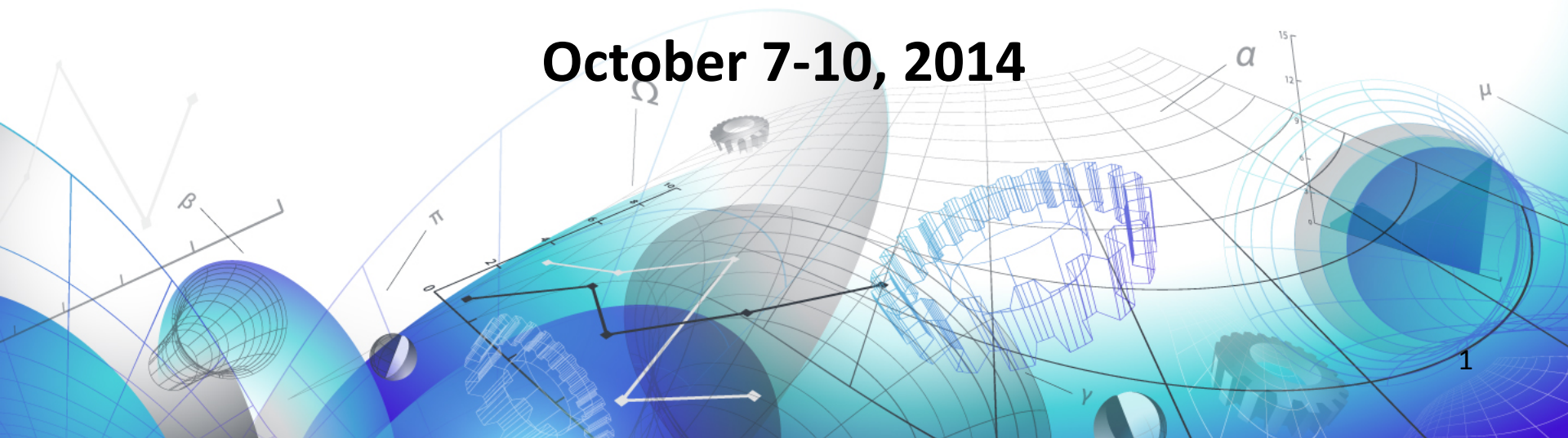
ALTASIM TECHNOLOGIES
REALIZING TOMORROW'S TECHNOLOGY

COMSOL CONFERENCE
2014 BOSTON

Thermal Analysis of Additive Manufacturing

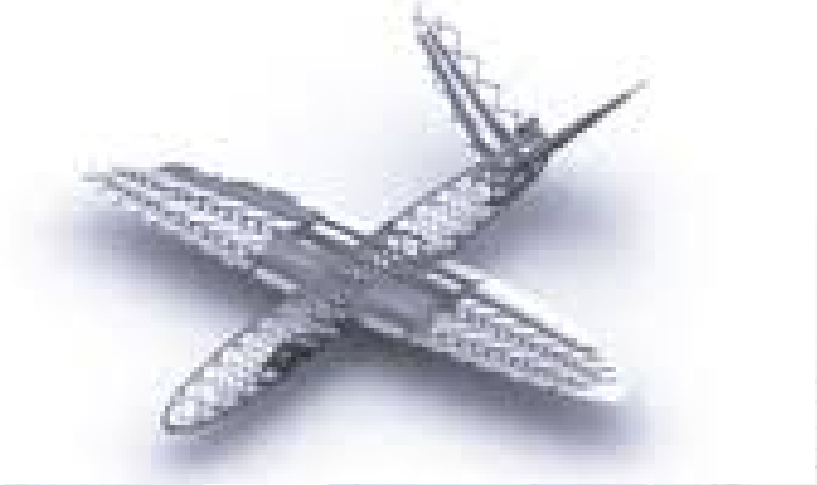
COMSOL Conference

October 7-10, 2014



Motivation

- **Additive manufacturing (3D Printing)**
  - **Direct material deposit**
  - **Rapid manufacture/prototype**
  - **Complex geometry**
  - **Reduced machining**



