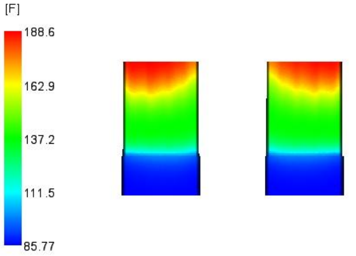
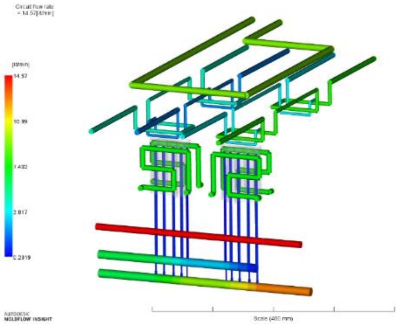
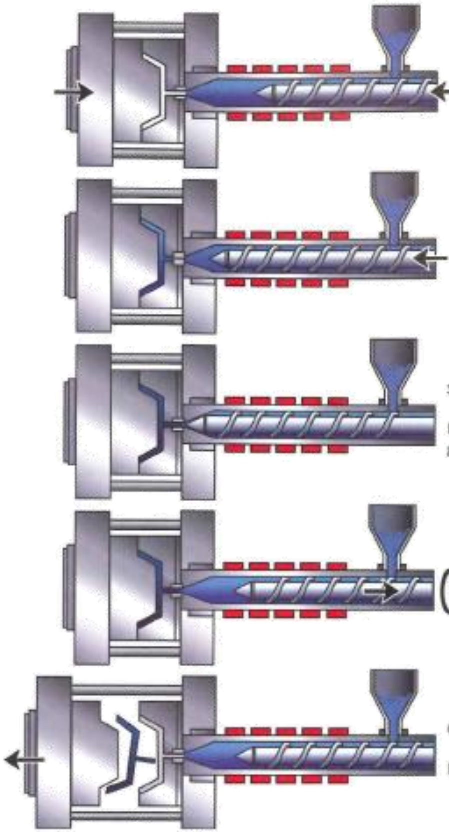
AUTODESK

Moldflow Summit 2025: Managing the Cost of Optimized Cooling, and it’s Influence on Part Quality



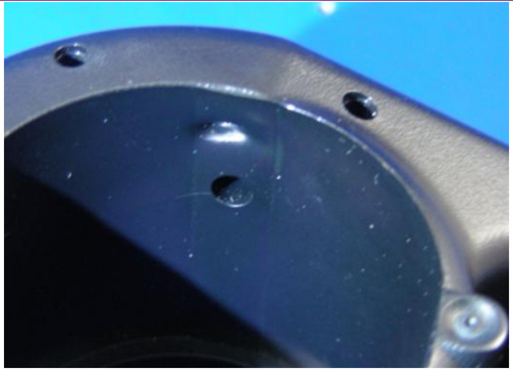


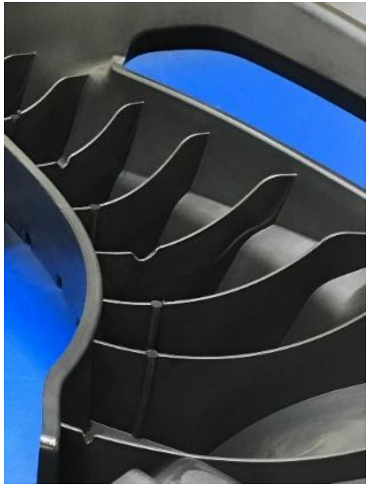
Erik Foltz, The Madison Group
Senior Managing Engineer|LinkedIn

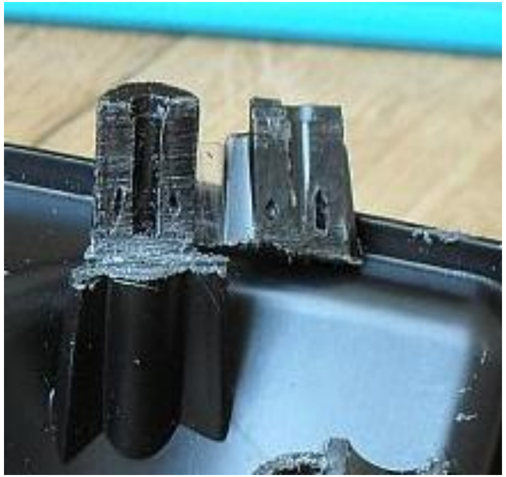


- Injection Molding:
  - Uses Reciprocating Screw to Prepare and Inject Molten Polymer
  - Pressure-Driven Process
  - Utilize for ***Cost-Effective, Mass-Manufacturing*** of Complex, **Dimensionally-Stable** Parts

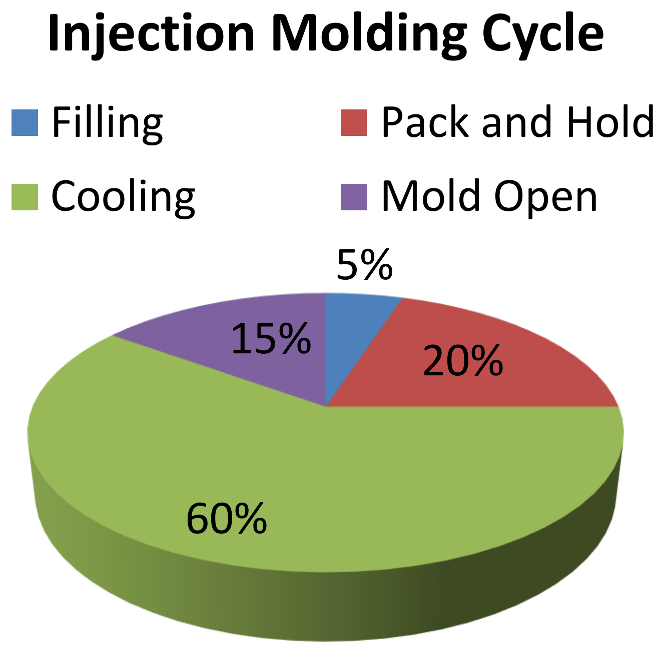
COMMON INJECTION MOLDING ISSUES







What is Affecting Part Quality?



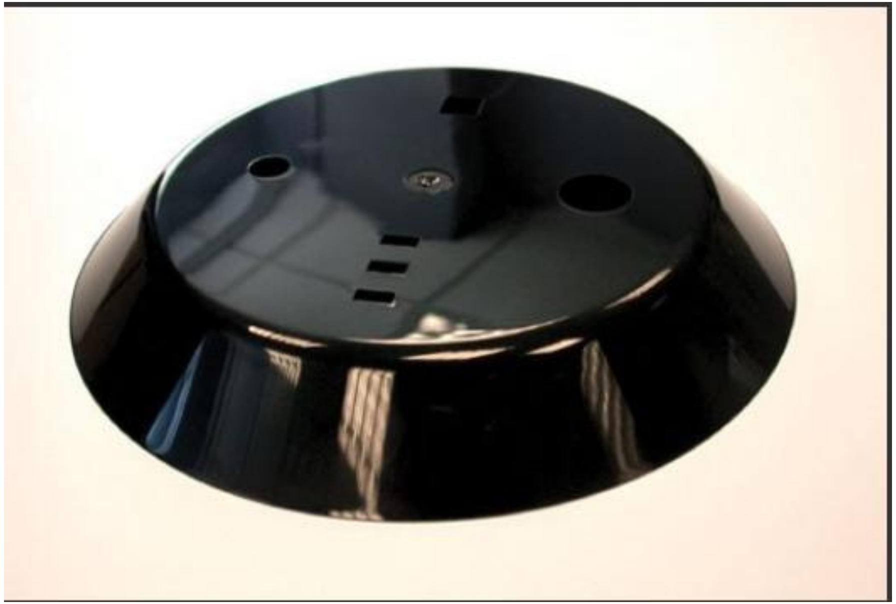
- Often Focus on Filling and Packing Stages To Troubleshoot Manufacturing Part Quality Issues.
- Cooling Stage is One Of the Longest Stages of Molding Cycle.
  - Can Have a Large Influence on Overall Part Quality and Performance…
  - AND COST!

How Cooling Affects Part Quality?

- Surface Appearance

Cold Mold

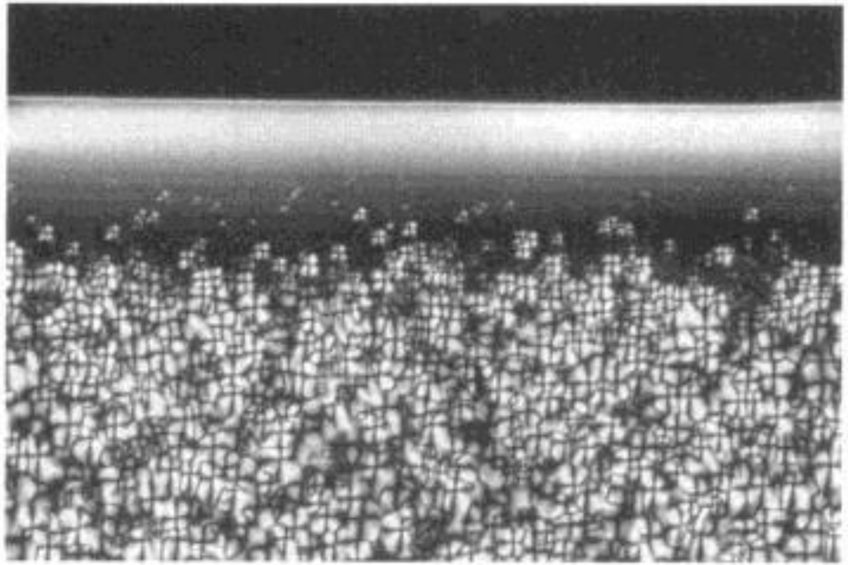
Hot Mold



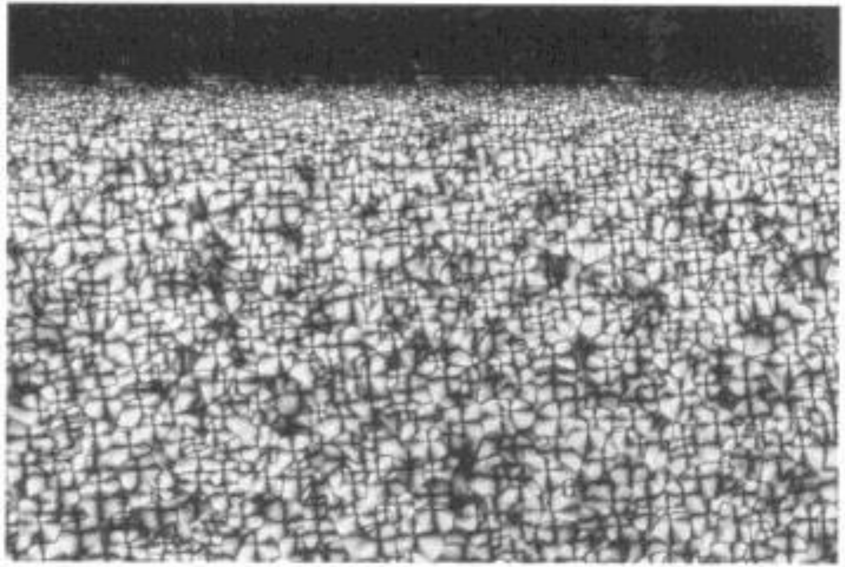
How Cooling Affects Part Quality?

