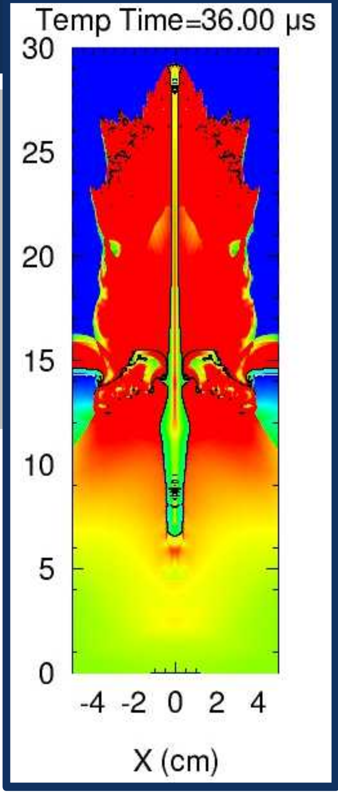
SAND2017-3959C

Characterizing In-Flight Temperature of Shaped Charge Penetrators in CTH



Presenter: Peter Sable

Authors: Nathaniel Helminiak, Arne Gullerud, Eric Harstad, Jeromy Hollenshead, Gene Hertel

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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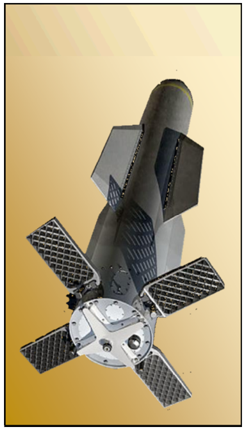
Agenda

- Motivation & Objective
- Experimental Premise
- Computational Setup
- Example Simulation
- Temperature Results
- Comparison of Jet Structure
- Additional Factors
- EFP Study
- Concluding Remarks
- Acknowledgements

A Quick Overview of Penetrators

- Penetrators [shown on the right] utilize a brute force application of kinetic energy to break and flow through a target.
- A brute force approach is to utilize massive amount of ordinance.
- More precise application of momentum penetration can be achieved via a long rod type penetrator
- Explosively formed penetrators and shape charges allow for a smaller initial form factor and use the same explosive charge to both propel and shape liners to the desired penetrating shape
- A typical EFP requires high amounts of heat and pressure which cause a liner to invert and collapse to the well known bullet shape

Explosively Formed Penetrator



Massive Ordinance Bomb

Kinetic Energy (Long Rod) Penetrator

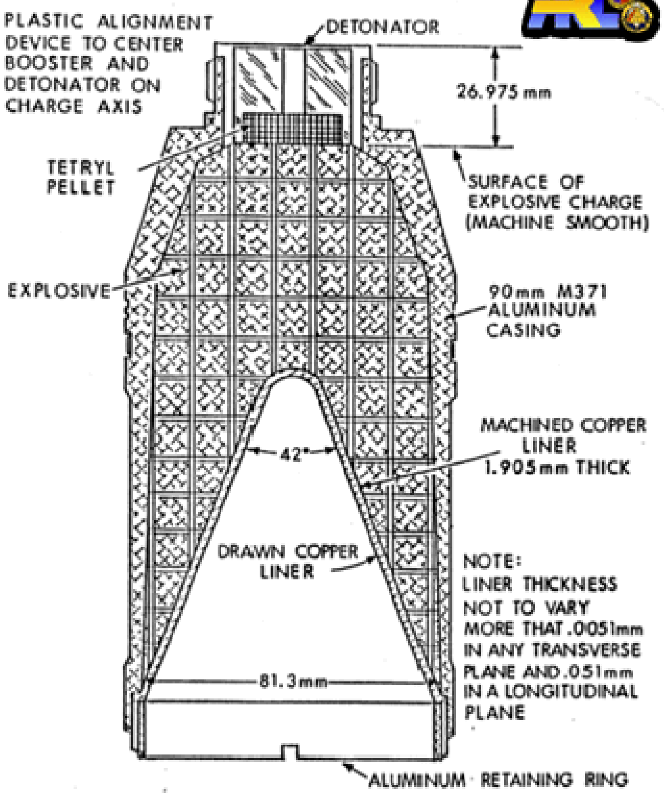
Shaped Charge (Jet)

Motivation & Objective

- Characterization of temperature within hypervelocity projectiles is a must to properly model the physics at play.
  - Shaped Charge Jets
  - Explosively Formed Projectiles

- Novel experimental measurement techniques allow for hypervelocity projectile temperature data.

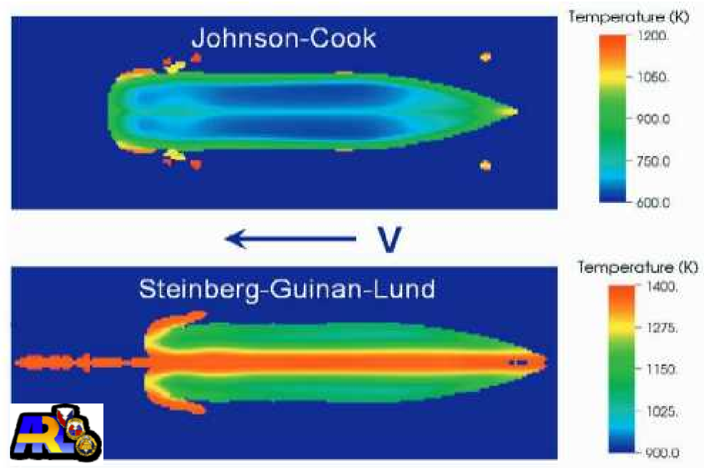
- **Goal:** Use recently acquired data evaluate the accuracy of CTH temperature calculations.

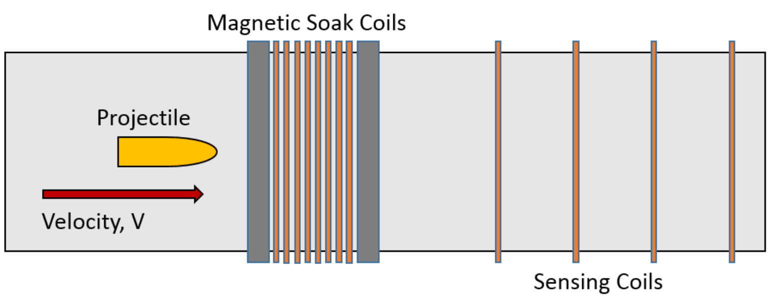


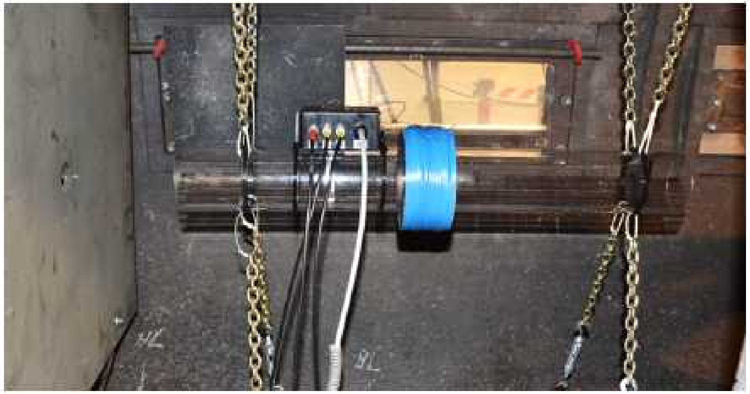
Experimental Premise

- Work done by the Army Research Laboratory experimentally measured temperatures.

- Saturated jet with an EM field. Decay of this field was measured via inductance – yielding conductivity and then temperature.



