Early Stage Melt Ejection in Laser Percussion Drilling

Presenter:
Harini Patlolla

Co-authors:
Profs. Tom A. Eppes & Ivana Milanovic
University of Hartford, USA

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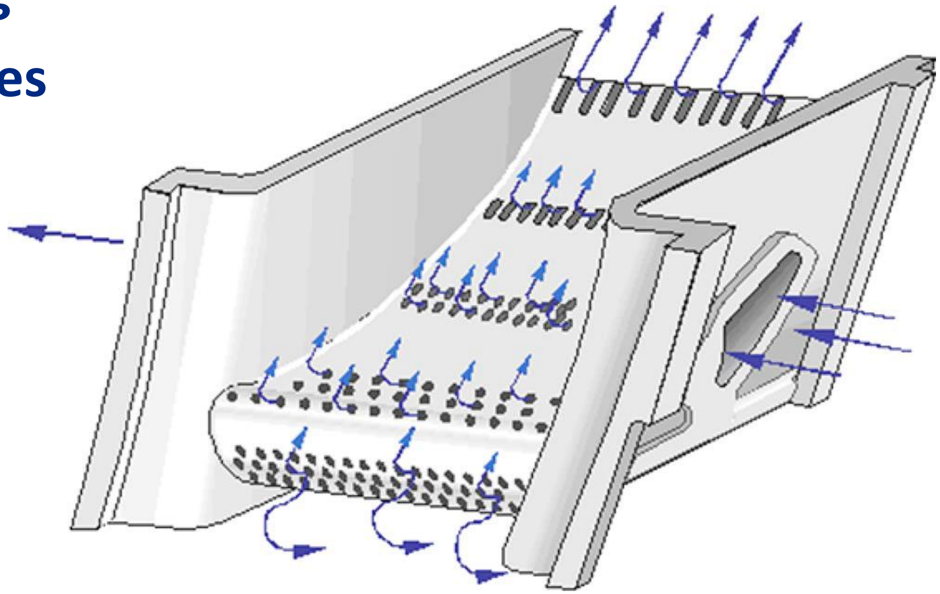
Project Motivation

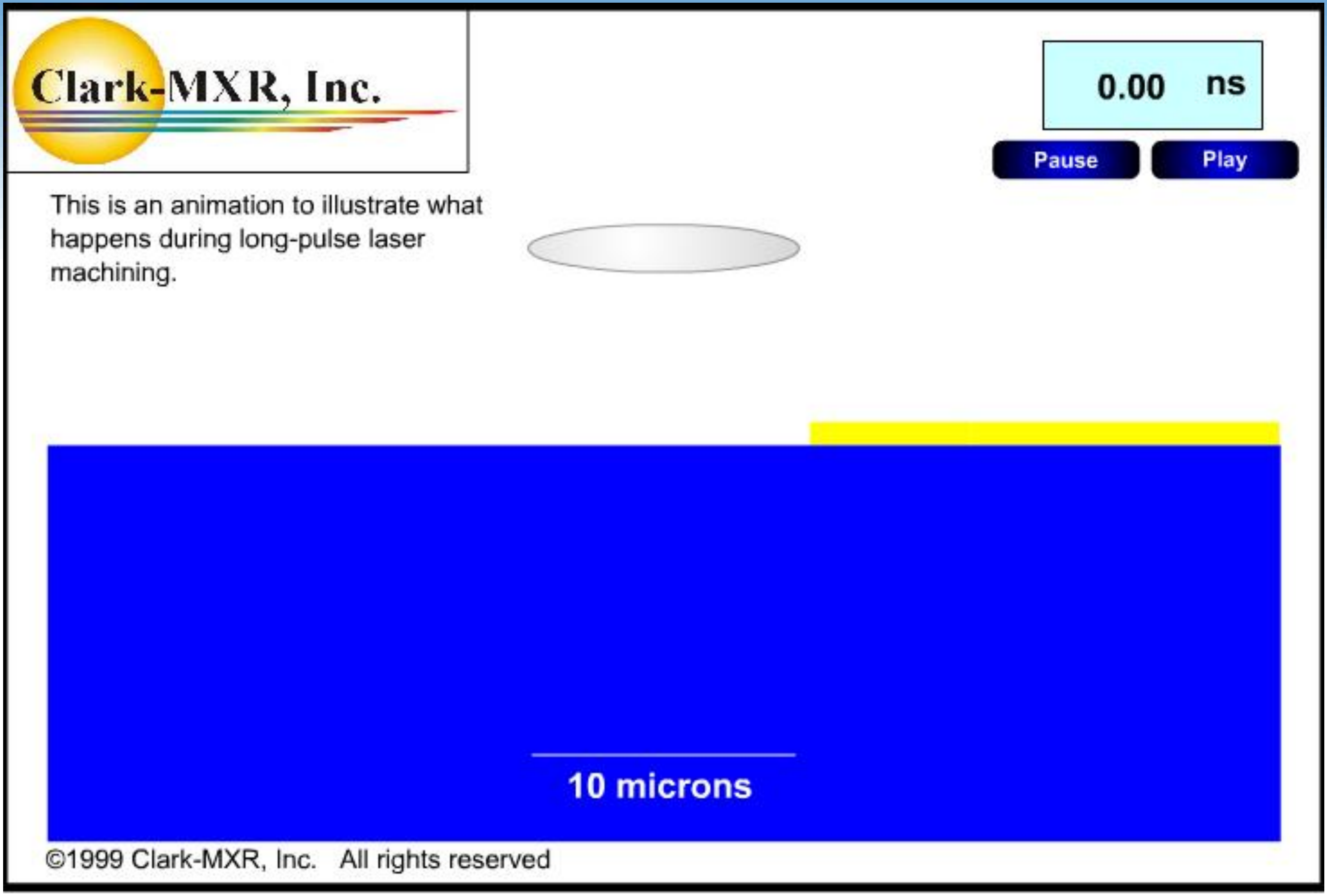
- Reduce manufacturing costs of turbomachinery
- Create more consistent hole quality
- Better understand metallurgical side-effects
- Develop methods to produce shaped holes
- 3D multiphysics model?

