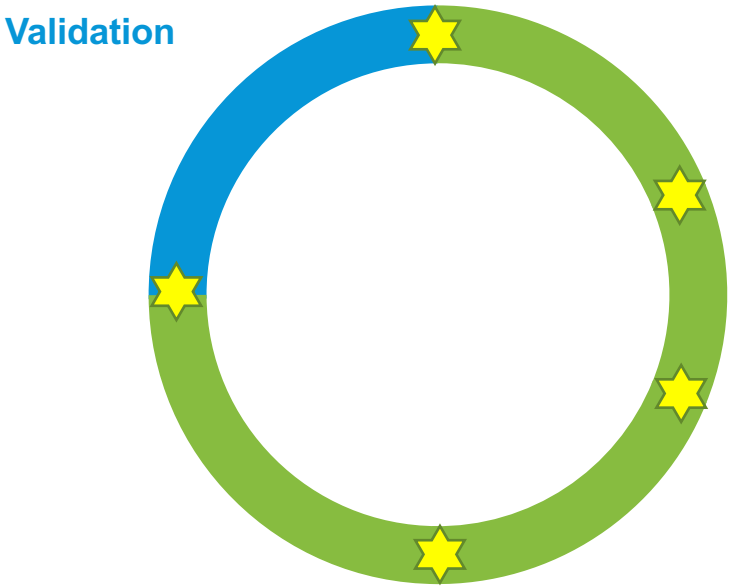
Learning Objectives

- Simulation Validation
  - Description
  - Benefits
  - Process
- Keys to successful simulation validation
- Case Study
- Future Work

Typical CAE Process



Closing the Loop with Simulation Validation



- Gather actual data
- Make changes and re-run
- Part metrology
- Compare vs. actual
- Historical database
- Simulation improvement

Simulation Validation

Simulation Validation

- Validate (Definition from the Oxford Dictionary)

“Check or prove the validity or accuracy of …(something)”

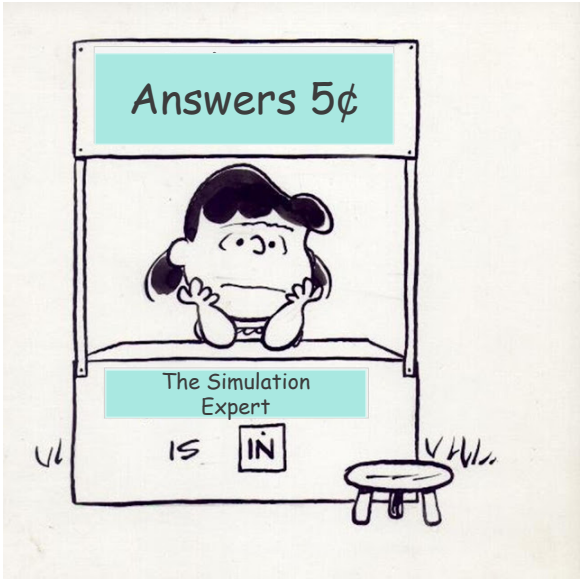
- The engineer’s job is make data driven decisions to solve complex problems
- Validation provides confidence in the results

The Million Dollar Question

- How accurate is Moldflow simulation?
- As analysts we have all been asked this question at one time or another.

The 5¢ Answer

IT DEPENDS.



- This is the typical answer given to this question
- We need to gain confidence in the results
- This is accomplished through simulation validation

Simulation Validation Benefits

- Completes the product development cycle
- Provides data points for historical database
- Helps Autodesk continuously improve simulation accuracy
- Builds confidence in simulation results

Simulation Validation Process

- Incorporate sensors into the tool
- Record actual process setup/machine data
- Capture actual melt/mold temperature
- Collect pressure curves for multiple cycles
- Collect multiple parts for part metrology
- Collect fill only part for short shot comparison
- Collect part/cavity/runner system weights

Simulation Validation Process, continued

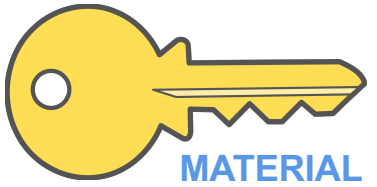
- Compare with initial simulation
- Measure actual part wall thickness
- Make necessary model adjustments and re-run simulation
- Measure parts with scanning or CMM
- Compare results and document for future use
- Share with Autodesk Simulation Validation team for future software enhancements

Keys to Successful Simulation Validation

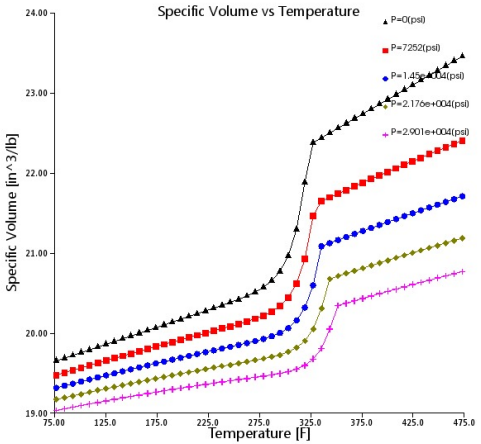
The Keys to Successful Simulation Validation

- Material characterization
- Model/Mesh preparation
- Custom machine information
- Accurate process conditions
- Capturing actual melt/mold temperature
- In cavity process monitoring
- Metrology for molded parts

Material Characterization



- The accuracy of the results depends on the quality of the material characterization.
- Material Quality Indicators
  - Filling
  - Packing
  - Warpage
- Three Levels



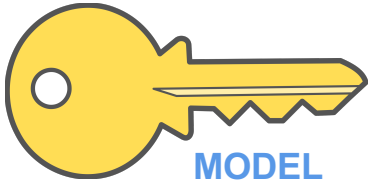
Material Quality Rating

- Gold Rating
  - High confidence in quality material data
- Silver Rating
  - Combination of well tested and supplemental material data
- Bronze Rating
  - Incomplete data sets and extensive use of supplemental data

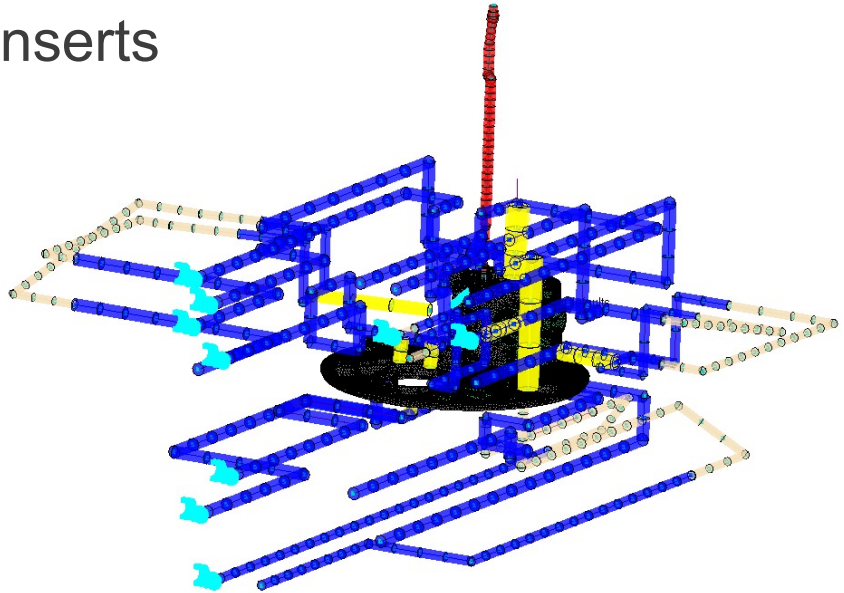
>>EXPERT TIP<<

- Use gold Level material data for accurate results
- Spend the money to get your material characterized
  - Contact
    Beaumont Technologies, Inc.
    http://www.beaumontinc.com/
    1-(814)-899-6390