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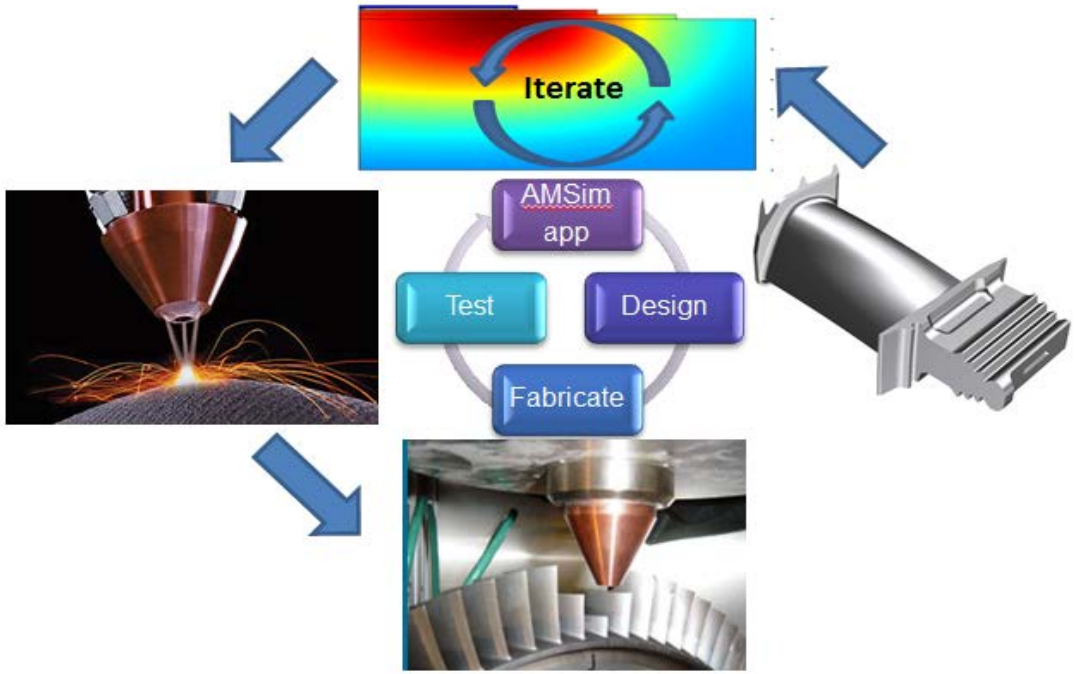
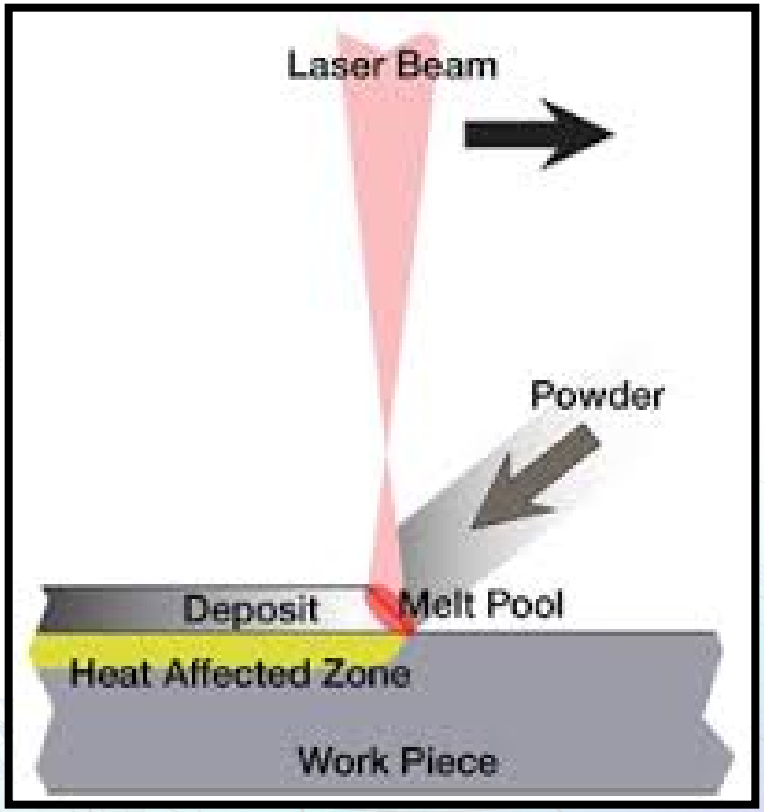
Process