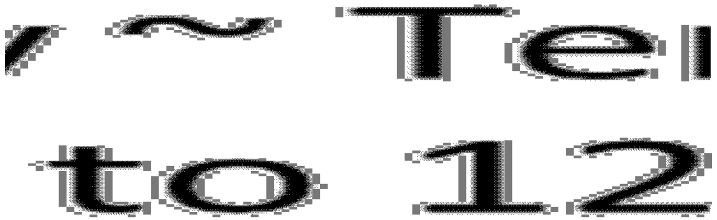




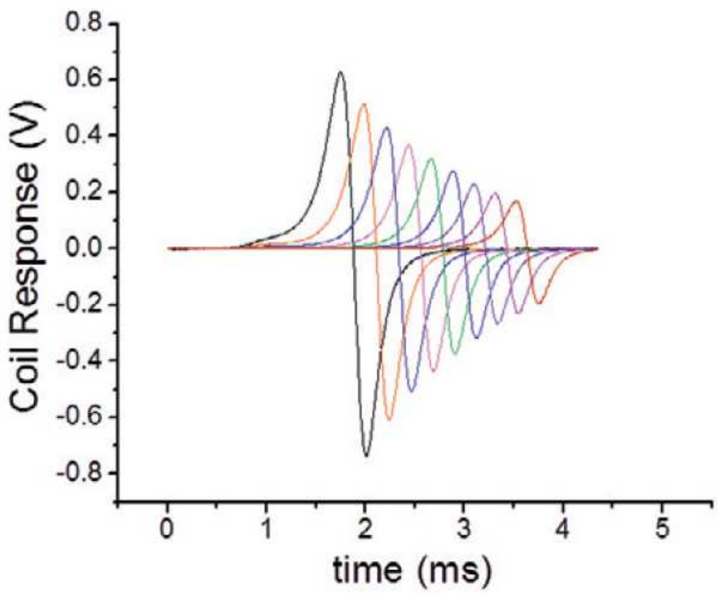
Experimental Premise

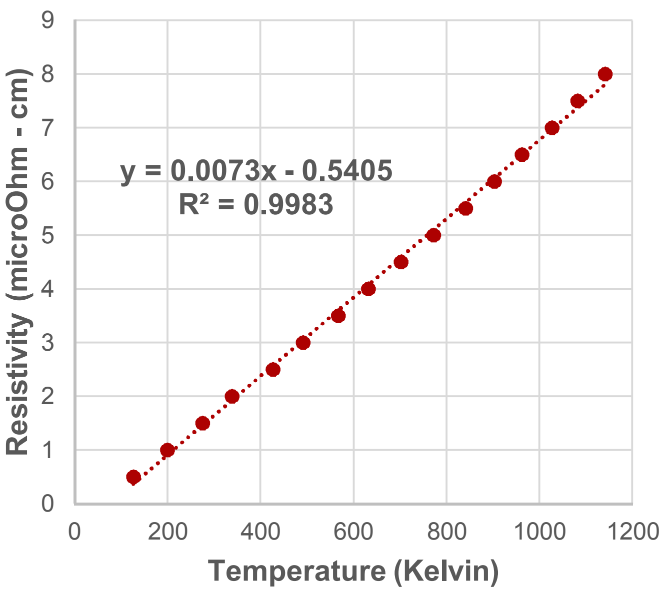
- Decay Time ~ Conductivity

$$\tau = \alpha \sigma_e d^2$$



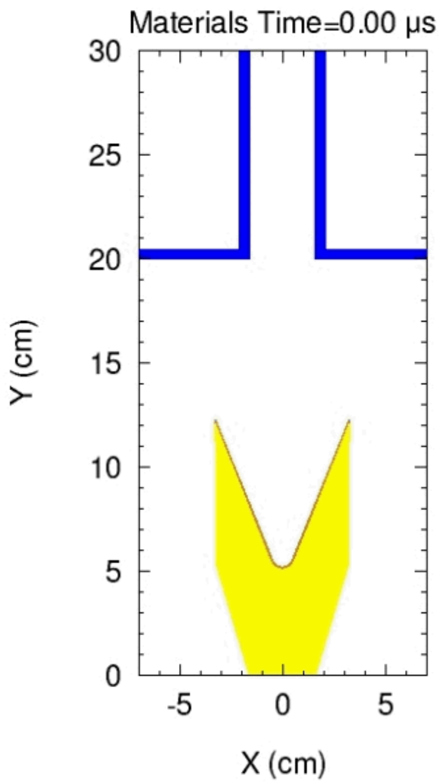
- Conductivity/Resistivity ~ Temp.
(Domenicali – 1961, up to 1200K)





Computational Setup (CTH)

- 2D Cylindrical
- Eq. of State
  - Copper – Sesame
  - LX-14 – JWL
  - Air (opt) - Sesame
- Copper Strength Model
  - Johnson-Cook
  - Steinberg-Guinan-Lund
  - Preston-Tonks-Wallace
  - Mechanical Threshold Stress



- Domain: 5 x 100 cm
- Cell Size: 0.0125 cm
  - 3.2 million total cells
  - 2 hour run time

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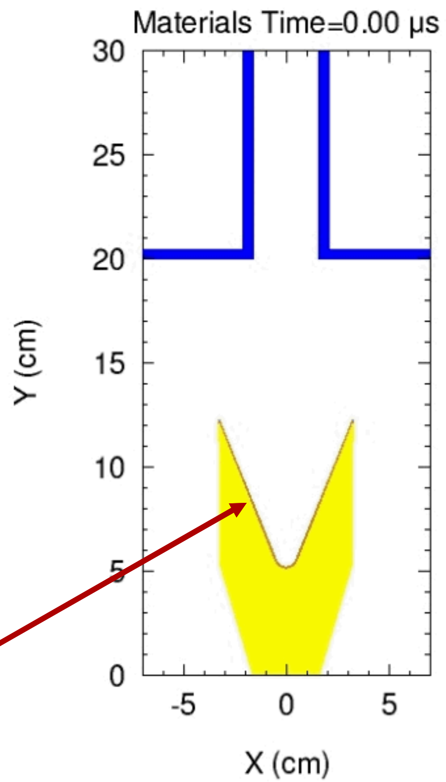

Copper Liner:
- 6.5 cm, diameter
- 1.2 mm, thickness
- 22 degree angle

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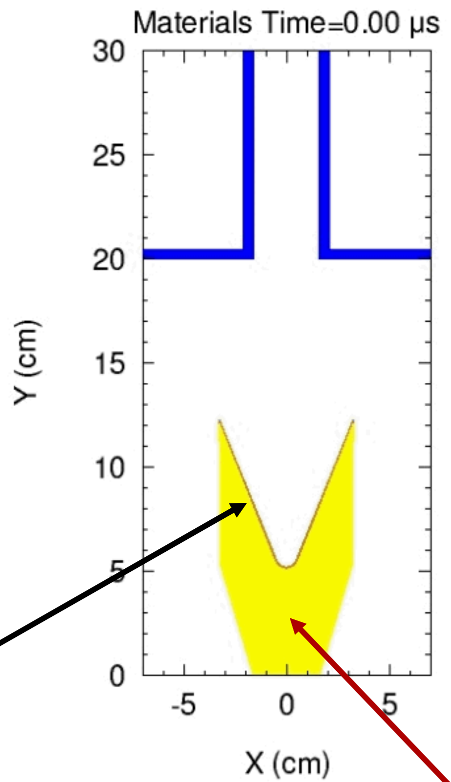

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LX-14 Explosive (Bare) with D = ~8.5 km/s

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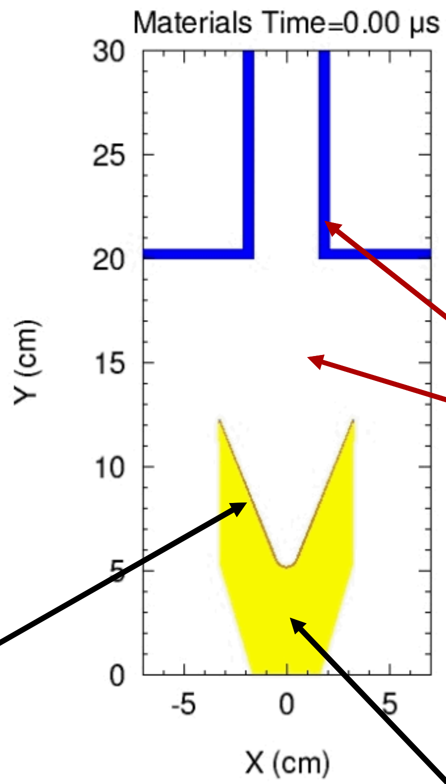

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Experiment Details:
- Polycarb. Housing
- Air v. Vacuum

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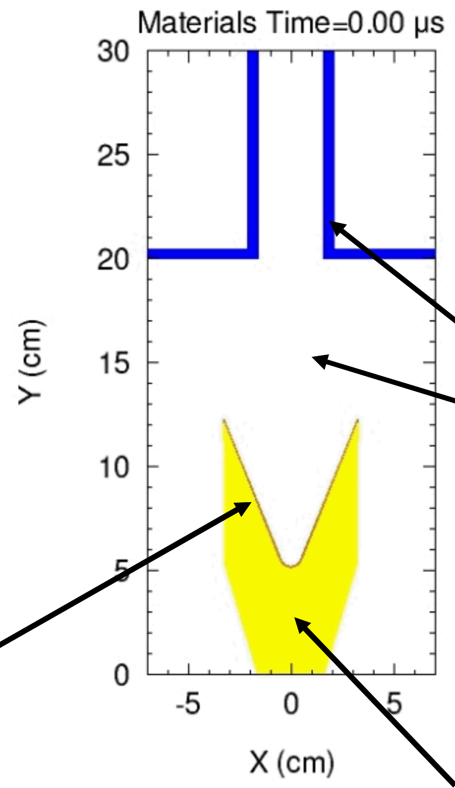