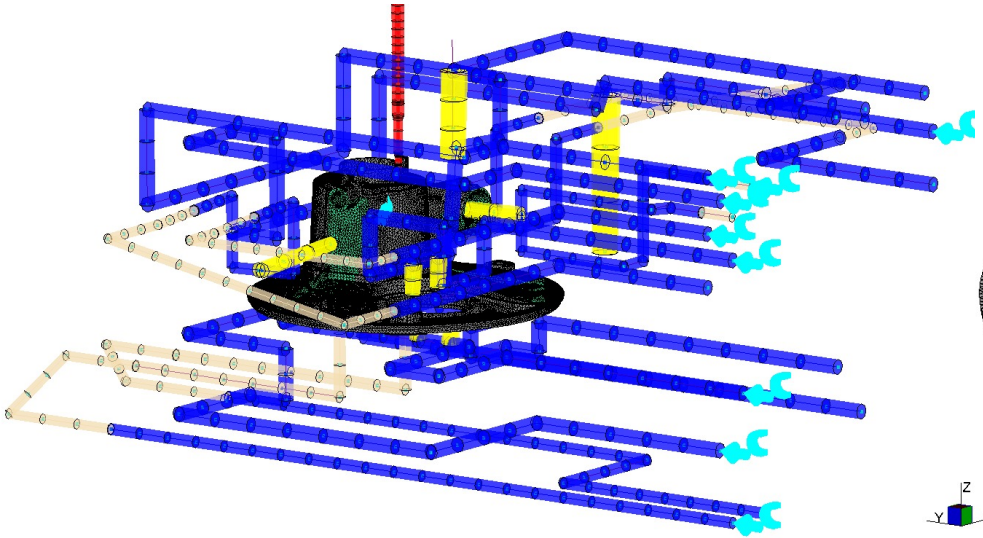
Part/Mold Modeling & Mesh

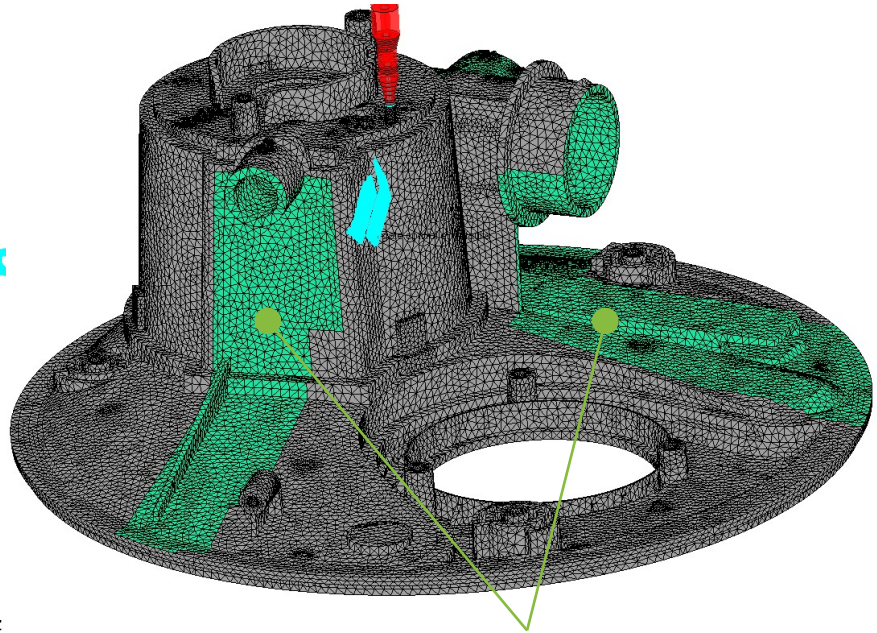


- Use Theory & Concepts – Model Requirements
- Apply mold material properties
- Cooling Lines and mold with inserts
- Machine nozzle
- Accurate wall thickness
- Use of expanded CAD Data
- Clamp Force calculations



Model with Inserts and Cooling Lines

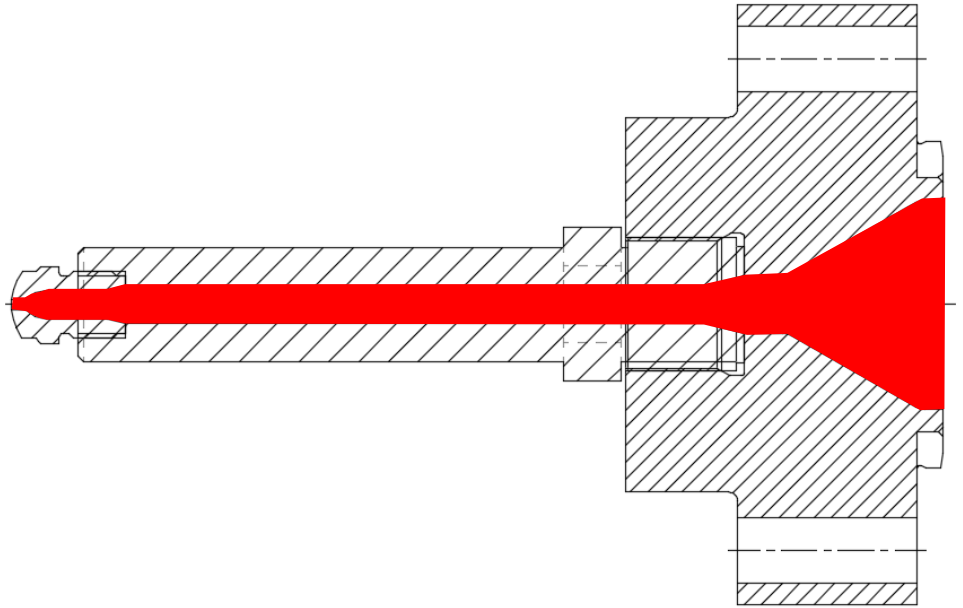




Assigned Moldmax Material
(part elements & water lines)

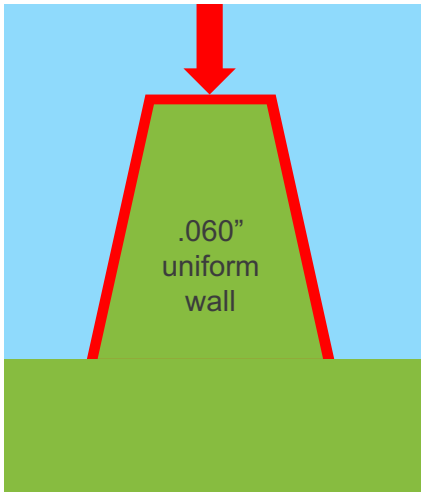
Include Machine Nozzle

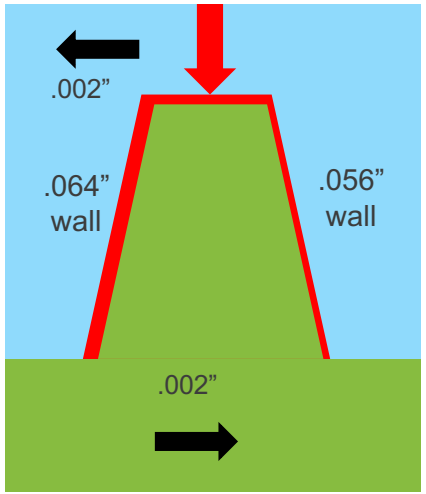
- Capture pressure drop through machine nozzle
- Can be significant



Measure Actual Part Wall Thickness

- A small amount of error in set-up or machining can have a significant impact on final part wall thickness or flow.
- Use band saw & calipers/micrometers
- Ultrasonic Thickness Gage



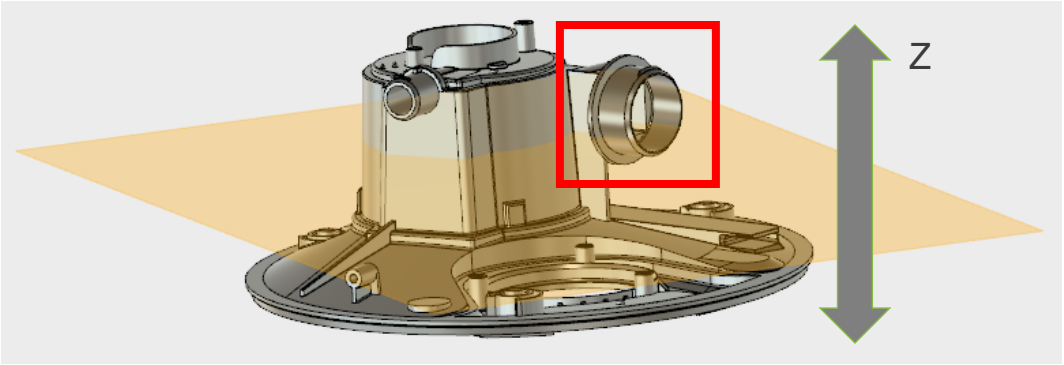


To Expand or not to Expand?

- That is the real question.
- Use original CAD for initial simulation
- Use expanded data for simulation validation.
  - Matches meshed mold and inserts
  - Matches cooling line geometry

Test Your Knowledge!

- How does the software calculate the projected area of a part mesh?

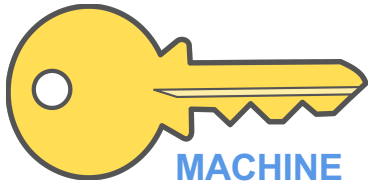


Sum of all surface areas projected onto X-Y plane

>>EXPERT TIP<<

- Use the “exclude from clamp force calculation” option in element properties
- This is especially true if you are conducting clamp force simulation validation

Process Conditions



- Machine settings
  - Fill & transfer
  - Pack/hold
  - Cooling
  - Mold open/close time
- Mold/melt temperature
- Valve gate settings
- Robot PTO time

PRESS #: 510

PRESS #:	5-10	MOLD # :	Liner			PART REMOVAL:	Robot
TONNAGE:	2300	CAVITIES (#):	1			RJG TEMPLATE:	Yes
MATERIAL:	ABS Cheil HG-0760GP (WHITE)			MTL STK#:	STK44674	SILO #: 3	RUN MODE: Auto
COLORANT:	N/A			COLOR STK #:	N/A	BOX #: N/A	LDR %: N/A

Clamp Close

	3	2	1	
Velocity	N/A	N/A	29.00	in/s
Pos	N/A	N/A	40.000	in
			Start MP	

Mold Protect

	1	
	2.00	in/s
Pres	800	psi
Time	3.00	s
Pos	34.630	in
	Mold Touch	

Injection

	3	2	1	
Vel	N/A	N/A	2.95	in/s
Limit	N/A	N/A	18000	psi
Trans	N/A	N/A	18000	psi
Pos	N/A	N/A	2.100	in
Time	N/A	N/A	3.50	s

