Material Properties versus Simulation Accuracy

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Presentation Summary

The usefulness of thermoplastic injection-molding simulation is influenced by many simulation inputs – such as the model of part geometry, mesh type and density, process settings, and plastic material properties both as a melt and a solid. This presentation will focus on the influence of the material properties data file – the .udb input file – on simulation precision and accuracy.

Presenter Background

- GM employee for 28 years
  - Chemical Engineer turned into a Manufacturing / Plastics Engineer
  - Time spent in both Manufacturing Engineering and Research & Development
- Currently Manager of the R&D Injection Molding Lab within the MSR Laboratory
  - Injection Molding Subject Matter Expert (SME)
  - Collaborate with Manufacturing, Materials, and Product Engineering on many projects
- Primary work focus:
  - The precision injection molding of battery and fuel cell components
  - Alternative tooling strategies
  - Moldflow simulation validation studies

R&D Injection Molding Lab

- Husky Hylectric 120 (H120)
- Clamping Force = 120 metric tons
- For thin wall stock, max part size:
  - *TPO: 48 in^2 (6 x 8 inches)*
  - *ABS / PC: 33 in^2 (3 x 11 inches)*
  - *Nylon 66: 27 in^2 (3 x 9 inches)*
- 4-Axis Husky Tracer Robot
- Interfaces: RJG (& MPX)

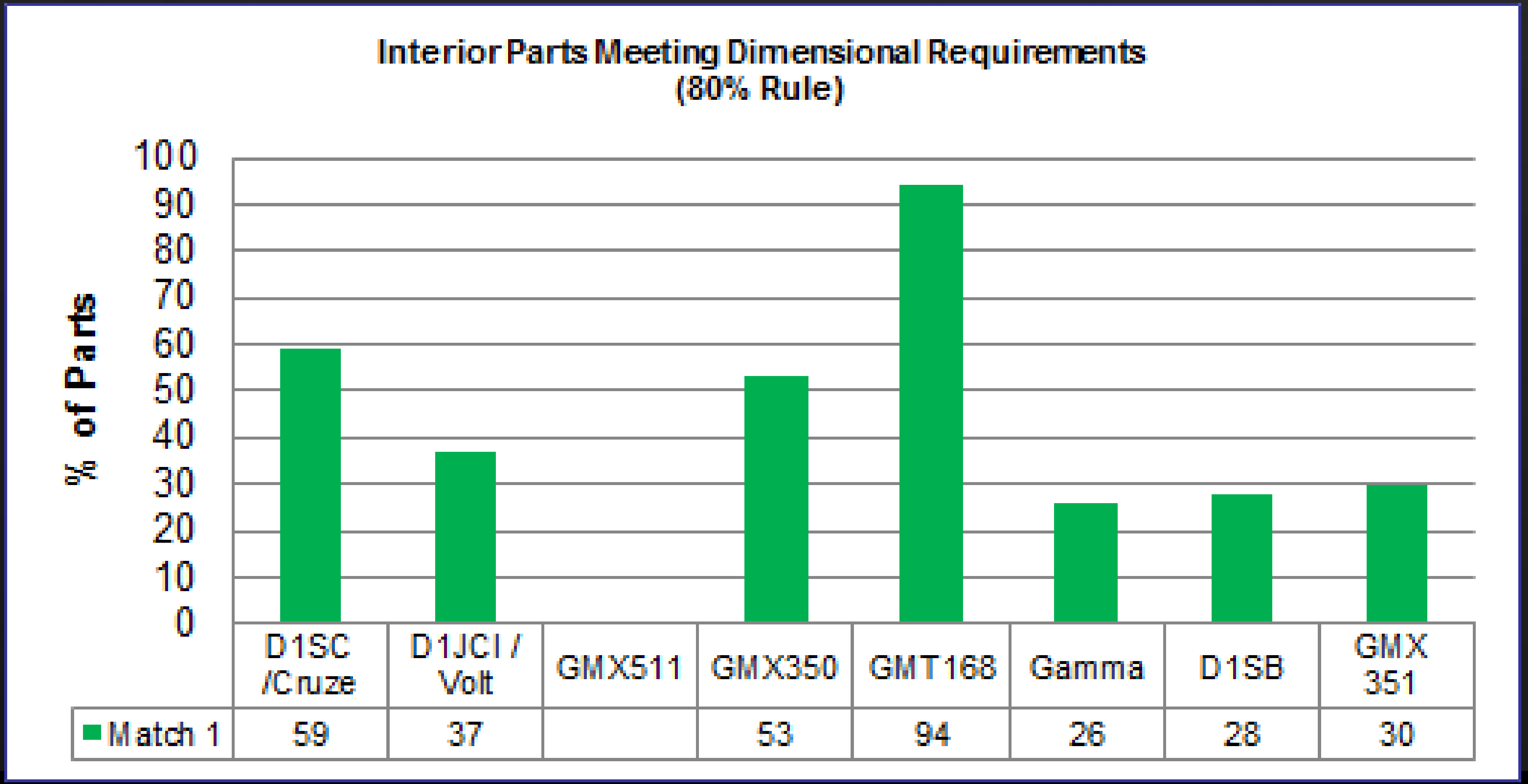
- Husky Quadloc 1350 (Q1350)
- Clamping Force = 1,350 metric tons
- For thin wall stock, max part size:
  - *TPO: 545 in^2 (~ 9 x 60 inches)*
  - *ABS / PC: 375 in^2 (15 x 25 inches)*
  - *Nylon 66: 300 in^2 (12 x 25 inches)*
- 6-Axis Fanuc Robot
- Interfaces: Gas Inject, RJG, (& MPX)

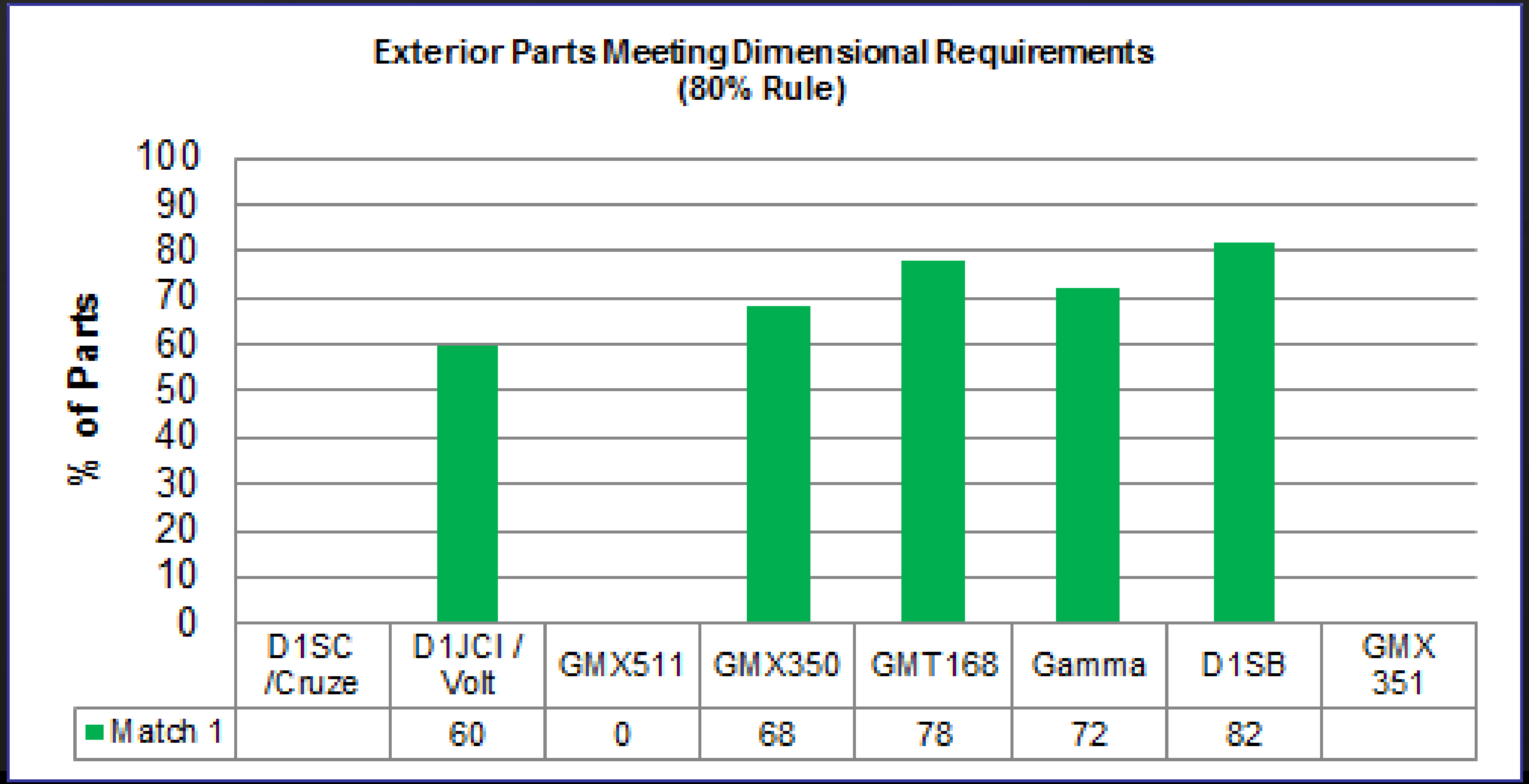
Why the interest in Material Characterization ?

- Experience with simulation indicates that the material properties data file is the leading source of error in all Moldflow analyses that are run for GM.
  - Quality of material properties data contained within the Moldflow database is suspect.
- If Moldflow analysis is be used to the benefit of the Corporation, then the fidelity of simulation results must improve.
  - Develop best practices for modeling and meshing part geometry on a commodity basis.
  - Improve the reliability of material properties data.

Crucial Role for Moldflow Analysis within GM

- For injection molded interior and exterior plastic components, GM's Global Vehicle Development Program (GVDP) allocates up to 12 weeks for adjusting production tool steel – "mold tuning" – to produce a part to print specifications prior to the first matching build event (M1).
  - M1 requirements – 80% of part dimensions to print – are not being met.
    - 53% of all interior parts are not meeting M1 requirements.
    - 28% of all exterior parts are not meeting M1 requirements.





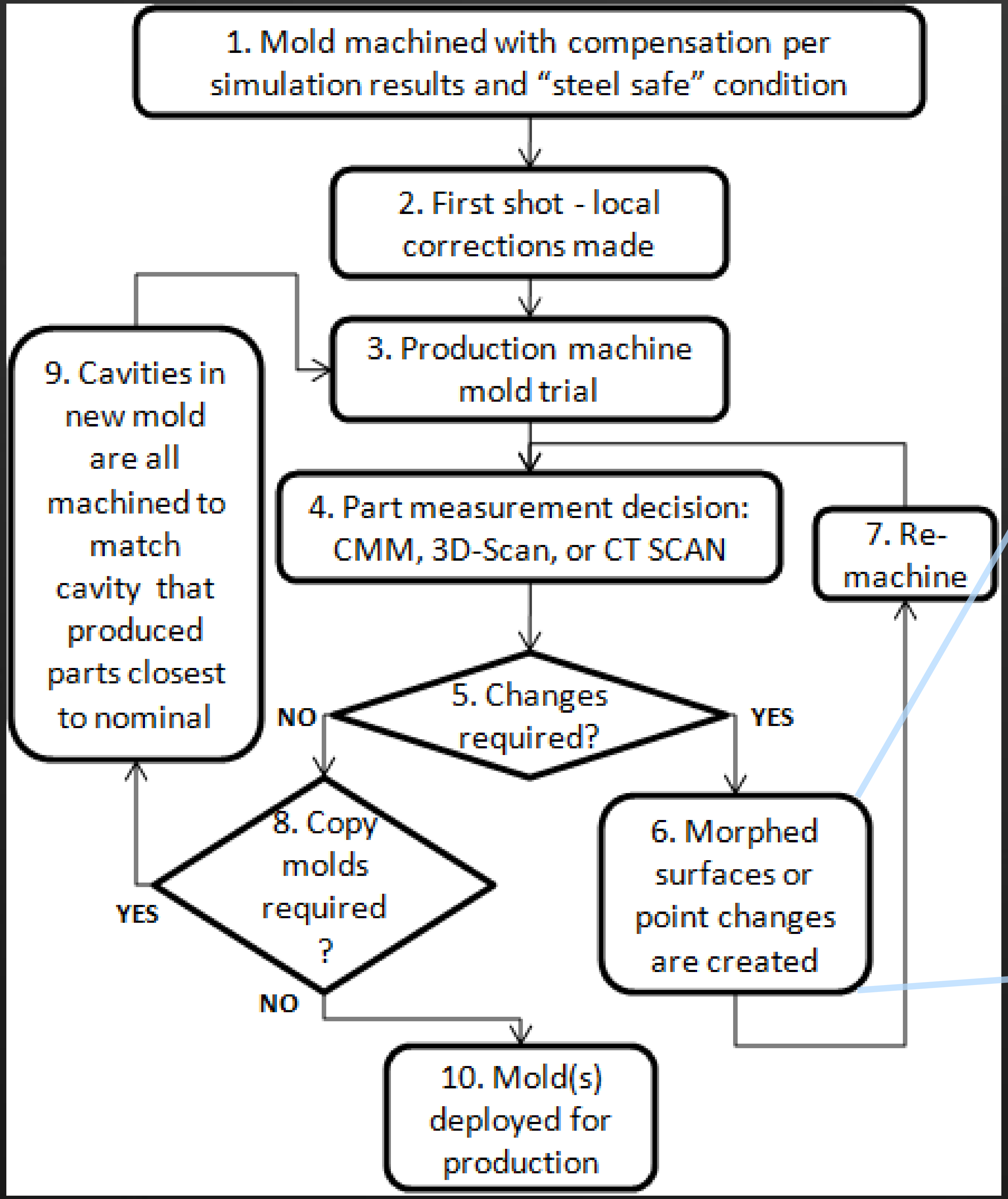
GM Moldflow Philosophy

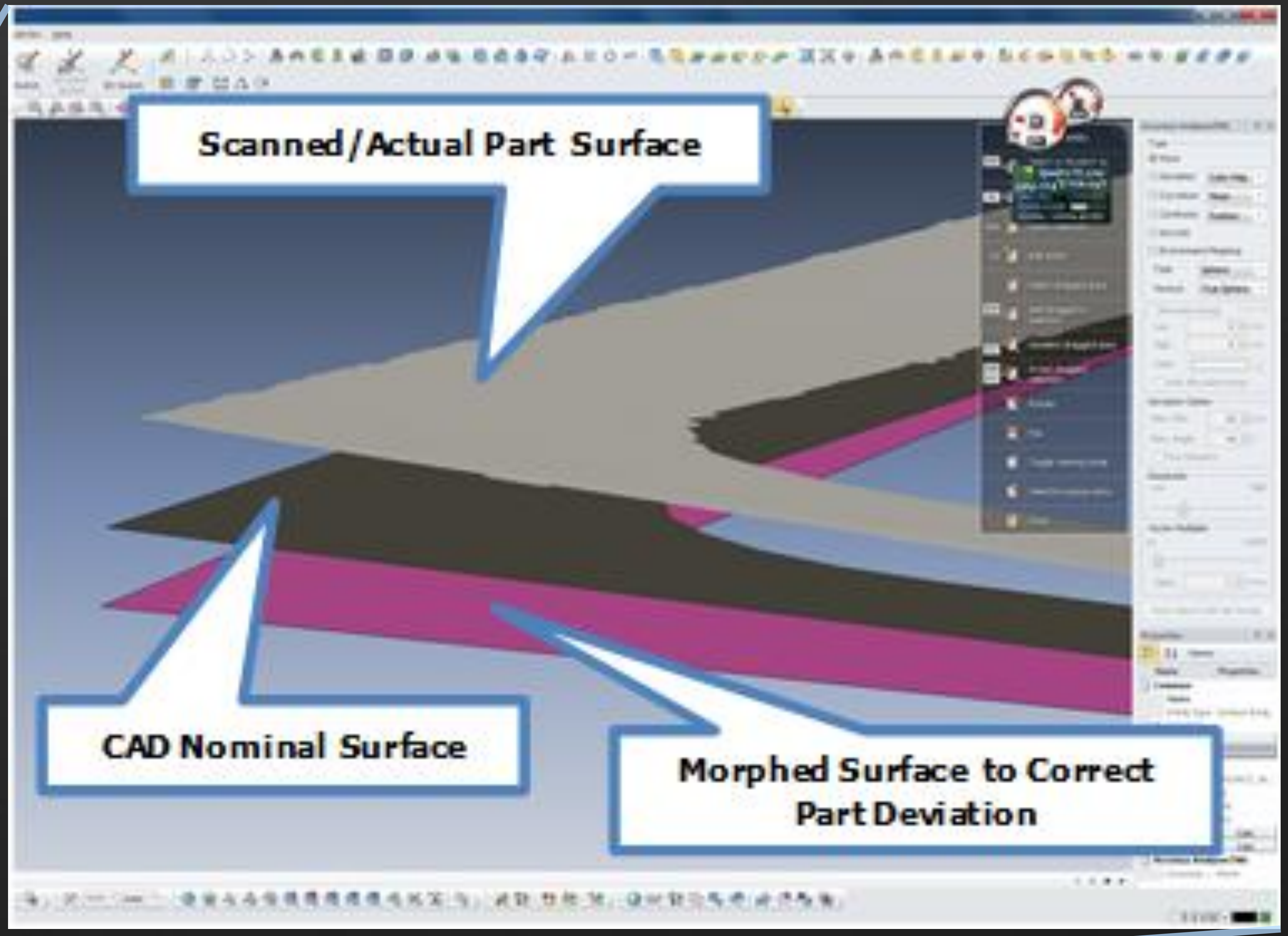
- M1 Requirements Scorecard must improve so as to impact the bottom-line of the Corporation – Moldflow analysis is crucial to improving the M1 Scorecard.