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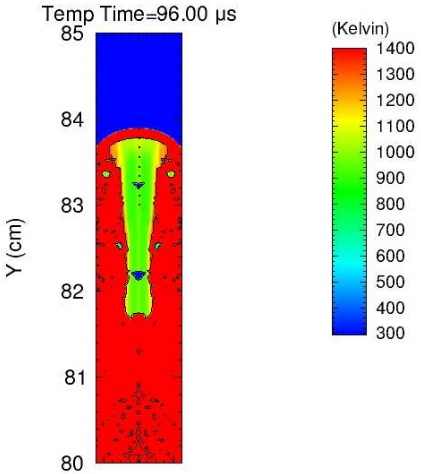
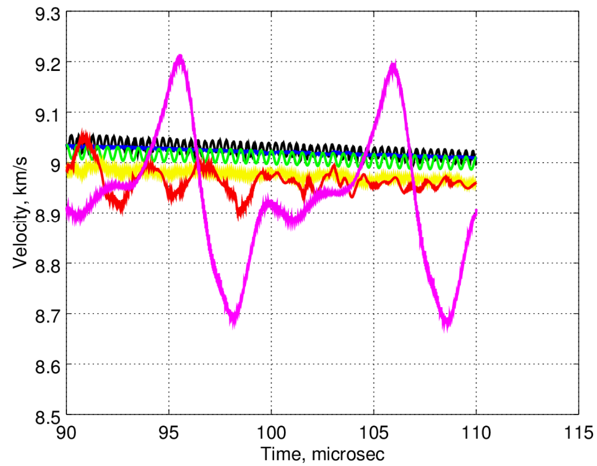
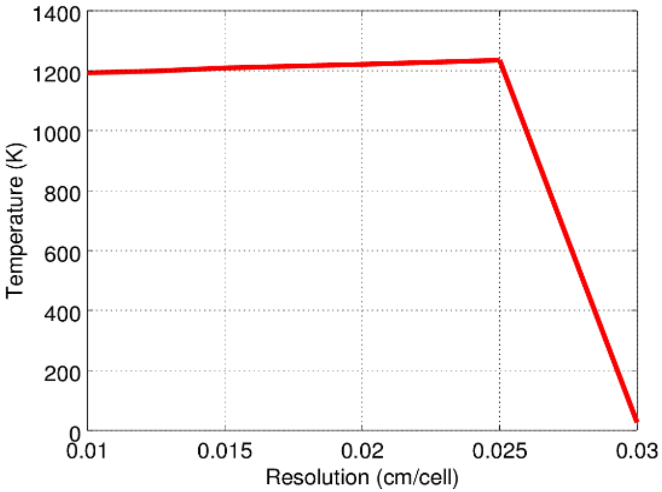
Mesh Resolution







- Cell Size: 0.0125 cm
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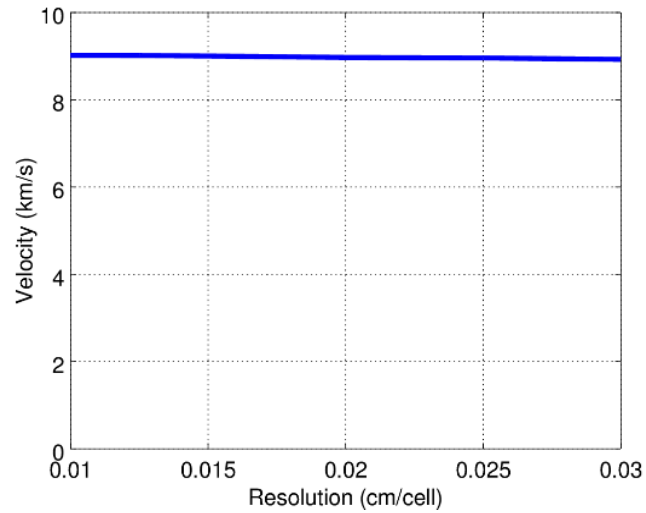
cm/cell
- 0.03
- 0.025
- 0.02
- 0.0125
- 0.01



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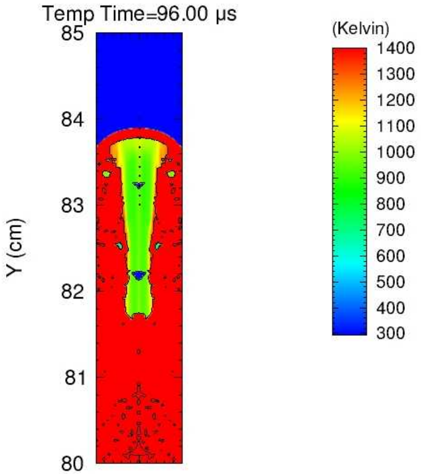
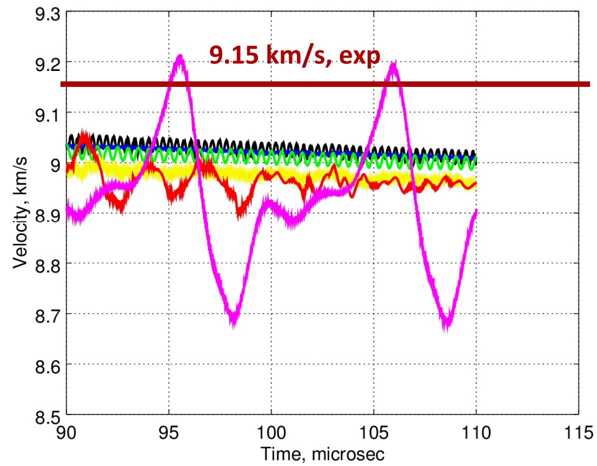
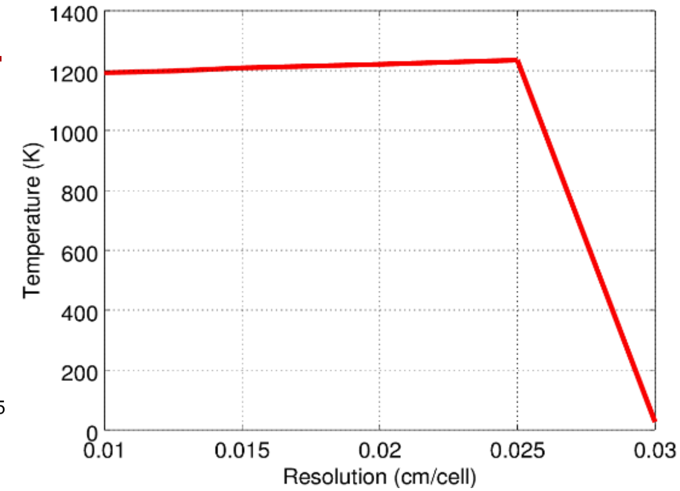
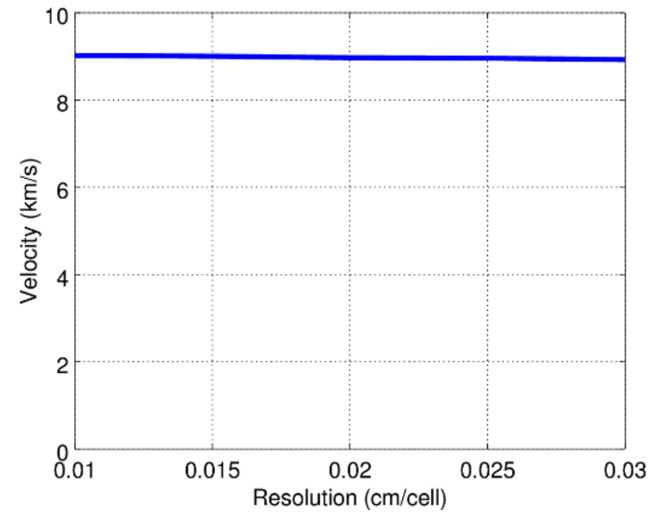




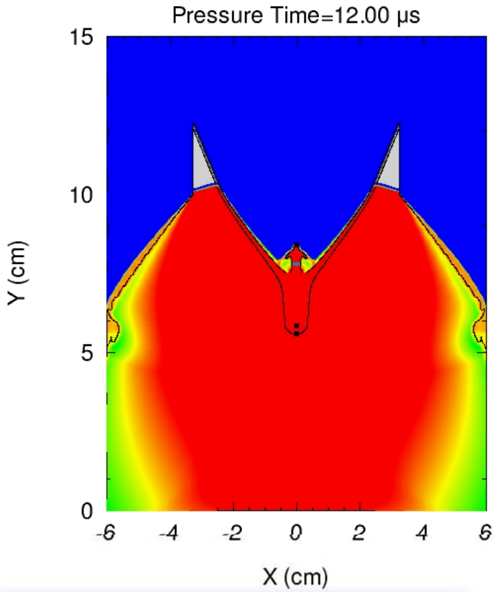


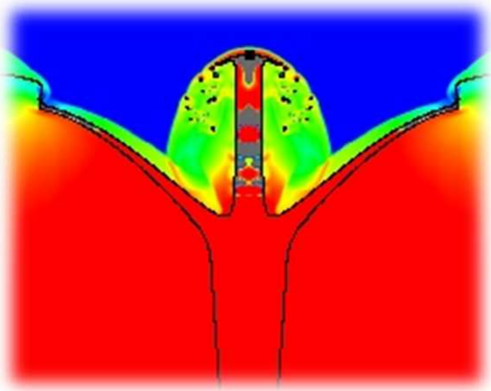
- Cell Size: 0.0125 cm
  - 3.2 million total cells
  - 2 hour run time
  - **Velocity Convergence**
  - **Temperature Convergence**
  - **Comparable to ALEGRA sims**