Process Data

Cycle Time (s)	75.40
Inj Fill Time (s)	
Cushion (in)	0.537
Transfer Pos (in)	2.000
Recovery Time (s)	13.5
Inj Peak Press (psi)	10961
Mold Open Time (s)	
Robot Time (s)	
Part Weight (lbs)	7.45
Shot Weight (lbs)	7.45

Clamp Open

	3	2	1	
Velocity	N/A	25.00	1.50	in/s
Position	N/A	74.500	42.100	in
Open Dwell Time			0.0	s
Tonnage Setting			2000	tons

Mold Height

	66.631 in
Ejt Back Position	
	1.956 in

Pack / Hold

Stages: 1

	3	2	1	
Vel	N/A	N/A	0.50	in/s
Prs	N/A	N/A	6200	psi
Time	N/A	N/A	12.00	s

Ejector Forward

On

	1	2	
Vel	2.800	2.800	in/s
Pos	4.750	7.000	in
Time	0.000	0.000	s

Start Ejt Fwd: 74.000 in; Pulses: 1

Extruder

Cool Time: 14.0 s; Ext Delay: 0 s; Shot Size: 9.500 in

Ejector Retract

	2	1	
Vel	1.500	4.00	in/s
Pos	1.969	2.300	in

Pulse Retract: 1.000 in; Ejt Back Limit Switch: On

	1	
Spd	100	rpm
Prs	750	psi

Decomp: Before / After

	Before	After	
Vel	0.10	0.75	in/s
Pos	0.000	0.500	in

Barrel Temperatures

	N	4	3	2	1	F
Set (F)	425	440	440	440	440	120

Actual Melt Temp (deg F): 454 Air Purge

Valve Gate Sequence

	1	2	3	4	5	6	7	8
Open (s)	0.50	1.00	0.00	0.75	0.50	3.50	1.25	1.25
Close (s)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Mold Gate: G1 G2 G3 G4 G5 G6 G7-G8 G9

Cores ON — Cores Used (#): 6 — Stationary Side #: 2,4,6 — Moving Side #: 1,3,5

Mold Water — TCU Fixed Side: Set (F) 120; Clr3(gpm); Clr4(gpm)

TCU Moving Side: Set (F) 120; Clr5(gpm); Clr6(gpm)

Seq	Core #	Action	Cycle Point	Vel%	(psi)	Timer	Delay (s)	Time (s)	Hold Pres	Str Pt (in)	Mon Pt (in)
1	3	Set	Parallel with Clamp Close	9	1500	N	-	-	Yes	75.000	-
2	1	Set	After Clamp Tonnage Build	65	1700	N	-	-	Yes	-	-
3	5	Set	After Clamp Tonnage Build	30	1500	Y	-	-	Yes	-	-
4	2	Set	After Clamp Tonnage Build	15	1800	N	-	-	Yes	-	-
5	4	Set	After Clamp Tonnage Build	25	1800	N	-	-	Yes	-	-
6	2	Pull	Before Clamp Decompress	20	1500	N	-	-	Yes	-	-
7	4	Pull	Before Clamp Decompress	25	1800	N	-	-	Yes	-	-
8	5	Pull	After Clamp Decompress	30	1600	N	-	-	Yes	-	-
9	3	Pull	After Clamp Decompress	15	1500	N	-	-	Yes	-	-
10	1	Pull	After Clamp Decompress	45	1650	N	-	-	Yes	-	-
11	6	Pull	Parallel w/Clamp Open	35	500	N	-	-	Yes	-	-
12	6	Set	Parallel w/Clamp Open	80	1000	N	0.50	-	Yes	-	-

Stationary Side Hyd Ejt

Hot Runner Temperatures

Zone #	1	2	3	4	5	6	7	8	9	10	11	12	
Temp (F)	400	415	415	415	415	415	400	415	415	400	415	415	Drops
Zone #	13	14	15	16	17	18	19	20	21	22	23	24	
Temp (F)	400	415	415	400	415	415	400	415	415	400	415	415	Manifolds
Zone #	25	26	27	28	29	30	31	32	33	34	35	36	
Temp (F)	400	415	415	400	415	415	415	415	415	415	415	415	Tips
Zone #	37	38	39	40	41	42	43	44	45	46	47	48	
Temp (F)	415	-	-	-	-	-	-	-	-	-	-	-	

Machine Digital Inputs/Outputs

INPUTS

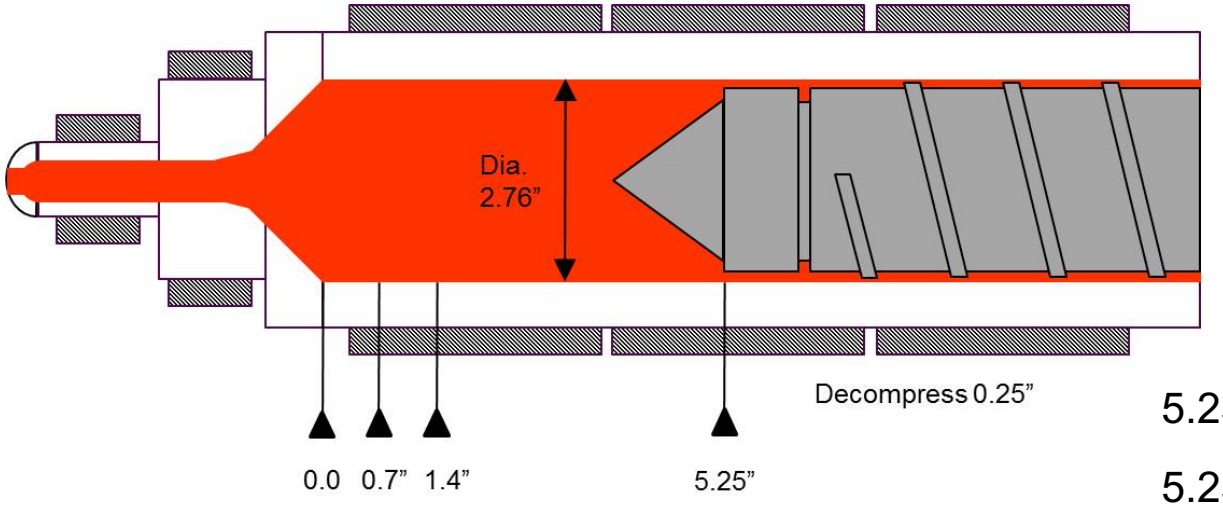
#	Function of Input	Time (s)	Description of Input
1	On Ejector is Retracted	0.0	Camera Trigger
2	Off		
3	Off		
4	Off		

OUTPUTS

#	Function Selection	Description of Output
1	On Clamp Close Permission	Stationary Camera
2	On Clamp Close Permission	Moving Camera
3	On Clamp Close Permission	Mold Water Flow Not OK
4	On Clamp Close Permission	H/R Water Flow Not OK

Test Your Knowledge!

- What is the shot size of the following machine setup?



5.25 -.25 -.7 = Shot Size = 4.3”

5.25 -.25 – 1.4 = Fill Stroke = 3.6”

>>EXPERT TIP<<

- Use absolute ram speed profile and transfer position for accurate results
- Do not be tempted to use a fill time and 98% volume switch-over

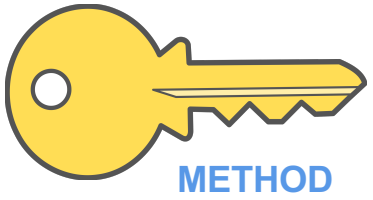
Custom Injection Molding Machine Database

- Required for simulation validation
- Specific machine information is needed

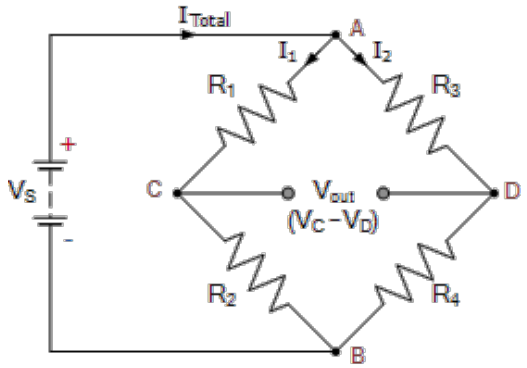
Injection stroke
Injection rate
Screw diameter
# of RAM speed steps
# of pressure steps

Maximum injection pressure
Intensification ratio
Hydraulic response time
Maximum clamp force

Using Cavity Pressure Sensors

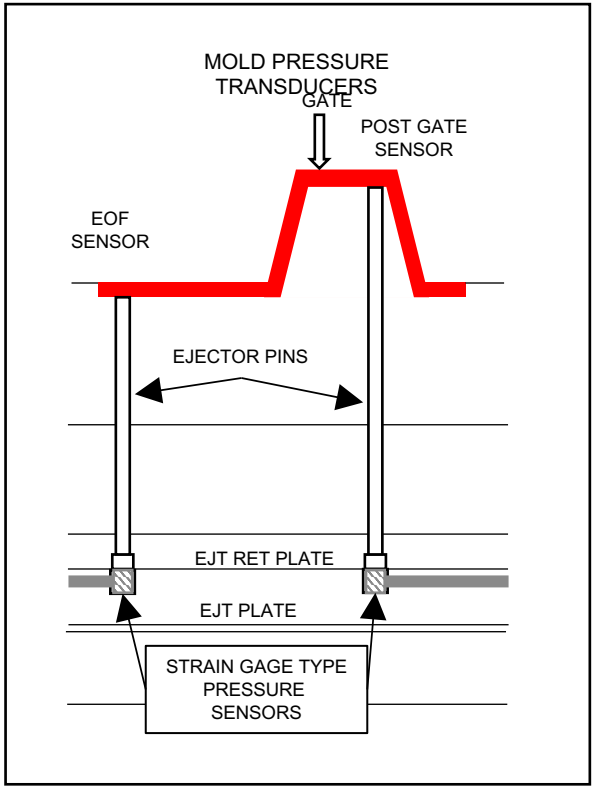


- Process Control (V/P transfer)
- Process Monitoring (Mtl variation, short shots)
- Process Setup Transfer (Machine to Machine)
- Traceability / Genealogy
- Quality Control
  - Cavity Rejects/Containment
  - Sorting
- Pressure Validation