- **Discrete layer addition**
- **95% of AM manufactured by Powder Bed Fusion**





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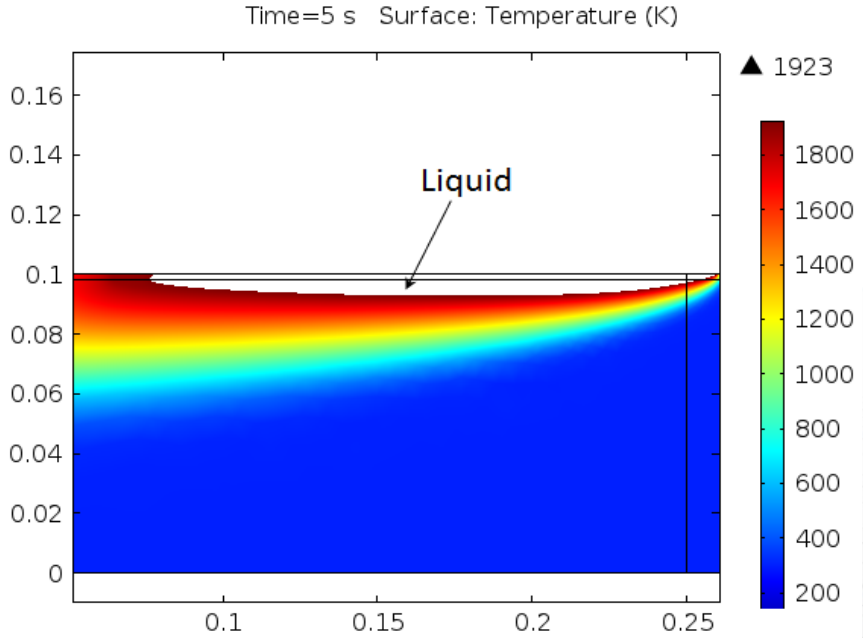
AM Model

- Time dependent material addition
- Moving heat source



- Heat flow
  - Conduction through bulk
  - Convection in molten metal pool
  - Radiation to environment
- Phase change:
  - Liquid to Solid
  - Solid to Liquid
  - Solid state