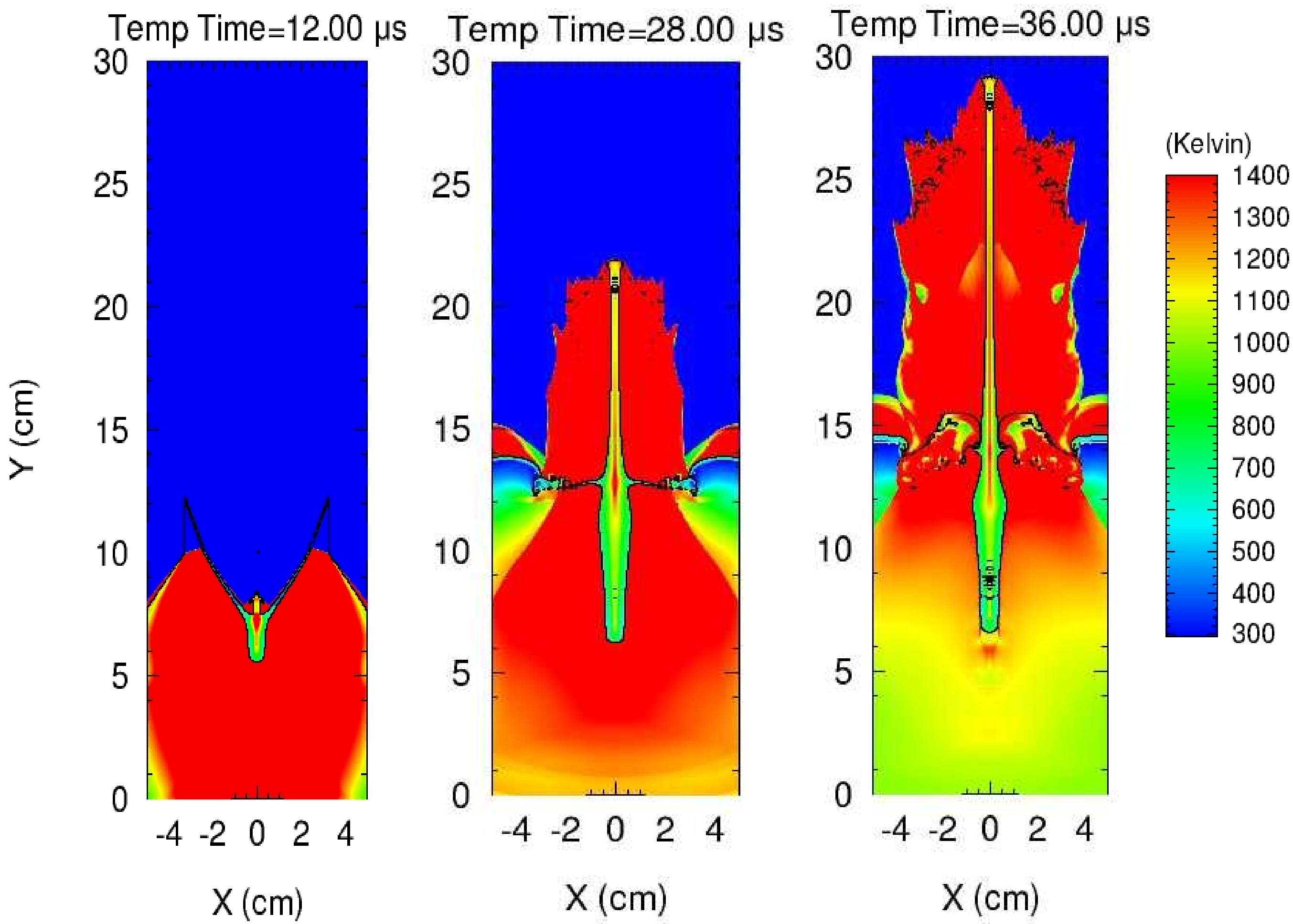
cm/cell
- 0.03
- 0.025
- 0.02
- 0.0125
- 0.01