Example: Turbine Blade Cooling Holes

- Each contains interior serpentine channels
- Allows surface film cooling
- Requires thousands of holes

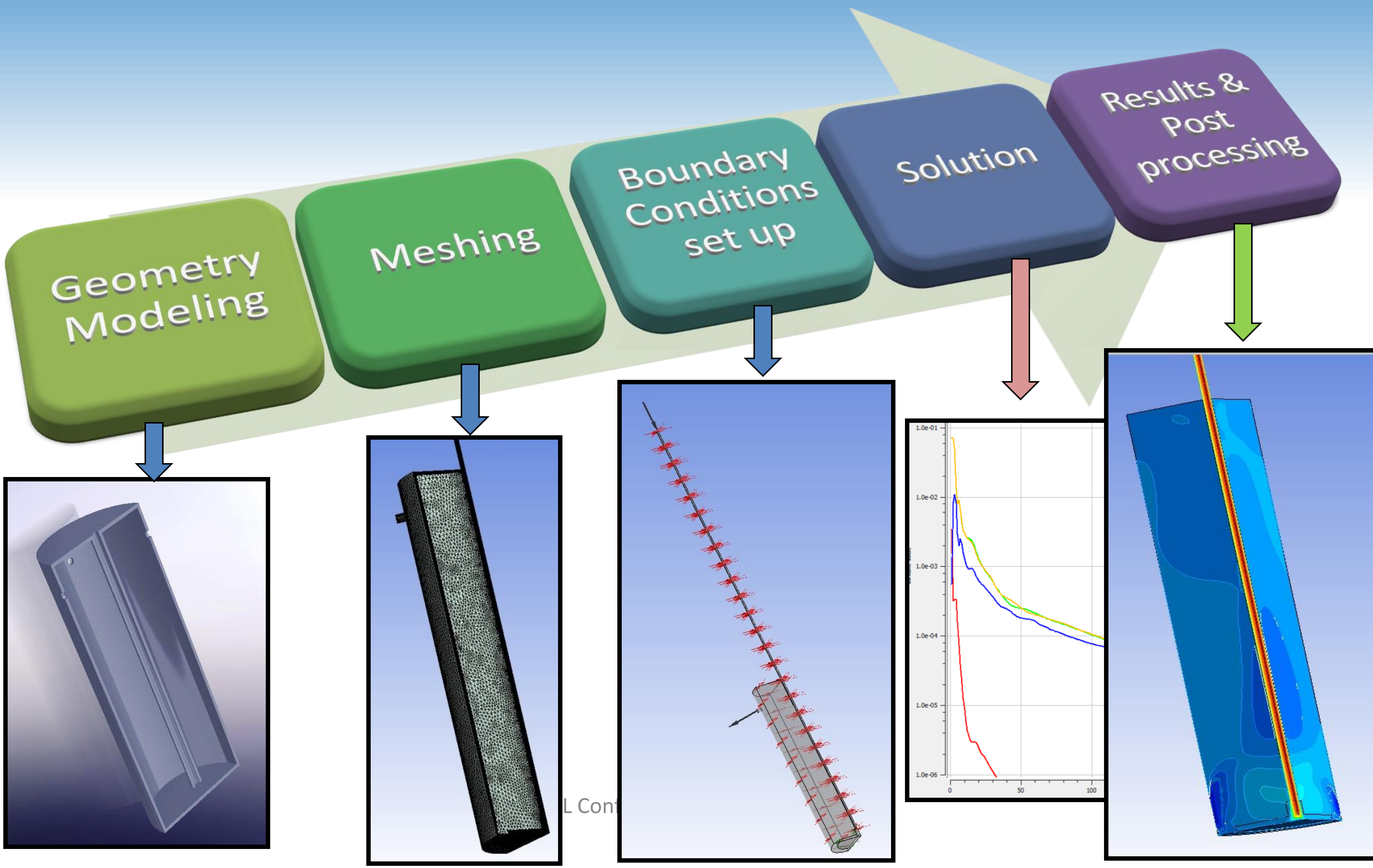


Laser Percussion Drilling



K. H. Leong, "Evolving laser processing applications," *ICALEO Conference Proceedings* ICALEO, Jacksonville, FL, 2003.

Multiphysics Modeling Procedure



Non-isothermal Flow in Fluids

$$\rho \frac{\partial u}{\partial t} + \rho(u \cdot \nabla)u = \nabla \cdot [-pI + \mu(\nabla u + (\nabla u)' - \frac{2}{3}\mu(\nabla \cdot u)I] + F$$

$$\rho C_p \frac{\partial T}{\partial t} + \rho C_p u \nabla T = \nabla \cdot (k \nabla T) + Q$$

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho u) = 0$$

where
u = velocity vector (m/s)
p = pressure (Pa)
ρ = density (kg/m^3)
μ = dynamic viscosity (Pas)
F = body force (gravity) (N/m^3)
C_p = specific heat (J/kgK)