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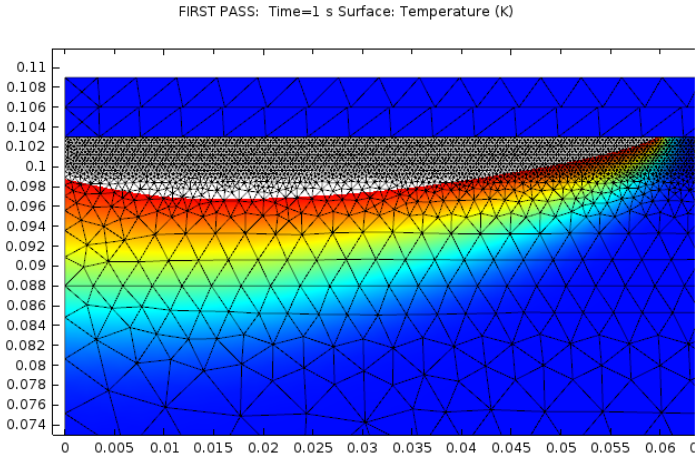
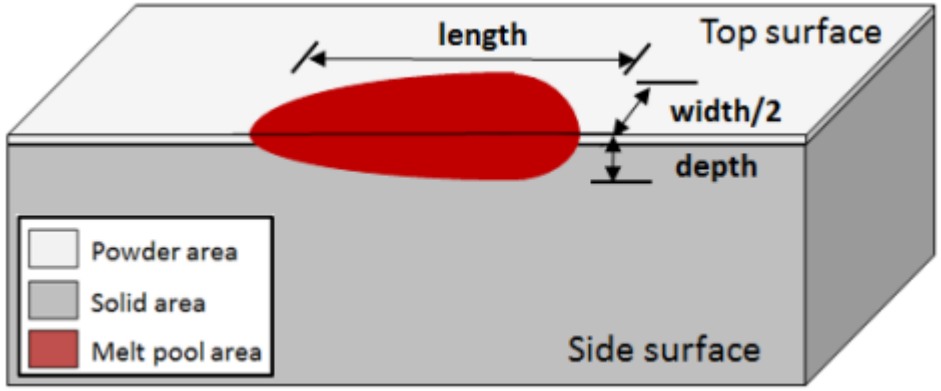
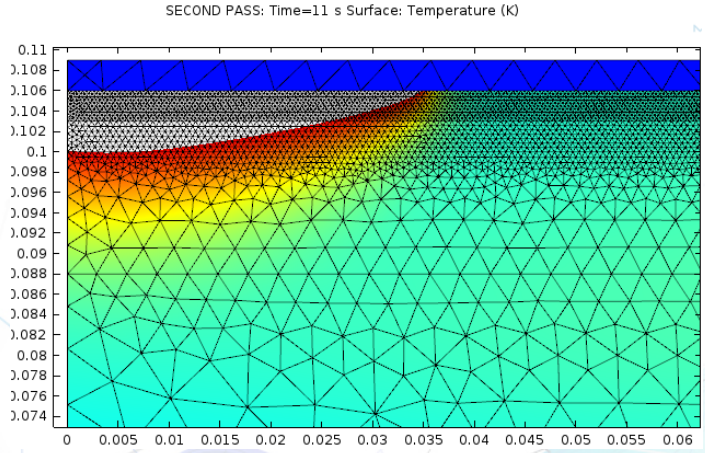
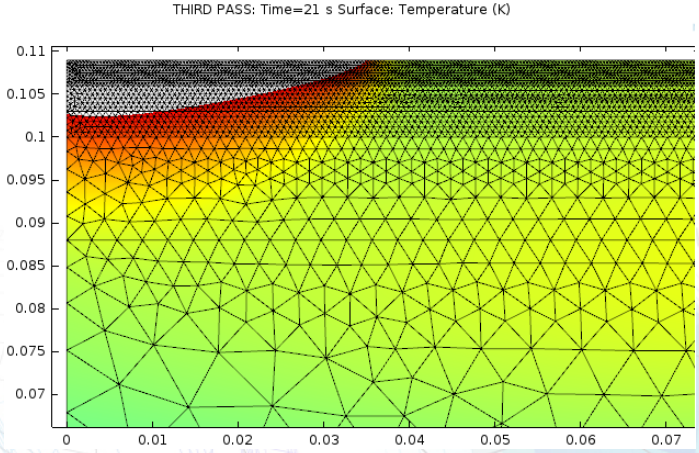
Analysis