- Degree of Crystallinity

Cold Mold



Hot Mold



How Cooling Affects Part Quality?

- Part Performance
  - High Temperature Performance
  - Long-Term (Creep) Behavior
  - Impact Strength

FIG. 1 Effect of Mold Temperature on Modulus vs. Temperature Behavior of a PPA

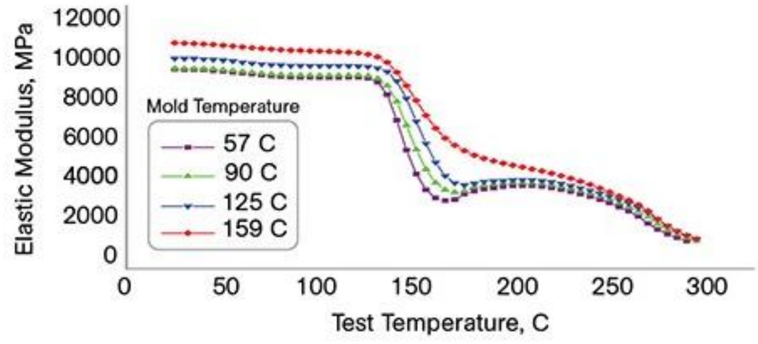
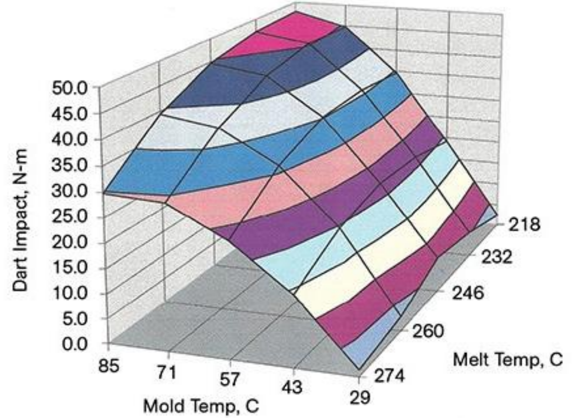


FIG.2 Effect of Melt and Mold Temperature On the Impact Performance of ABS



Images Source: Sepe, MoldMaking Technologies

How Cooling Affects Part Quality?

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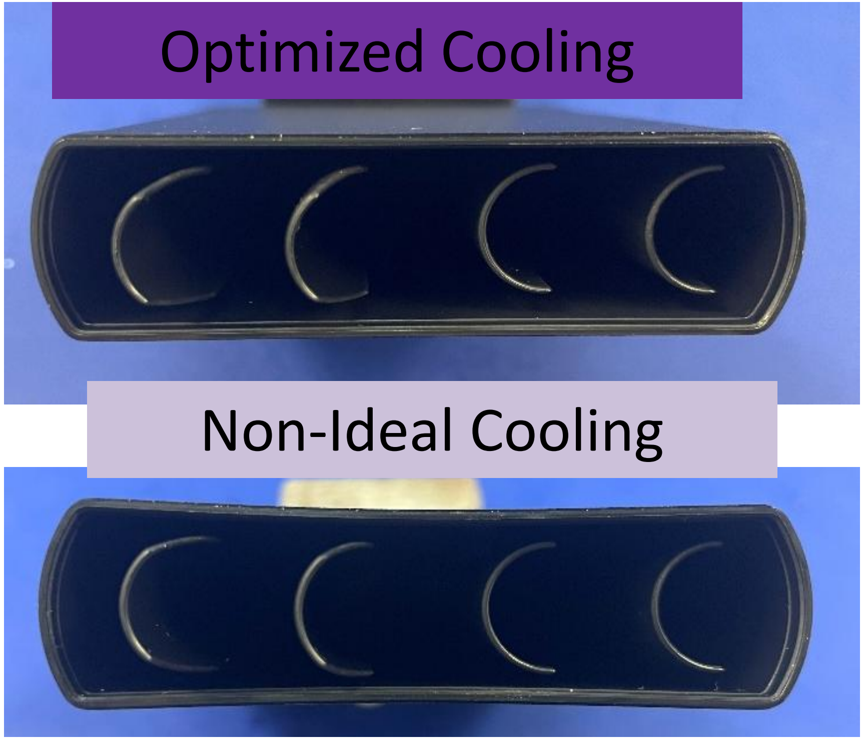
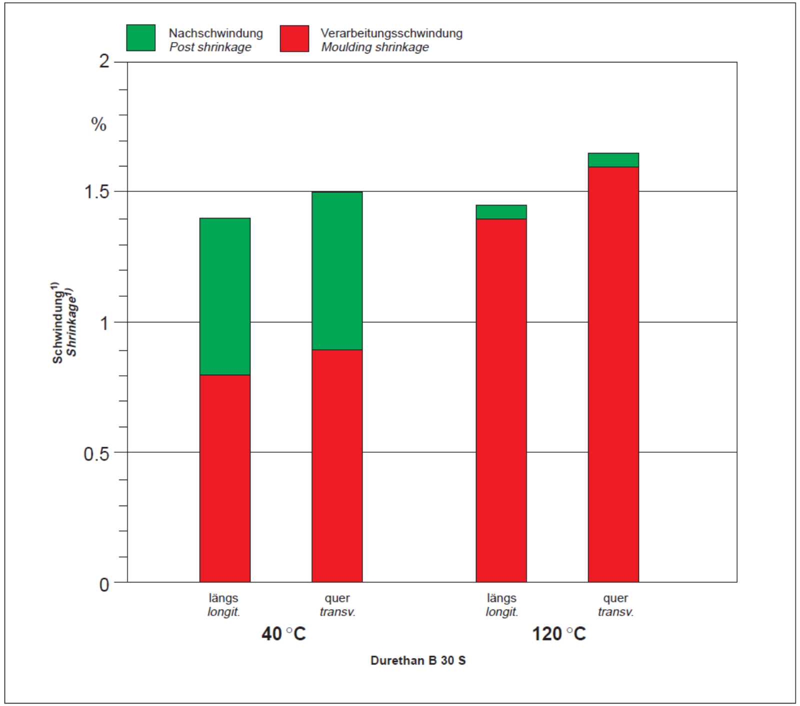
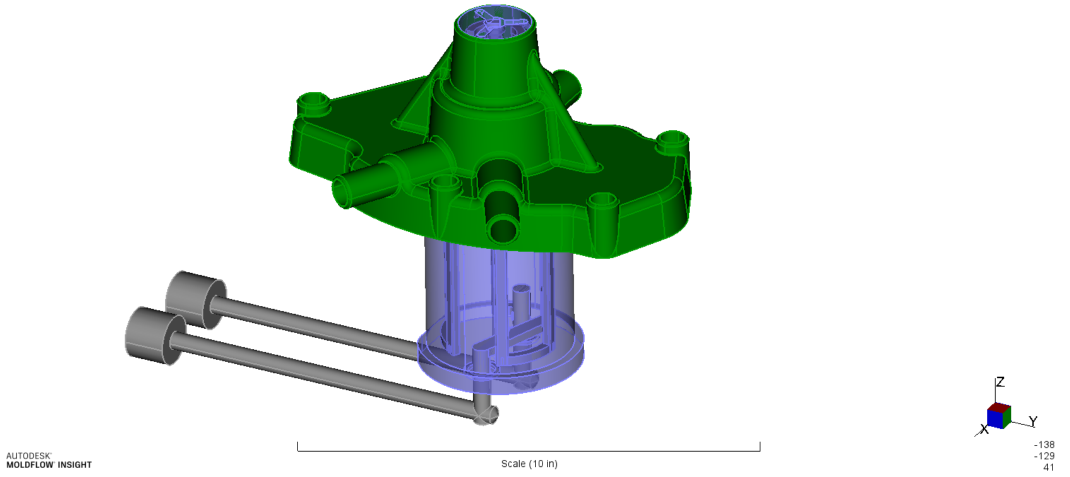
- Dimensional Stability of a Part





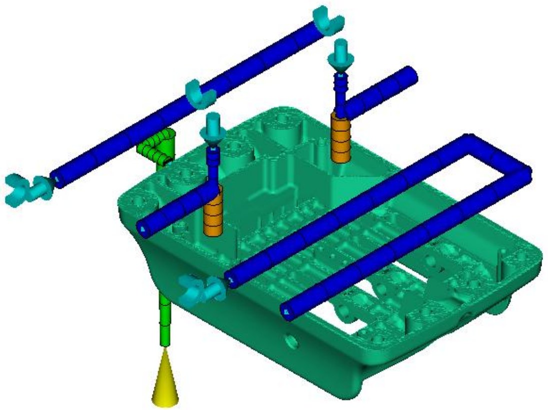
What Influences Cooling of Part?

- As Part Cools Heat Must Travel From Plastic To Coolant.
- Need To Consider:
  - Plastic Design
  - Plastic Material Selection
  - Cooling Line Layout (Mold)
  - Mold Steel Selection (Mold)



Mitigating Risk of Missing the Balance

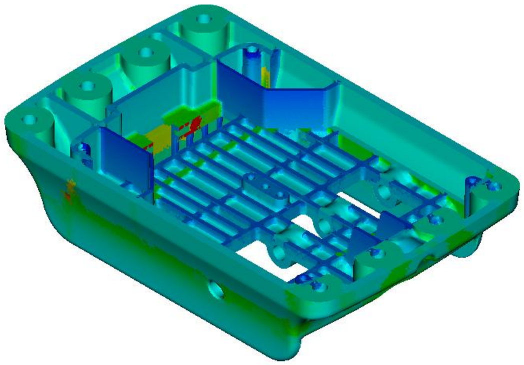
- Often Believed In Order to Address Cooling Issues, a Mold Design is Needed.