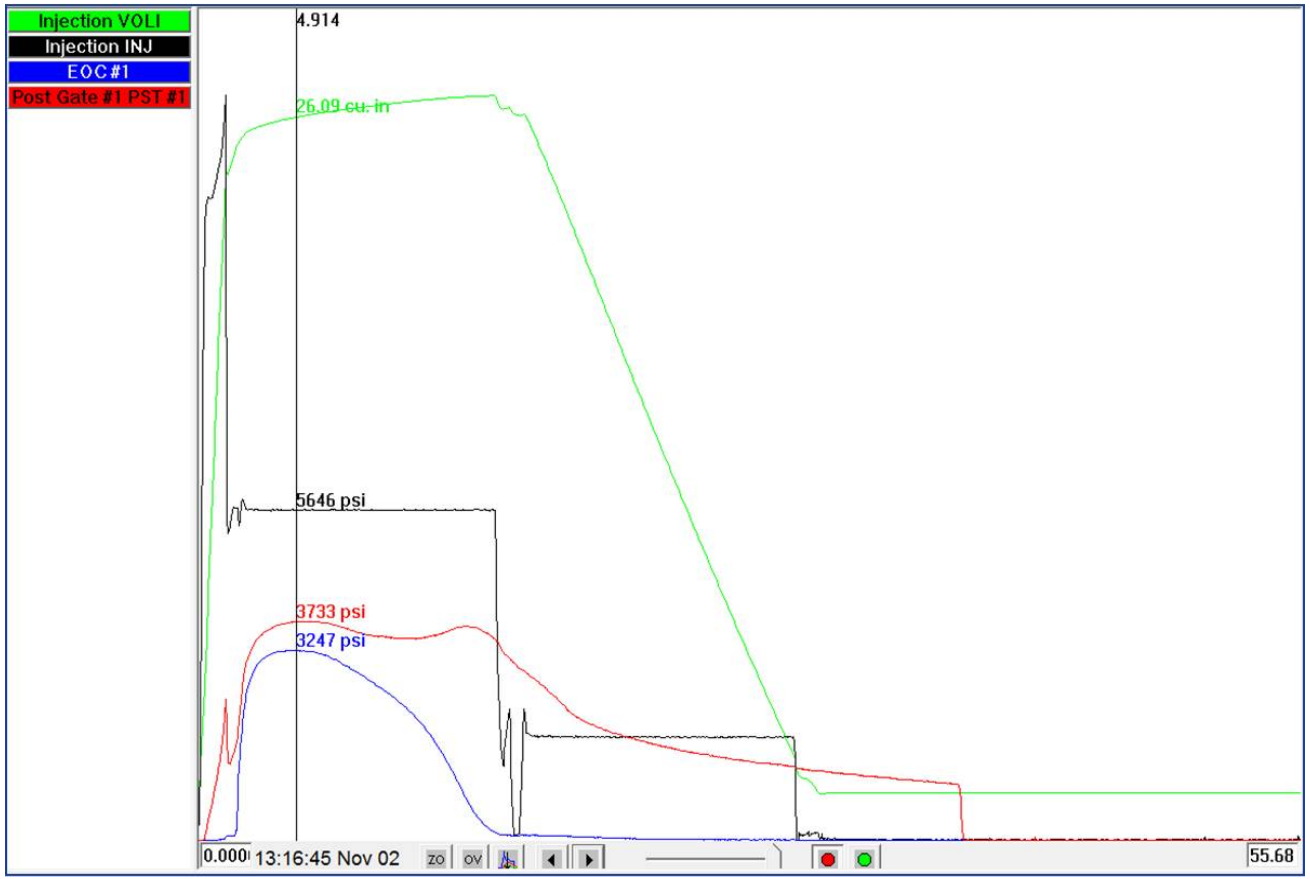


Pressure Sensor Locations

- Post Gate Sensor (PG)
  - As close to the gate as possible
- End of Fill Sensor (EOF)
  - As close to end of fill as possible



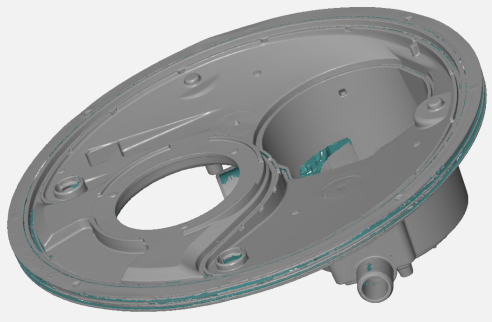
Pressure Trace

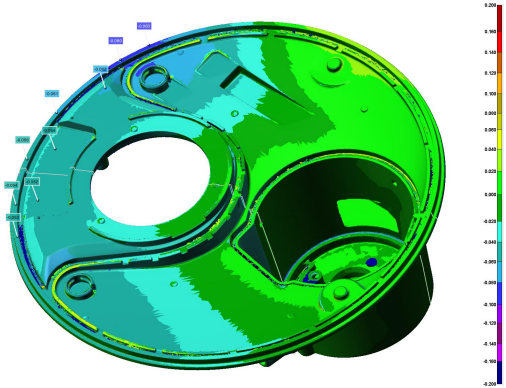


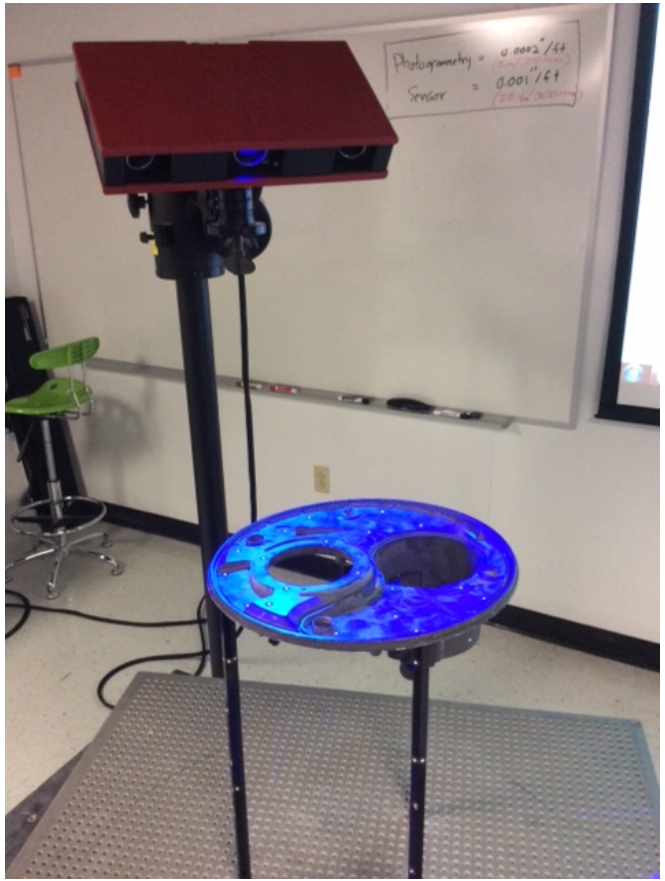
Decoupled Molding® DII (RJG, Inc.)