  GM Moldflow Mission Statement

- GM Manufacturing Engineering – Global Paint & Polymers Center (GPPC) – owns Moldflow analysis within the Corporation.
  - GPPC to use Moldflow Insight analysis as a virtual tool design aid to reduce the number of tuning cycles to produce a part to print specifications.
    - GM intends to cut steel according to Moldflow Insight output – specifically, shrink and warp results.
      - Reduce the time to tool and improve the M1 Requirements Scorecard.
    - GM will develop in-house Moldflow expertise, develop in-house Moldflow best practices, and drive Moldflow software improvements by working directly with Autodesk Moldflow and our consultants.

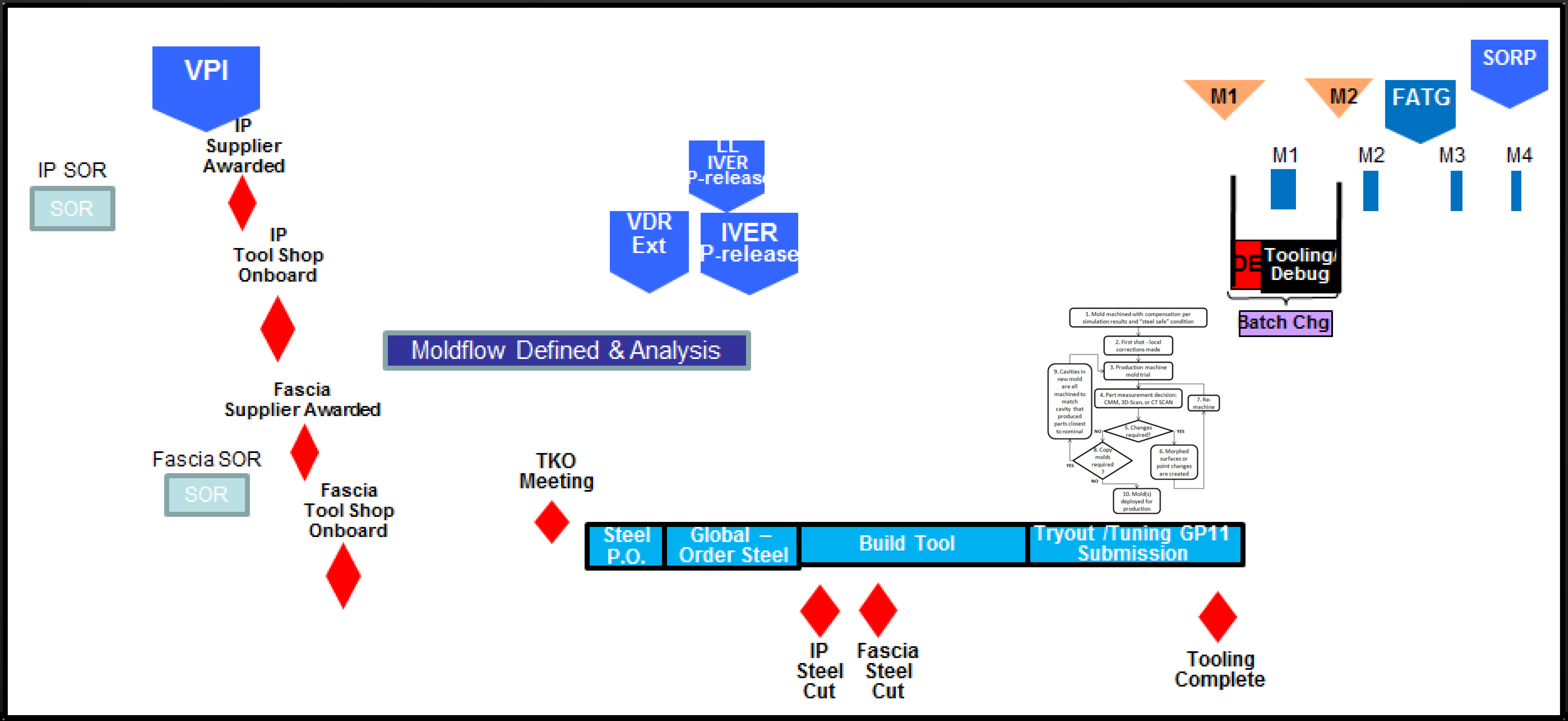
Current Mold Construction and Mold Tuning Process





Current Mold Construction and Mold Tuning Process

Moldflow analysis is not sourced until Tier 1 supplier is chosen.



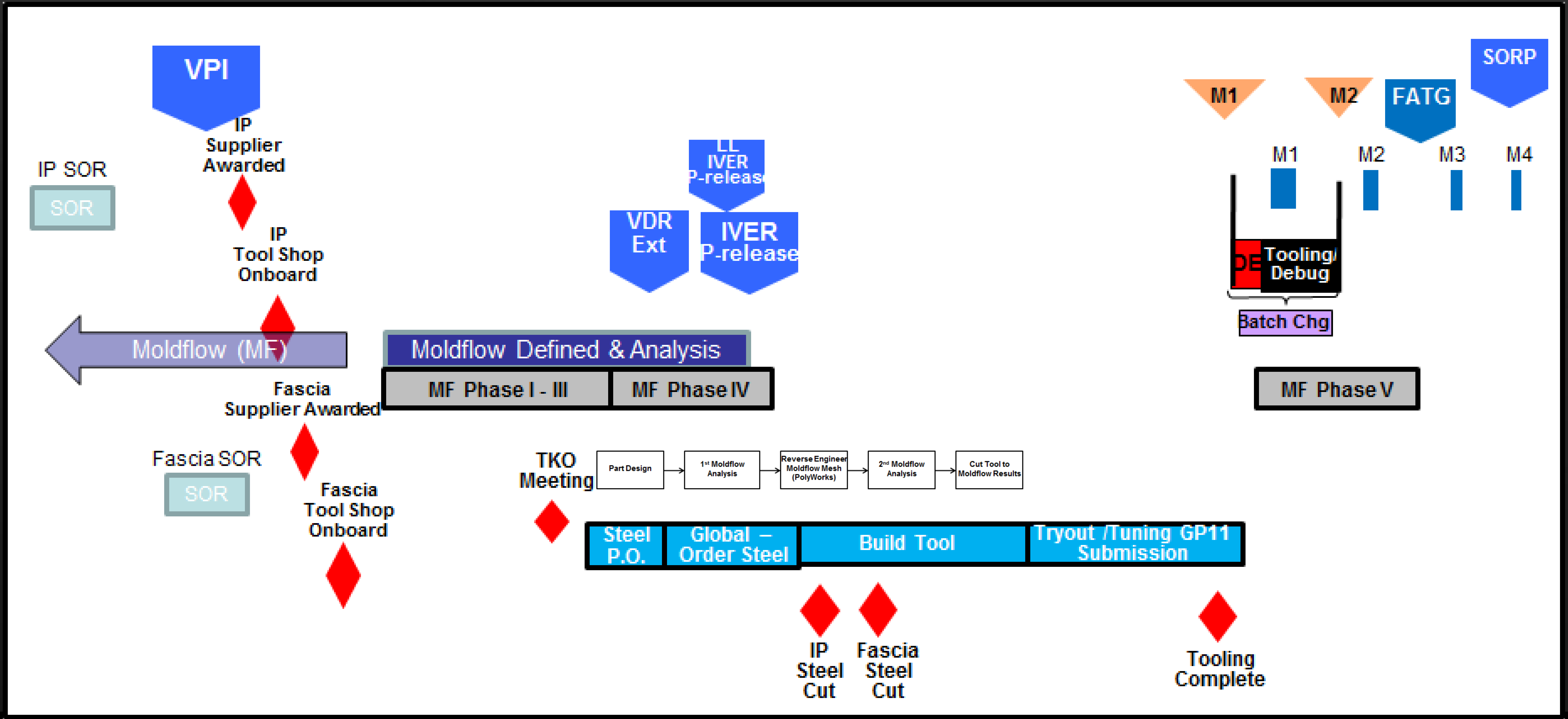
Desired State of Mold Construction and Mold Tuning

- Virtual Mold Tuning Process

Part Design → 1st Moldflow Analysis → Reverse Engineer Moldflow Mesh (PolyWorks) → 2nd Moldflow Analysis → Cut Tool to Moldflow Results

GM Moldflow Strategy

Moldflow Analysis for Upfront Product Development and Design for Manufacturability (DFM)



GM Moldflow Strategy

Moldflow Analysis for Upfront Product Development and Design for Manufacturability (DFM)

- Reduce Process Variation through Standardization
  - GMW16355 – Global Moldflow Specification – defines how GM does a Moldflow analysis for both an in-house analyst as well as a contracted external supplier of Moldflow services.
    - Approved contracted suppliers of Moldflow services – Professional-level (Silver) Certification in 2011 and Expert-level (Gold) Certification in 2012.
    - Types of analyses for a given commodity – i.e.; fill + pack analysis sequence for fascia.
    - Acceptable mesh type (mid-plane, dual-domain or 3D) and mesh quality statistics for a given analysis.
    - Minimum report requirements for five (5) phases of Moldflow analysis.

GM Moldflow Strategy

- Approved Expert-level (Gold) Certified suppliers of Moldflow services to GM:
  CAE Services / Beaumont Technologies / Bozilla Corp / FEAMold / Autodesk Korea
- Five Phases of Moldflow Analysis:
  - Phase I: Establish number of gates and gate location(s).
  - Phase II: Establish cold runner or hot manifold layout and design.
  - Phase III: Establish cooling channel layout and design.
  - Phase IV: Establish optimum process for dimensional stability.
  - Phase V: Reconciliation and validation of Moldflow results to first shots trial data.

GMW16355 Moldflow Scorecard

Moldflow Source	
Analyist Name	
Tooling Source	
Molding Source	
GPPC Engineer	
Program	
Part Commodity	
Target Completion	
Actual Completion	

Analysis Depth (Check which level of analysis was completed)

Fill		Pack		Cool		Warp	

Process Correlation

	Phase 4			Phase 5			Score	
	Analysis	Actual	% Diff	Analysis	Actual	% Diff	Phase 4	Phase 5
Total Fill Time			0			0		
Pressure @ Transfer			0			0		
Total Pack/Hold Time			0			0		
Cooling Time			0			0		
Melt Temp			0			0		
Cavity Temp			0			0		
Core Temp			0			0		
Pressure to Fill Part								
Pressure to Fill Nozzle, Sprue, Runner and Gate								
Δ (Pressure drop across Gate		0	0		0	0		
Pressure to Fill Nozzle, Sprue, and Runner								
Δ (Pressure drop through feed system)		0	0		0	0		
Nozzle Pressure Drop								
Gate Freeze Time			0			0		
						Sub-Total Score	#DIV/0!	#DIV/0!

GM Moldflow Strategy

Moldflow Analysis for Upfront Product Development and Design for Manufacturability (DFM)

- Reduce Process Variation through Standardization
  - In-house Training of GM Manufacturing Engineers,
    - GPPC developing in-house expertise by requiring Manufacturing Engineers to be certified Moldflow users.
      - 100% of Manufacturing Engineers at Associate-level (Bronze) Certification in 2011.
      - 50% of Manufacturing Engineers at Professional-level (Silver) Certification in 2012.

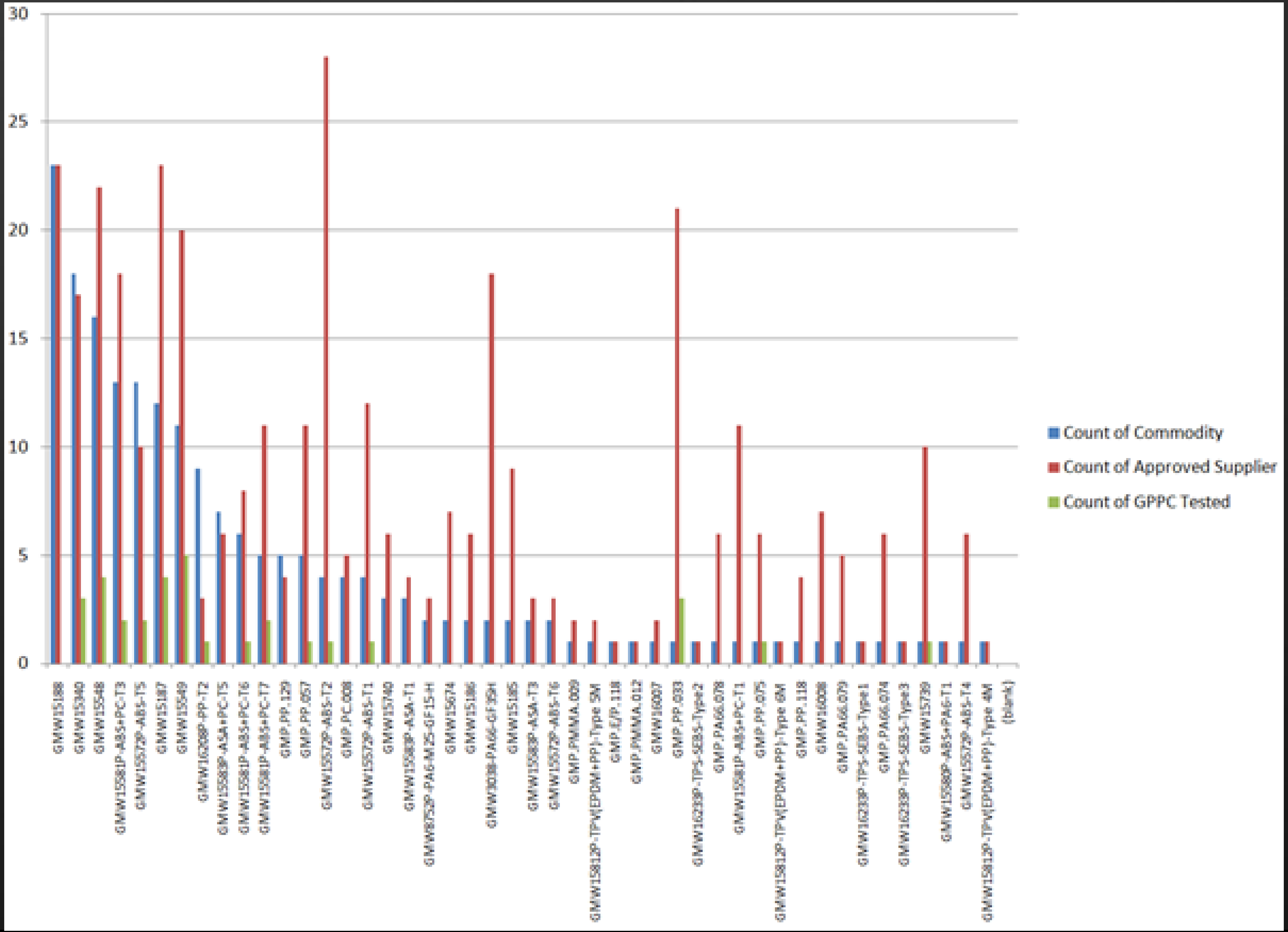
GM Moldflow Strategy

Moldflow Analysis for Upfront Product Development and Design for Manufacturability (DFM)

- Require MPL-150 testing for all present and future GM production thermoplastic materials.
  - Work to standardize Autodesk Moldflow Plastic Labs – all procedures; specifically, standardization of the shrink test plaque between the Melbourne Lab and the Ithaca Lab.
  - GM characterizing 150 of our most used production materials over three years – 2011 through 2013.
    - Return-of-Investment (ROI) for MPL-150 testing for a single material is the elimination of just one mold “tuning” loop.

GM Moldflow Strategy

GM characterizing 150 of our most used production materials over three years (2011 through 2013).



GM Moldflow Strategy

Continuous improvement to answer the question: Is GM doing Moldflow analyses correctly ? (Basic and Applied Research Activities)

- Part Model
  - Is the correct mesh-type (mid-plane, dual-domain or 3D) being used for a given commodity ?
    - Establish best practice for a given commodity.
    - How much detail needs to be included in the mesh ?
      - For instance, establish the number of layers that are required through the part thickness for a given commodity.
- Expected Variation in Analysis Results
  - Will Expert-level certified users produce the same result given the same input data (starting point) ?
    - Are certain Expert-level certified users better at analyzing a particular commodity than other Expert-level users ?

GM Moldflow Strategy

Continuous improvement to answer the question: Is GM doing Moldflow analyses correctly ? (Basic and Applied Research Activities)

- What is the sensitivity of analysis results on the material properties input file (the .udb file), issues of concern are:
  - Use of a .udb file provided by the material supplier – the .udb file contains supplemental material data from a 3rd party.
  - Use of a surrogate .udb file – the .udb file does not exist for the production material.
  - Use of .udb files for a global GM material that is compounded in different regions of the World.
  - Use of a .udb file generated by Autodesk Moldflow Plastics Lab(s) that is older than two years instead of using a .udb file generated by Autodesk Moldflow Plastics Lab(s) that is based on a recent lot of material (effect of lot-to-lot variation).