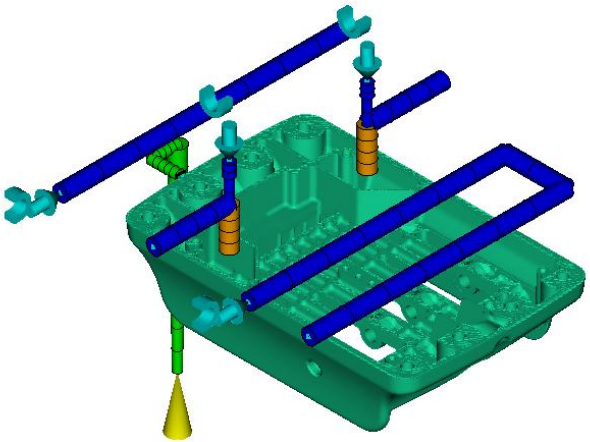
Product Development Stage	Cooling Line and Mold Construction Considered
Part Design	No
Prototype Tooling	No
Initial Mold Design (Cavitation, Mold Actions, Feed System Design, Tool Steel Selection)	No
Moldflow Analysis	Maybe
Ejection System Design	No
Finalized Mold Design	Yes
Mold Qualification	Yes

Mitigating Risk of Non-Ideal Cooling

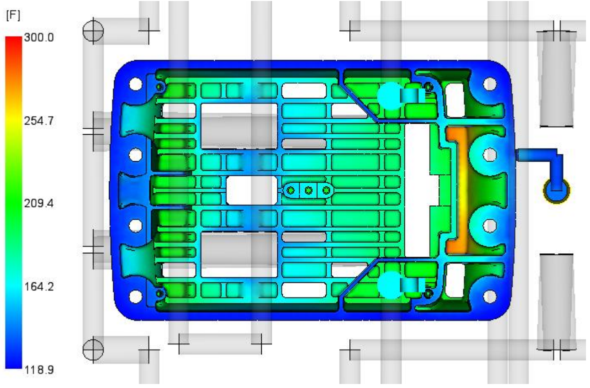
Part Design/ Quoting



Initial Mold Design

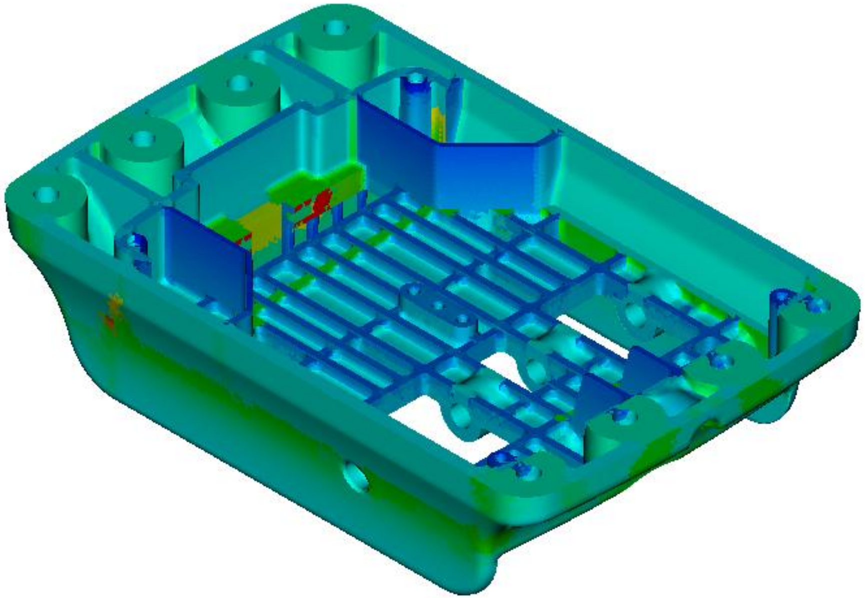


Mold Optimization



ADDRESSING COOLING: PART DESIGN/QUOTING

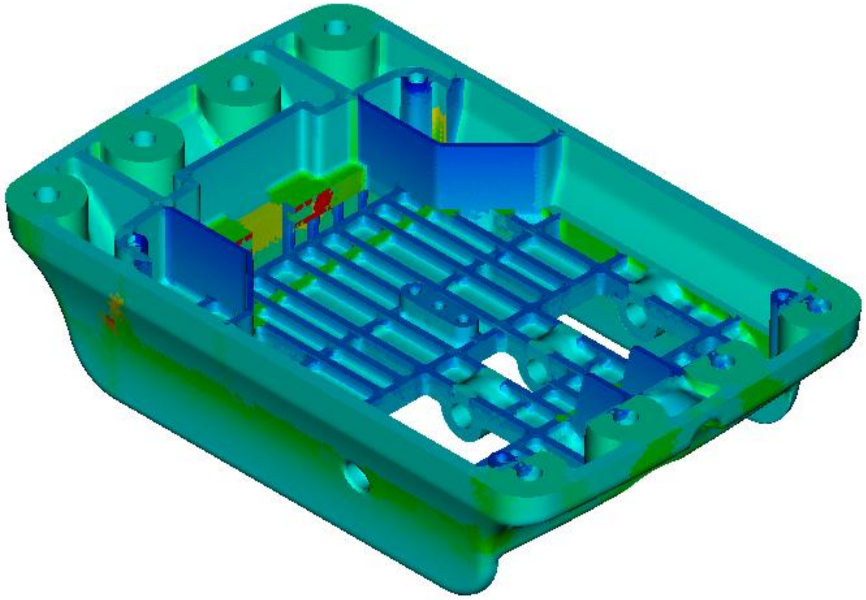
- Part Design Has Significant Influence on Overall Molded Part Cost and Quality.
  - Nominal Wall Section
  - Ribbing Design
  - Material Selection



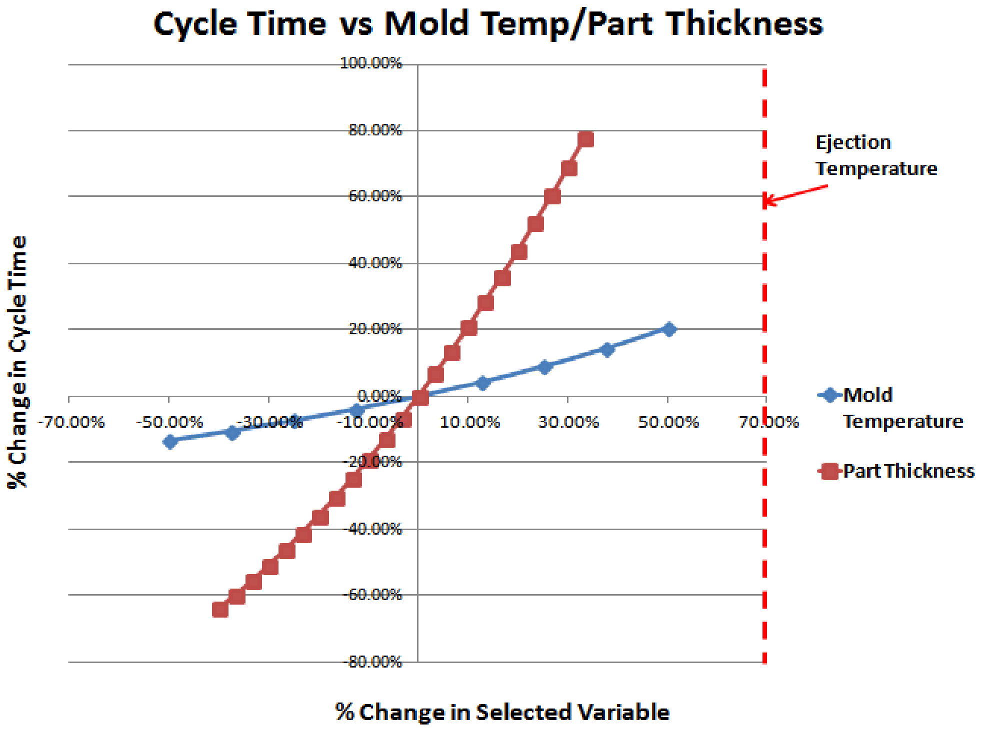
Addressing Cooling: Part Design/Quoting

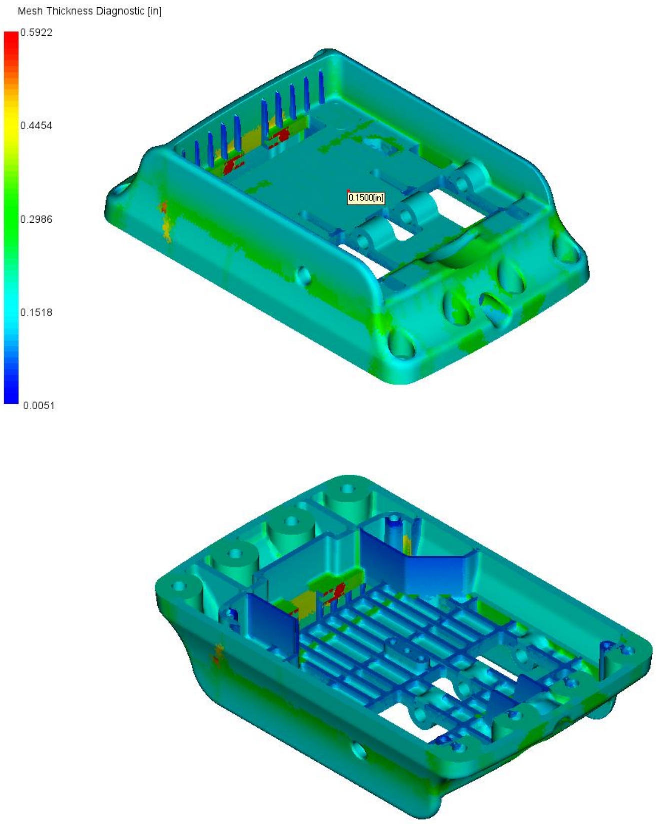
- Part Designer Responsibility:
  - Nominal Wall Selection
  - Ribbing Design
  - Material Selection

$$C_{part} = \frac{C_{mold} + C_{material} + C_{process}}{Mold_{yield}}$$



PART DESIGN/QUOTING: NOMINAL WALL





PART DESIGN/QUOTING: NOMINAL WALL

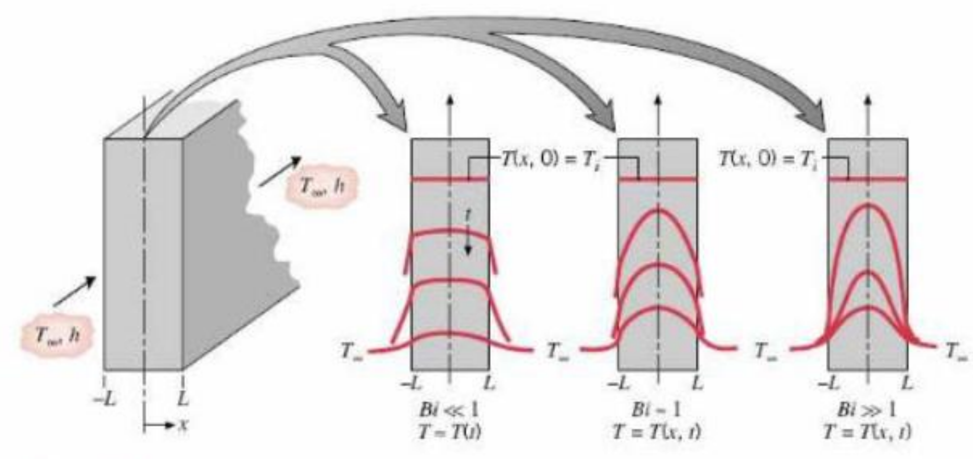
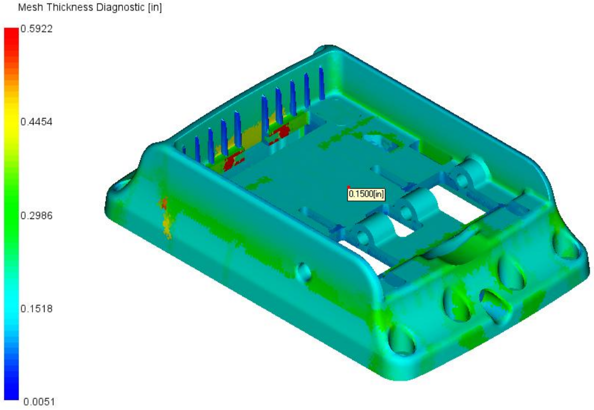


FIGURE 5.4 Transient temperature distributions for different Biot numbers in a plane wall symmetrically cooled by convection.