Ti-6Al-4V

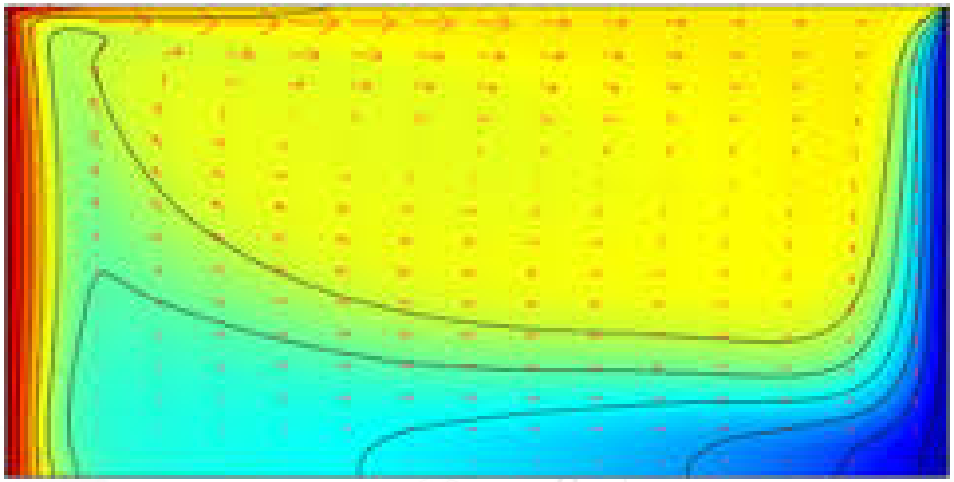




Conditions: Zhiqiang Fan and Frank Liou (2012

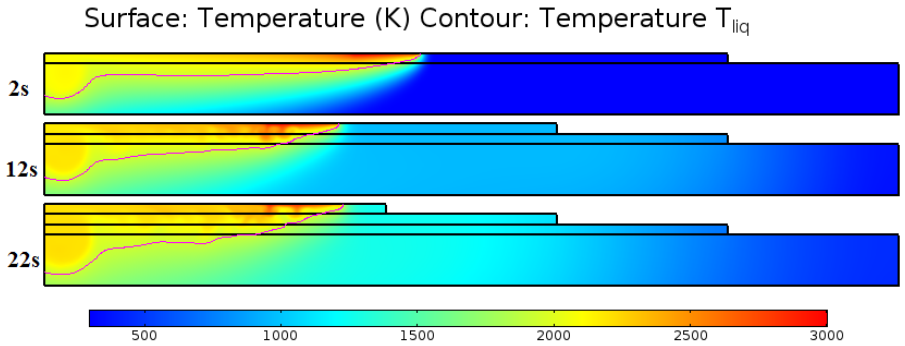
Marangoni Convection

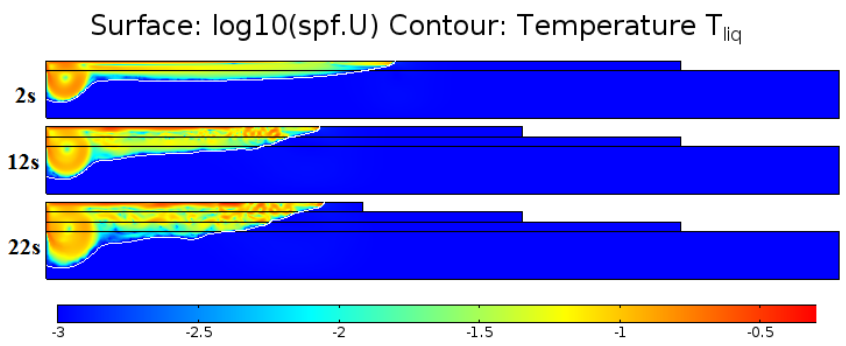
- Surface tension gradient due to:
  - Temperature distribution
  - Species concentration
- Mass transfer away from regions of low surface tension