Material Properties versus Simulation Accuracy

Case Study # 1:

*Using a .udb file that contains supplemental data from the material supplier versus a MPL-150 generated .udb file created at Autodesk Moldflow Plastics Lab.

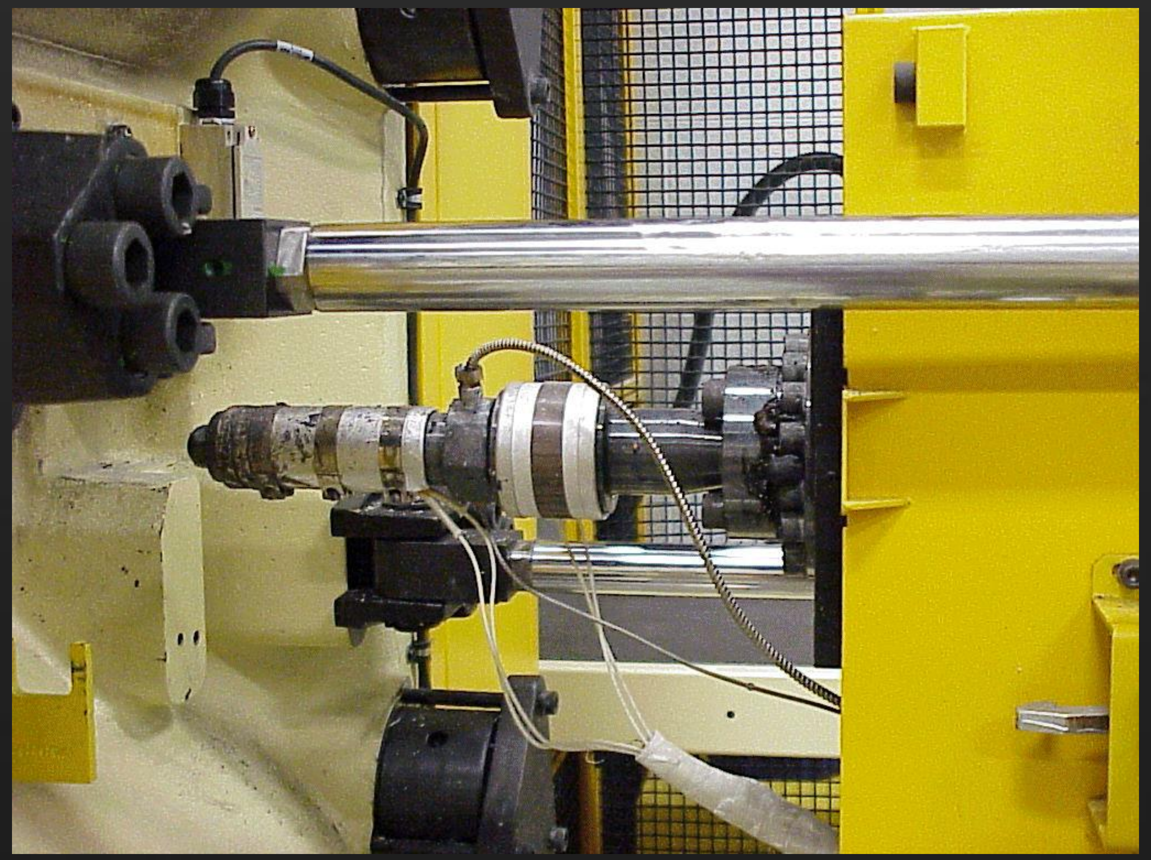
*Use of .udb files for a global GM material that is compounded in different regions of the World.

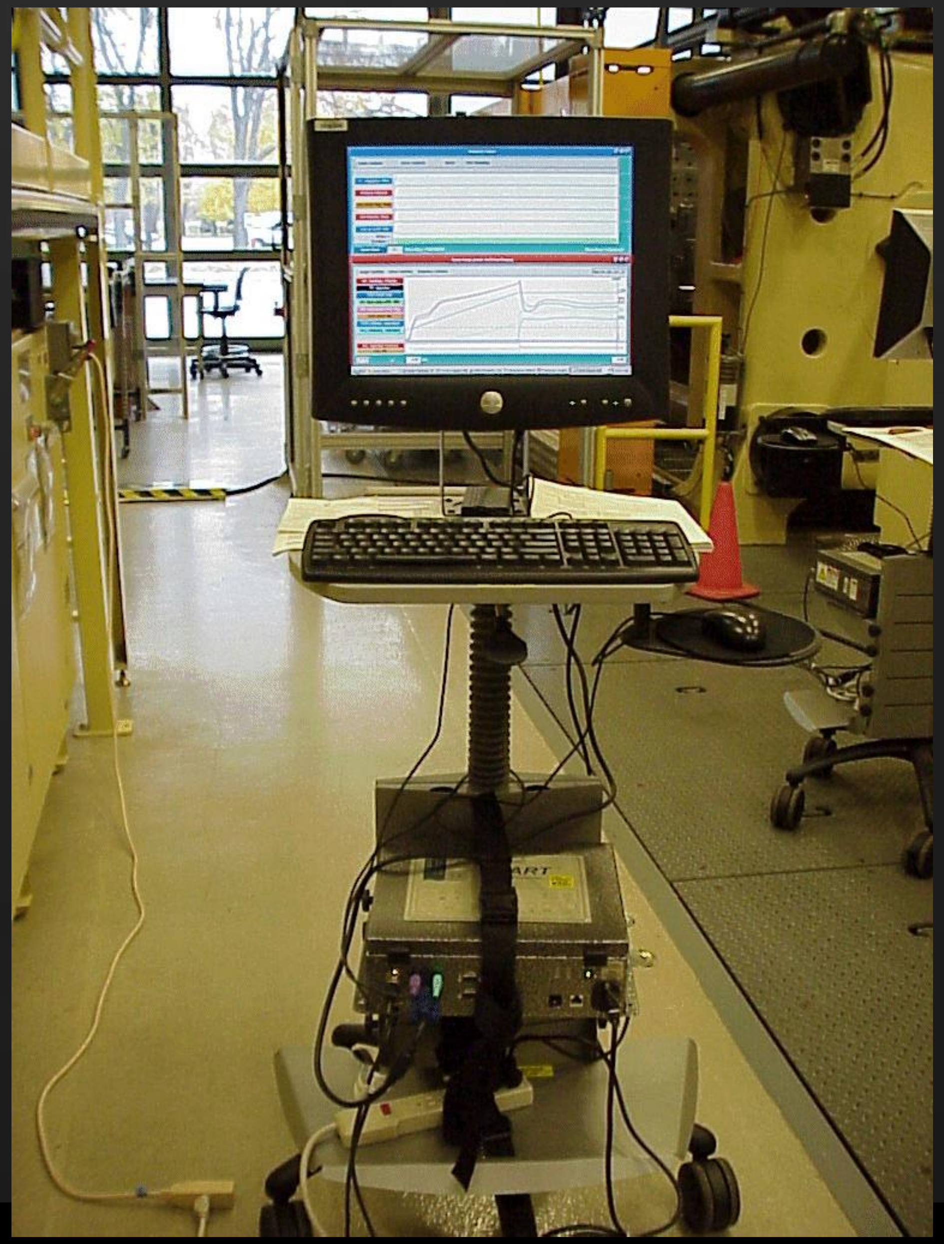
- Material: LyondellBasell Hifax TRC779X (a semi-crystalline thermoplastic)
  - .udb file # 1 provided by LyondellBasell Industries (LBI) – mostly 3rd party data from 2007
  - .udb file # 2 generated by Autodesk Moldflow Plastics (Ithaca) Lab in July of 2011 for the North American version of 779X
  - .udb file # 3 generated by Autodesk Moldflow Plastics (Ithaca) Lab in September of 2011 for the Korean version of 779X

Material Properties versus Simulation Accuracy

Case Study # 1:

- Simulating the fill time versus fill pressure curve for an end-gated, 3 x 10 inch (76.2 x 254 mm) flat plaque injection molded using the Husky H120 IMM.
  - Experimental fill time versus fill pressure data was generated according to the principles of Scientific Injection Molding at a melt temperature of 425ºF (218ºC).



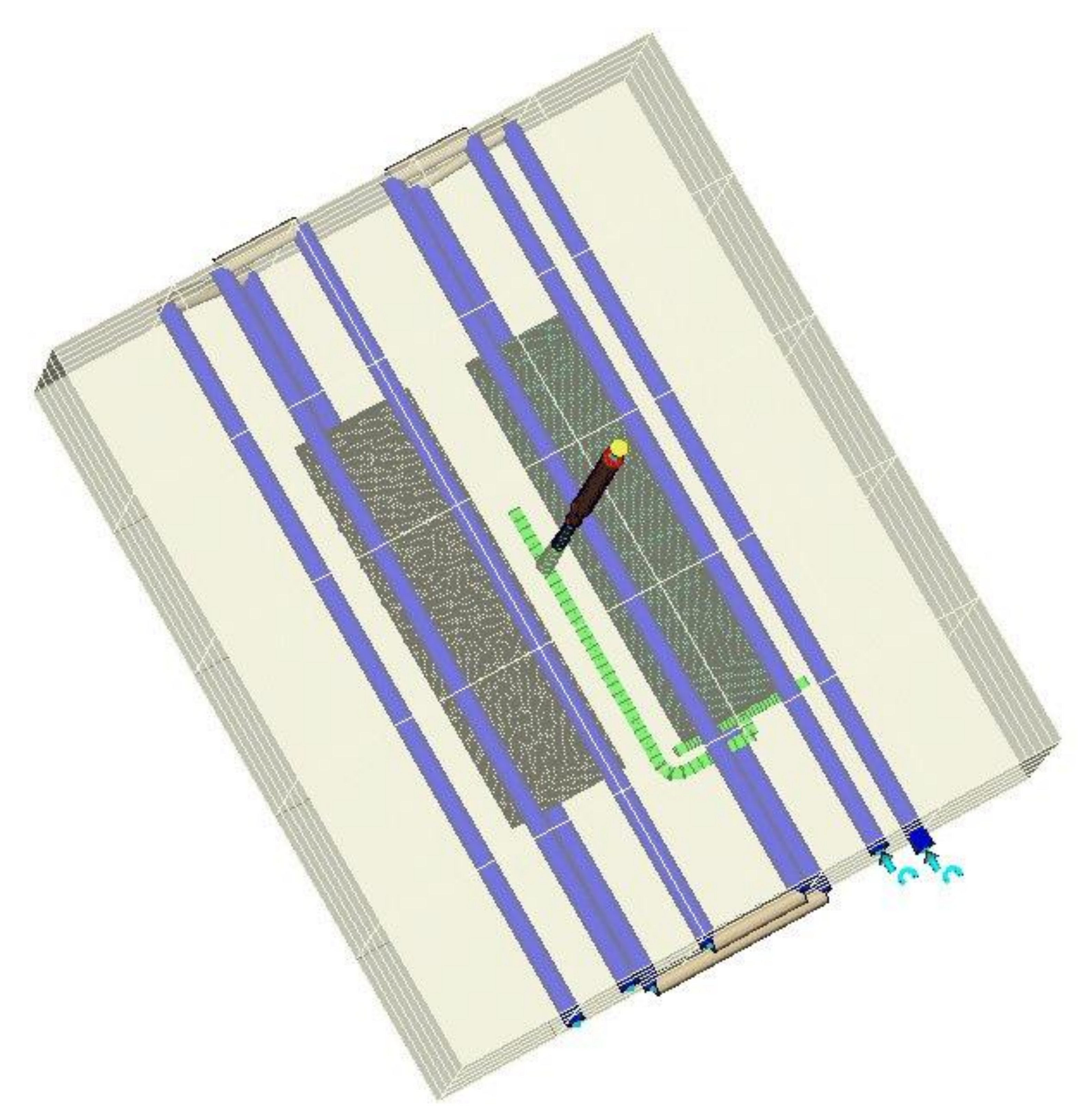


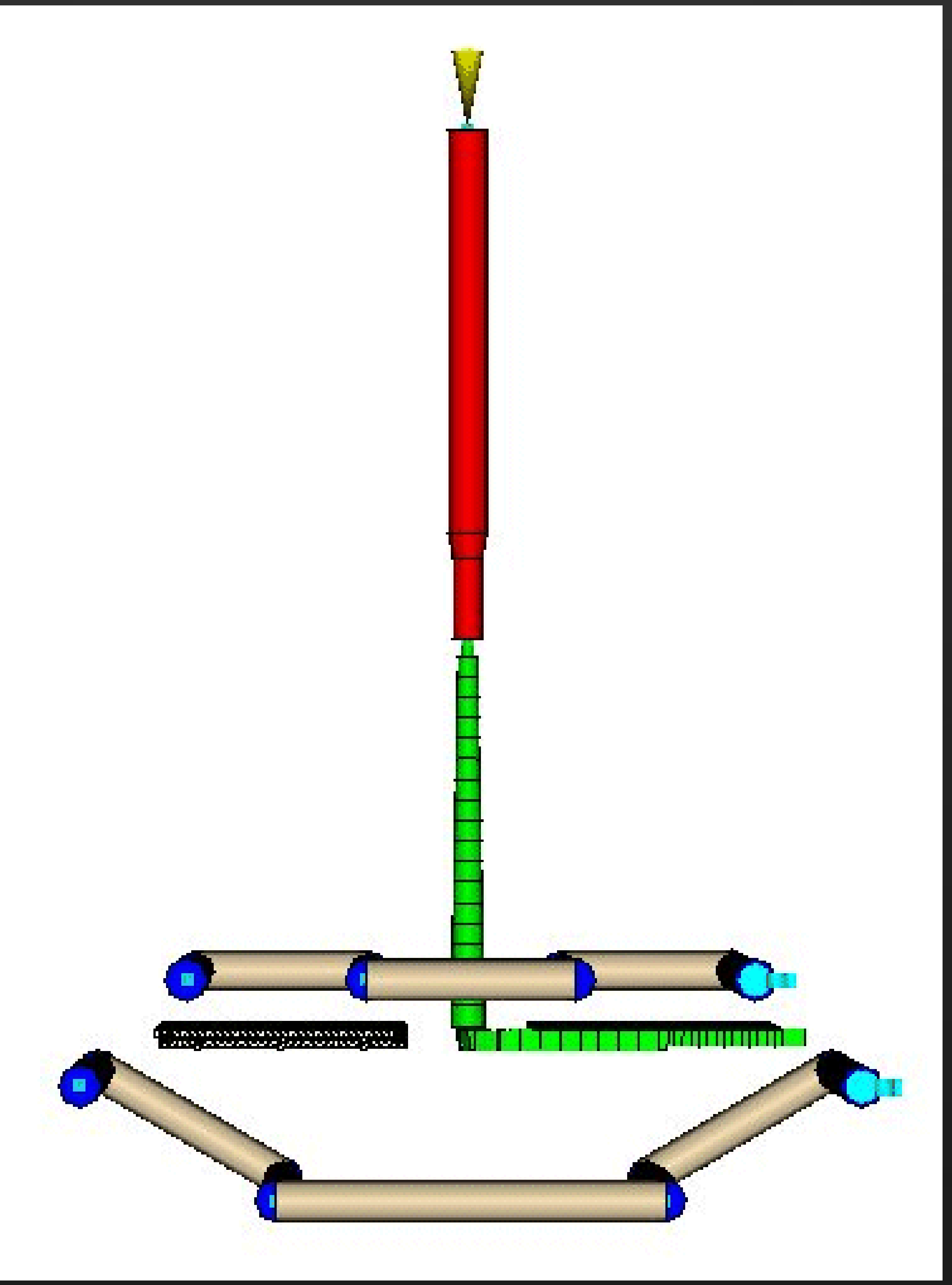
Material Properties versus Simulation Accuracy