- Establish fill only part
  - Fill as fast as the machine, mold and part quality will allow without being pressure limited
  - 95-98% Full
- Transfer to pressure control
  - Finish filling the cavity
  - Complete Pack/Hold (packing pressure 50-80% of max fill pressure)

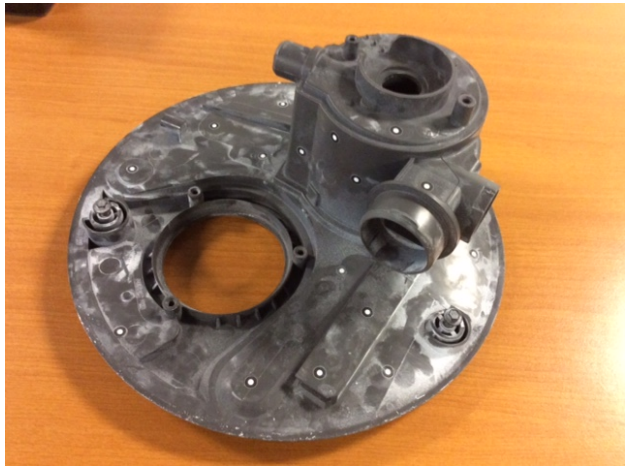
Part Metrology



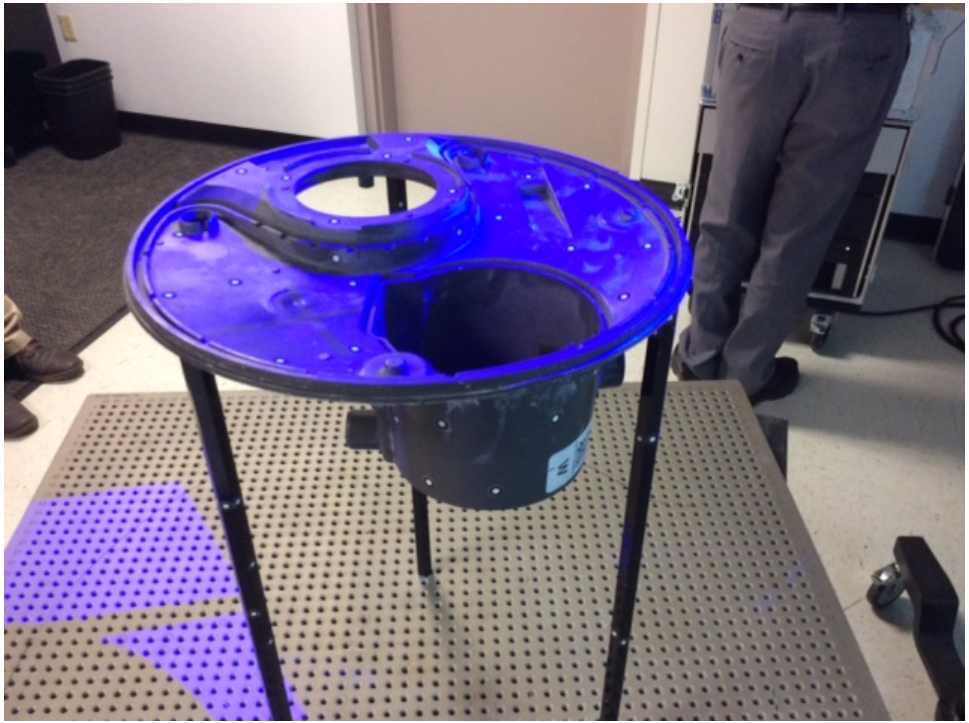




Scanning Setup

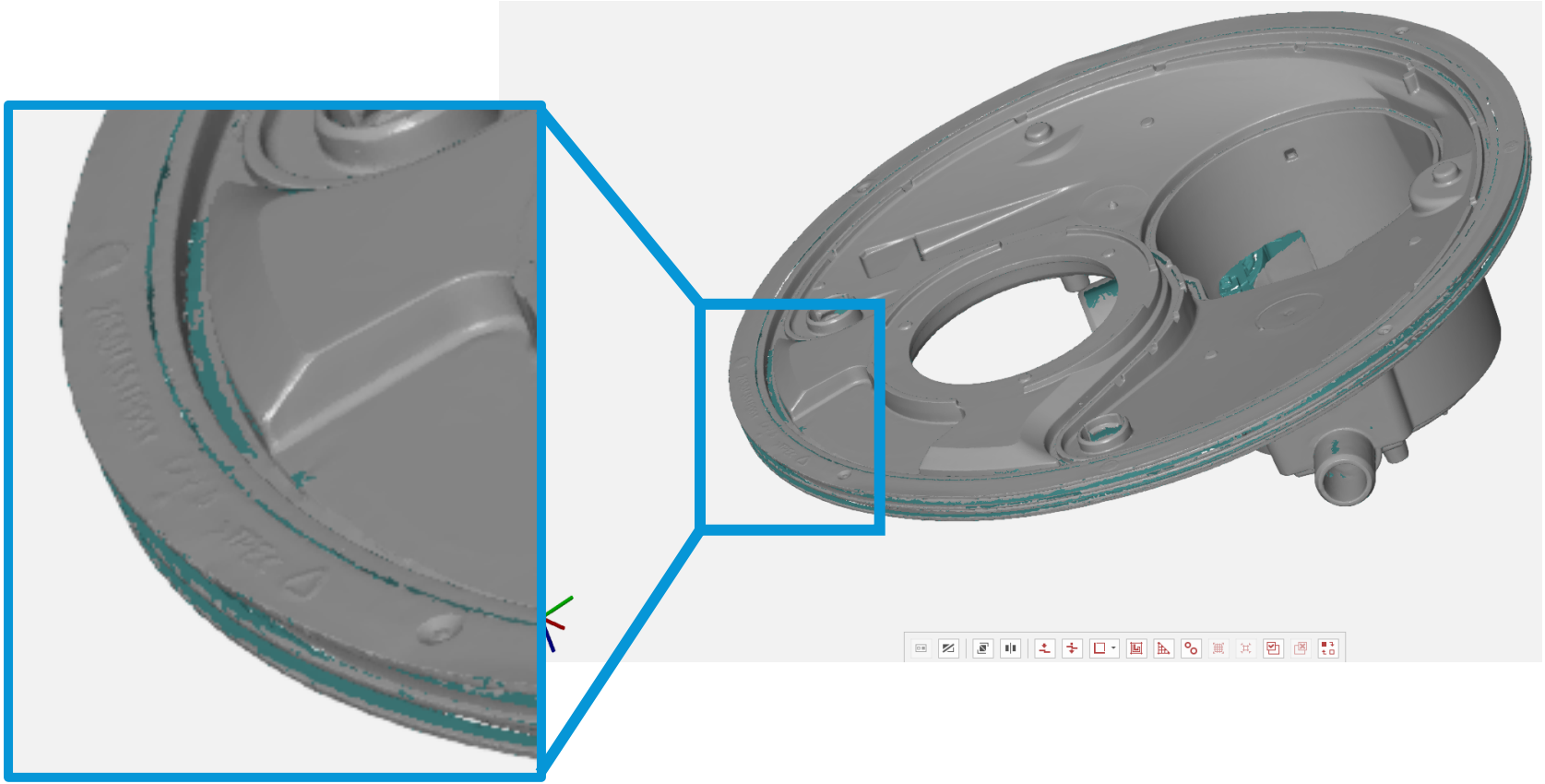


Targets applied to part



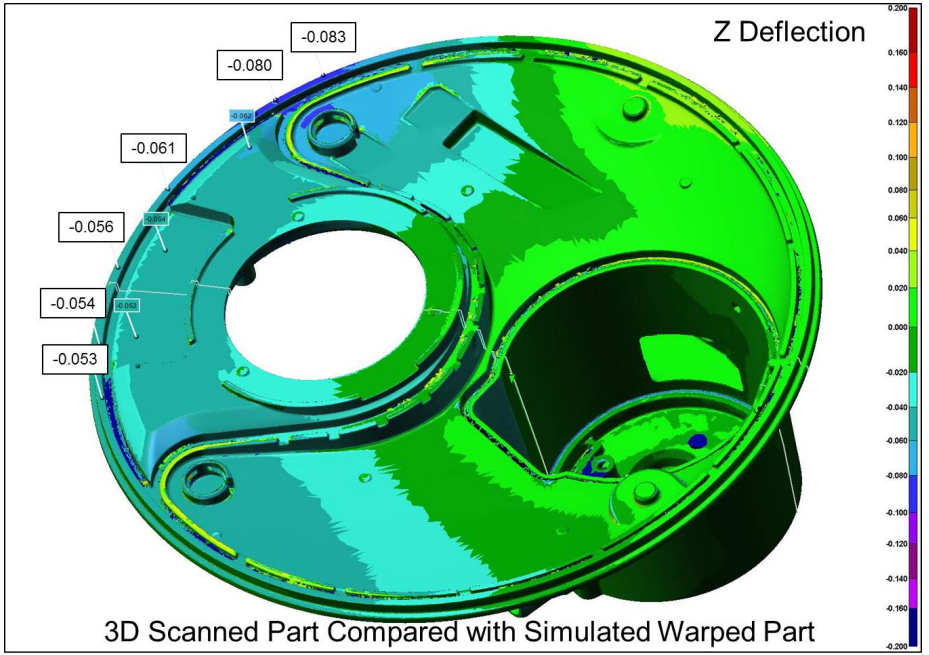
Blue Light 3D Scanning
Simple Fixture. Part in free state

3D Scanned Part



Part Deviation Analysis

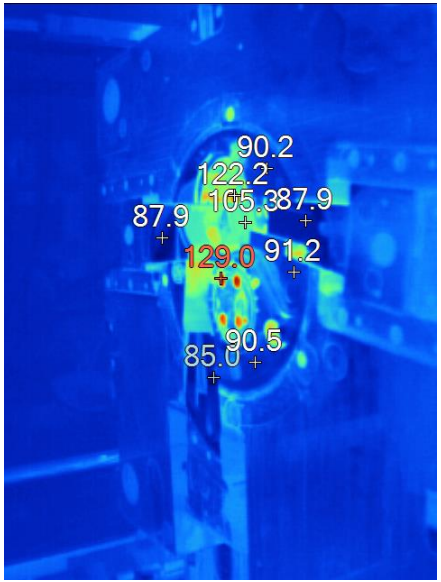
- Data is compared to show deviations
  - Scanned part to CAD
  - Simulated warped part CAD to scanned part
- Allows use of custom anchor planes
- Uses GDT with custom reports from analysis