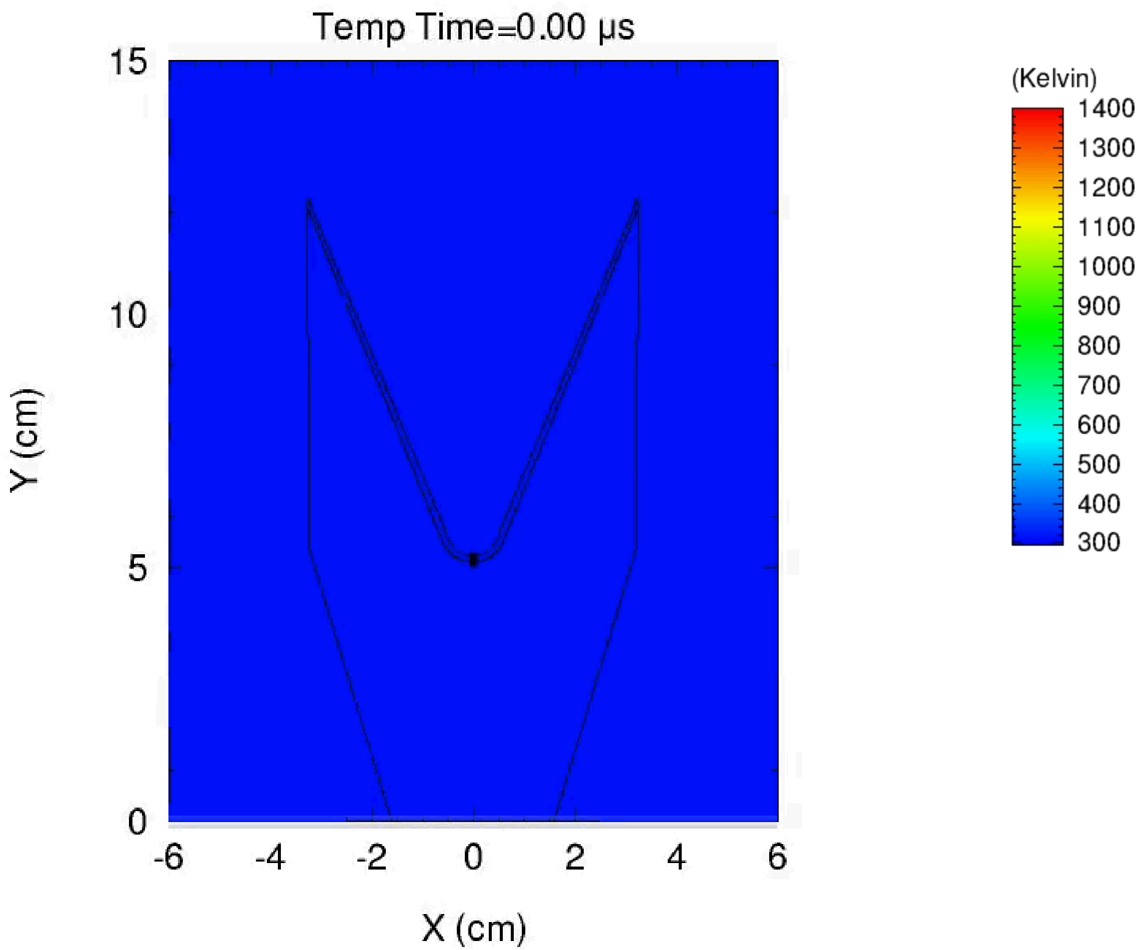
Example Simulation



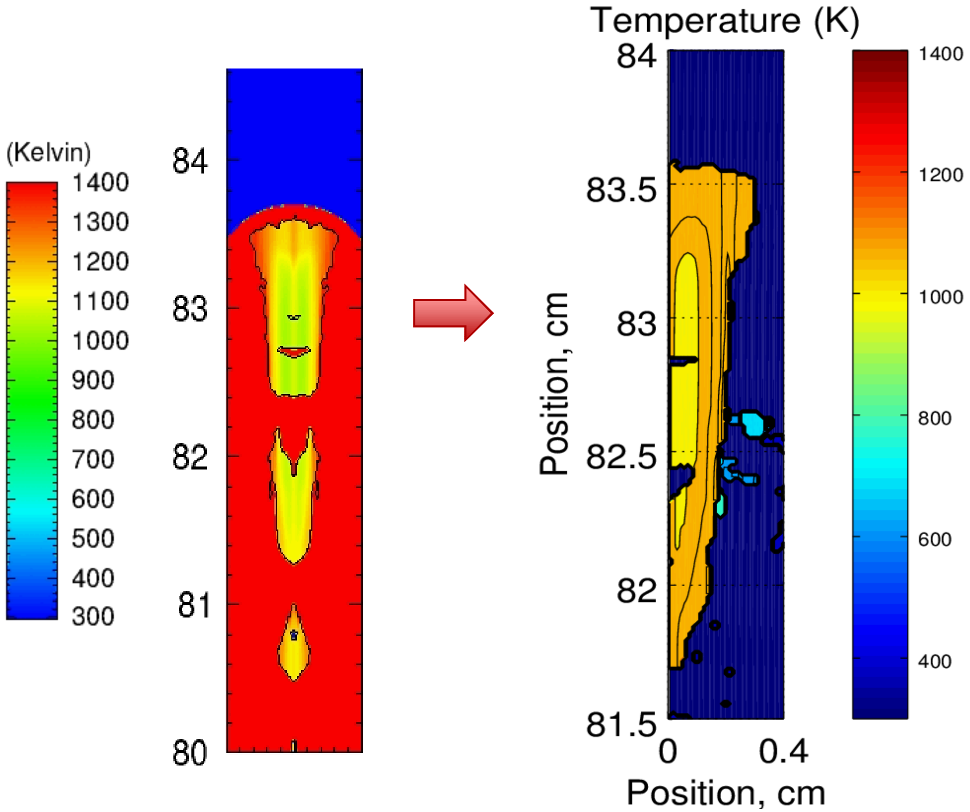




Example Simulation - Videos

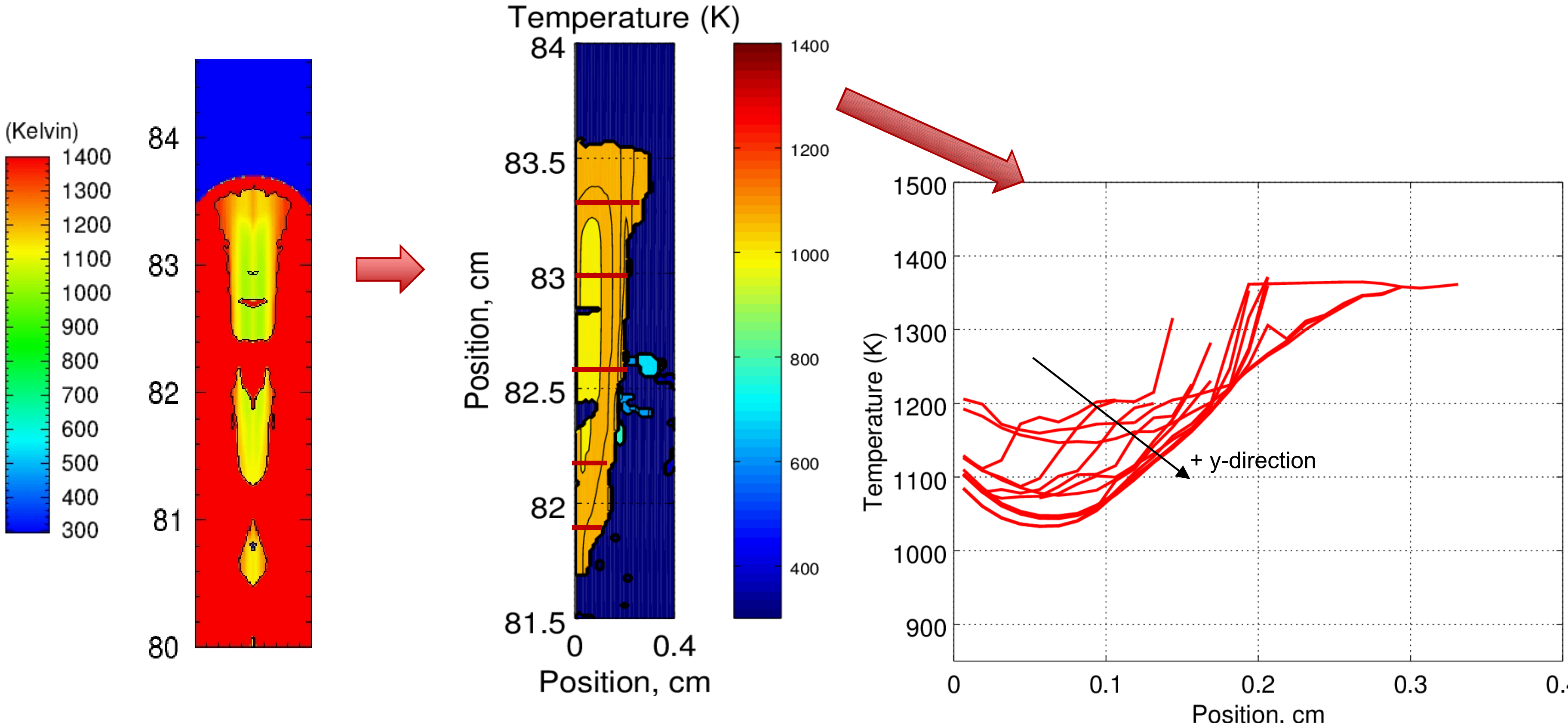


Results - Temperature



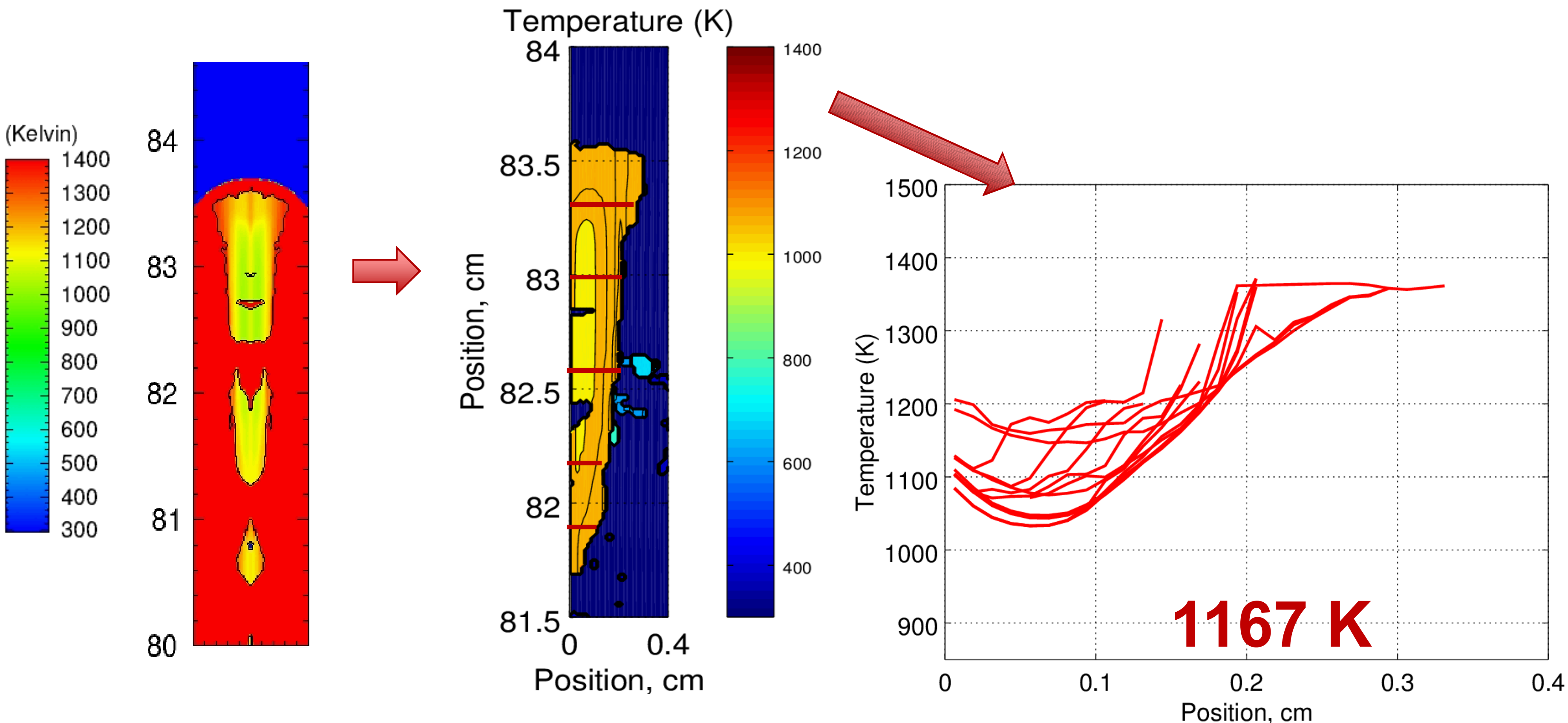
Steinberg-Guinan-Lund

Results - Temperature



Steinberg-Guinan-Lund

Results - Temperature



Steinberg-Guinan-Lund

Results - Temperature

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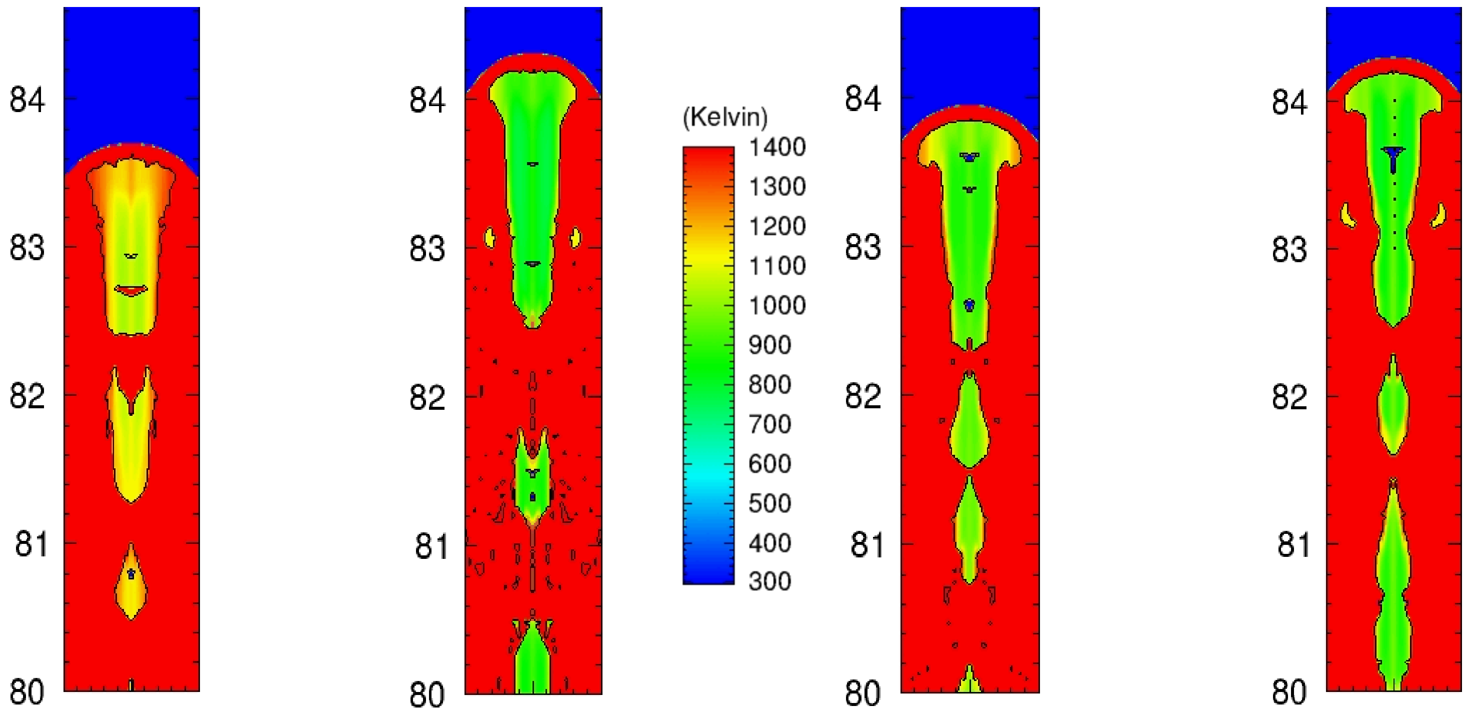

Steinberg-Guinan-Lund

Johnson-Cook

Preston-Tonks-Wallace

Mechanical Threshold Stress

Results - Temperature

Software	Strength Model	Temp. (K)	Experimental Temp. (K)	Percent Error
CTH	Johnson-Cook	958	**1190±50**	**22%**
	Steinberg-Guinan-Lund	1167		**1.9%**
	Preston-Tonks-Wallace	1012		**15%**
	Mechanical Threshold Stress	964		**19%**
ALEGRA	Johnson-Cook	850		**29%**
	Steinberg-Guinan-Lund	1260		**6%**

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Strength Models

- Johnson Cook: An Empirical Formulation of Strength
- Steinburg-Guinan-Lund: A semi empirical model developed for high strain rate and extended to low strain rate