T = absolute temperature (K)
k = thermal conductivity
Q = incident heat source (W/m^2)

Physical Dimensions & Mesh

Statistics

Complete mesh

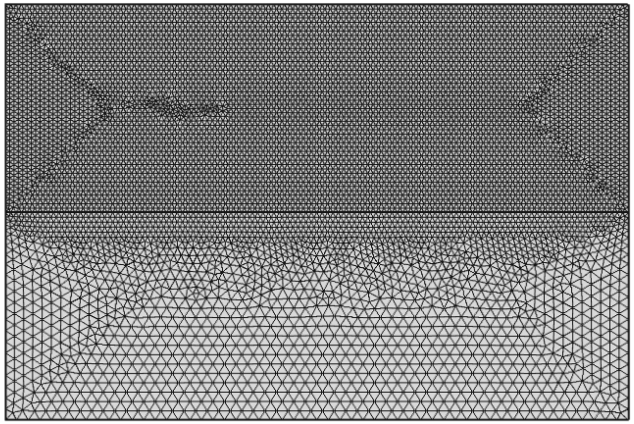
Element type: All elements

Triangular elements: 15214
Edge elements: 406
Vertex elements: 6

Domain element statistics

Number of elements: 15214
Minimum element quality: 0.7526
Average element quality: 0.9903
Element area ratio: 0.06944
Mesh area: 54 mm^2
Maximum growth rate: 1.835
Average growth rate: 1.051

Region	Width (mm)	Height (mm)
Air	3	6
Target	3	3



Material Properties (Iron)

Parameter	Value
Thermal conductivity (W/mK)	76.2
Ratio of specific heat	1.4
Initial temperature (K)	1,000
Melting temperature (K)	1,808
Vaporization temperature (K)	3,100
Phase change transition range (K)	50
Latent heat of melt (kJ/kg)	247
Latent heat of vaporization (kJ/kg)	6088