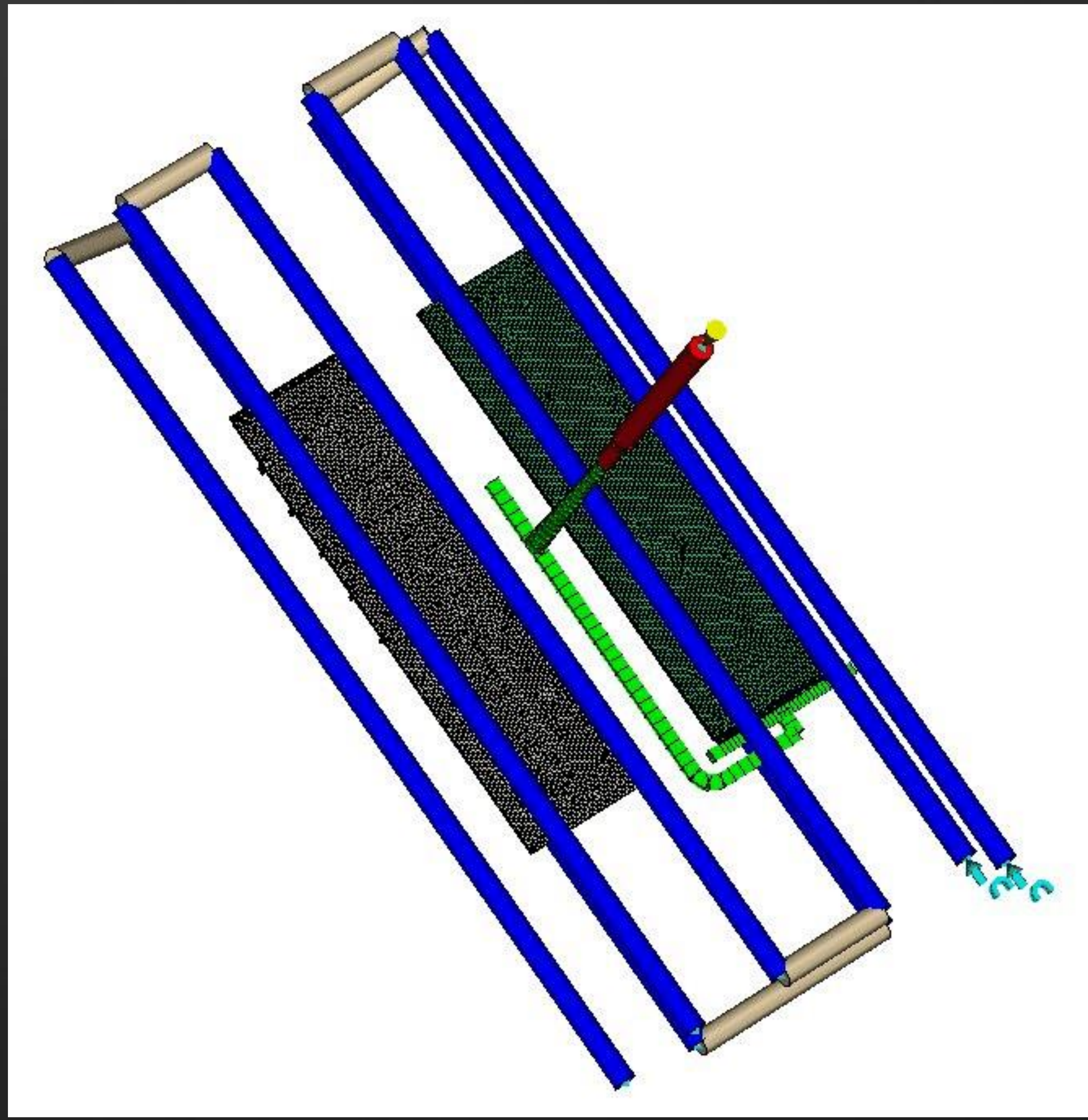
Case Study # 1:

- Fill + Pack analysis sequence run using a uniform and isothermal mold surface temperature.
  - Other analysis sequences run:
    - Cool + Fill + Pack
    - Fill + Cool + Fill + Pack
    - Fill + Pack + Cool + Fill + Pack
- Mesh-type (mid-plane, dual-domain or 3D) was chosen based on best-fit to the experimental data.

Case Study # 1: Fill Time vs. Fill Pressure Curve 3x10 Plaque

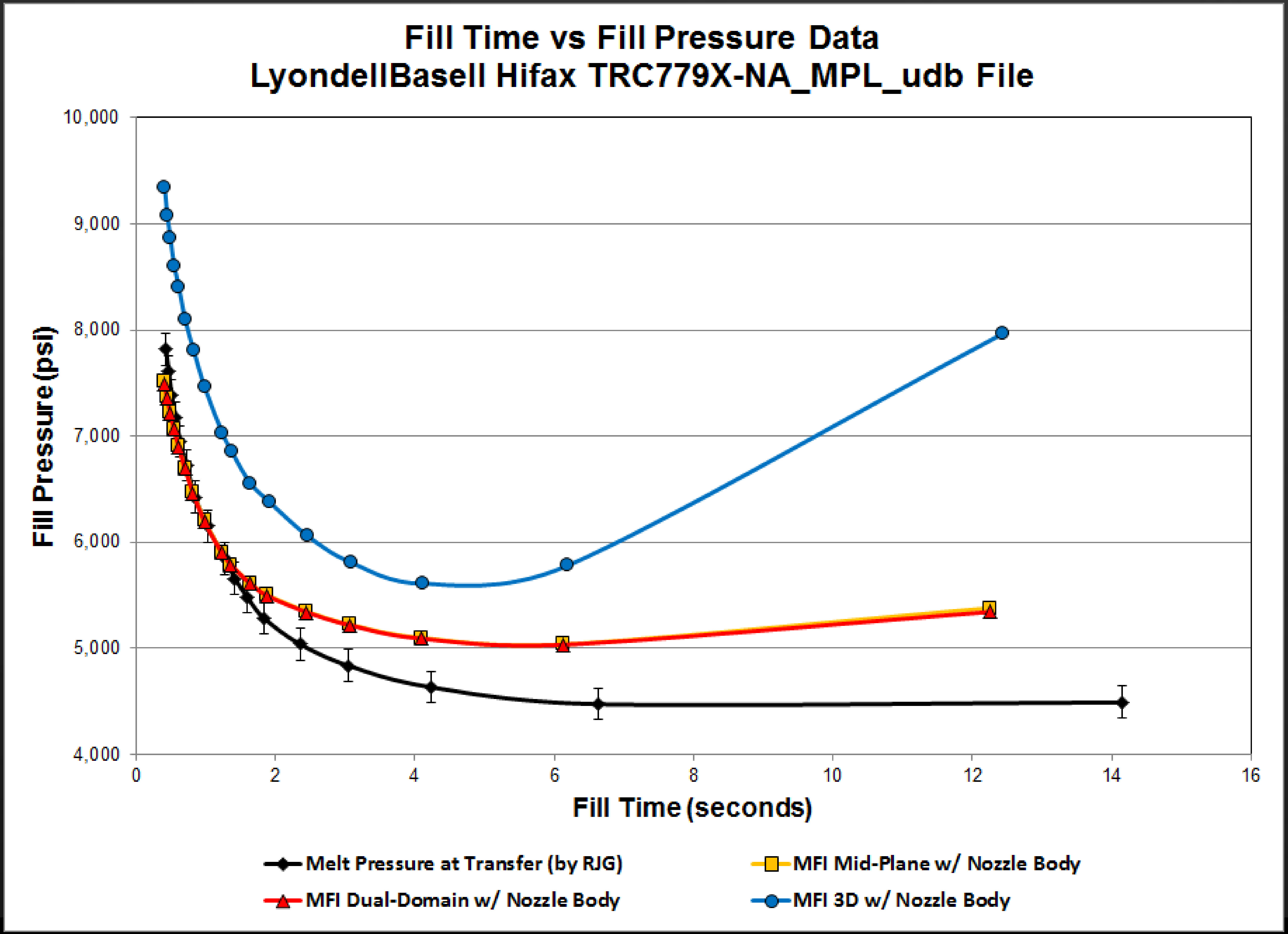






Case Study # 1: Fill Time vs. Fill Pressure Curve 3x10 Plaque

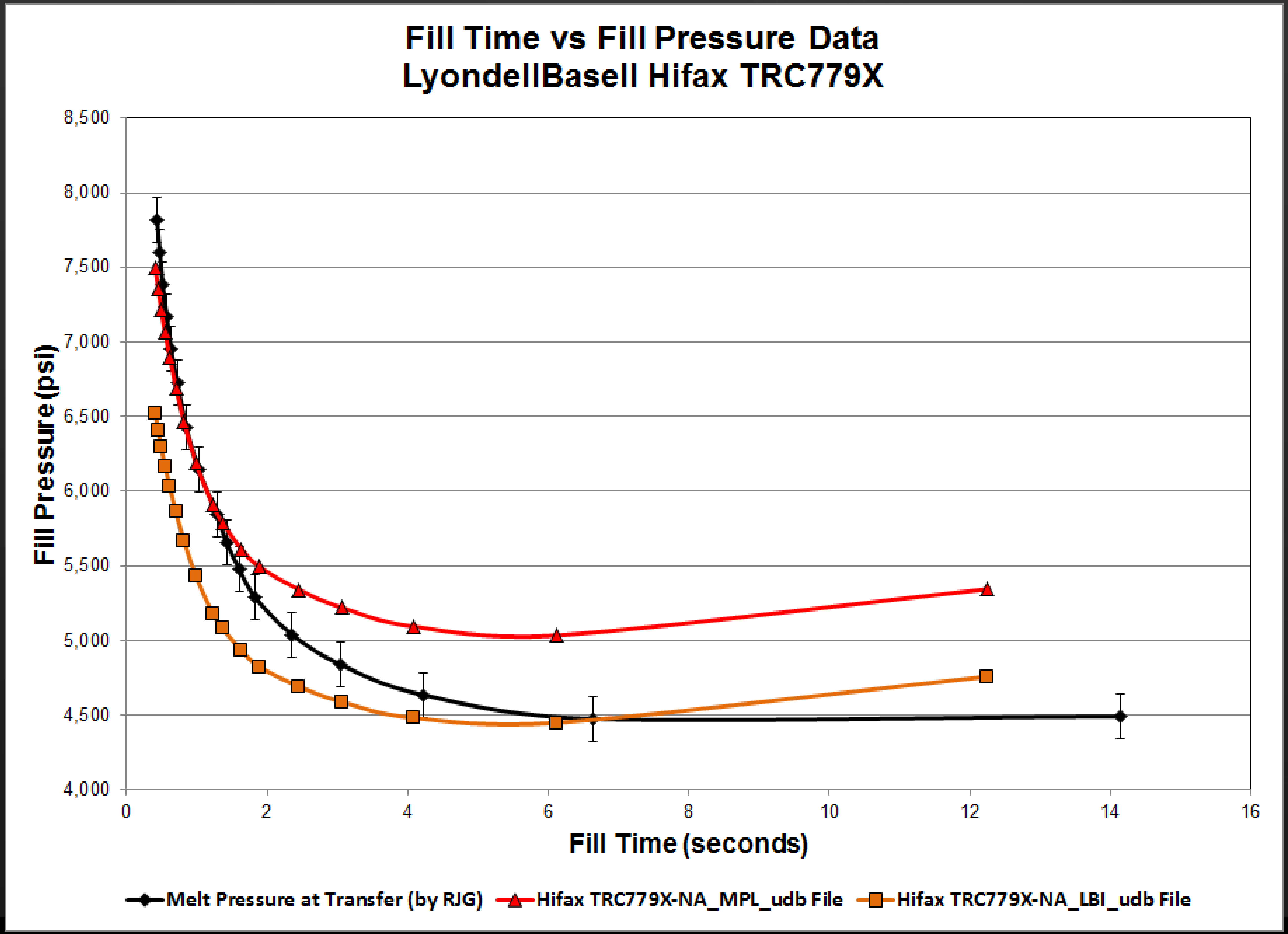
- Effect of mesh-type on simulation accuracy:



Best-Fit Mesh:
Dual-Domain with 36,963 elements.
Mesh Match Percentage = 99.8 %
Reciprocal Mesh Match Percentage = 99.6 %

Case Study # 1: Fill Time vs. Fill Pressure Curve 3x10 Plaque

- Effect of .udb file on simulation accuracy:



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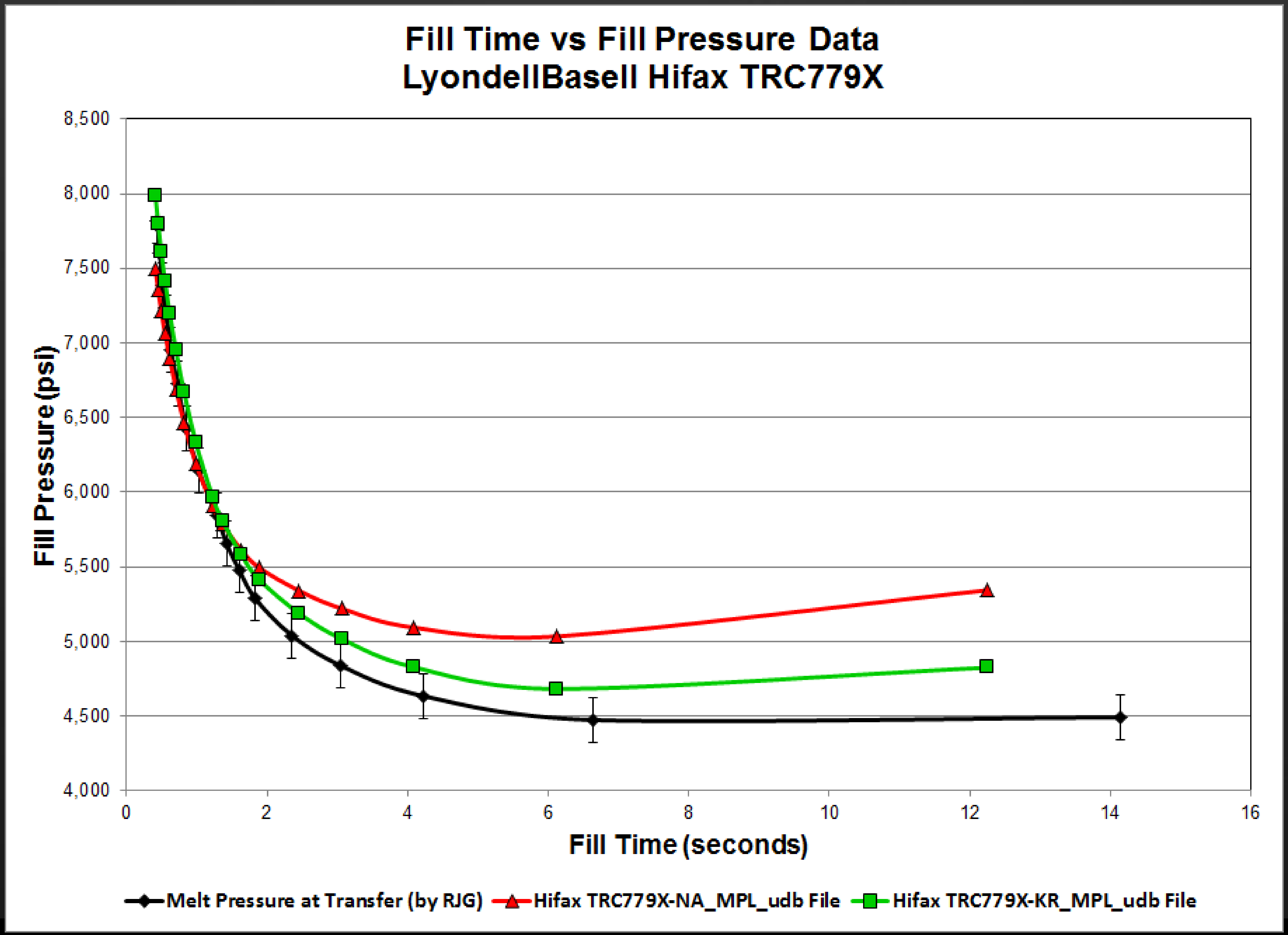


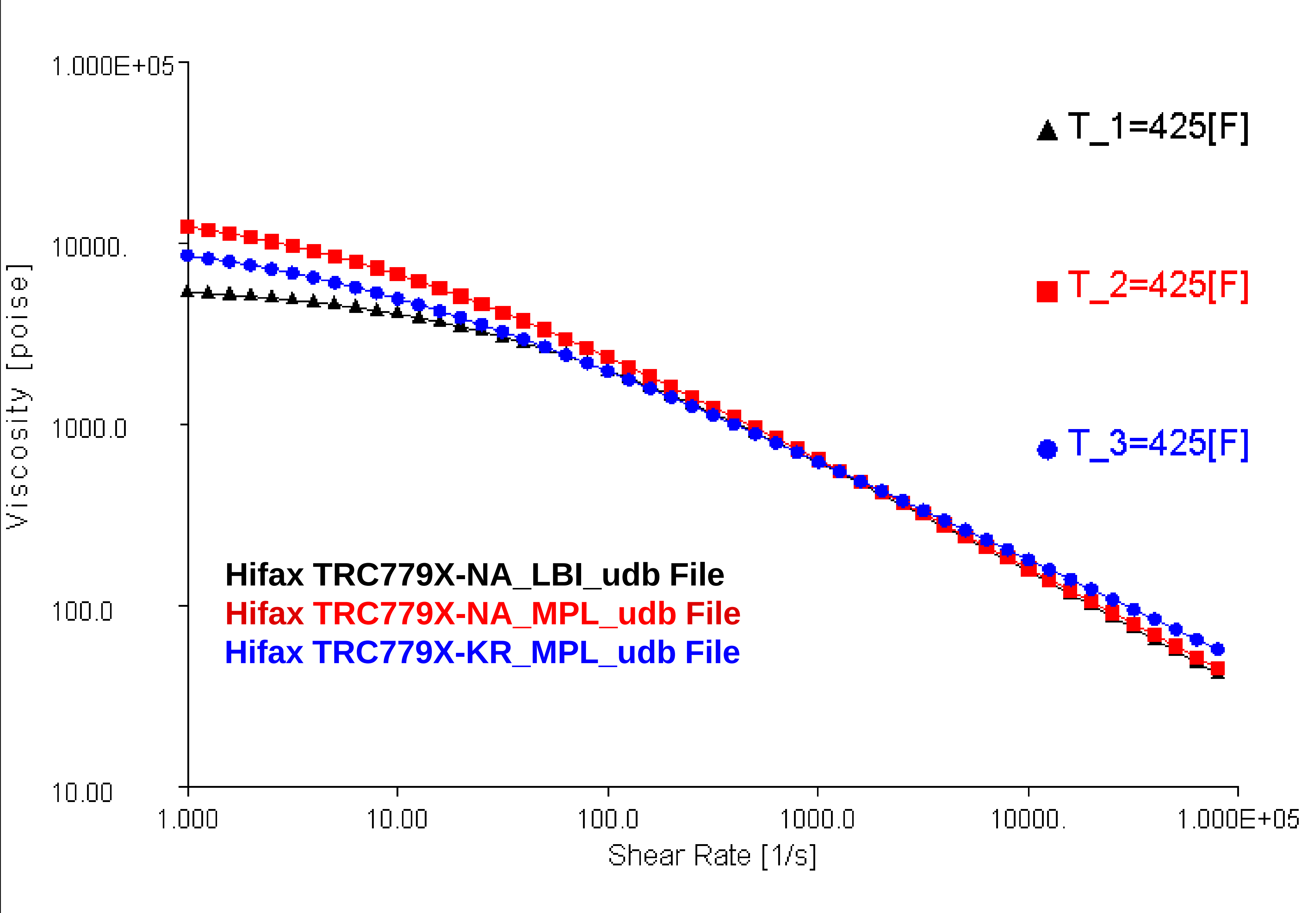
Case Study # 1: Fill Time vs. Fill Pressure Curve 3x10 Plaque