$$t = \frac{s^2}{\pi^2 a_{eff}} \ln\left(\frac{4}{\pi}\frac{T_M - T_W}{T_E - T_W}\right)$$

t- Cooling Time

s - Part Wall Thickness

a_{eff} – Effective Thermal Diffusivity

T_M – Molten Plastic Temperature

T_W – Mold Wall Temperature

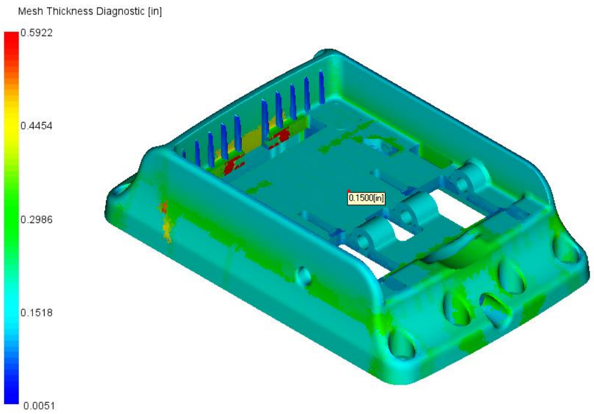
T_E – Ejection Temperature

Image Source: BASF

Part Design/Quoting: Nominal Wall

Material	Diffusivity
Steel	$11.72 * 10^{-5}$
PC	$8.0 * 10^{-6}$
PET	$10.5 * 10^{-6}$
PMMA	$7.0 * 10^{-6}$
PA66	$7.5 * 10^{-6}$
PP	$8.5 * 10^{-6}$
HDPE	$8.0 * 10^{-6}$

$$t = \frac{s^2}{\pi^2 a_{eff}} \ln\left(\frac{4}{\pi} \frac{T_M - T_W}{\underline{T_E} - T_W}\right)$$



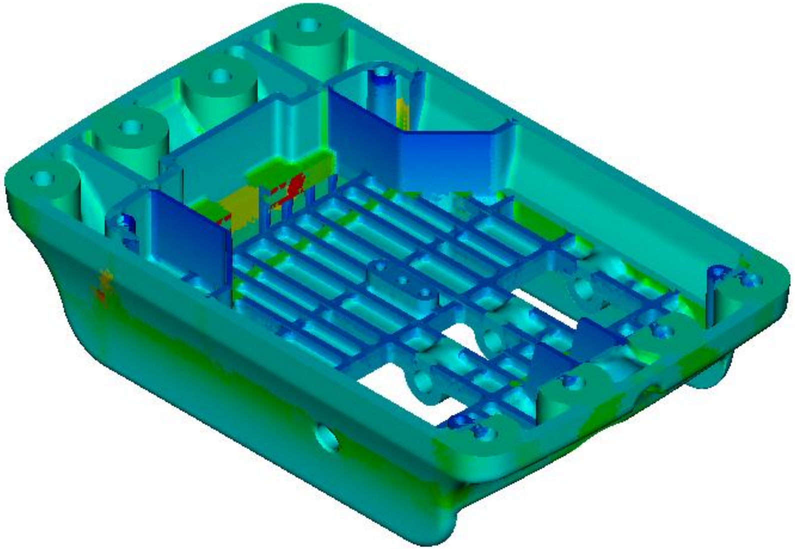
- s – Part Wall Thickness
- a_{eff} – Effective Thermal Diffusivity
- T_M – Molten Plastic Temperature
- T_W – Mold Wall Temperature
- T_E – Plastic Ejection Temperature

Image Source: BASF

Addressing Cooling: Material Selection

- Part Designer Responsibility:
  - Nominal Wall Selection
  - Ribbing Design
  - **Material Selection**

$$C_{part} = \frac{C_{mold} + C_{material} + C_{process}}{Mold_{yield}}$$



ADDRESSING COOLING: MATERIAL SELECTION

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- Two Similar "Drop-In" Materials From Same Family Can Yield Very Different Cooling Times Results.

$$t = \frac{s^2}{\pi^2 a_{eff}} \ln\left(\frac{4}{\pi} \frac{T_M - T_W}{T_E - T_W}\right)$$

Material A – Ejection Temperature of 349 °F

Mold surface temperature	176	F
Melt temperature	518	F
Mold temperature range (recommended) (T_W)		
Minimum	140	F
Maximum	212	F
Melt temperature range (recommended) (T_M)		
Minimum	491	F
Maximum	545	F
Absolute maximum melt temperature	572	F
Ejection temperature (T_E)	348.8	F

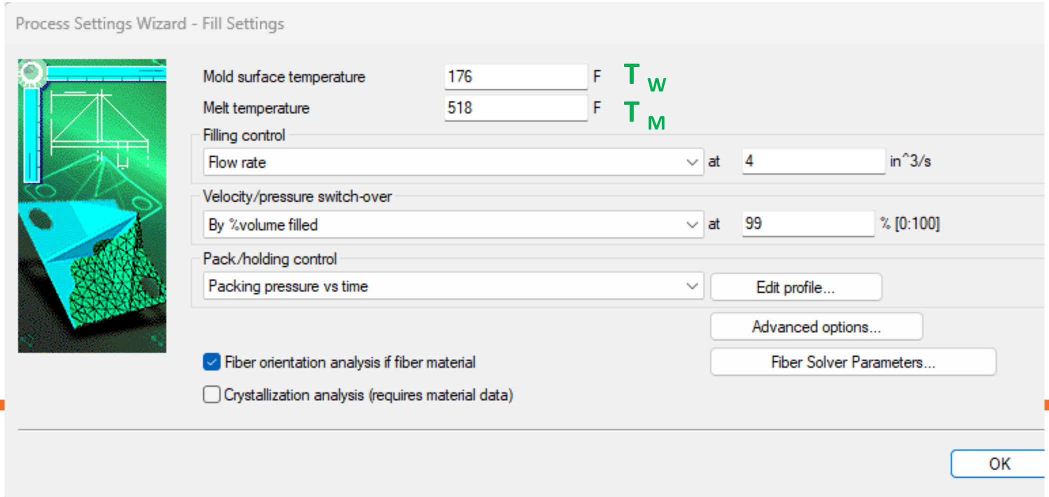
Material B – Ejection Temperature of 415 °F

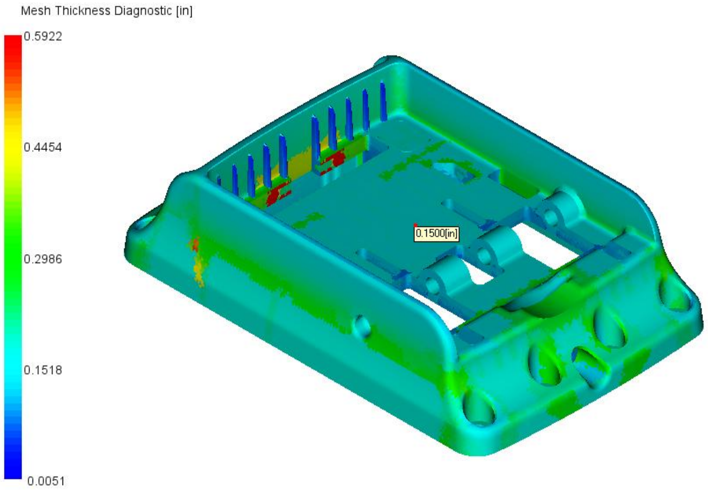
Mold surface temperature	185	F
Melt temperature	545	F
Mold temperature range (recommended)		
Minimum	158	F
Maximum	212	F
Melt temperature range (recommended)		
Minimum	518	F
Maximum	572	F
Absolute maximum melt temperature	662	F
Ejection temperature	415.4	F

ADDRESSING COOLING: MATERIAL SELECTION

- Utilizing Tools Like Injection Molding Simulation Can Help Quickly Identify How Variations in Molding Parameters Will Influence the Time to Reach the Ejection Temperature.

$$t = \frac{s^2}{\pi^2 a_{eff}} \ln\left(\frac{4}{\pi}\frac{T_M - T_W}{T_E - T_W}\right)$$

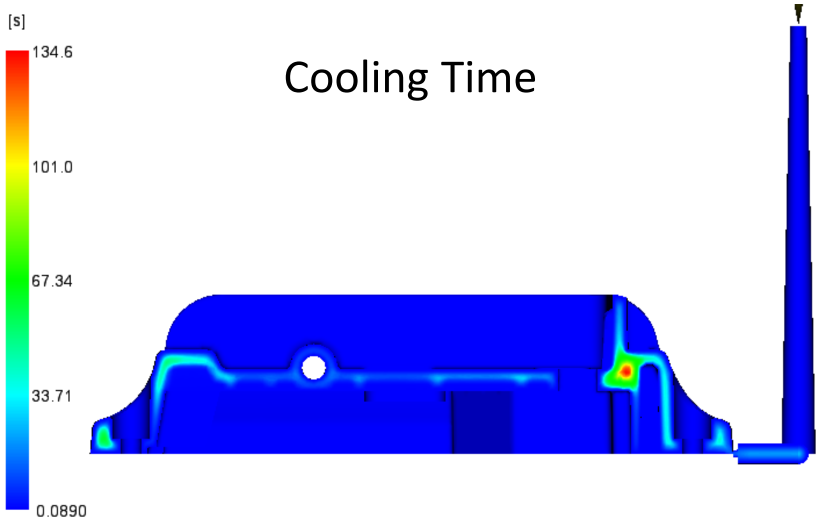




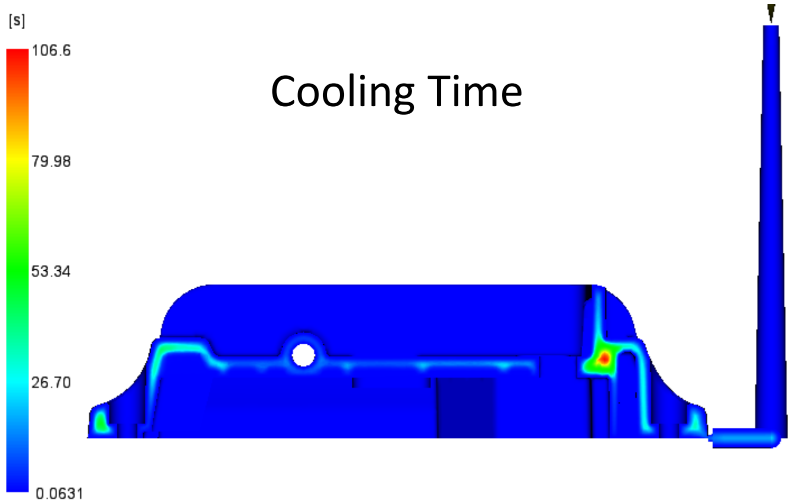
ADDRESSING COOLING: MATERIAL SELECTION

- Utilizing Tools Like Injection Molding Simulation Can Help Quickly Identify Those Differences During Design Stage Prior to a Mold Being Constructed.