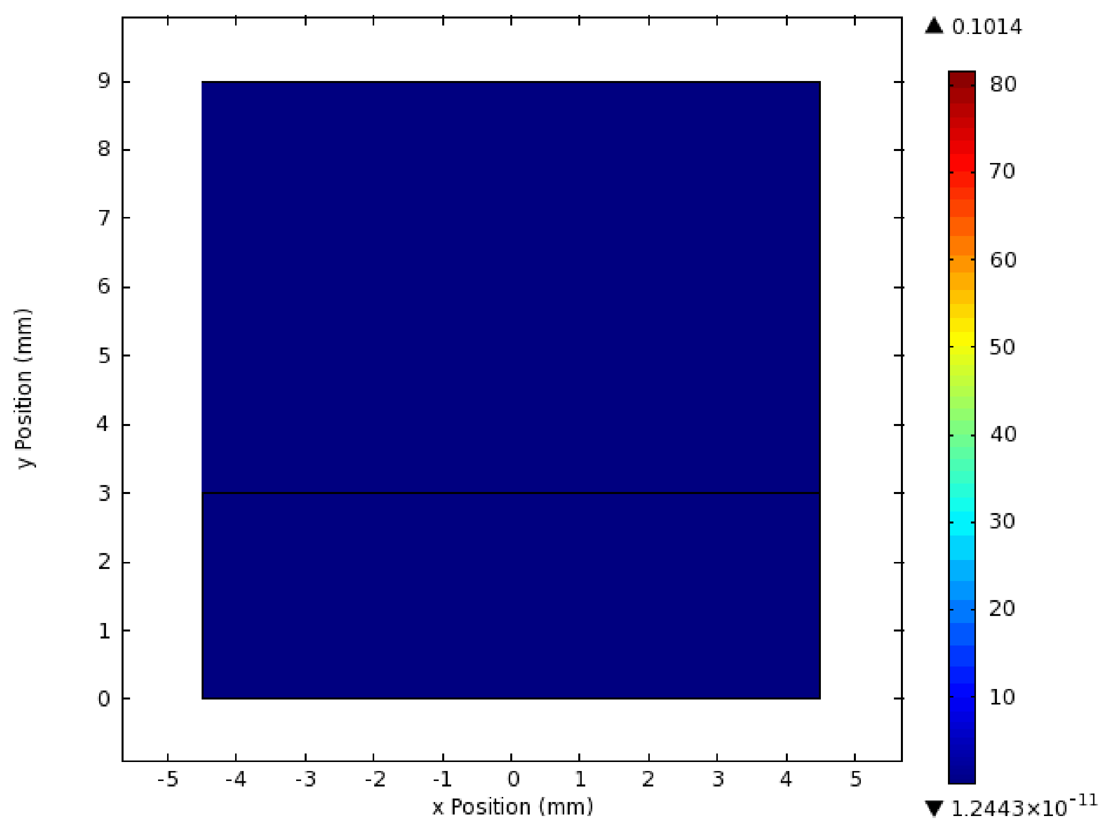
Additional Material Properties (Iron)

Parameter	Value
Dynamic Viscosity (Pa-s)	
- Solid	1
- Liquid, Gas	0.006
Density (kg/m^3)	
- Solid, Liquid	7,870
- Gas	$p/(R_{spec}*T)$

Heaviside functions used to transition properties from solid → liquid → gas.