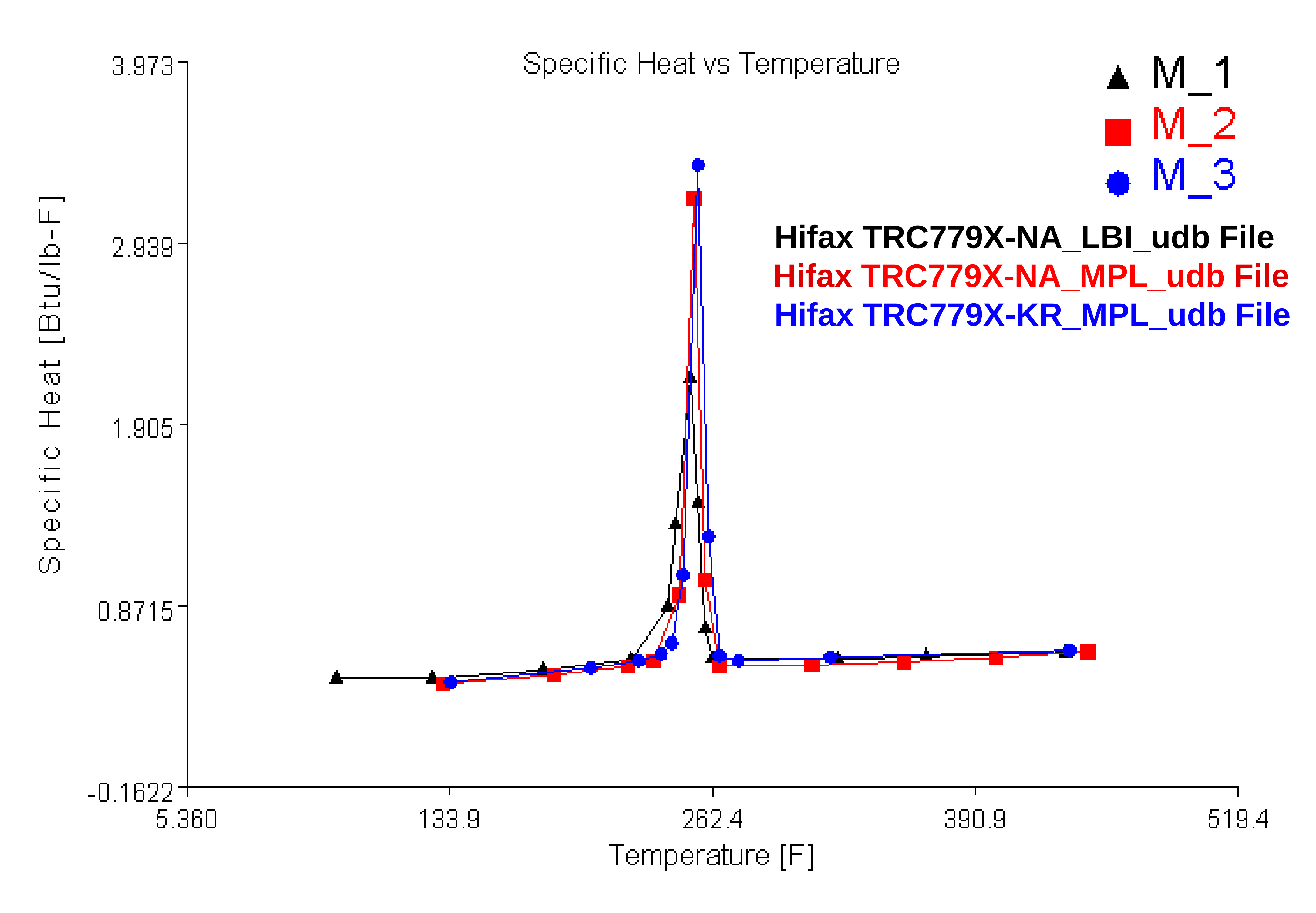
- What are the differences in the material properties data:

Manufacturer	Basell Polyolefins	GENERAL MOTORS COMPANY CONFIDENTIAL	GENERAL MOTORS COMPANY CONFIDENTIAL
Trade Name	Hifax TRC 779X (CRIMS-2012)	Hifax TRC 779X	Hifax TRC779X-KR
Family Abbreviation	TEO	TPO	TPO
Fibers / Fillers	15% Mineral Filled	18% Talc Filled	20% Mineral Filled
Autodesk Moldflow Material ID	30055	30507	30547
Autodesk Moldflow Grade Code	SN4942	SN6163	SN6231
Rheology	Standard Capillary Rheology	Injection Molding Rheology	Injection Molding Rheology
Date	03-APR-07	06-JUL-11	28-SEP-11
Source	Other	Unknown	Unknown
Default Model	Cross/WLF	Cross/WLF	Cross/WLF
Thermal Conductivity	Line - Source	Line - Source	Line - Source
Date	03-APR-07	13-JUN-11	07-SEP-11
Source	Other	Unknown	Unknown
Specific Heat	DSC cooling	DSC cooling	DSC cooling
Date	03-APR-07	02-JUN-11	07-SEP-11
Source	Other	Unknown	Unknown
pvT	Indirect Dilatometry	Indirect Dilatometry	Indirect Dilatometry
Date	03-APR-07	06-JUN-11	28-SEP-11
Source	Other	Unknown	Unknown
Shrinkage	CRIMS	CRIMS	CRIMS
Date	10-14-11	08-JUL-11	28-SEP-11
Source	Moldflow Plastics Labs	Unknown	Unknown
Resin identification code	Unknown	7	7
Energy usage indicator	Unknown	1	1
Fill Quality Indicator	Unknown	Gold	Gold
Pack Quality Indicator	Unknown	Gold	Gold
Warp Quality Indicator	Unknown	Gold	Gold

Case Study # 1: Fill Time vs. Fill Pressure Curve 3x10 Plaque

- What are the differences in the material properties data:





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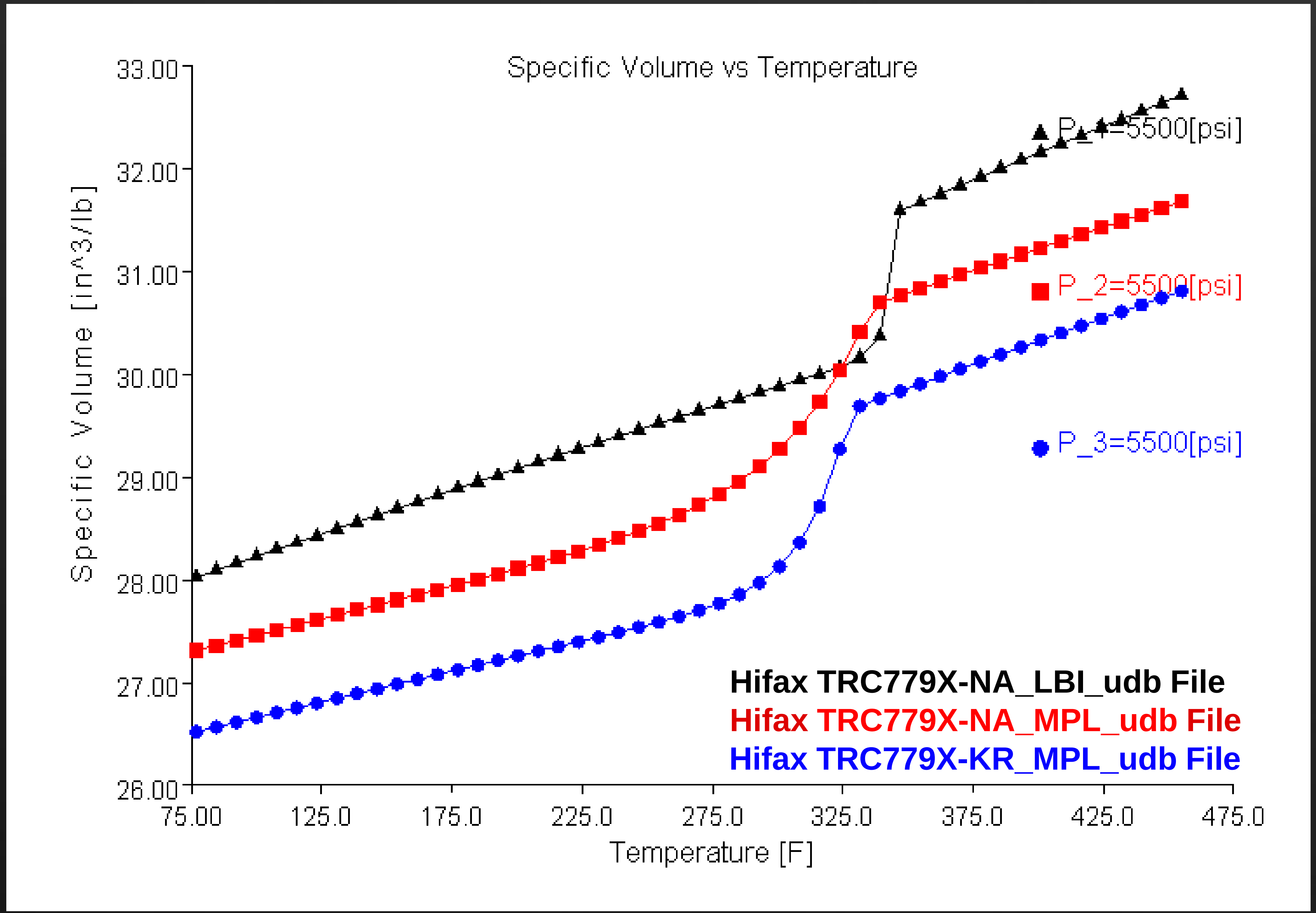
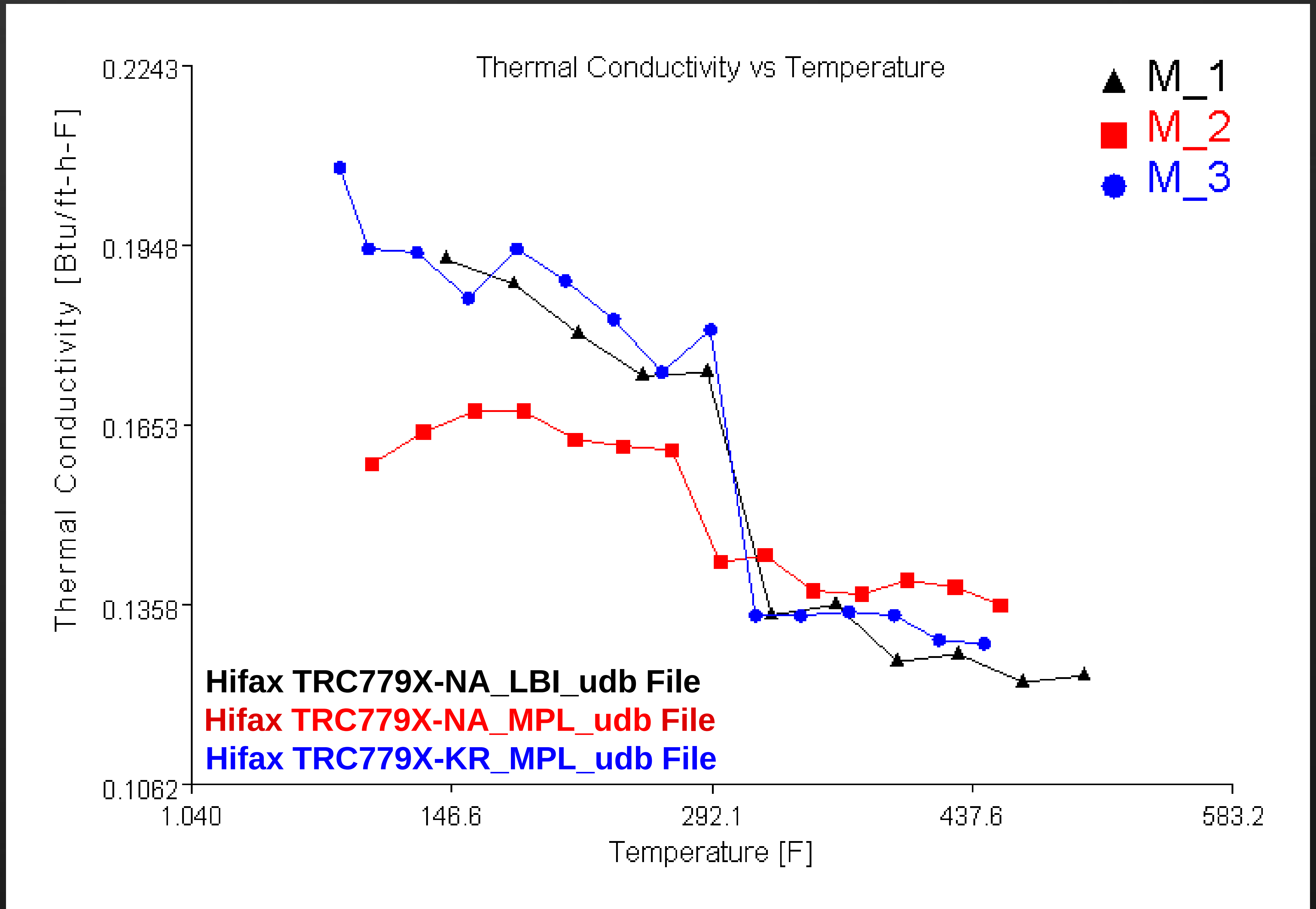




Material Properties versus Simulation Accuracy

Case Study # 2:

*Using a .udb file that contains supplemental data from the material supplier versus a MPL-150 generated .udb file created at Autodesk Moldflow Plastics Lab.