- Preston-Tonks-Wallace: Includes mirco structural considerations for strain rates up to 10^7 s^{-1}
- Mechanical Threshold Stress: Models Flow Stress for very high strain rates up to 10^{11} s^{-1}

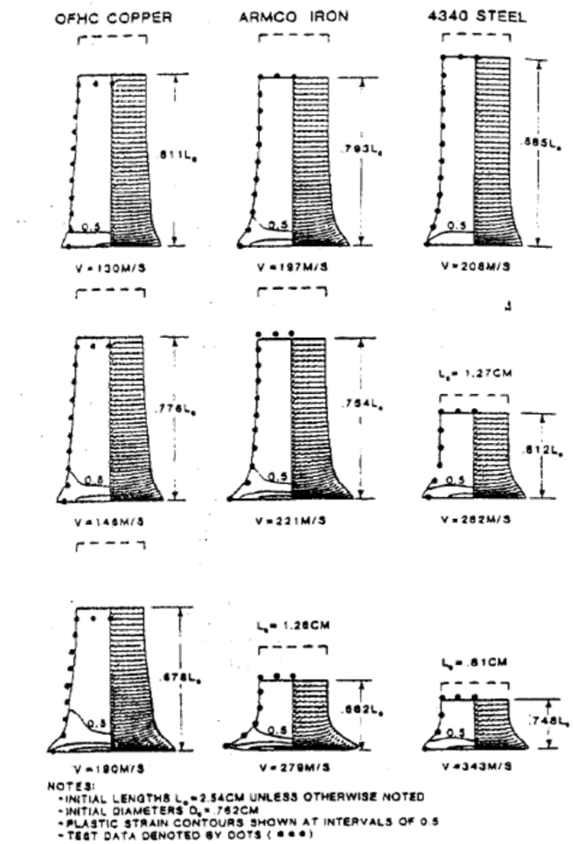


Figure 9. Comparison of Computed Shapes and Test Results for Cylinder Impact Tests at Various Velocities

Johnson, G. R. and Cook, W. H., 1983. A constitutive model and data for metals subjected to large strains, high strain rates and high temperatures. In: Proc. 7th International Symposium on Ballistics: pp. 541-547.

Results - Temperature

- Johnson-Cook

$$\sigma_y(\varepsilon_p, \dot{\varepsilon_p}, T) = \left[A + B(\varepsilon_p)^n\right]\left[1 + C ln\left(\frac{\dot{\varepsilon_p}}{\dot{\varepsilon_{p0}}}\right)\right]\left[1 - \left(\frac{T - T_0}{T_m - T_0}\right)^m\right]$$

- Steinberg-Guinan-Lund

$$\sigma_y(\varepsilon_p, \dot{\varepsilon_p}, T) = [\sigma_a f(\varepsilon_p) + \sigma_t(\dot{\varepsilon_p}, T)]\left(\frac{\mu(p,T)}{\mu_0}\right)$$

$$\dot{\varepsilon_p} = \left[\frac{1}{C_1}\exp\left[\frac{2U}{kT}\left(1 - \frac{\sigma_t}{\sigma_p}\right)^2\right] + \frac{C_2}{\sigma_t}\right]^{-1}$$