Material A – Ejection Temperature of 349 °F



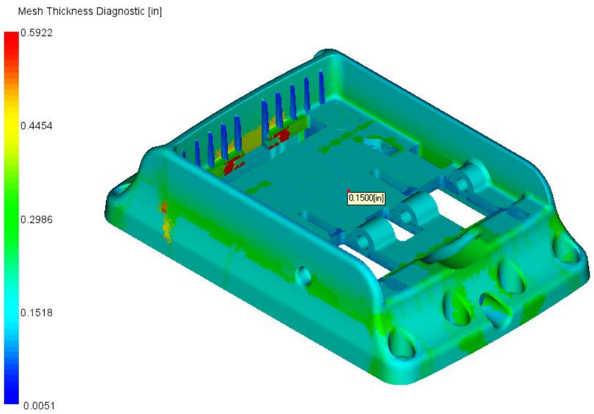
Material B – Ejection Temperature of 415 °F

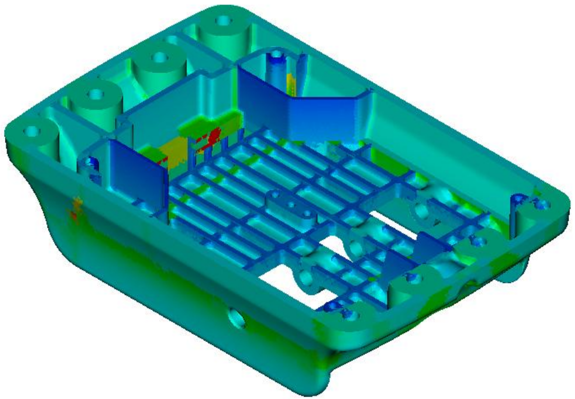


ADDRESSING COOLING: PART DESIGN

- Part Designer Responsibility:
  - Nominal Wall Selection
  - Ribbing Design
  - Material Selection

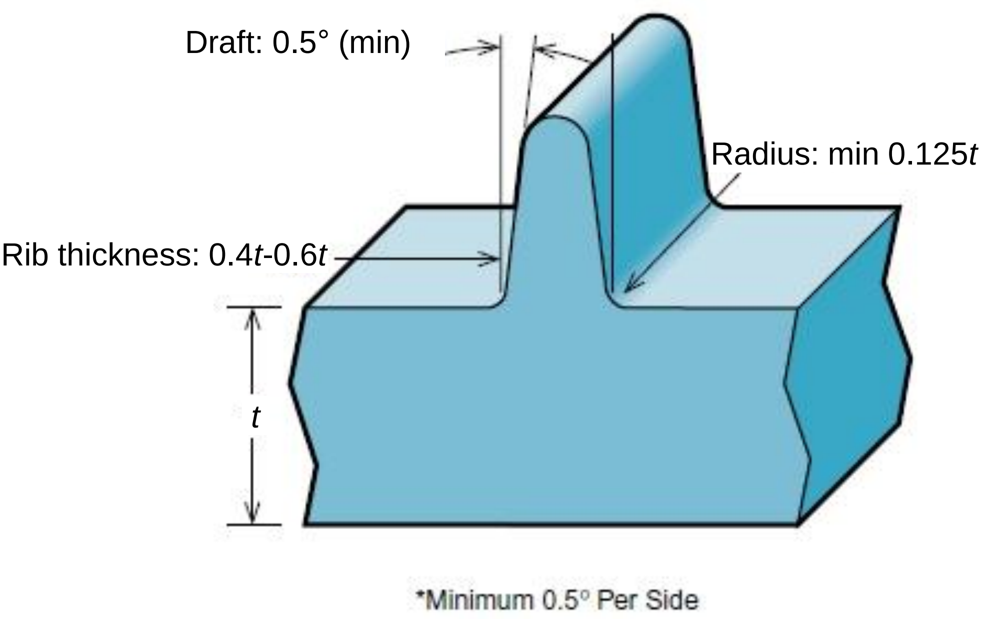
$$C_{part} = \frac{C_{mold} + C_{material} + C_{process}}{Mold_{yield}}$$

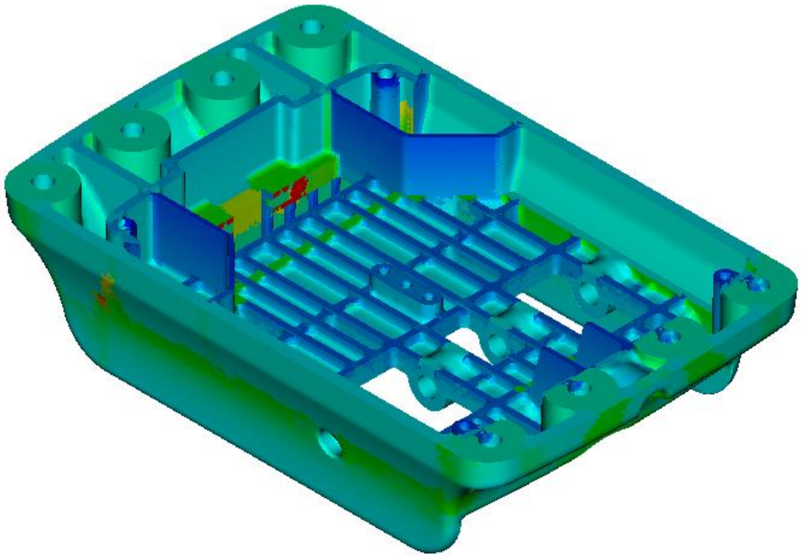




What are Features Add Difficulty?

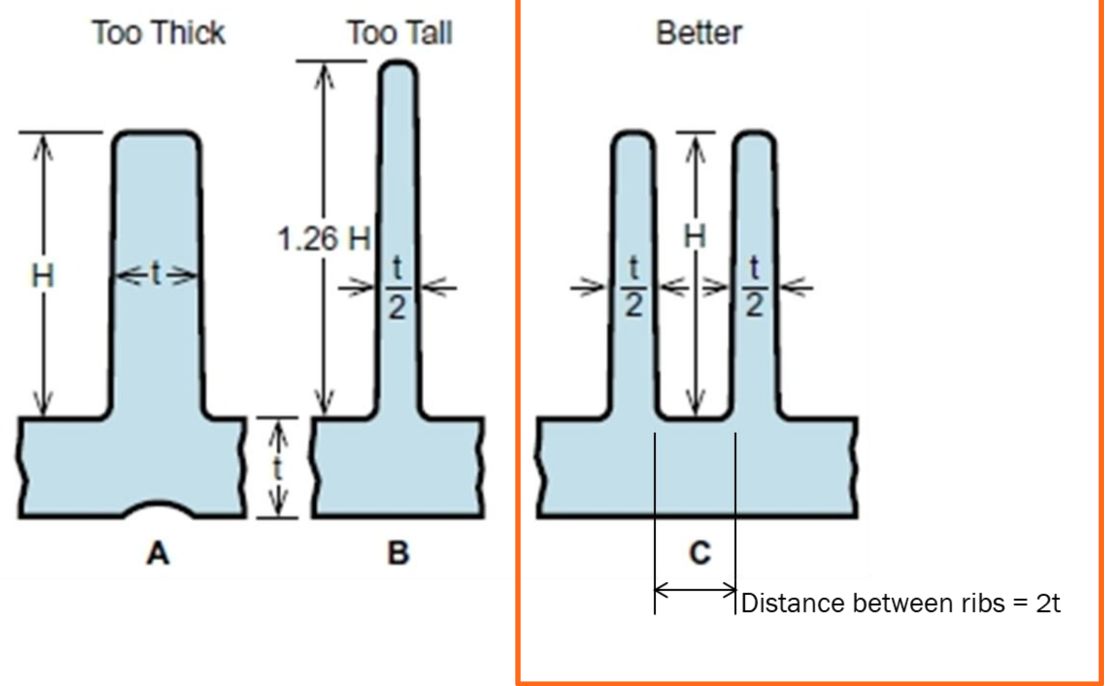
- Ribbing Can Be Added to Help Reduce Wall Thickness and Maintain Similar Stiffness.

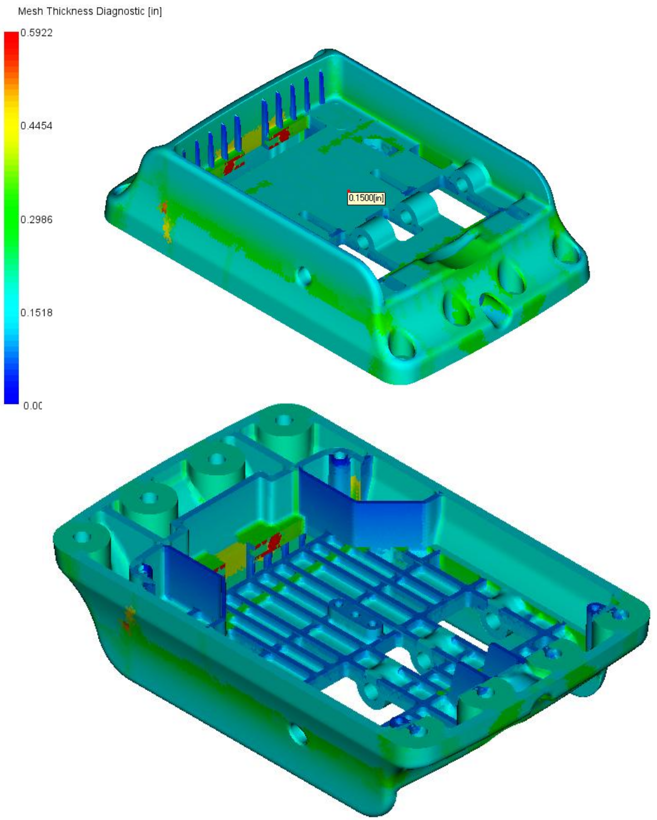




WHAT ARE FEATURES THAT ADD DIFFICULTY?

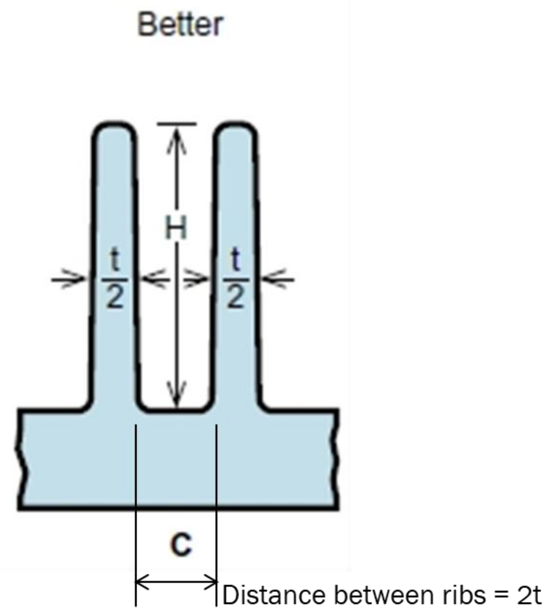
- Want to Ensure Ribbing is Not Too Tall to Create Thin Steel Condition that will be Difficult To Cool.