*Use of .udb files for a global GM material that is compounded in different regions of the World

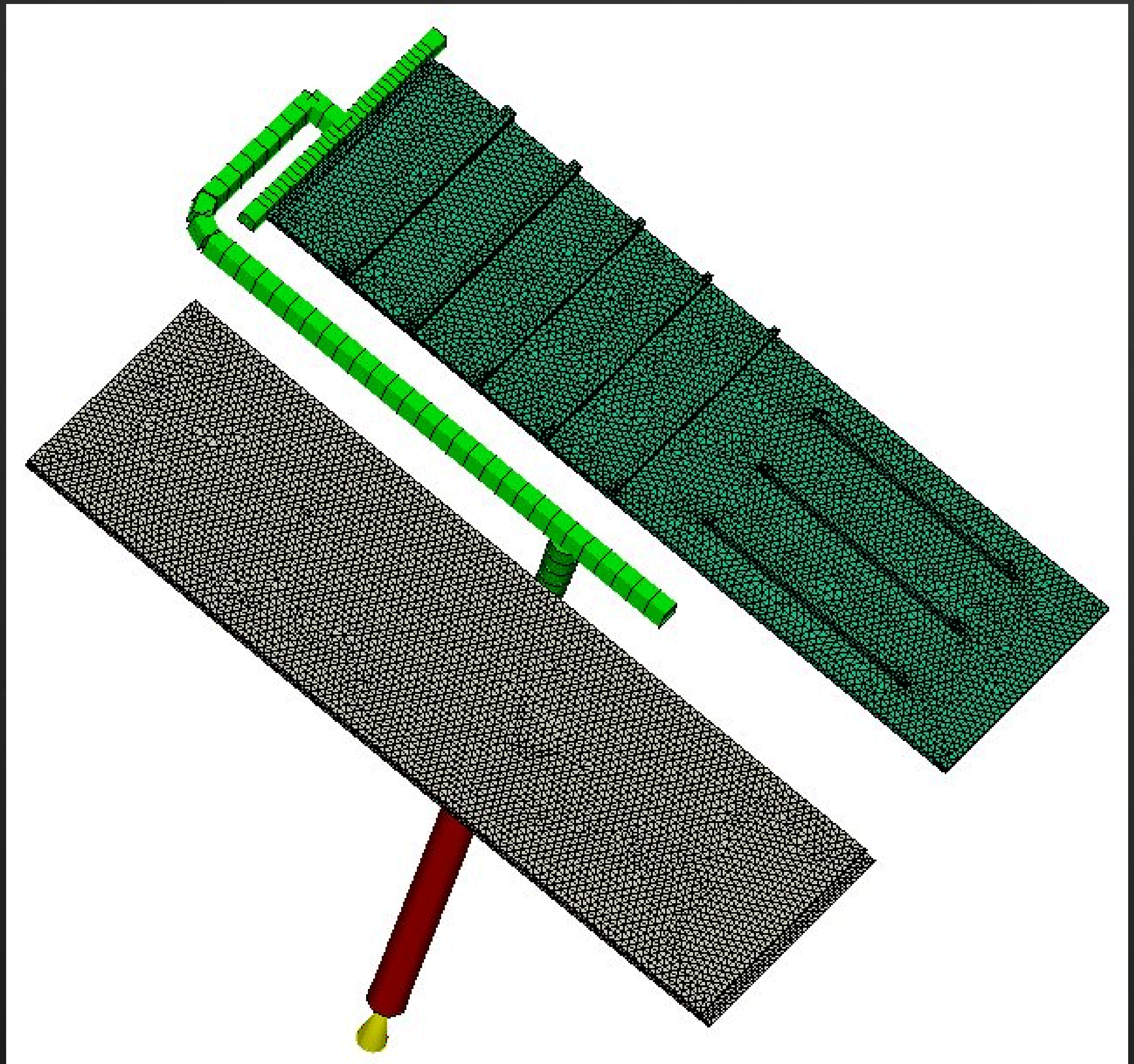
- Material: LyondellBasell Hifax TRC779X (a semi-crystalline thermoplastic)
  - .udb file # 1 provided by LyondellBasell Industries (LBI) - mostly 3rd party data from 2007 but CRIMS generated by Autodesk Moldflow Plastics Lab in October of 2011
  - .udb file # 2 generated by Autodesk Moldflow Plastics (Ithaca) Lab in July of 2011 for the North American version of 779X
  - .udb file # 3 generated by Autodesk Moldflow Plastics (Ithaca) Lab in September of 2011 for the Korean version of 779X

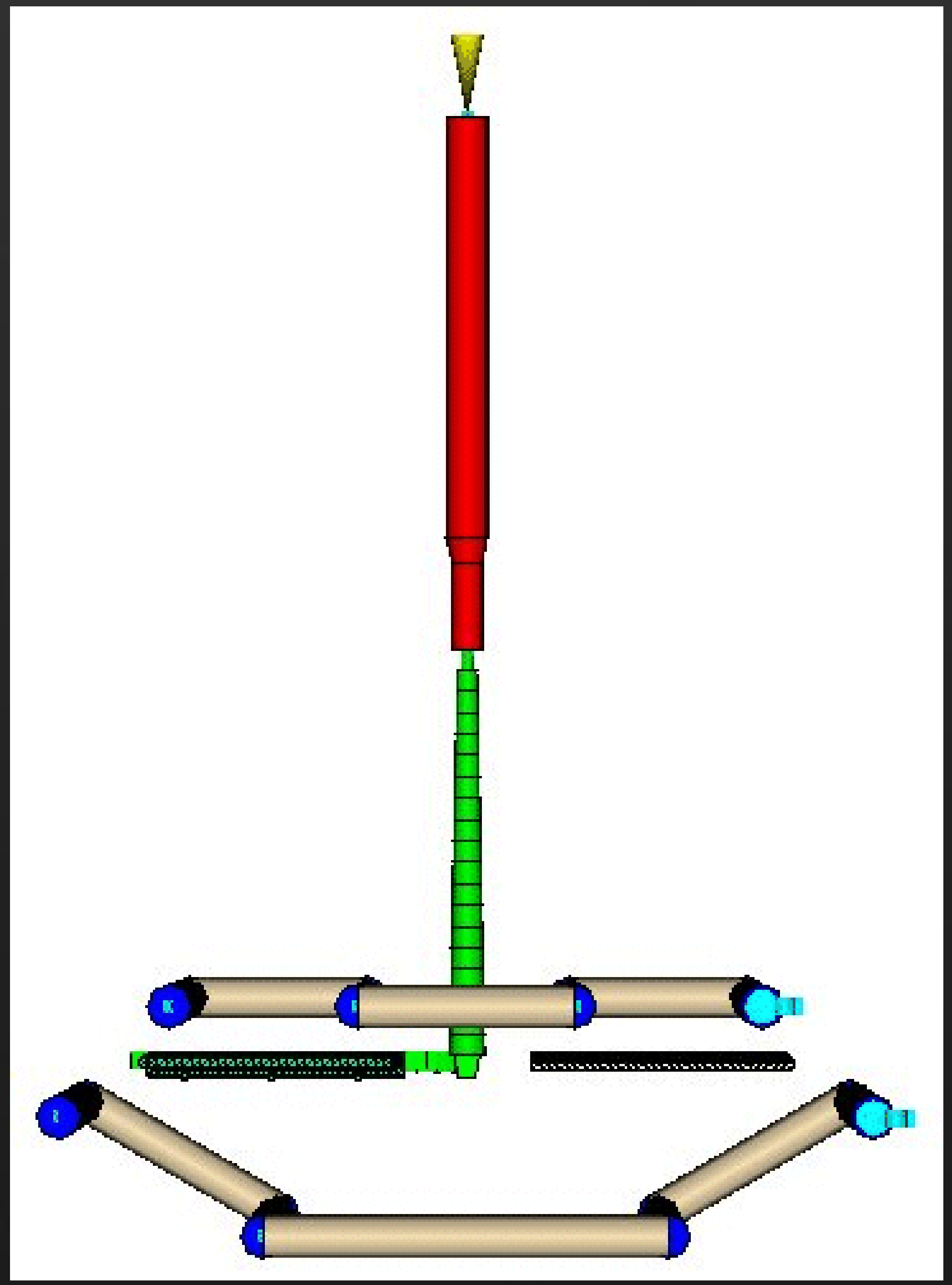
Material Properties versus Simulation Accuracy

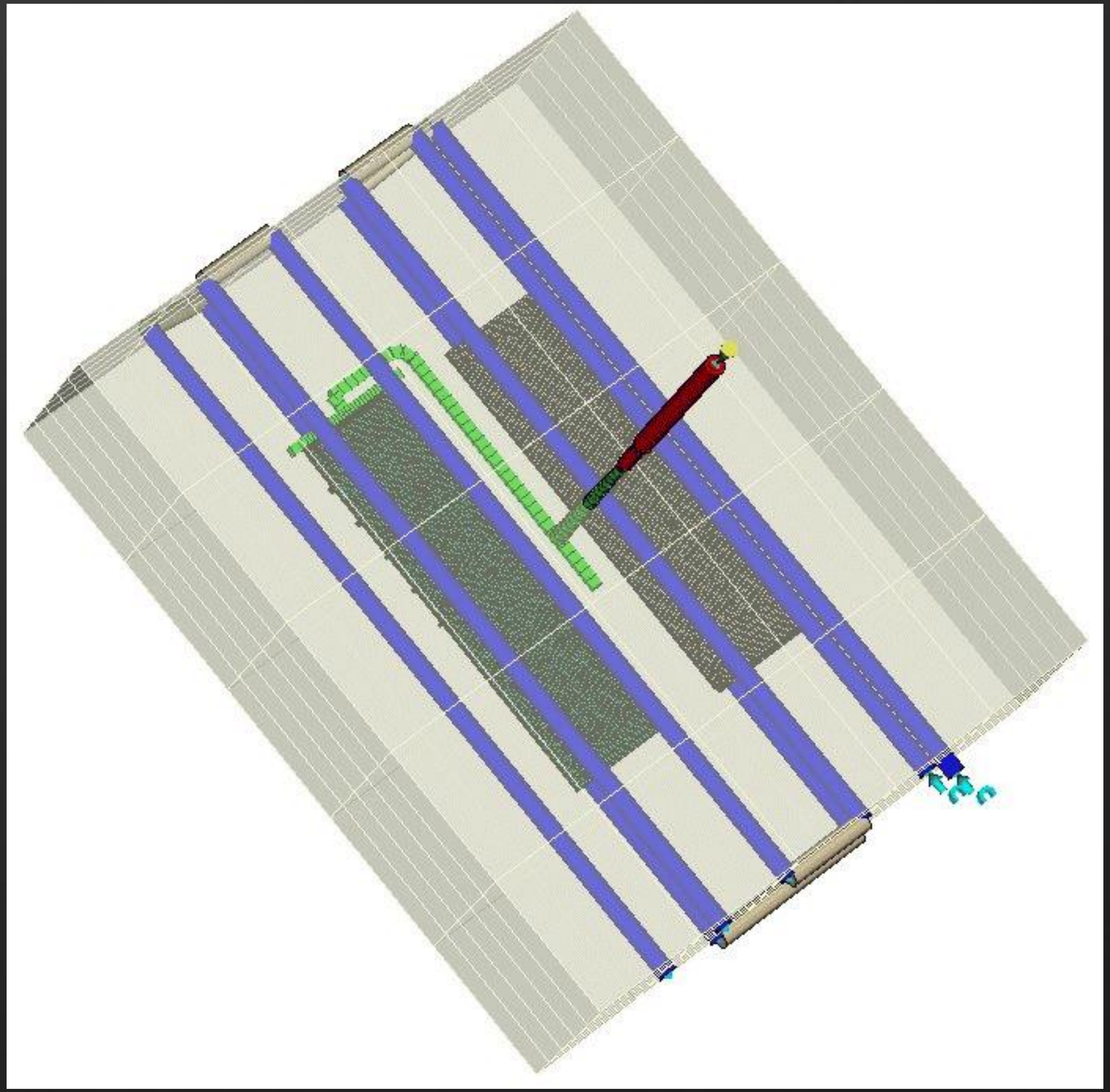
Case Study # 2:

- Simulating the warp of an end-gated, 3 x 10 inch (76.2 x 254 mm) ribbed plaque that was filled at a melt temperature of 450ºF (232ºC) and at the minimum of the fill time versus fill pressure curve.
  - Ram speed of Husky H120 IMM set to 0.4 inches/second (10.2 mm/second)
- Fill + Cool + Fill + Pack + Warp analysis sequence run using a dual-domain mesh.
  - Mesh contained 36,963 elements.
  - Mesh Match Percentage = 98.8 %
  - Reciprocal Mesh Match Percentage = 99.0 %