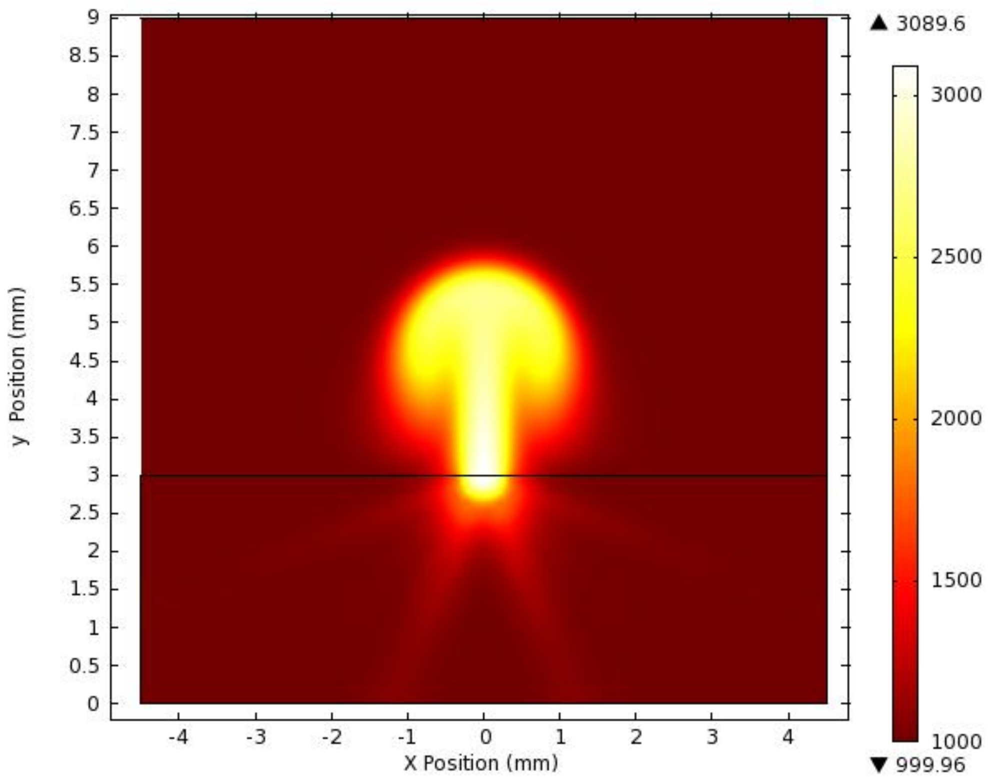
Velocity vs. Time

- **Nd:YAG laser**
- **800 W output power**
- **1,000K ambient**
- **Normal incidence**
- **Gaussian beam profile**
- **Parallel polarization**



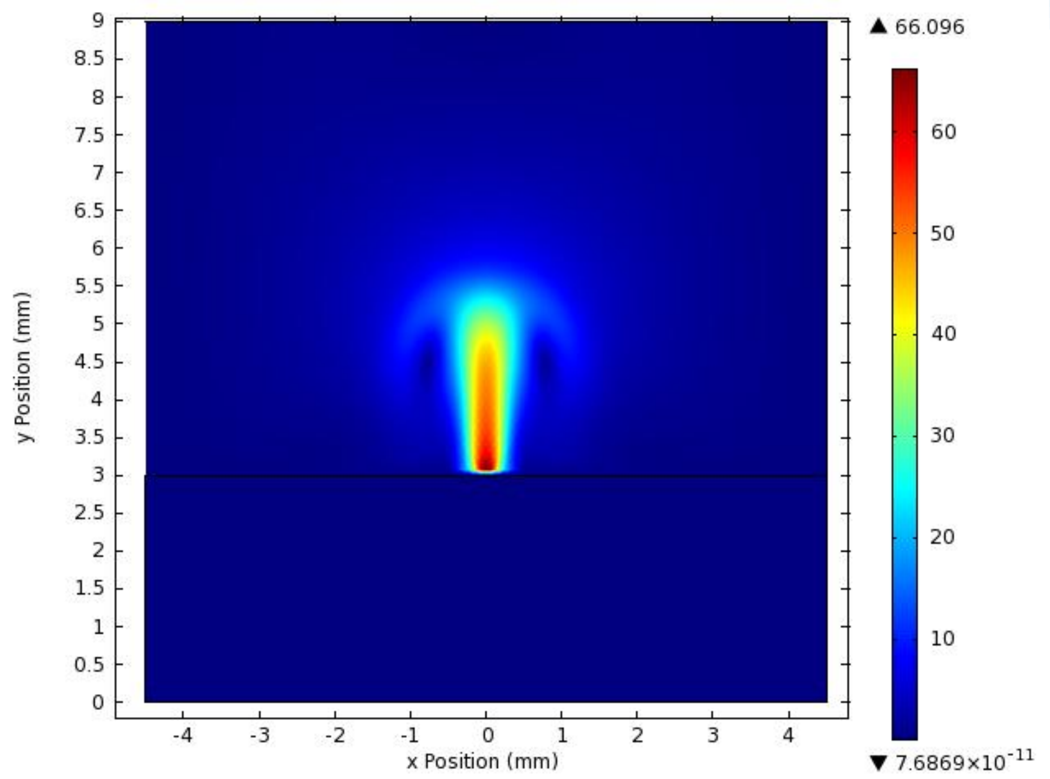
Surface Temperature Distribution (3.2 msec)