Results - Temperature

- Preston-Tonks-Wallace

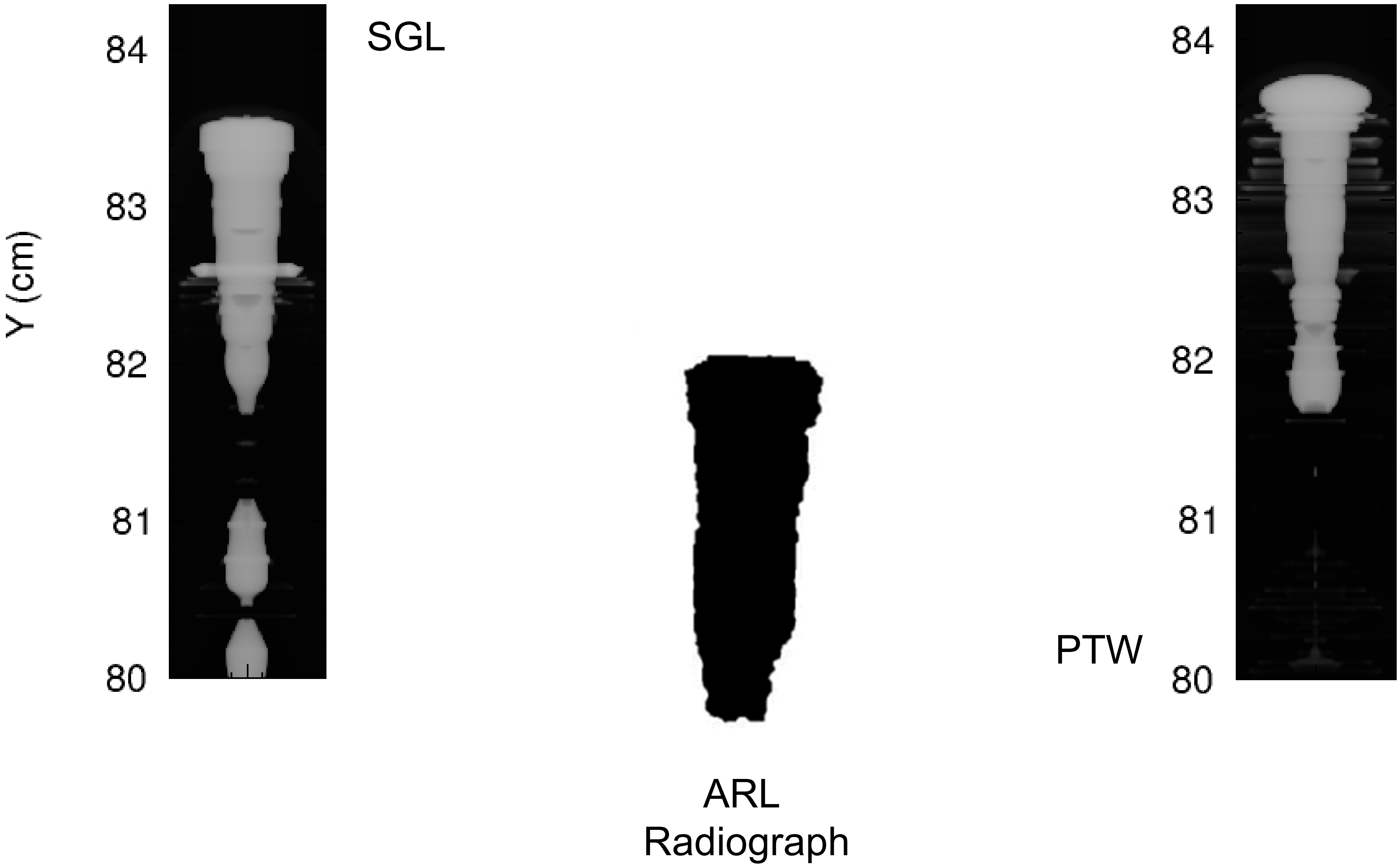
$$\sigma_y(\varepsilon_p, \dot{\varepsilon_p}, T) = \begin{cases} 2\left[\tau_s + \alpha \ln\left[1 - \varphi \exp\left(-\beta - \frac{\theta \varepsilon_p}{\alpha\varphi}\right)\right]\right]\mu(p,T) \\ 2\tau_s \mu(p,T) \end{cases}$$

- Mechanical Threshold Stress

$$\sigma_y(\varepsilon_p, \dot{\varepsilon_p}, T) = \sigma_a + (S_i\sigma_i + S_e\sigma_e)\left(\frac{\mu(p,T)}{\mu_0}\right)$$

$$S = \left[1 - \left(\frac{kT}{gb^3\mu}\ln\left(\frac{\dot{\varepsilon_0}}{\dot{\varepsilon}}\right)\right)^{\frac{1}{q}}\right]^{1/p}$$

Comparison of Jet Structure



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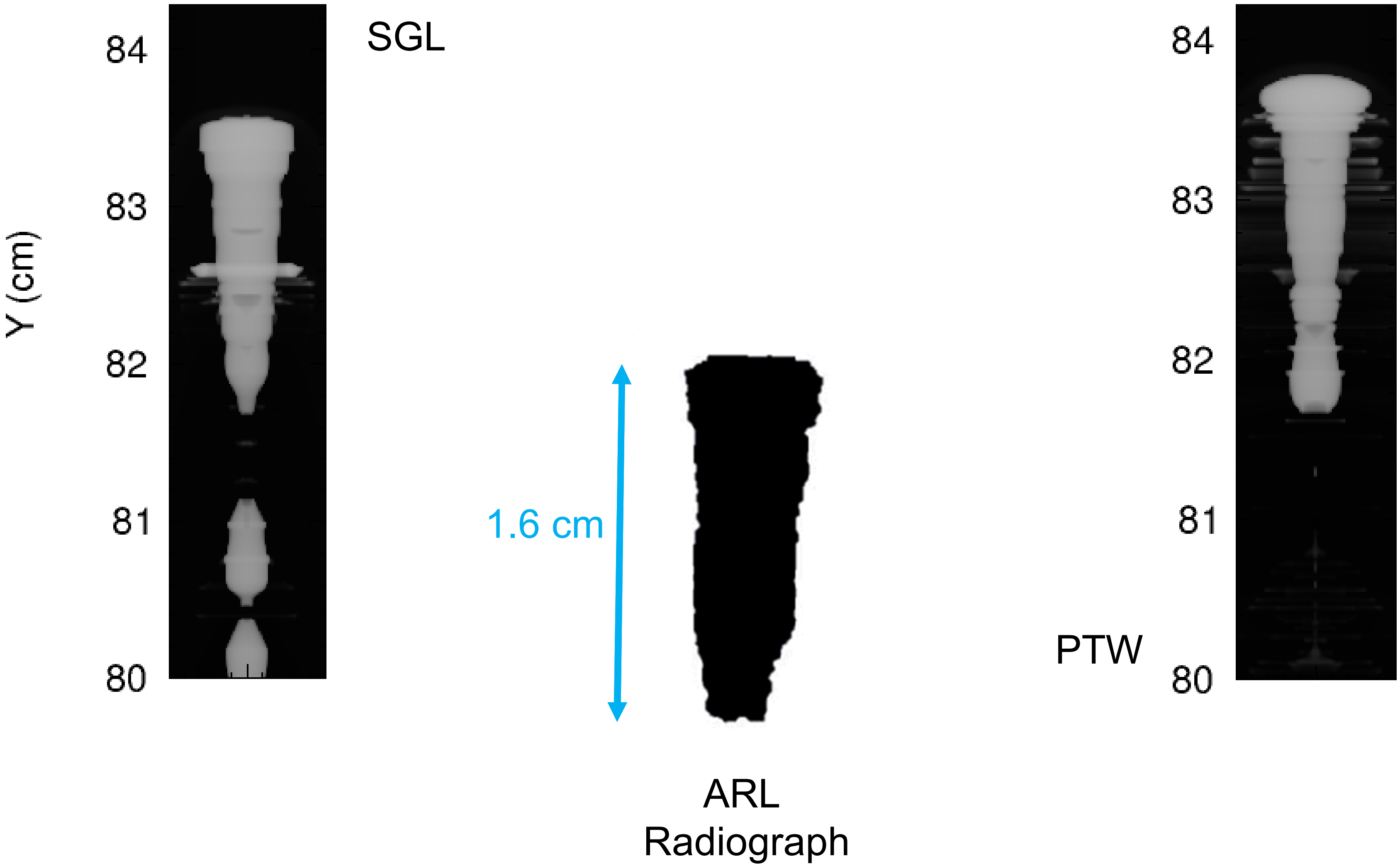
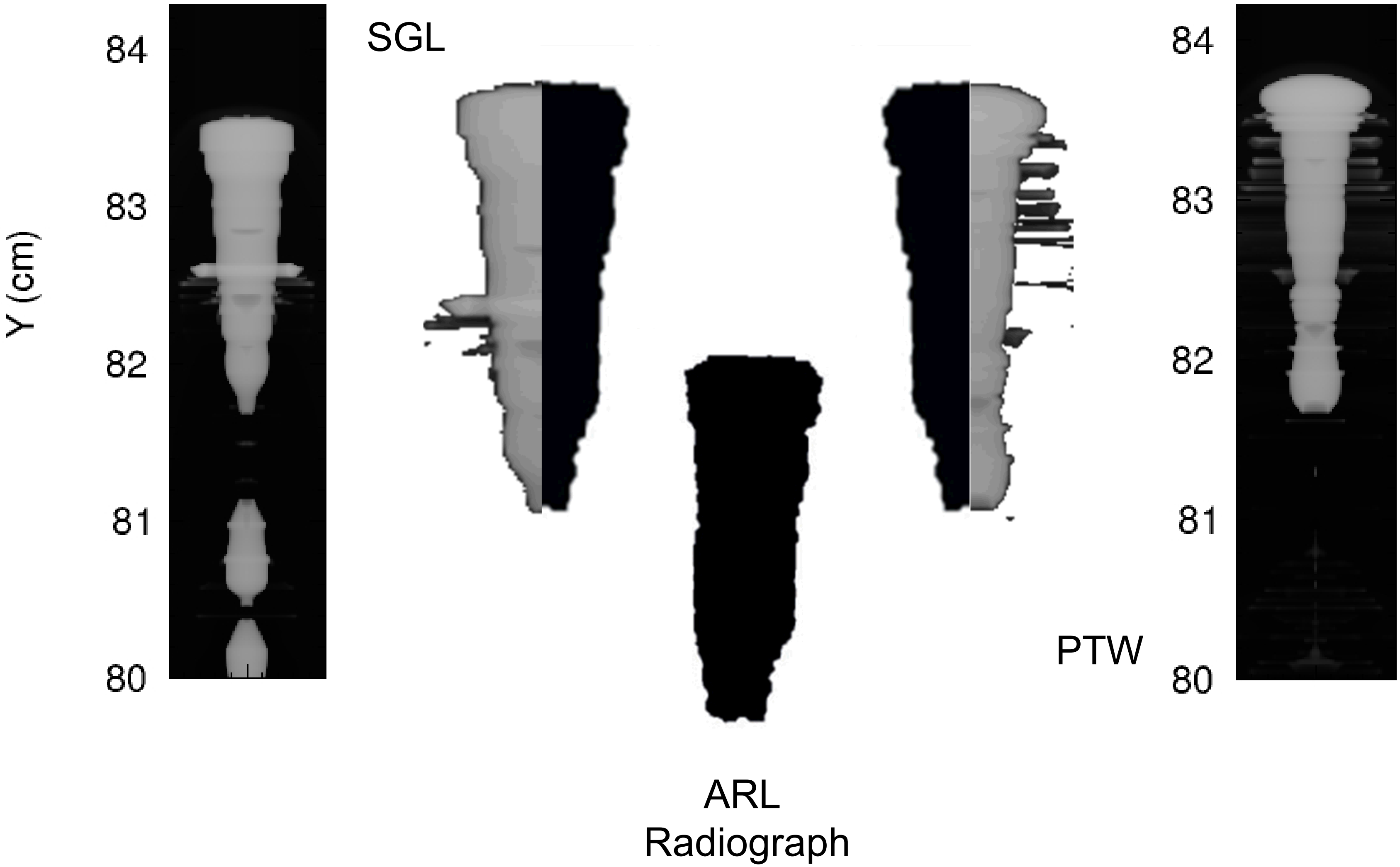
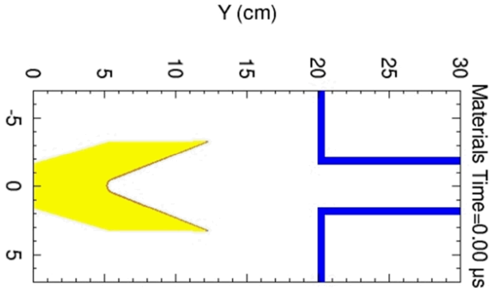