Case Study # 2: Warp of 3x10 Ribbed Plaque

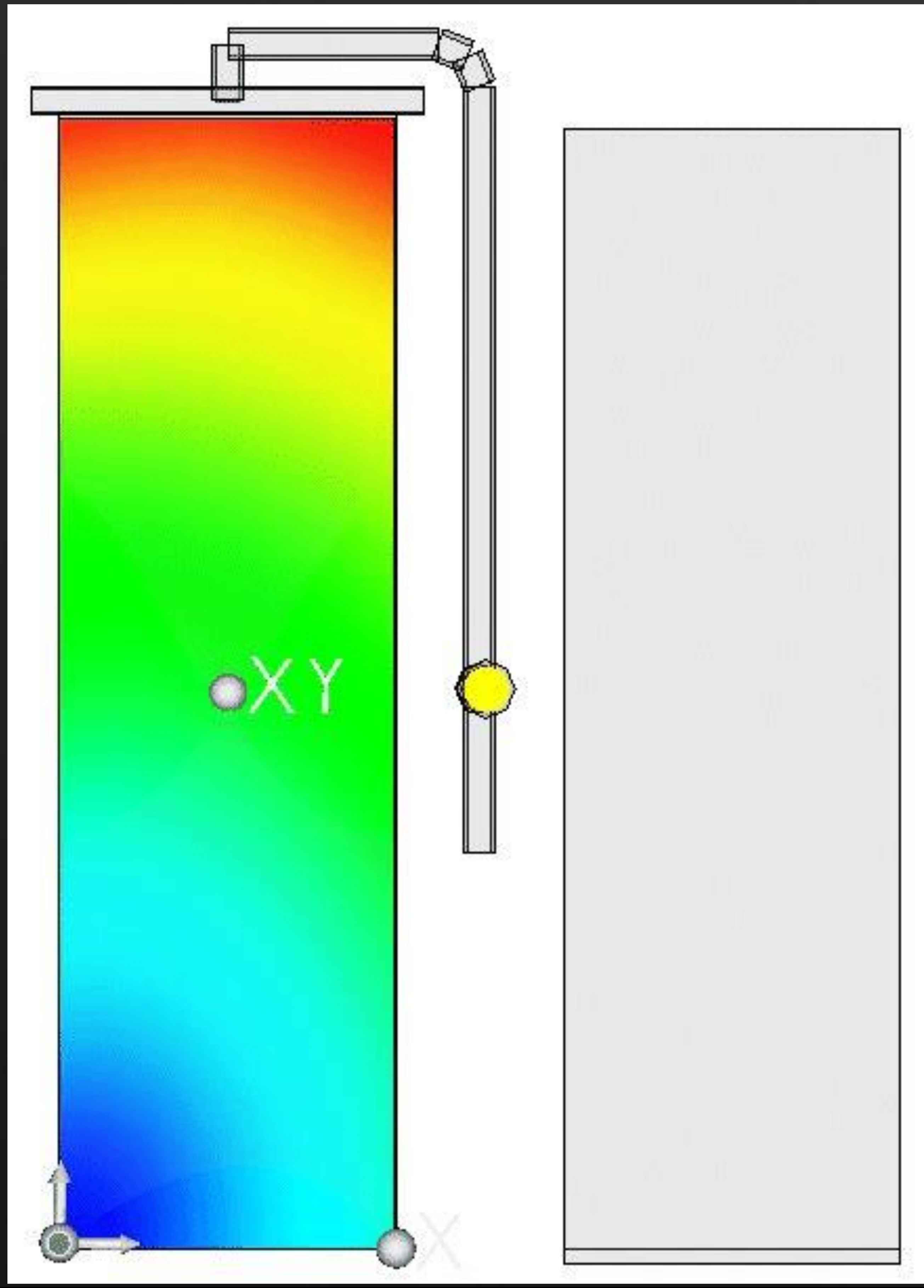


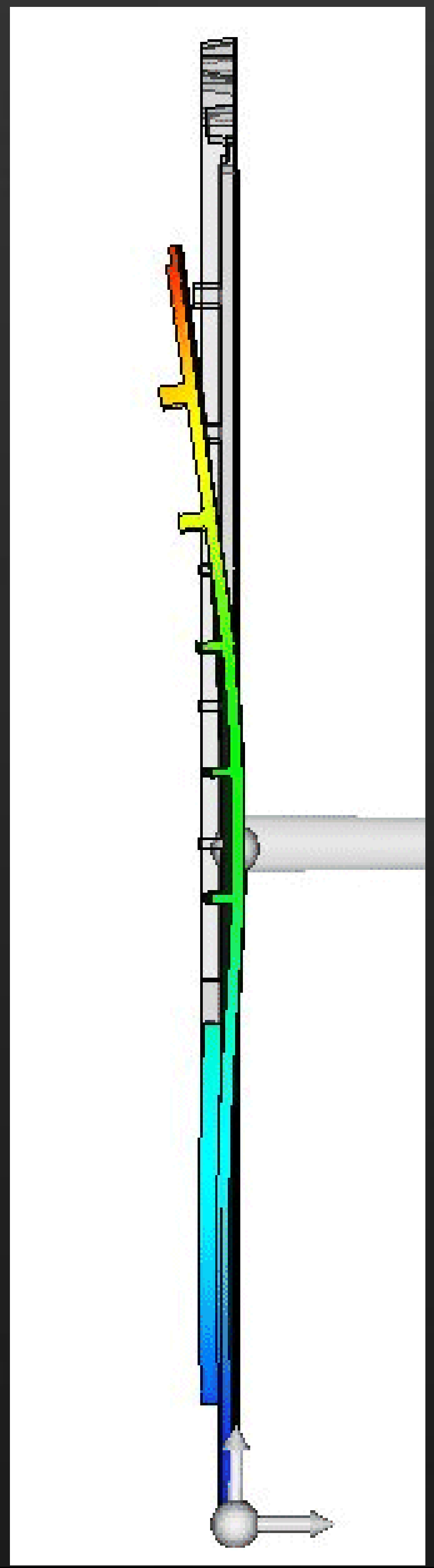


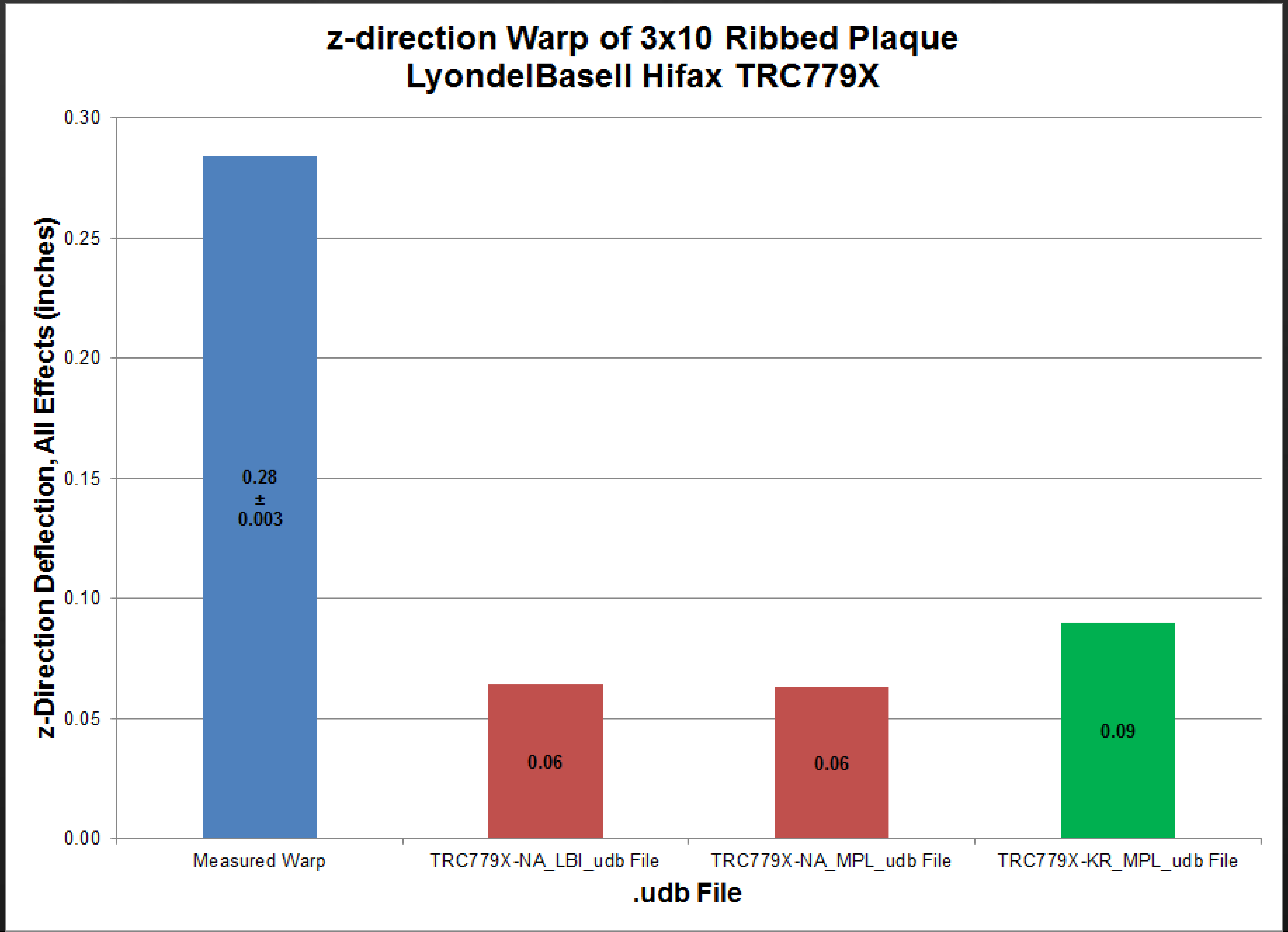


Case Study # 2: Warp of 3x10 Ribbed Plaque

- Warp in z-direction measured by establishing an xy anchor plane:







Material Properties versus Simulation Accuracy

Case Study # 3:

* For a given GM material specification, using a surrogate .udb file for a "like" material because the MPL-150 generated .udb file for the actual production material is not available.

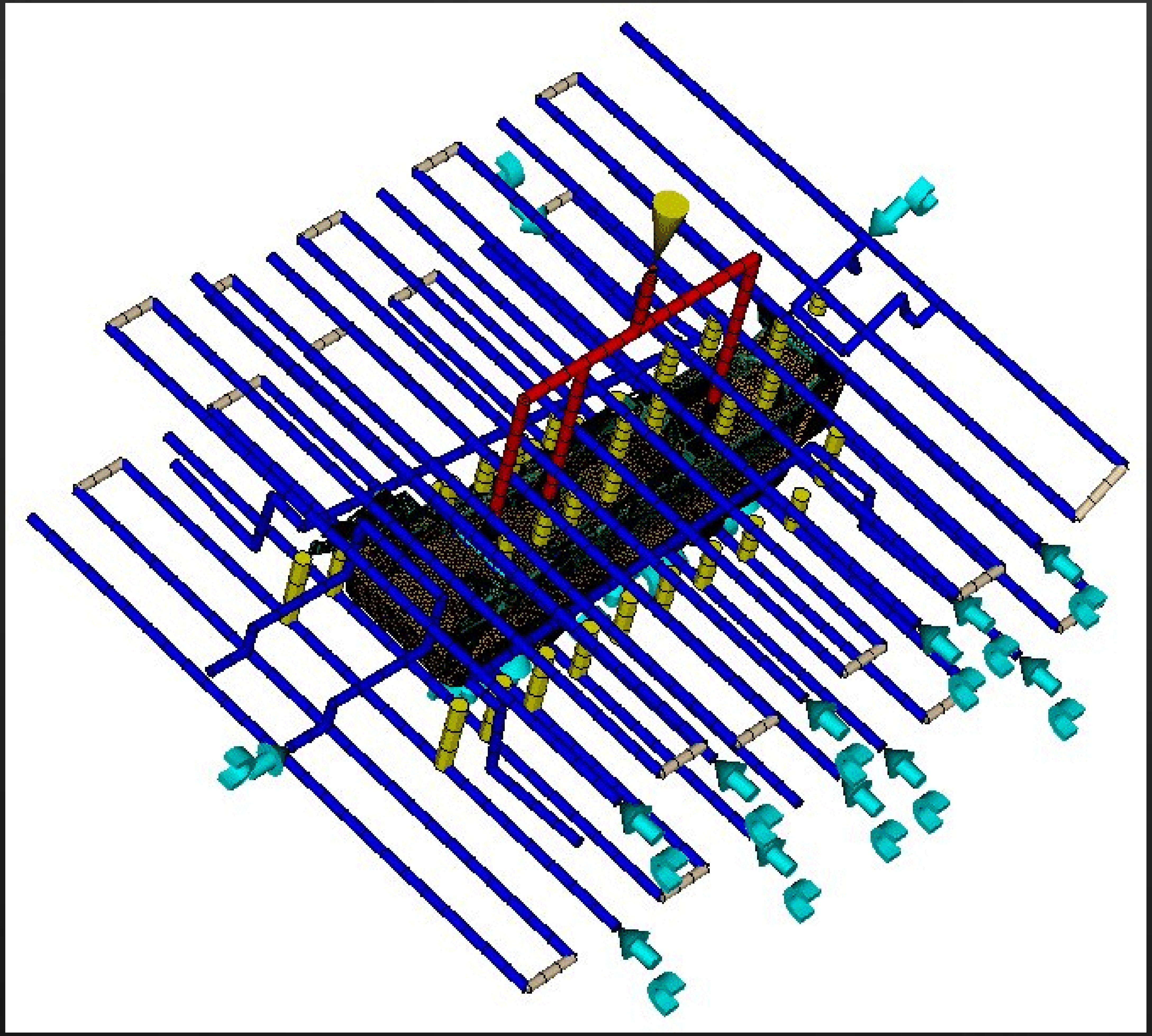
- Material Files:
  - Surrogate Material: Samsung SI43G (semi-crystalline thermoplastic)
    - .udb file generated by Autodesk Moldflow Plastics Lab in November of 2009.
      - Mechanical properties data is supplemental.
  - Production Material: LyondellBasell Hostacom HKG743T (semi-crystalline thermoplastic)
    - .udb file generated by Autodesk Moldflow Plastics (Ithaca) Lab in April of 2011.

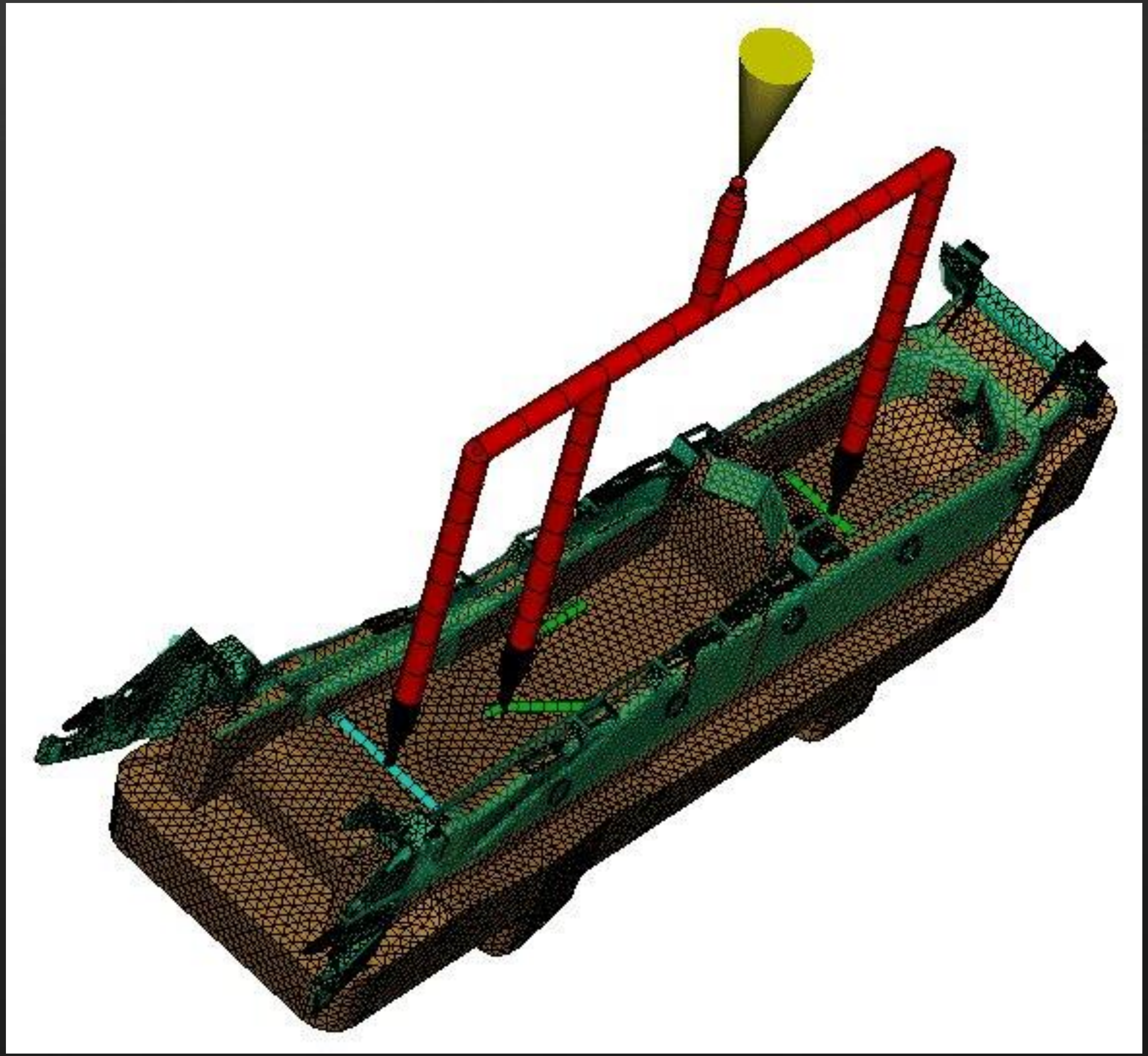
Material Properties versus Simulation Accuracy

Case Study # 3:

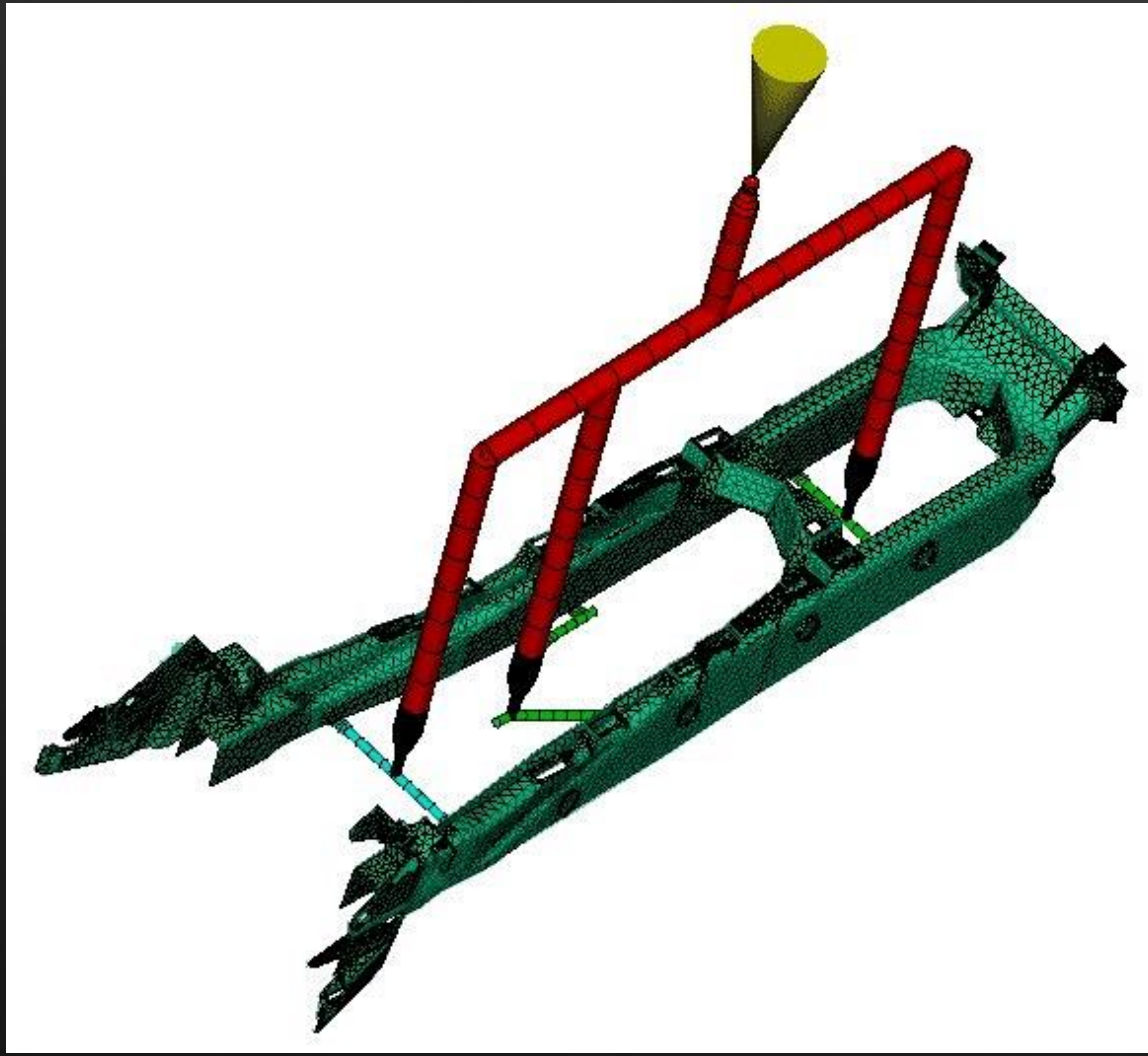
- Simulating the warp of the Alpha Console Structure.
- Cool + Fill + Pack + Warp analysis sequence run using:
  - A melt temperature of 450ºF (232ºC).
  - A uniform mold surface temperature of 120ºF (49ºC).
  - A fill time of 2.5 seconds.
- A mid-plane mesh was used having 40,181 elements.
  - Small deflection warp analysis run.