Maximum temperature = 3,089K



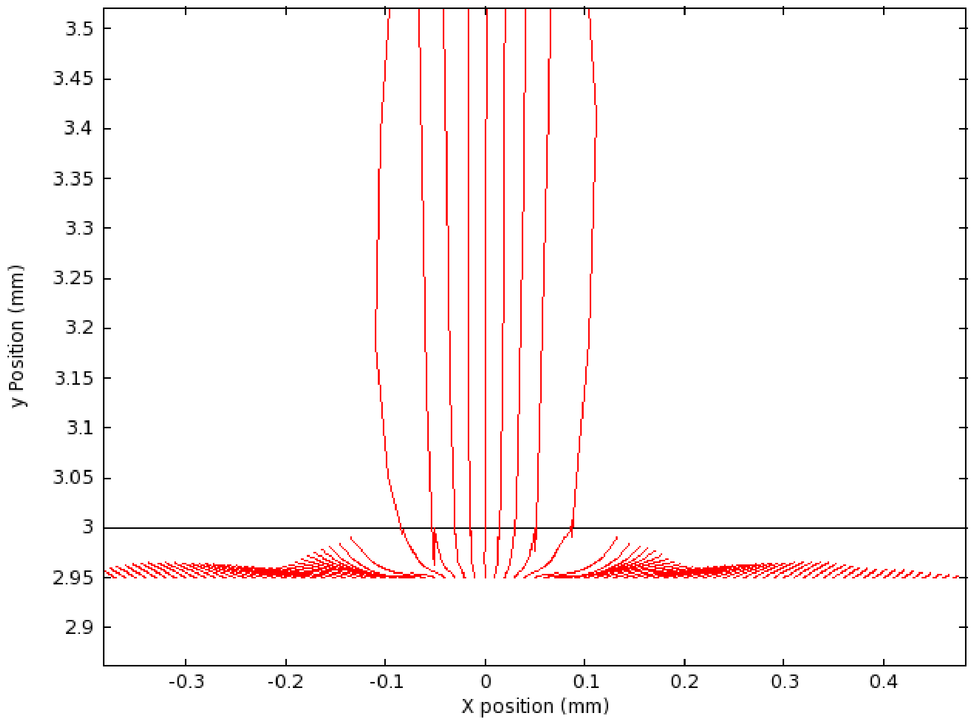
Total Velocity (3.2 msec)

Maximum velocity = 66 m/s

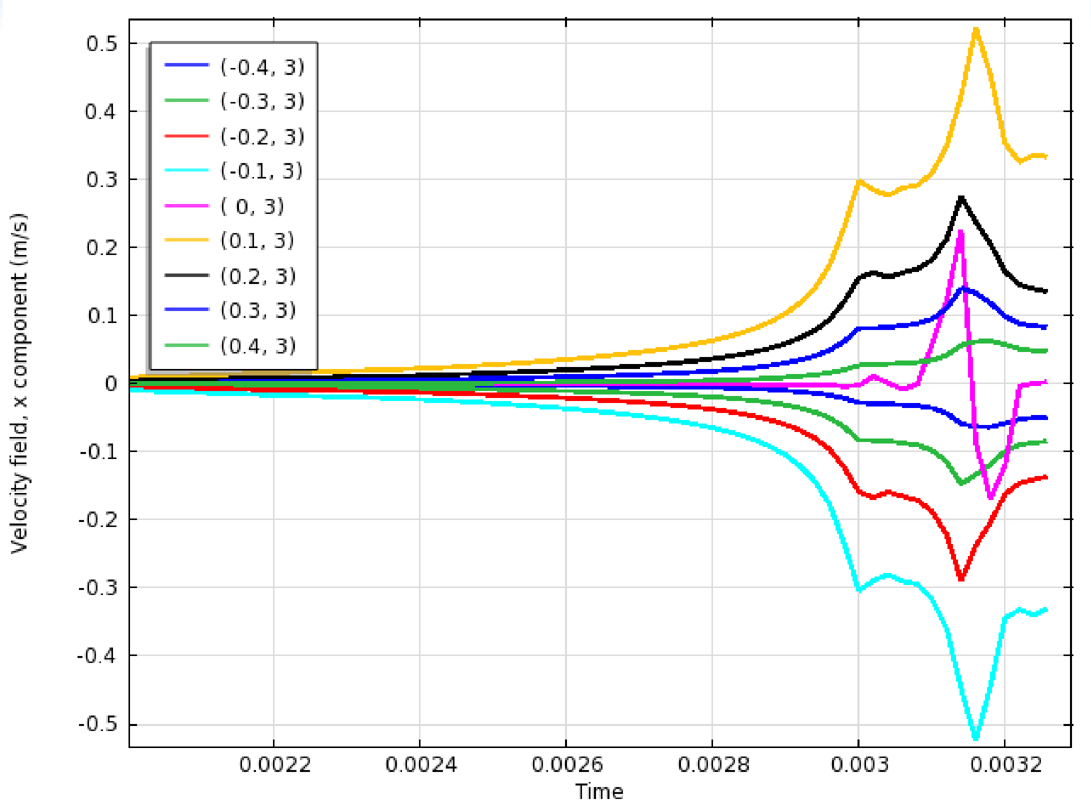


Particle Flow From Target Interior (3.2 msec)