3D Scanned Part Compared with Simulated Warped Part

Melt/Mold Temperature

- Obtaining accurate melt and mold temperature readings can be a challenging task.
- Handheld pyrometers (rapid response)
  - Melt temperature
  - Mold surface temperature
- Thermal imaging cameras
  - Use for Mold/Part Temperature
  - Check part at ejection
  - Check mold at ejection and before clamp close



In-Mold Thermocouples

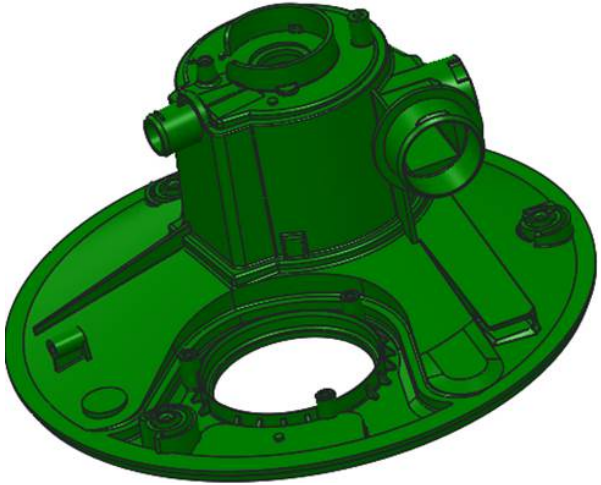
- Team up with pressure transducers in your instrumented mold
- Captures transient mold temperature
  - Temperature of steel throughout the entire cycle
  - Capture mold start up temperature to equilibrium
- Add thermocouples to slides/lifters

Simulation Validation Case Study

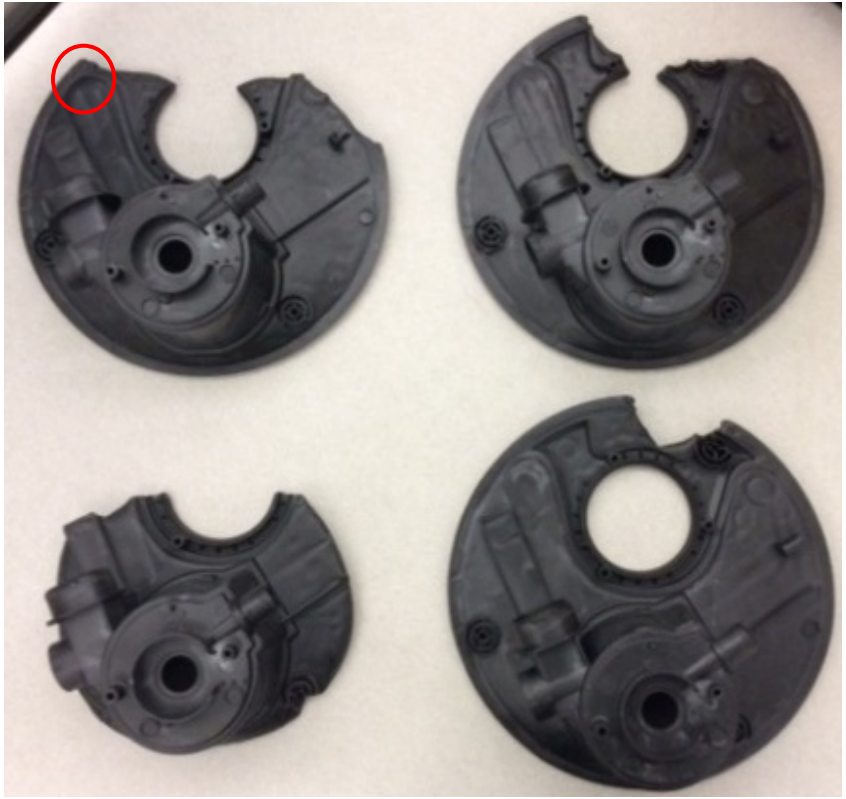
AUTODESK.

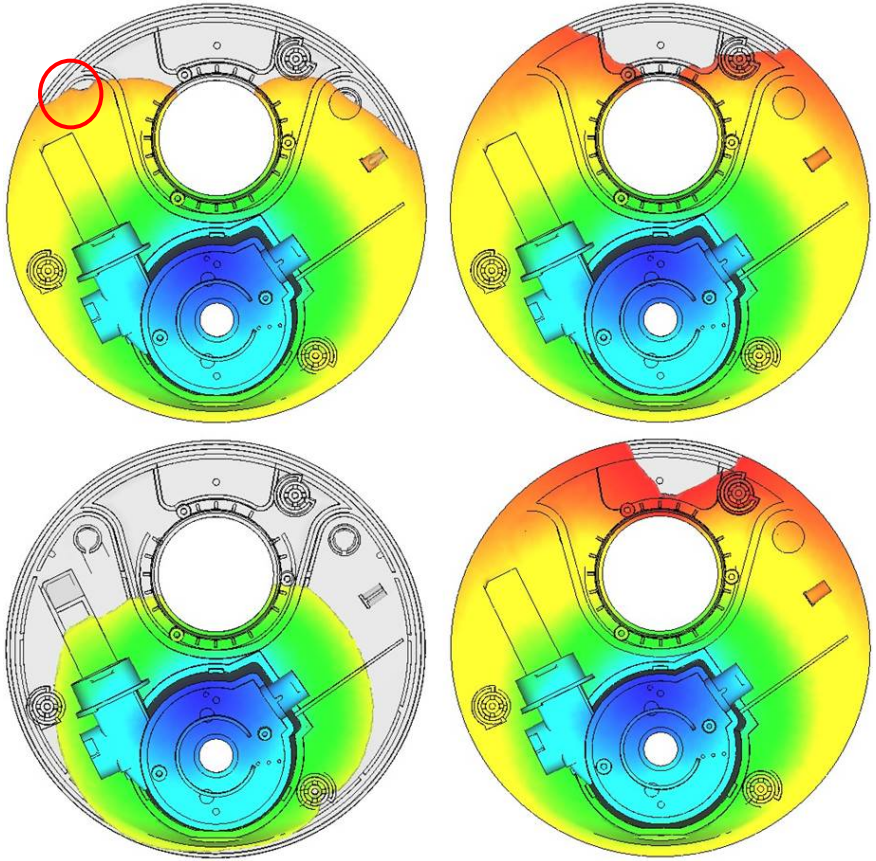
Simulation Validation Case Study

Part: Appliance Part
Material: Filled PP (Gold Data)
Gate: Valve Gate
Analysis Type: Dual Domain & 3D mesh
Analysis Sequence: Fill, Cool, Fill, Pack, Warp
Mold Shrinkage: Cut to .012in/in

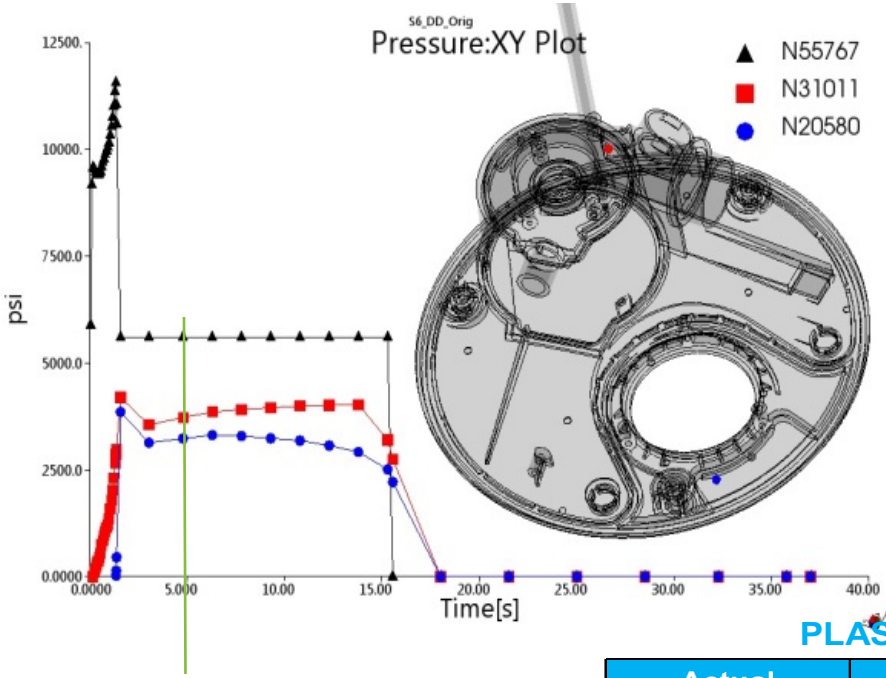


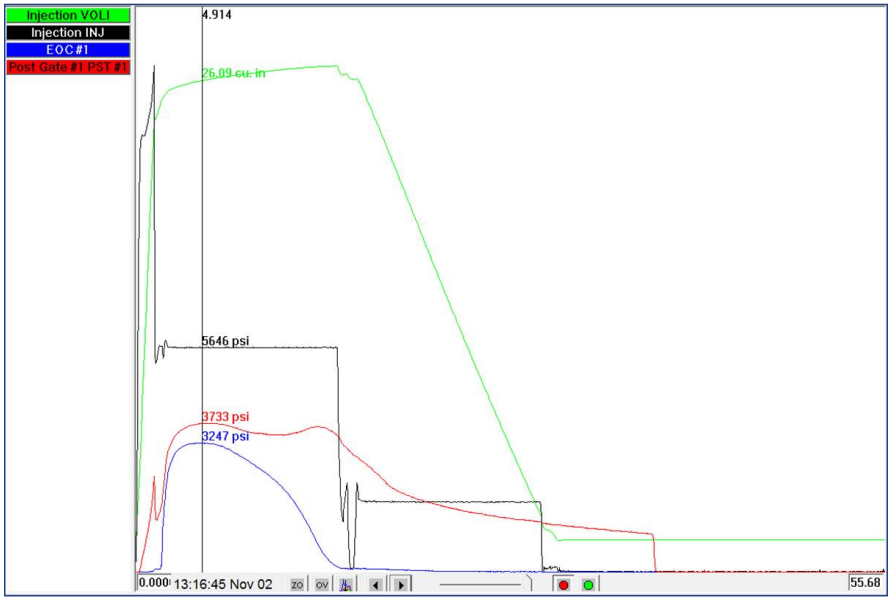
Short Shot Sequence





Pressure Trace vs. Simulation (Continued)