Case Study # 3: Warp of Alpha Console Structure

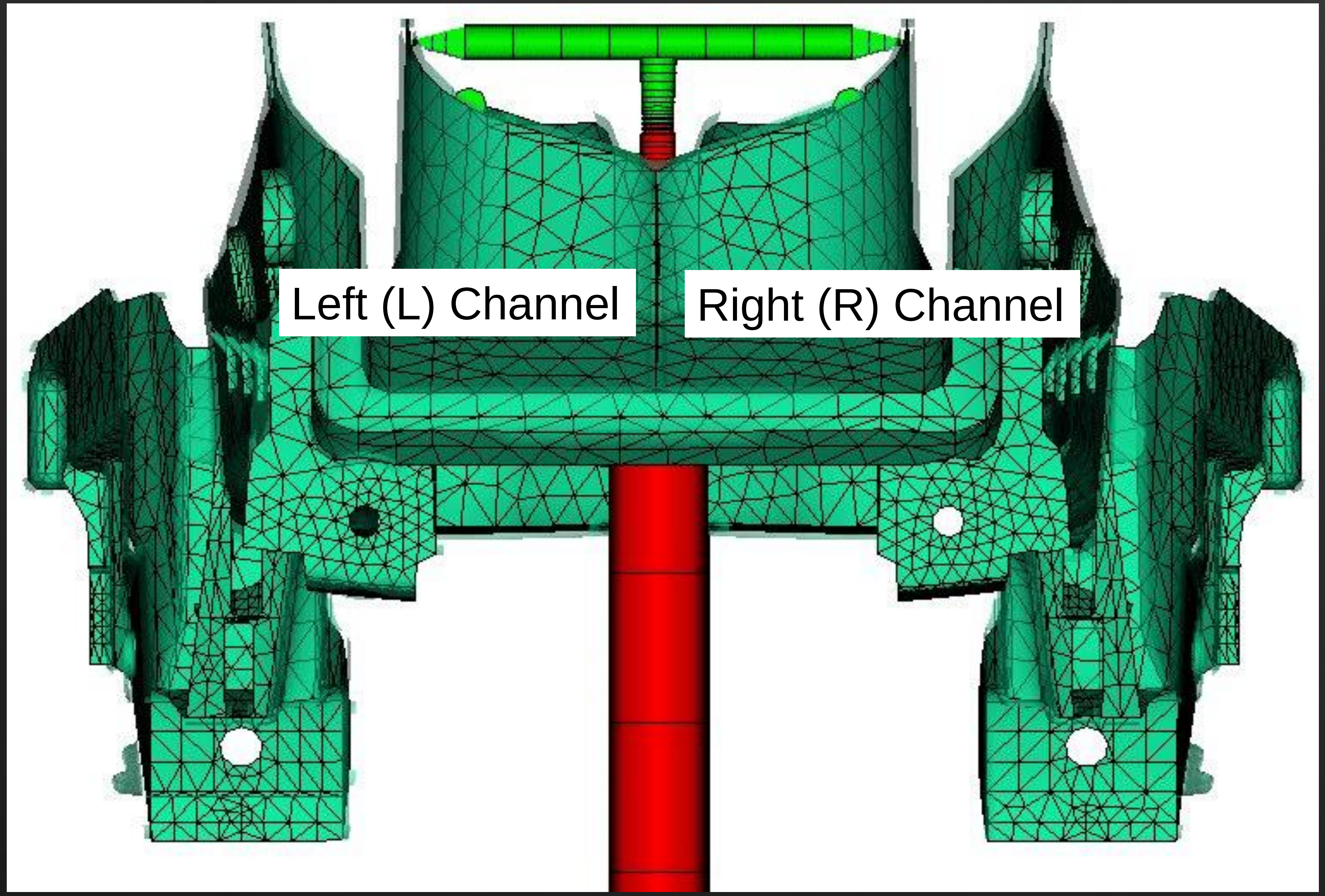


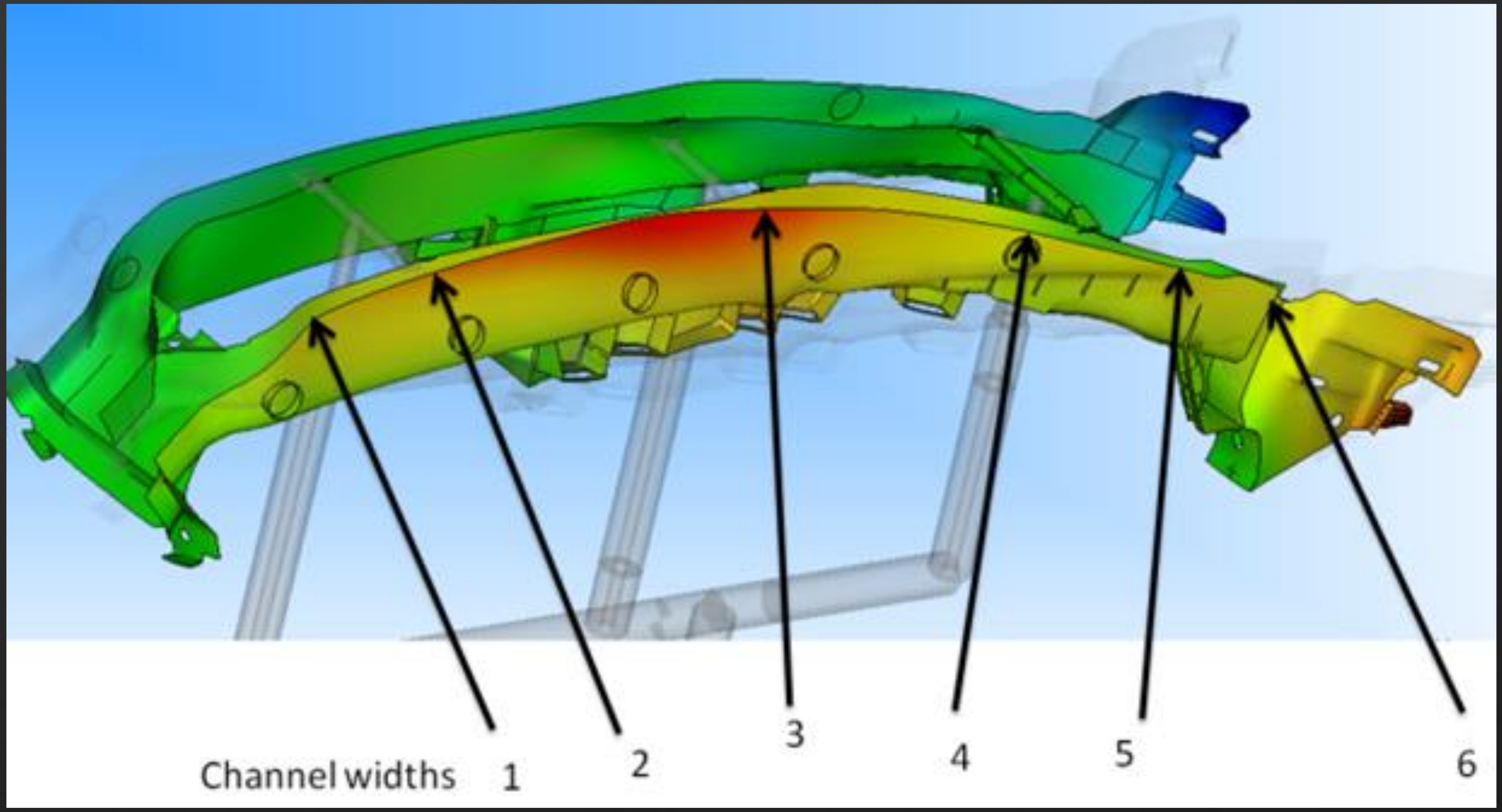


Case Study # 3: Warp of Alpha Console Structure



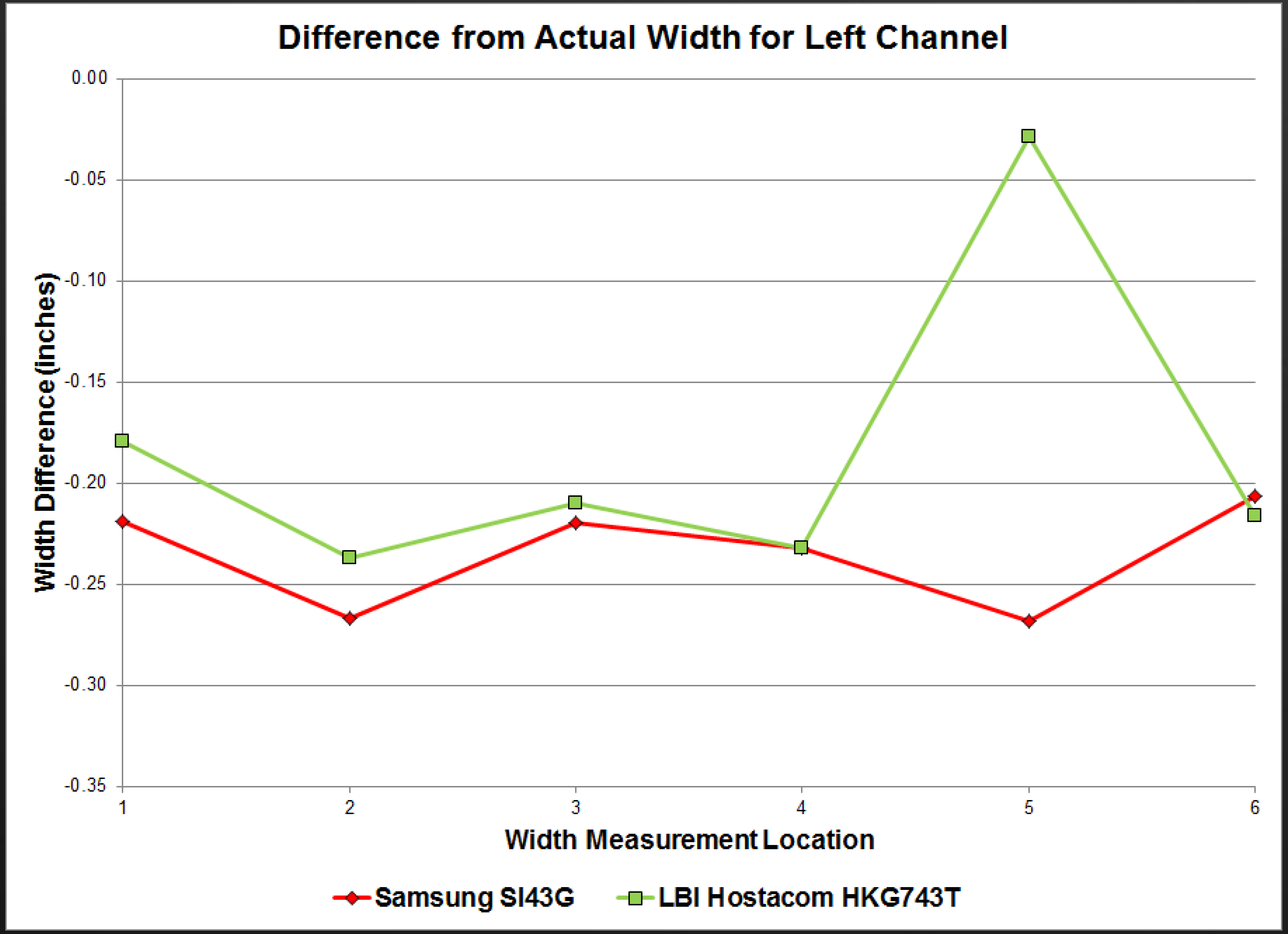
Case Study # 3: Measuring Warp of L & R Channel Width

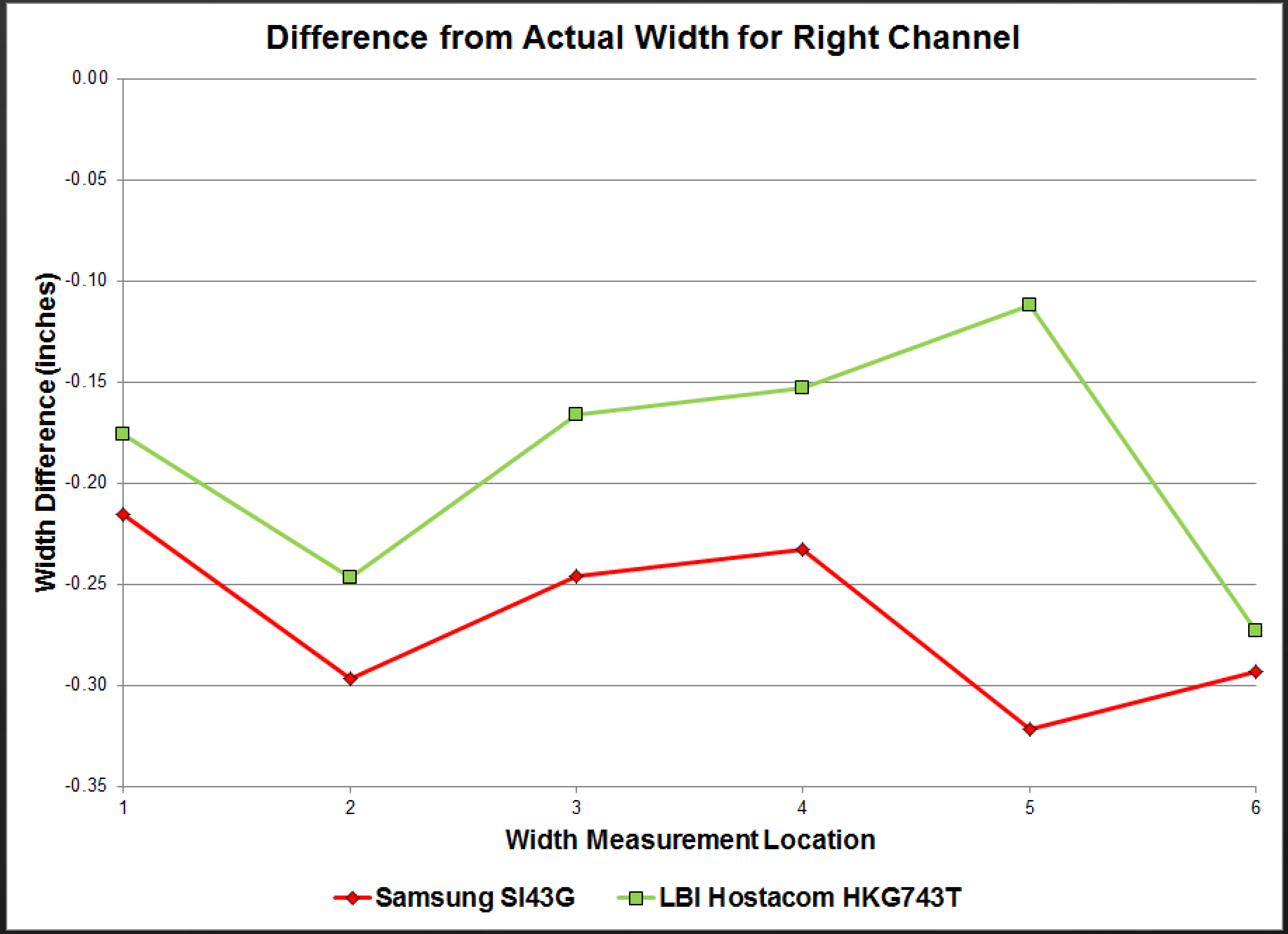




Case Study # 3: Measuring Warp of L & R Channel Width

- Effect of .udb file on warp of left and right channel width:





Concluding Comments

- The usefulness and applicability of results from Autodesk Moldflow 2012 depends on the “goodness” of the material properties contained within the .udb file.
- The analyst must have a high degree of confidence in the lab – the Autodesk Moldflow Plastics Lab – generating the material properties data file for the purpose of simulating the thermoplastic injection-molding process.

Concluding Comments

- Based on the data presented here and past experience within GM, it is our belief that:
  - The use of a .udb file provided by a material supplier containing 3rd party supplemental material properties data is not acceptable.
  - The use of a surrogate .udb file in place of that for the production-intent material is not acceptable.
  - The use of an Autodesk Moldflow Plastics Lab generated .udb file older than 2 to 3 years is not acceptable.
- GM will strive to maintain an up-to-date and confidential material properties data base of our most heavily used thermoplastic materials – no MPL-150 generated material file shall have a lifespan of more than 2 to 3 years.

Presentation Additional Material – Simulation Accuracy

- Sensitivity of Autodesk Moldflow 2012 Insight results on quality of .udb file.

  Using a .udb file that contains supplemental data from the material supplier versus a MPL-150 generated .udb file created at Autodesk Moldflow Plastics Lab.

  - Simulating the fill time versus fill pressure curve for an end-gated, 3 x 10 inch (76.2 x 254 mm) flat plaque; experimental fill time versus fill pressure data was generated according to the principles of Scientific Injection Molding. Fill + Pack analysis sequence run using a uniform and isothermal mold surface temperature. Mesh type (mid-plane, dual-domain or 3D) was chosen based on best fit to experimental data.
    - Material: SABIC Cycolac BDT6500 (an amorphous thermoplastic)
      - .udb file # 1 provided by SABIC Innovative Plastics US, LLC
      - .udb file # 2 generated by Autodesk Moldflow Plastics (Ithaca) Lab in November of 2011

Presentation Additional Material – Simulation Accuracy

- Sensitivity of Autodesk Moldflow 2012 Insight results on quality of .udb file.

  Using a .udb file that contains supplemental data from the material supplier versus a MPL-150 generated .udb file created at Autodesk Moldflow Plastics Lab.

  - Simulating the shrink of a side-gated, 4 x 6 inch (101.6 x 152.4 mm) flat plaque that was filled at the minimum of the fill time versus fill pressure curve. Cool + Fill + Pack + Warp analysis sequence run using a dual-domain mesh for the part.
    - LyondellBasell Materials: Profax SG802N and Hostacom HKG743T

      For each material -
      - .udb file # 1 provided by LyondellBasell Industries
      - .udb file # 2 generated by Autodesk Moldflow Plastics (Ithaca) Lab in 2011

Presentation Additional Material – Simulation Accuracy

- Sensitivity of Autodesk Moldflow 2012 Insight results on quality of .udb file.

  Using a .udb file that contains supplemental data from the material supplier versus a MPL-150 generated .udb file created at Autodesk Moldflow Plastics Lab.

  - Simulating the warp of an end-gated, 3 x 10 inch (76.2 x 254 mm) ribbed plaque that was filled at the minimum of the fill time versus fill pressure curve. Cool + Fill + Pack + Warp analysis sequence run using both a dual-domain and 3D mesh for the part.
    - Material: SABIC Cycolac BDT6500 (an amorphous thermoplastic)
      - .udb file # 1 provided by SABIC Innovative Plastics US, LLC
      - .udb file # 2 generated by Autodesk Moldflow Plastics (Ithaca) Lab in November of 2011

Presentation Additional Material – Simulation Accuracy

- Sensitivity of Autodesk Moldflow 2012 Insight results on quality of .udb file.

  Using a MPL-150 generated .udb file for a material that is older than 2 years versus a MPL-150 generated .udb file created using a recent lot of the same material.

  - Simulating the fill of the first generation Volt battery repeating frame. Cool + Fill + Pack + Warp analysis sequence was run using a 3D mesh to determine the localized shrink of the material.
    - Material: BASF Ultramid 1503-2F
      - .udb file # 1 generated by Autodesk Moldflow Plastics Lab in November of 2009
      - .udb file # 2 generated by Autodesk Moldflow Plastics (Ithaca) Lab in November of 2011