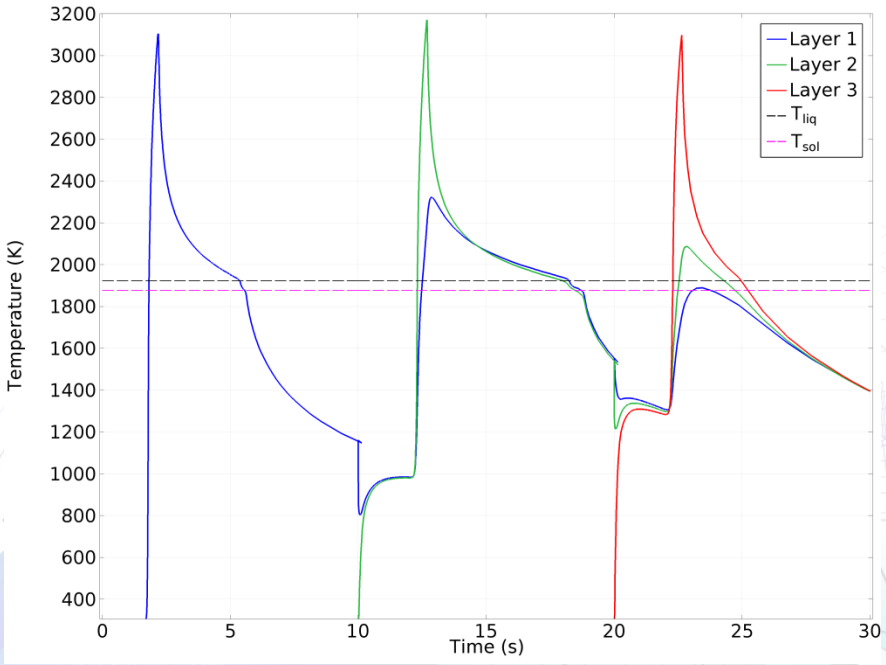


Temperature/Flow Transient

Including Marangoni Effect







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