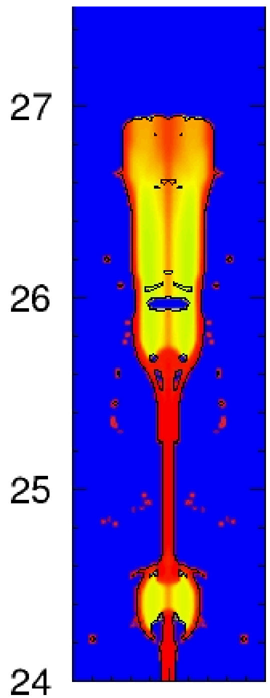
Comparison of Jet Structure

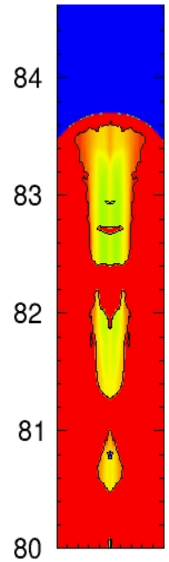


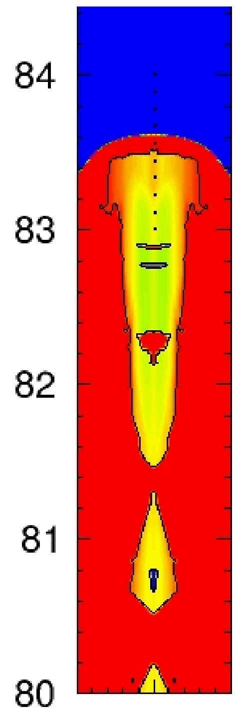
Additional Factors



Vacuum Conditions
- Closer to experiment
- 1204 K
- 1.2% Error



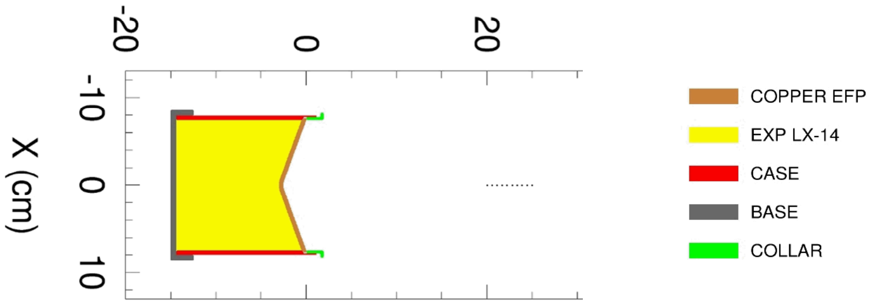


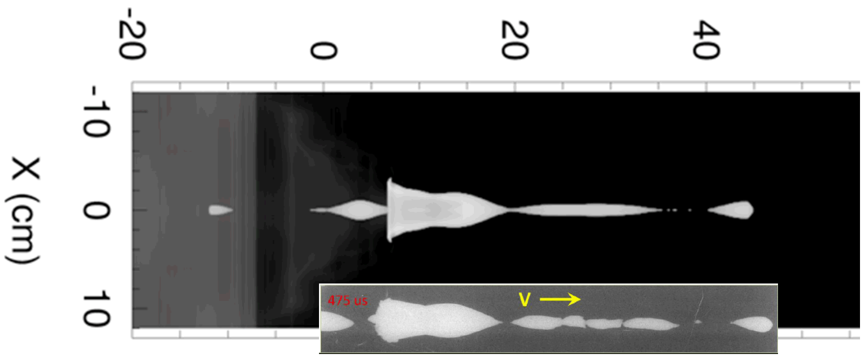


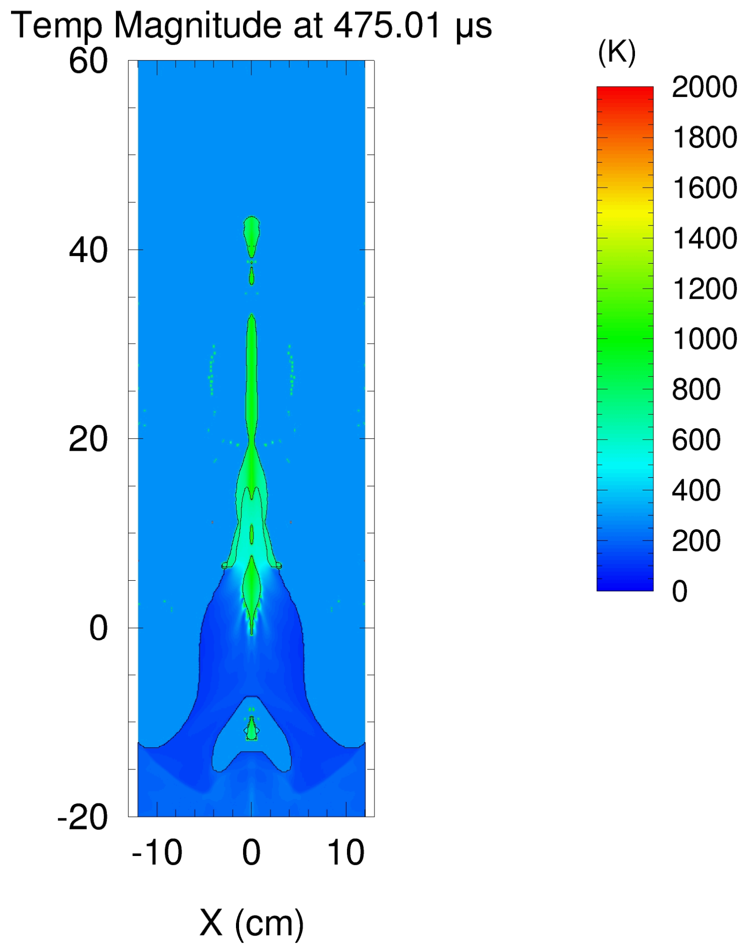
Fracture Model
- Johnson-Cook
- 1158 K
- 2.6% Error

EFP Study

- See our poster/presentation!







Concluding Remarks

- Data is now available to benchmark dynamic temperature calculations.
- Choice of strength model is critical in shaped charge applications, due to the fundamental role of plasticity in jet formation.
- Of commonly used strength models in CTH, Steinberg Guinan Lund appears to most accurately predict in-situ temperatures of shaped charge jets.
- In addition to temperature, most models capture jet formation and shape well when comparing to experimental radiographs.

Acknowledgements

- The authors would like to thank Dr. Casey Uhlig of the U.S. Army Research Laboratory, who performed the experimental basis of this work, for answering our many questions to ensure an accurate computational model. Sandia is a multi-program Laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94-AL85000.

Thank You! Questions?