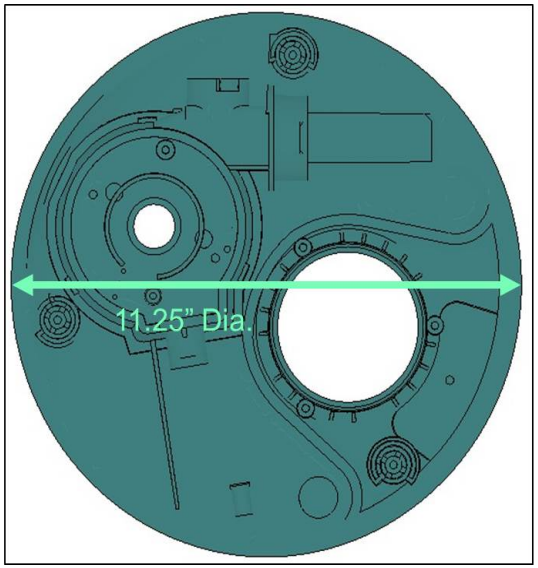
PLASTIC PRESSURE VALIDATION

	Actual	DD	DD w/ Nozzle*	3D
Nozzle (psi)	12,480	9,786	11,562*	10,067
Post Gate (psi)	3,733	3,757	3,757	4,002
End of Fill (psi)	3,247	3,246	3,246	3,710

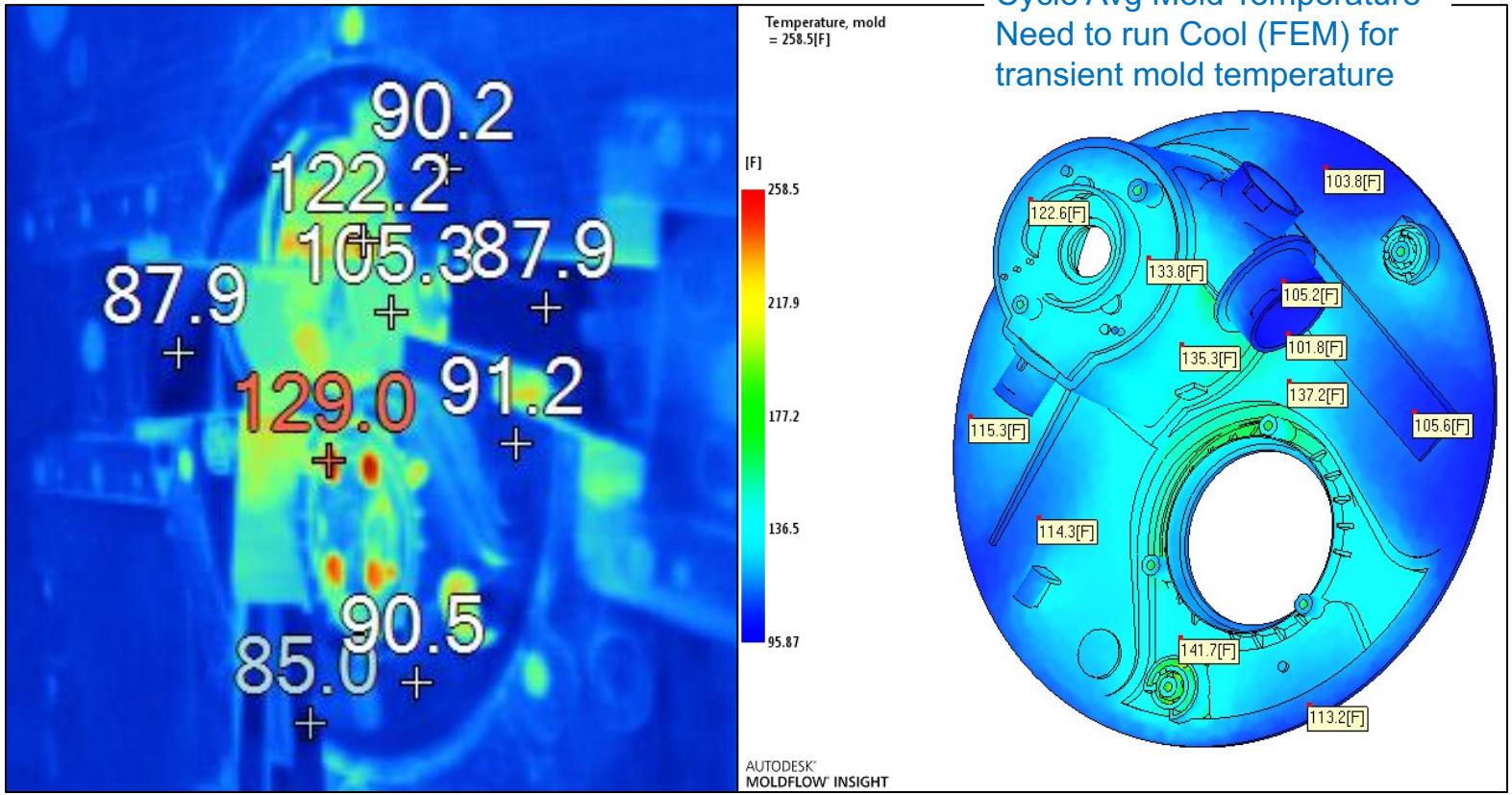
5600 psi packing/hold pressure
Actual pressures from in cavity pressure sensors
*Machine nozzle pressure loss = 1,776 psi