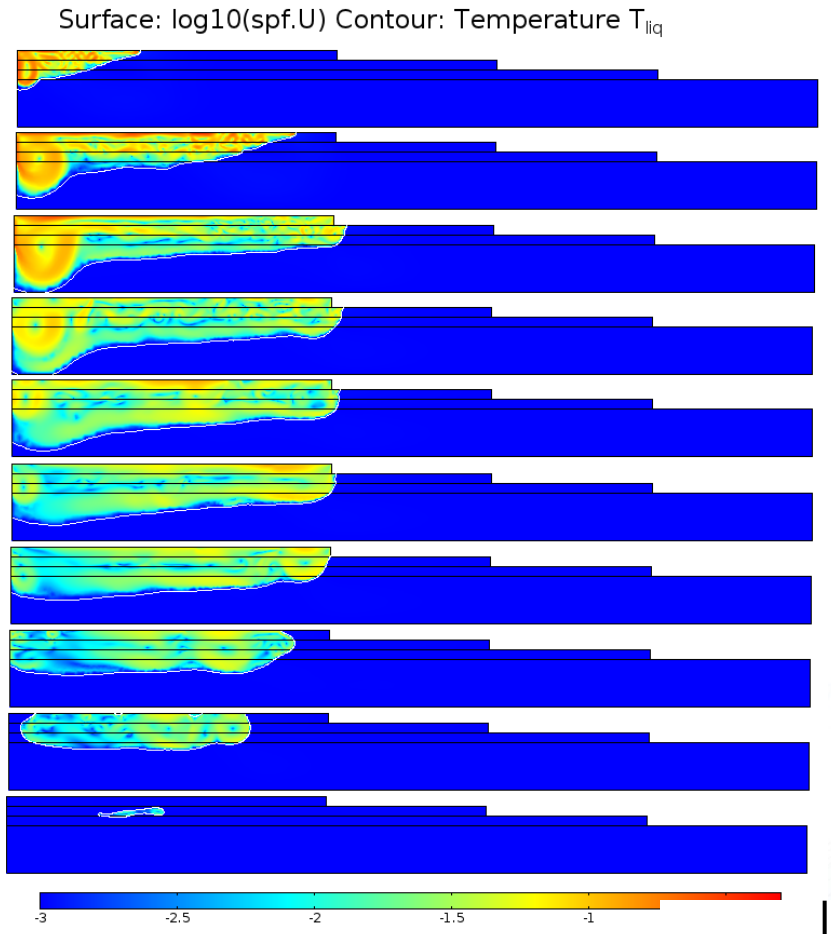
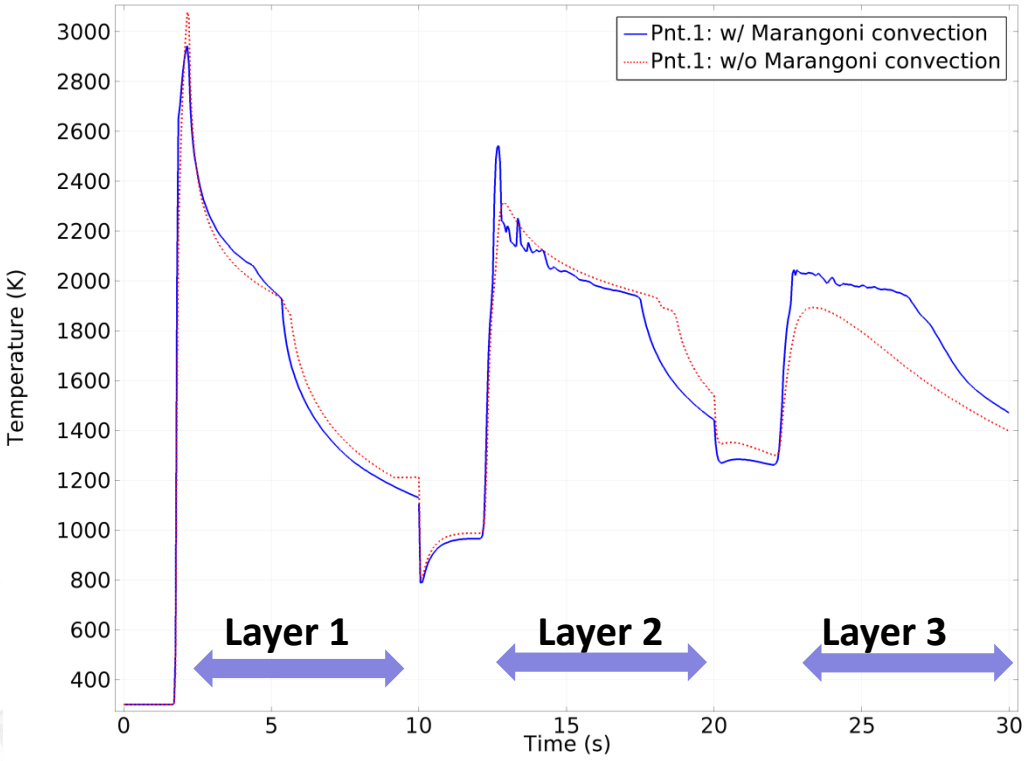
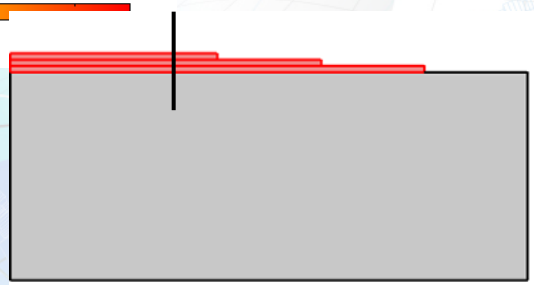
Influence of Marangoni Effect