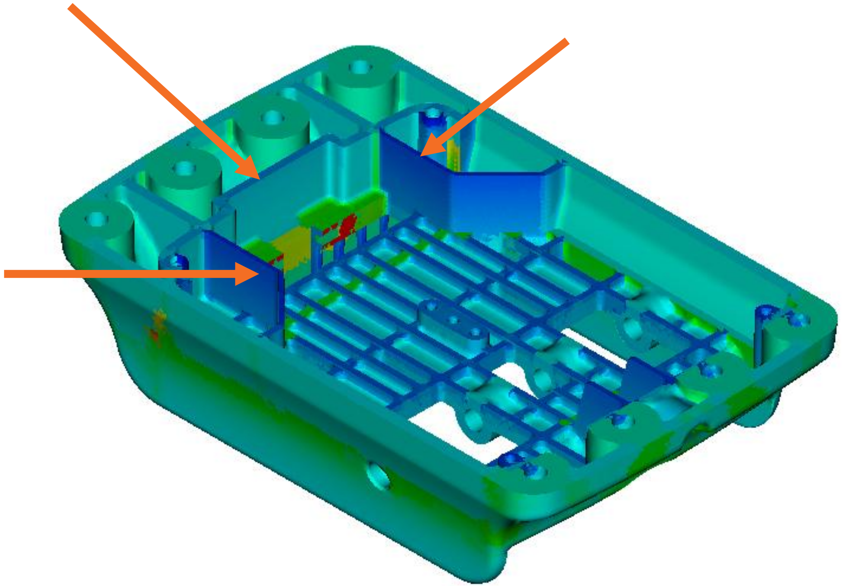




WHAT ARE FEATURES THAT ADD DIFFICULTY?

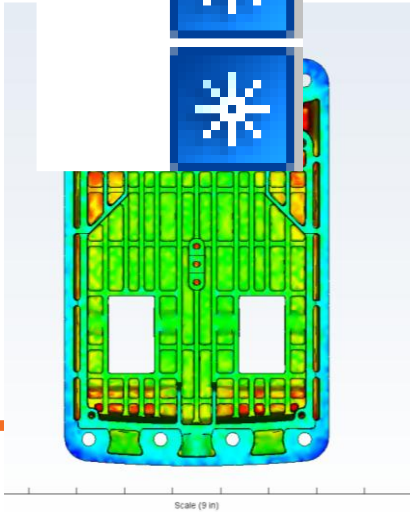
- If Ribs Create Steel Conditions That Have an Aspect Ratio of Greater than 3X1, It May Be Difficult to Get Cooling Into Those Sections, and They May Run Hot.





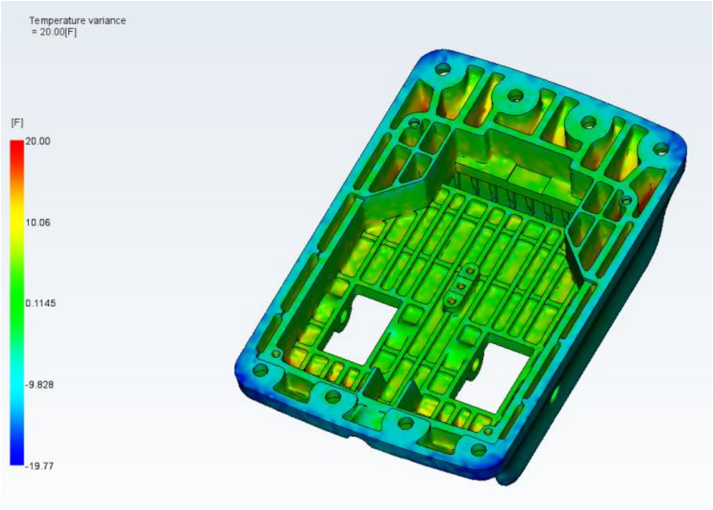
How to Know If They Are Problem Areas?

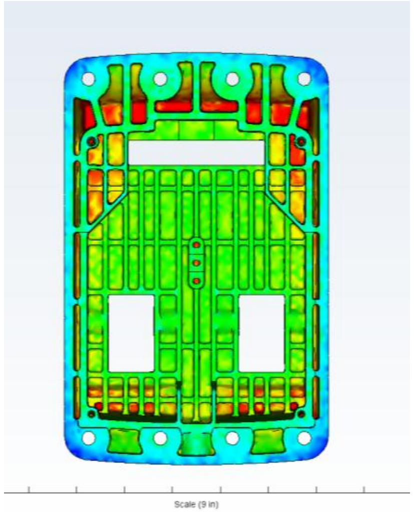
- ***Mold Designers and Part Designers*** Can Identify Potential Hot Spots Without Having A Cooling Line Layout/Mold Design By Running Injection Molding Simulation.
- ***Cooling Quality Result:***
  - Requirements:
    - Part Design
    - Material Selected
  - Assumptions:
    - No Cooling Lines Placed In the Mold
    - Part is Buried in Steel
  - Result: Expected Mold Surface Temperature Variation at the End of the Molding Cycle.



HOW DOES THAT AFFECT MY PART QUALITY

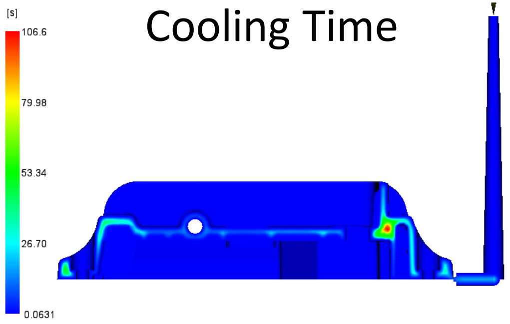
- ***Mold Designers and Part Designers*** Can Identify Potential Hot Spots Without Having A Cooling Line Layout/Mold Design.
- **May Influence:**
  - **Mold Material Selection**
  - **Quoted Cycle Time/Part Cost**

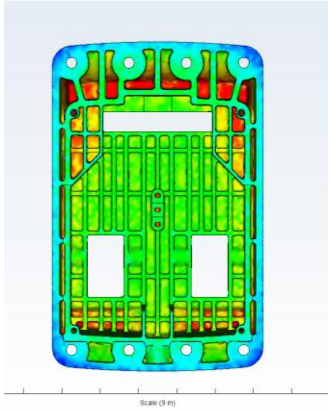




Addressing Cooling: During Part Design

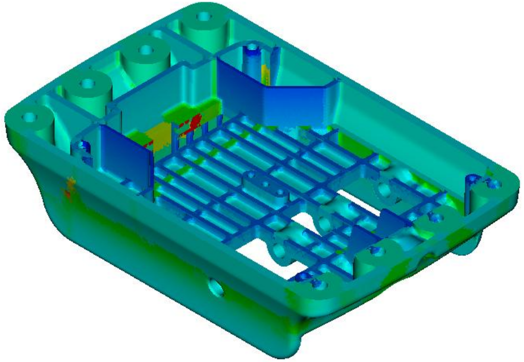
- Injection Molding Simulation Can Help Part Designers and Mold Designers:
  - Get More Realistic Cycle Times for Their Given Part Design.
  - Help Select Between Equivalent Resins.
  - Understand the Potential Risks of Cooling a Given Part Design Without the Need for a Mold Design.



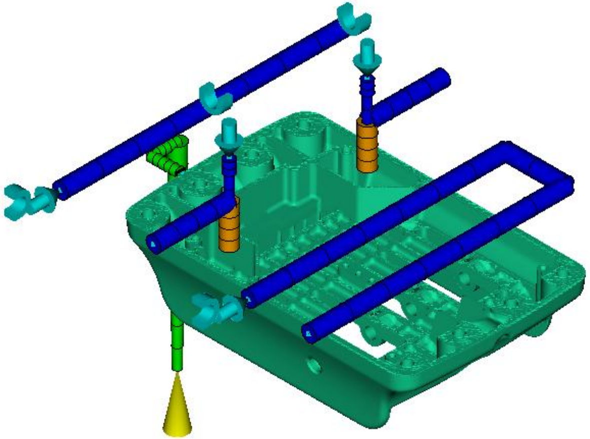


MITIGATING RISK OF MISSING THE BALANCE

Part Design/ Quoting

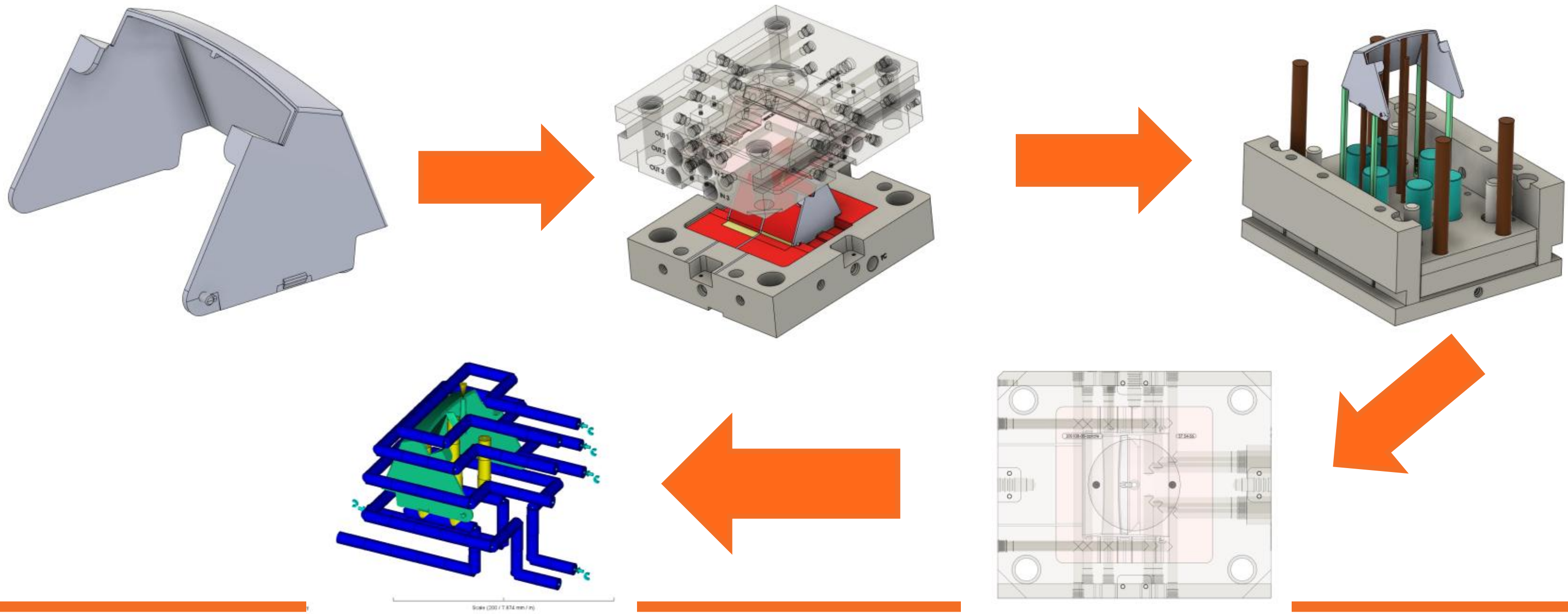


Initial Mold Design



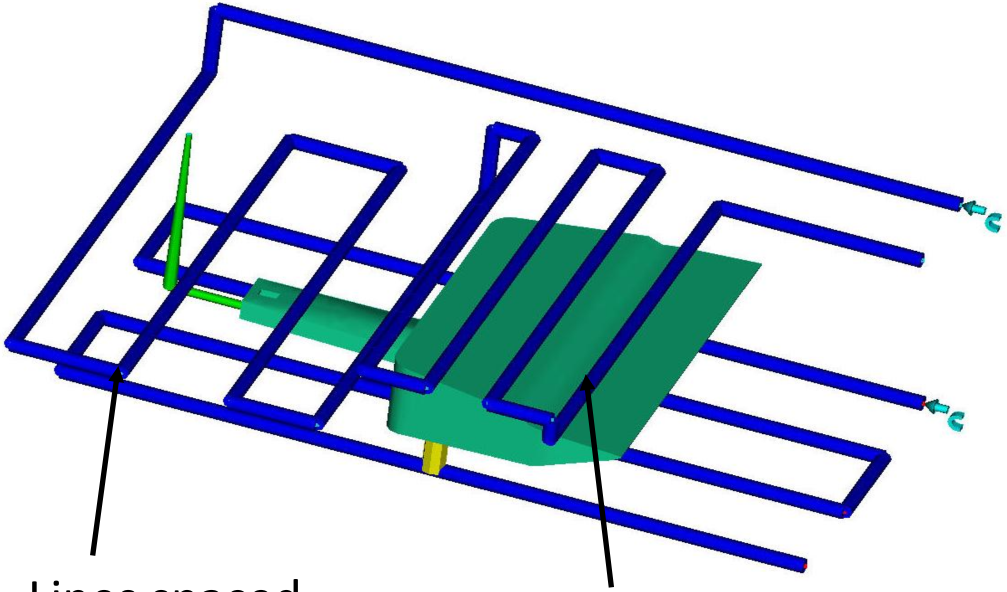
Where is Cooling's Priority In Mold Design?