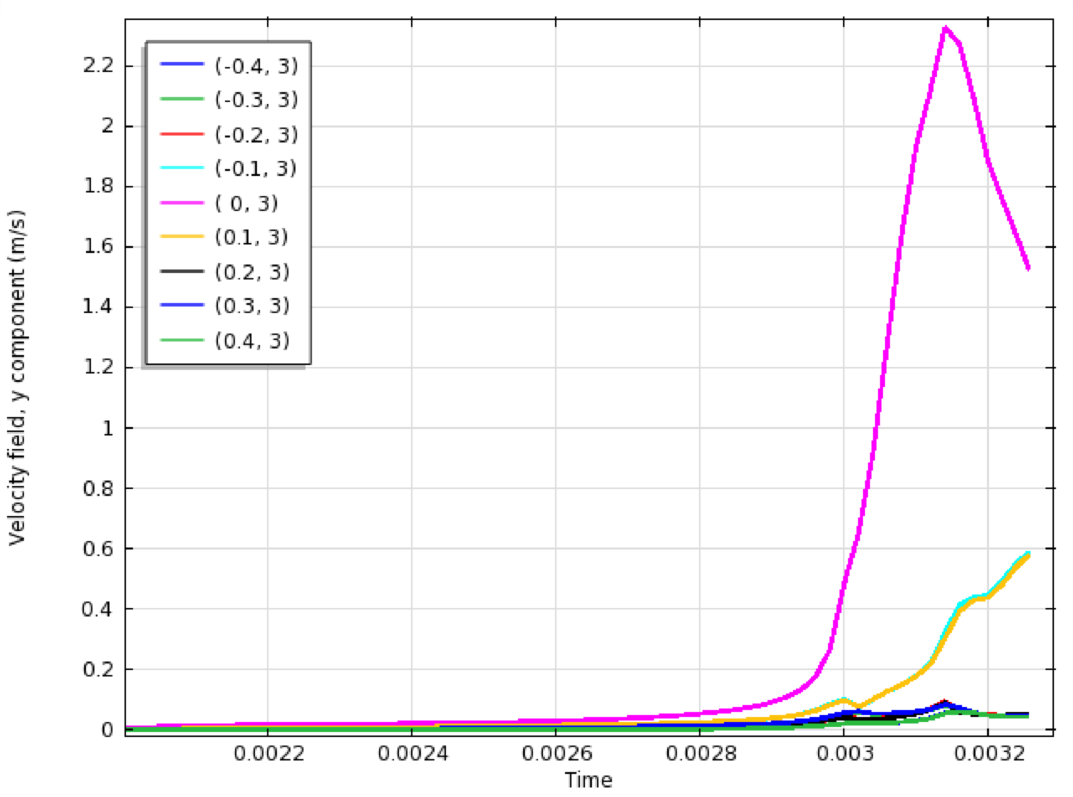
50 µm below target's surface



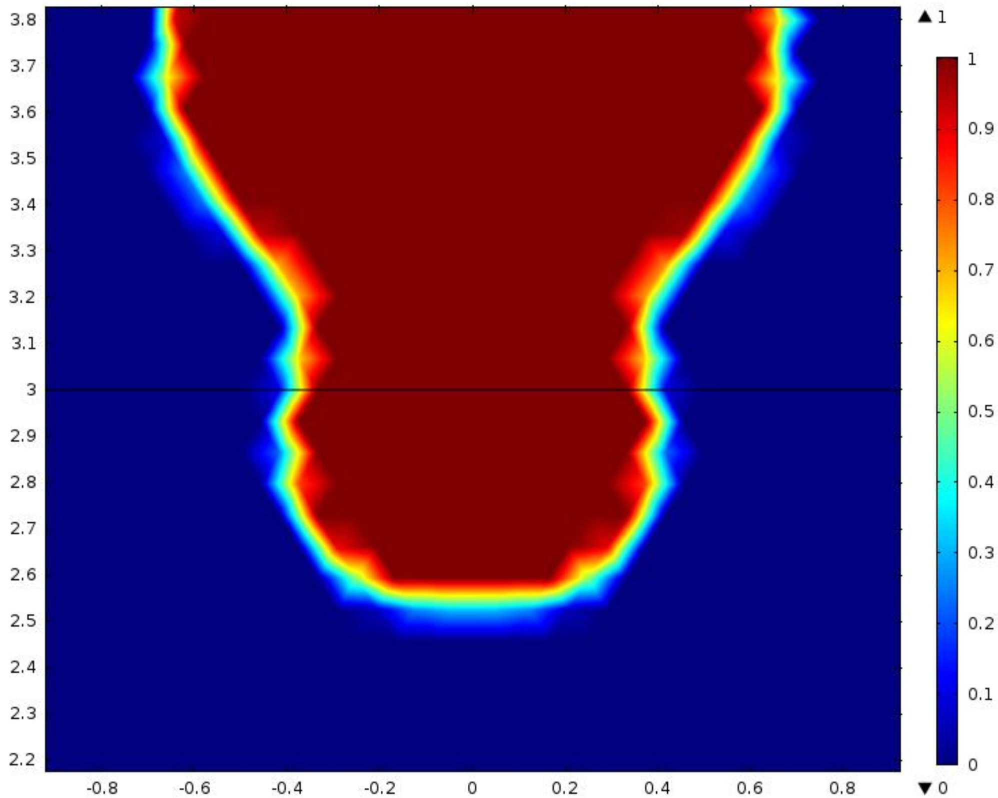
Horizontal Motion (3.2 msec)



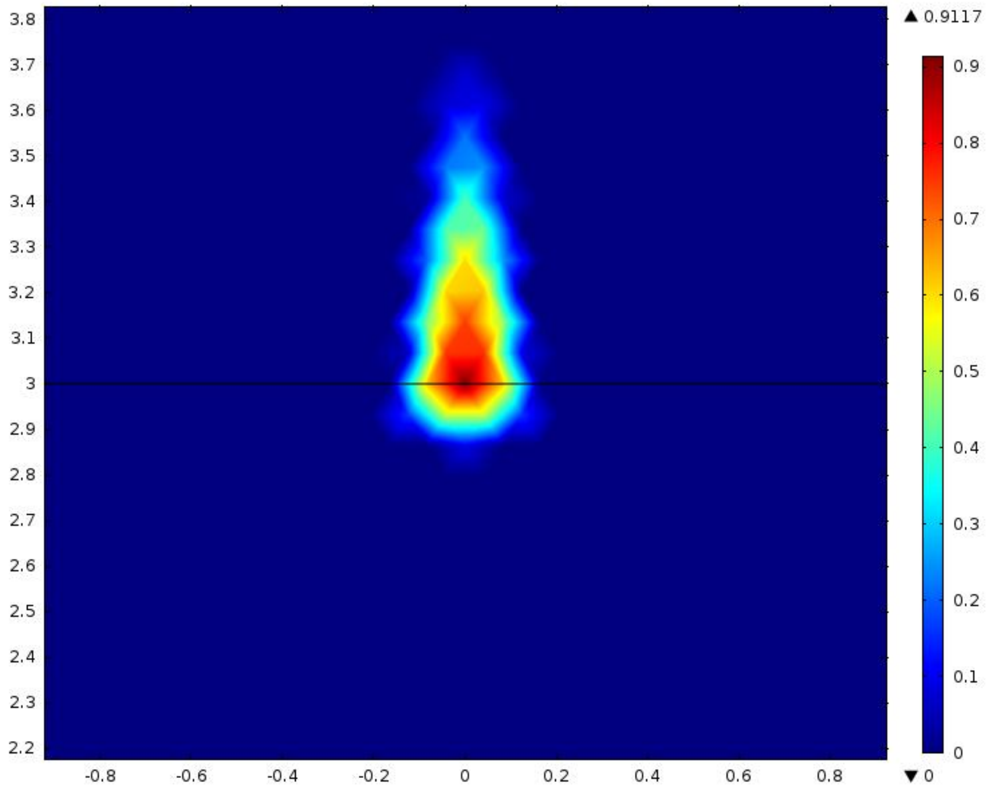
Vertical Motion (3.2 msec)



Liquid Fraction (3.2 msec)



Vapor Fraction (3.2 msec)



Conclusions

- Early stages of melt and evaporation investigated
- Phase transitions created with temperature dependent properties
- Time dependent studies performed for iron as the target
- Surface temperature and velocity fields computed
- Early stage target material flows illustrated
- Target liquid & vapor fractions identified

Thanks!

Questions? Comments? Feedback?