Part Shrinkage vs Simulation

	Actual	DD	3D
Dia (in)	11.2606	11.25	11.29
Shrinkage (%)	1.05%	1.21%	0.81%



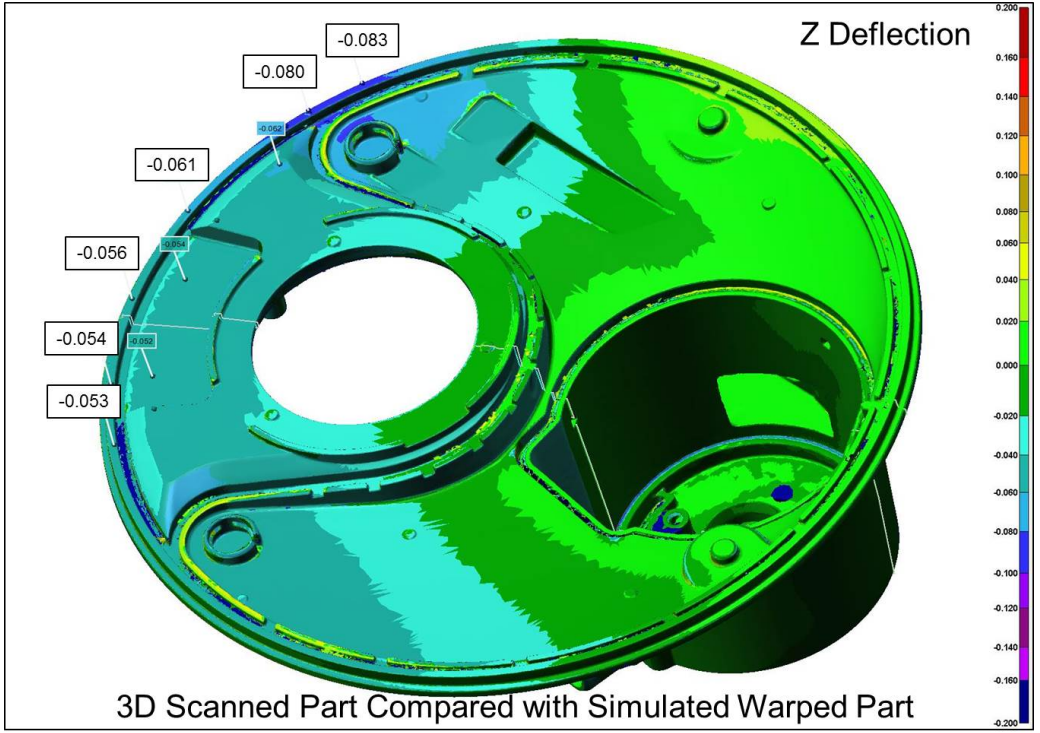
Mold Temperature vs Simulation



Cycle Avg Mold Temperature
Need to run Cool (FEM) for
transient mold temperature

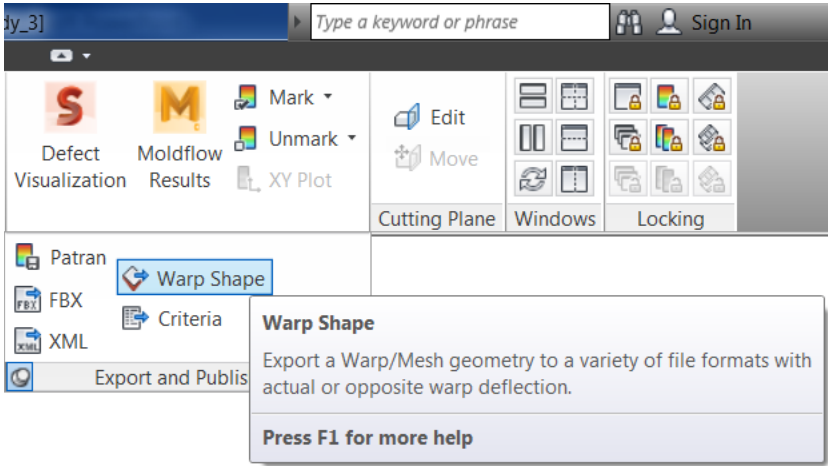
Part Deflection Validation

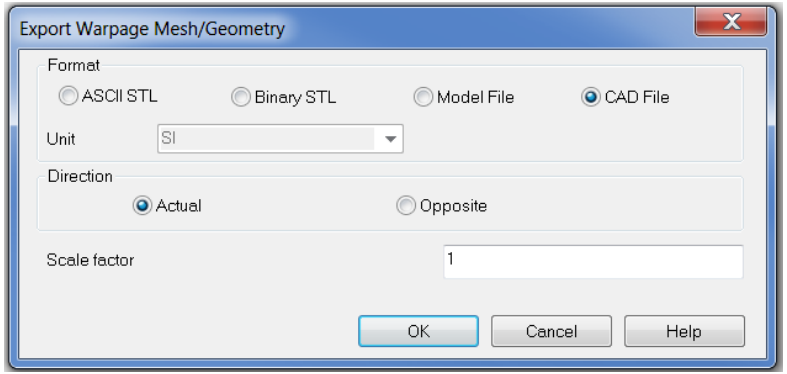
- Deviation analysis from Polyworks software
- Compares scanned molded part with exported warped CAD from Moldflow



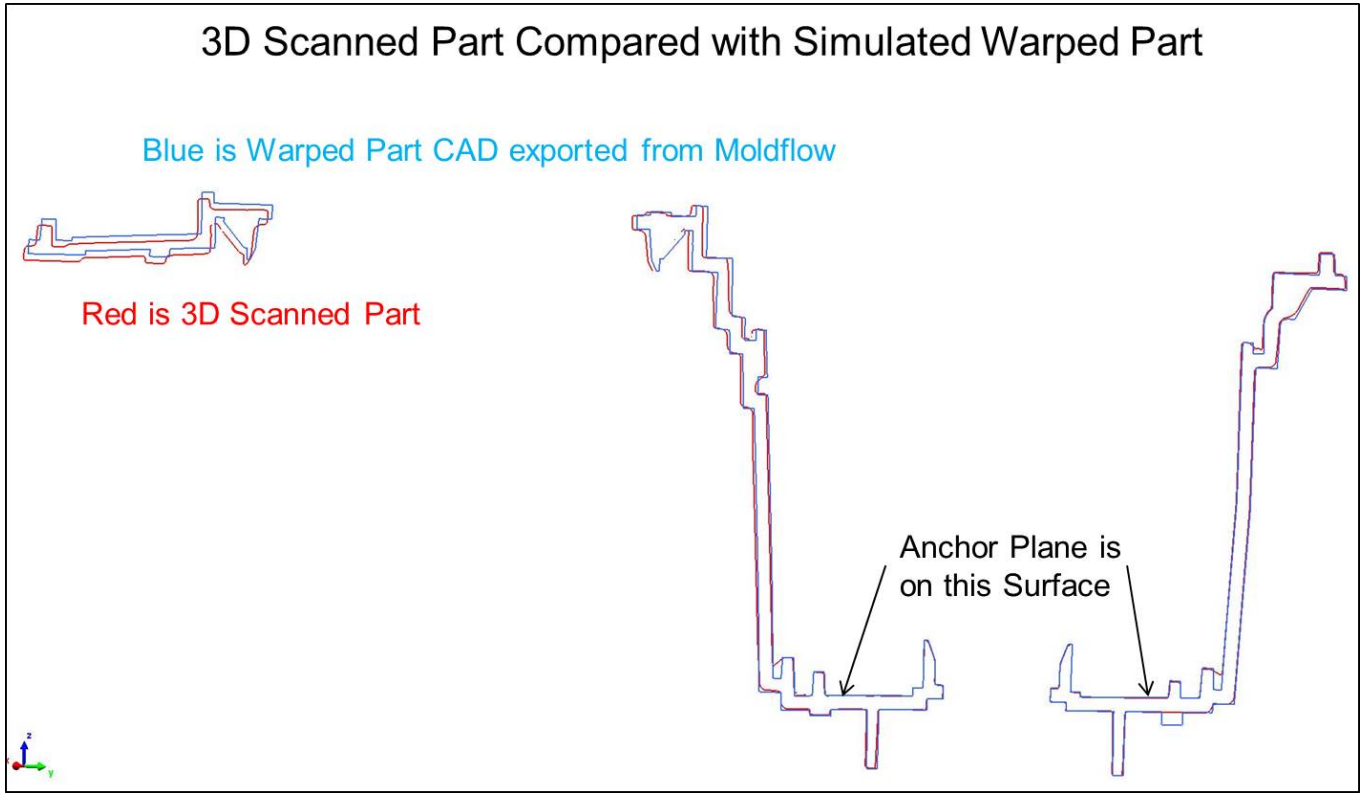
Exporting Warped CAD Geometry

- 3D Printed warped parts
  - Evaluate assemblies
- Can export actual or opposite direction
- Useful for early prototype builds

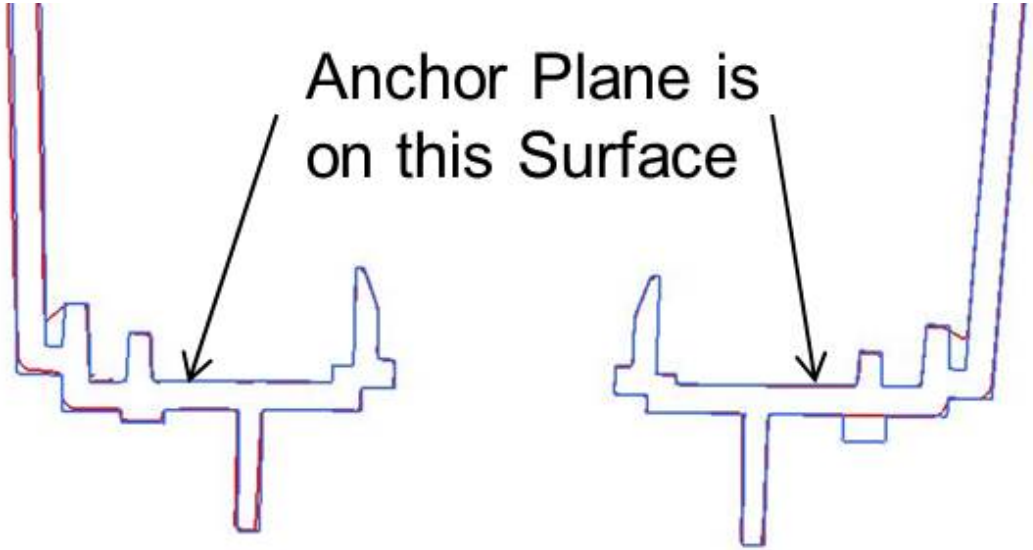




Part Deflection Validation (continued)

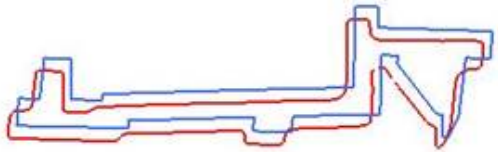


Part Deflection Validation (continued)

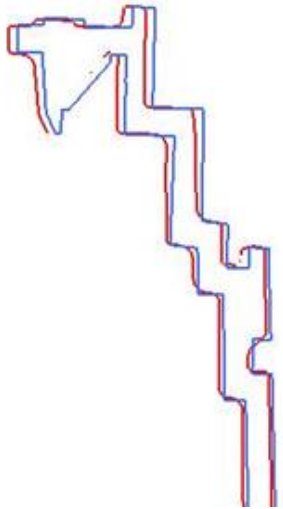


Part Deflection Validation (continued)

Blue is Warped Part CAD exported from Moldflow



Red is 3D Scanned Part



Summary

- Learned about of simulation validation
- Discussed the keys to success
- Learned about the importance of sensors for validation
- Reviewed preliminary case study results
- Investigated how to use scanning to compare predicted vs actual dimensions

Future Work

- Model & mesh mold in 3D
  - Core/Cavity
  - MoldMax Slides
- Run with Insight v2018
- Conduct 3D simulation with Cool (FEM)
- Conduct optimization analysis
- Currently working with Moldflow Validation Team (Syed.Rehmathullah@autodesk.com)

AUTODESK®

Make anything.