- Despite Influence on Part Quality and Overall Mold and Part Cost, Cooling Is Typically One of the Last Areas to Be Addressed In The Mold Design.
- Need to Design Around Mold Functionality and Part Ejection.



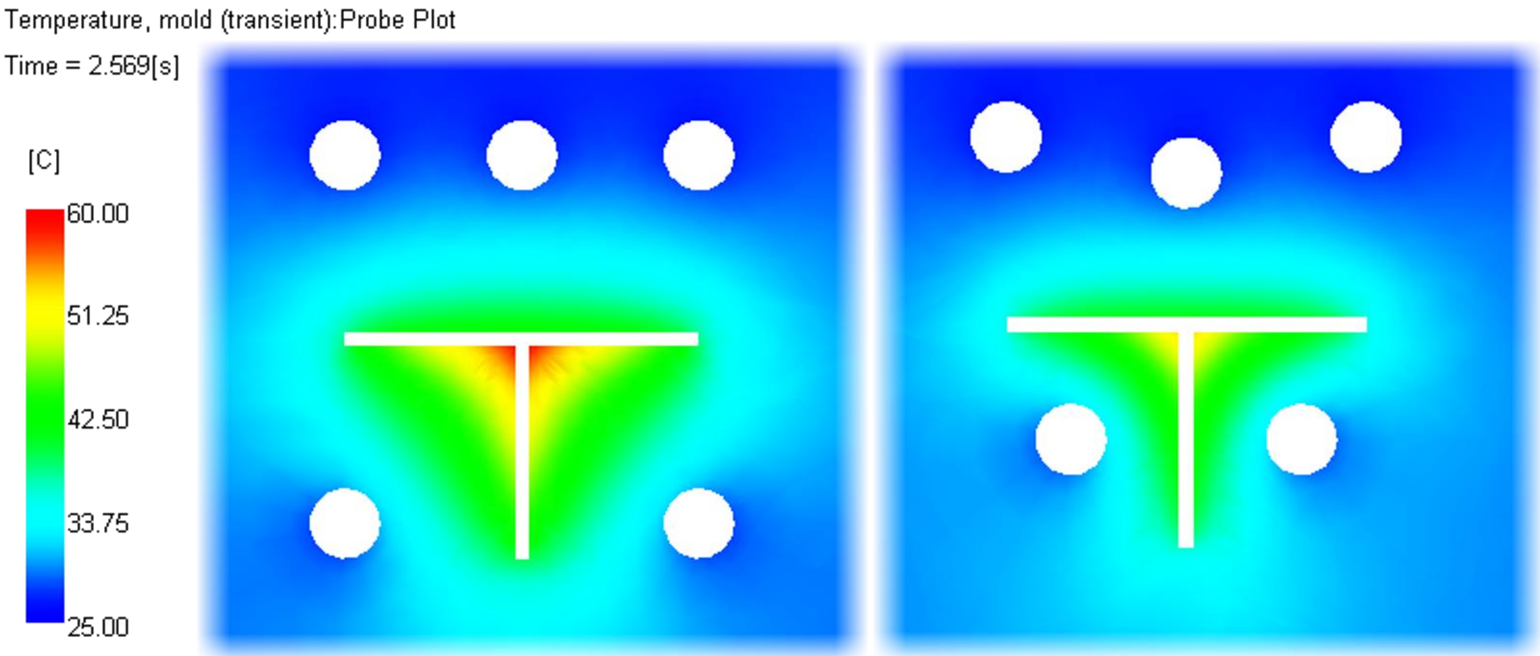
Cooling Line Layout

- Cooling Lines Are Typically Drilled or Machined Into Tool Steel.
- Cooling Line Placement is Determined by Achieving "Uniform" Mold Temperature
  - Increasing Cooling Line Density in High-Heat Load (Hot) Areas
  - Reducing Cooling Line Density in Low-Heat Load (Cool) Areas



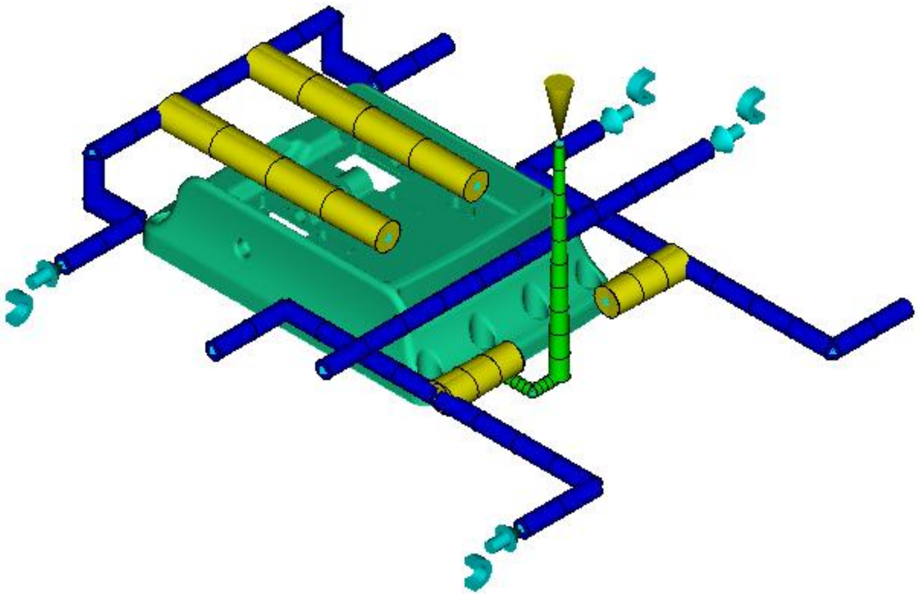
COOLING LINE LAYOUT

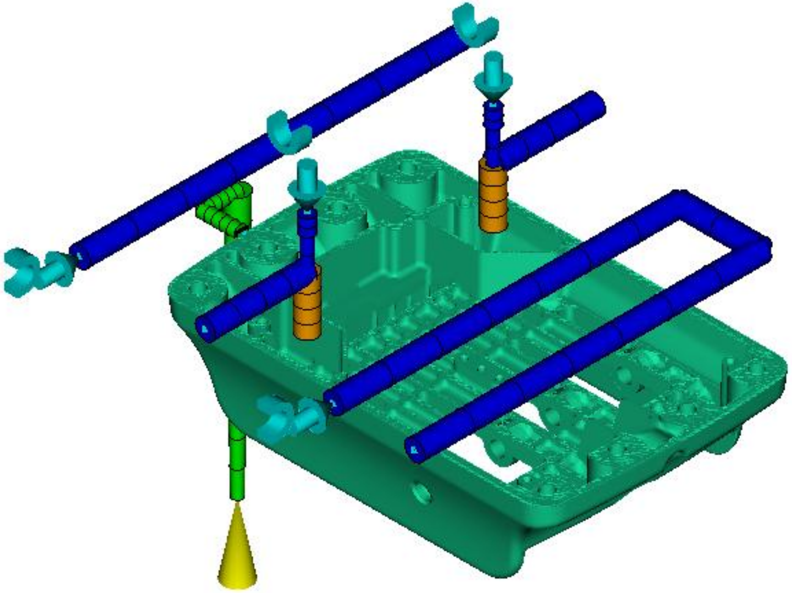
- True Goal is To Achieve a Uniform "Uniform" Cooling Rate in the Part.



Cooling Deep Cores

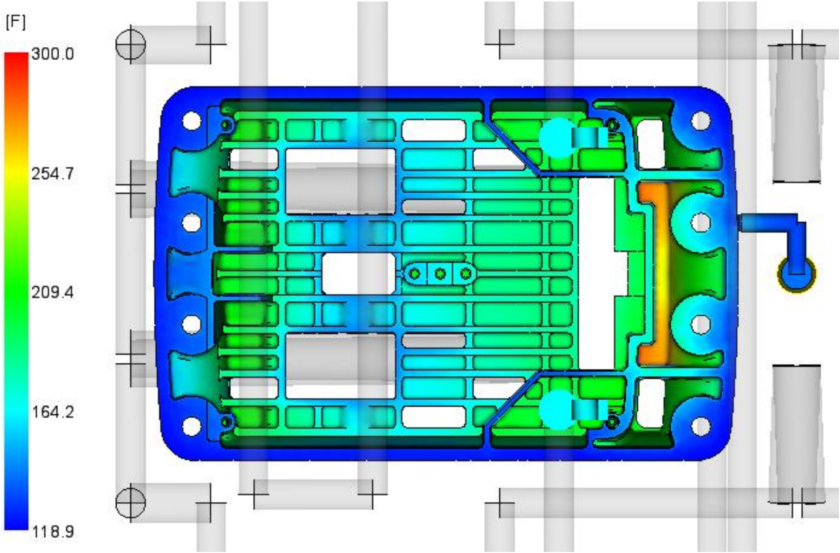
- Injection Molding Simulation Can Be Used to Model In a Cooling Line Layout.
- Can Model In Cooling Lines, Bubblers and Baffles.