Temperature on layer 1





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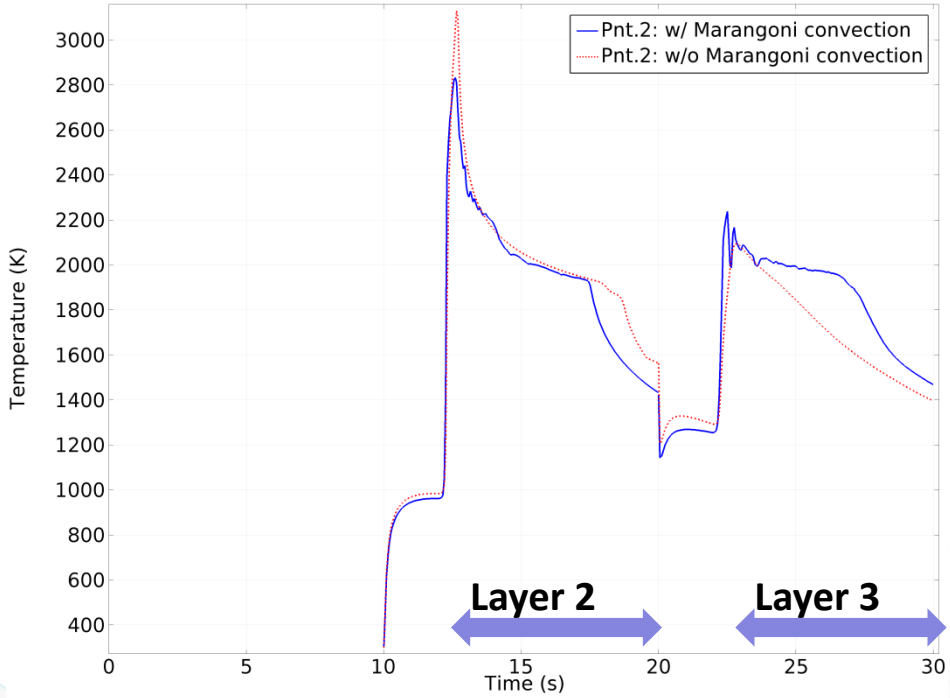
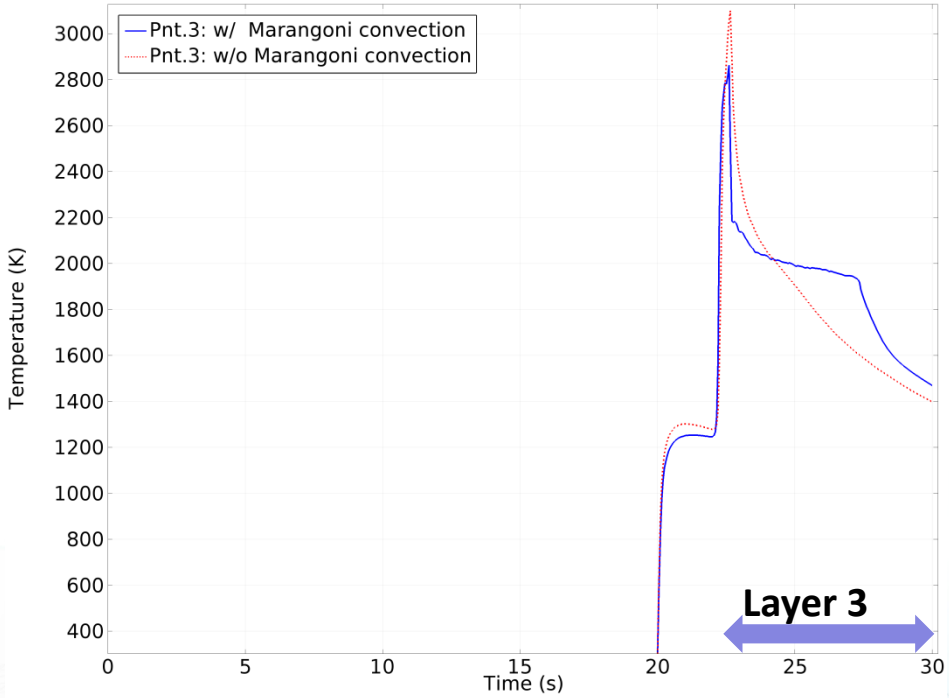
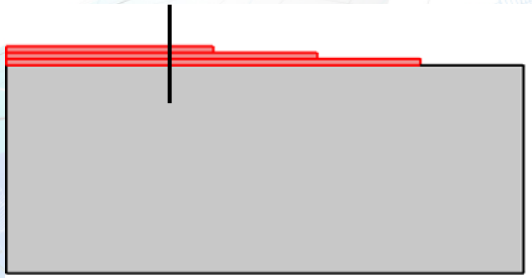
Influence of Marangoni Effect

Temperature on layer 2



Temperature on layer 3





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Conclusions

- **Marangoni effect important for local temperature distribution close to molten metal pool**
- **Marangoni induced convection is significantly reduced away from molten metal pool**
- **For complex components containing multiple layers the effect is minimal**