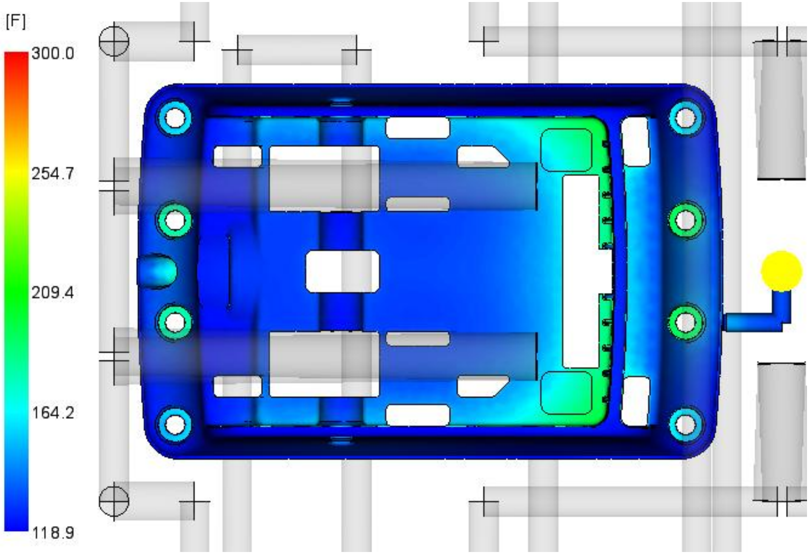




Cooling Analysis Results: Mold Surface Temperature

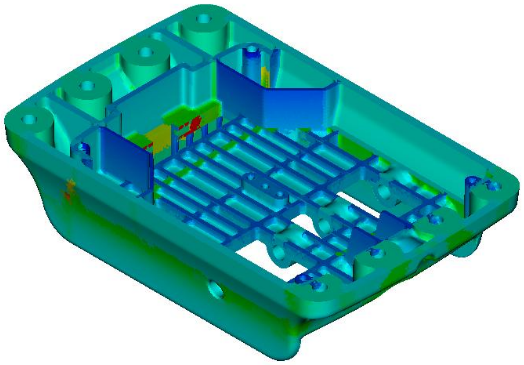
- By Modeling In The Cooling Line Layout, Can Get An Idea of Mold Surface Temperature Distribution, and If Cycle Time is Realistic.



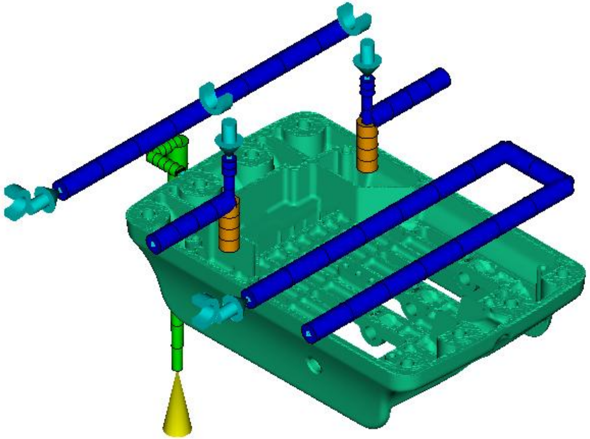


MITIGATING RISK OF MISSING THE BALANCE

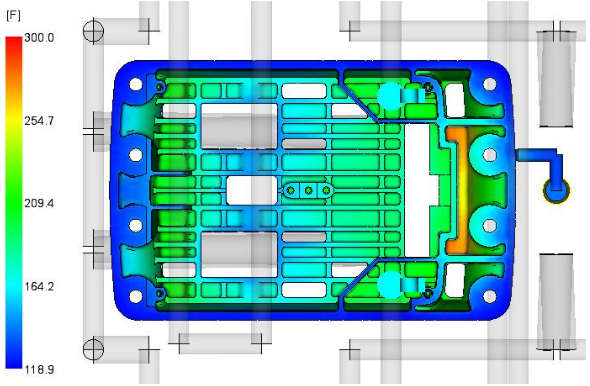
Part Design/ Quoting



Initial Mold Design



Mold Optimization



What If High Conductivity Alloys Aren't An Option?

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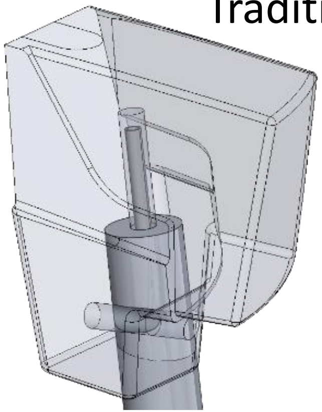
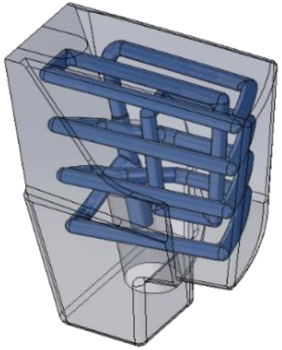
- High Conductivity Alloys Are a Great Option When Wear and High Mold Surface Temperatures Are Not Required.
- Additionally, High Conductivity Inserts Don't Perform Well When Stressed Due to Molding Pressure.
- Additive Technologies Helps Ease This Restriction By Placing Cooling Lines Where the Heat Load is Highest.

Traditional



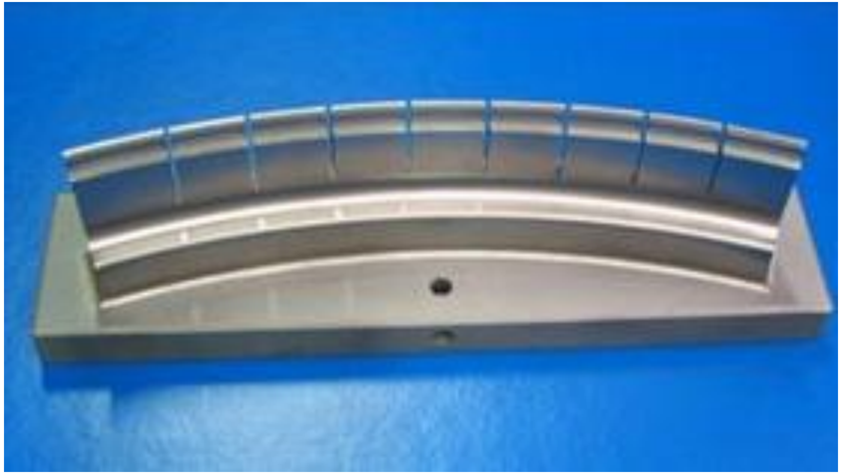
NXC MFG

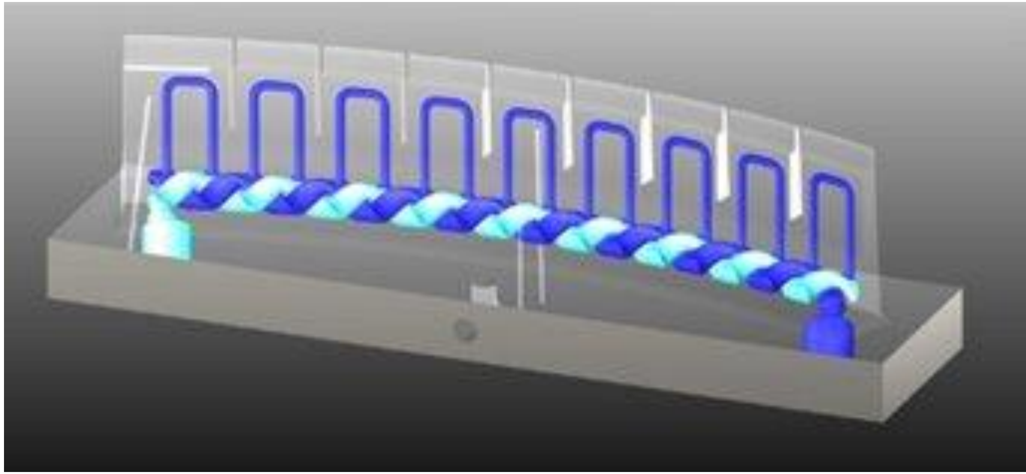
Additive Tooling



Additive Tooling

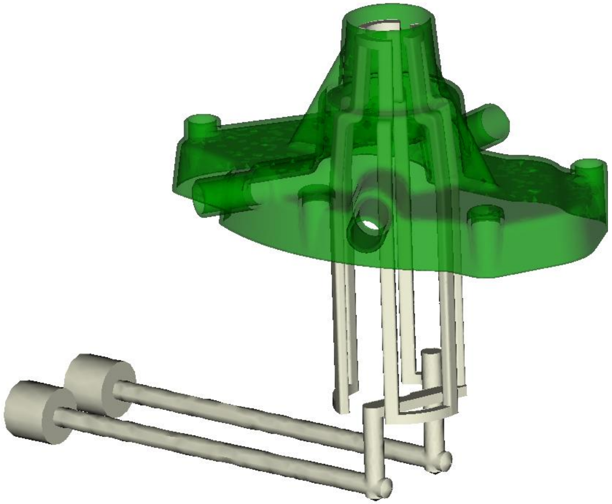
- Can Use Traditional Mold Materials That Have Better Wear and Strength Properties.
  - H-13
  - 420 SS

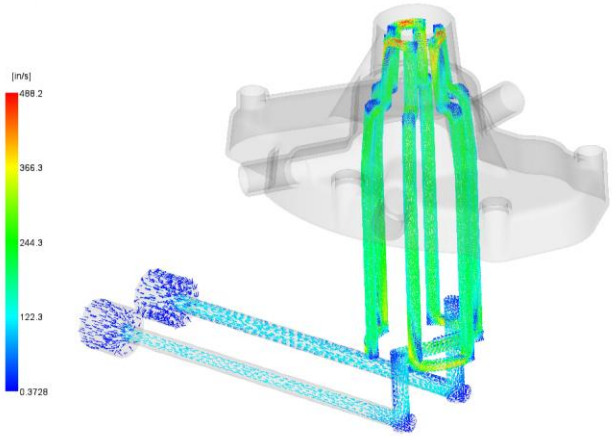


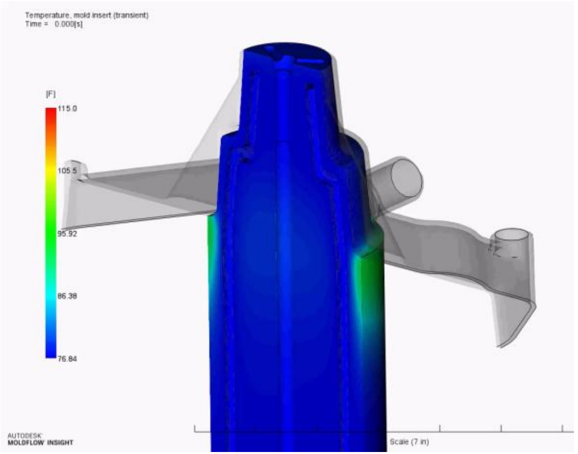


HOW CAN I HIGHLIGHT THE BENEFIT?

- Conformal Cooling Line Layouts Can Be a Great Option to Better Conform to the Part Geometry and Minimize Hot Spots.







Cooling Strategies Using Simulation

- Cooling Phase is an Important Aspect of Plastic Manufacturing to Control Part Cost and Quality.
- Using Simulation Early On Allows for Risks of Poor Cooling to Be Identified Early on In the Design Process to Help Address Potential Hotspots in the Mold.
    - Can Start With Part Design, Material, and Gate
    - Can Help Drive Decisions About Cooling Line Layout
- Once a Cooling Line Layout Is Established, Injection Molding Simulation Allows for Determination on How to Avoid Hot Spots In the Mold, and What is Required To Achieve Maximum Efficiency of the Design.
- If Conventional Solutions Do Not Solve the Problem, Utilization of Injection Molding Simulation Allows for Potential Alternative Mold Cooling Strategies to Be Evaluated Prior to Investment.

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Questions?

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