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Dynamic Shock Compression of Copper to Multi-Megabar Pressure

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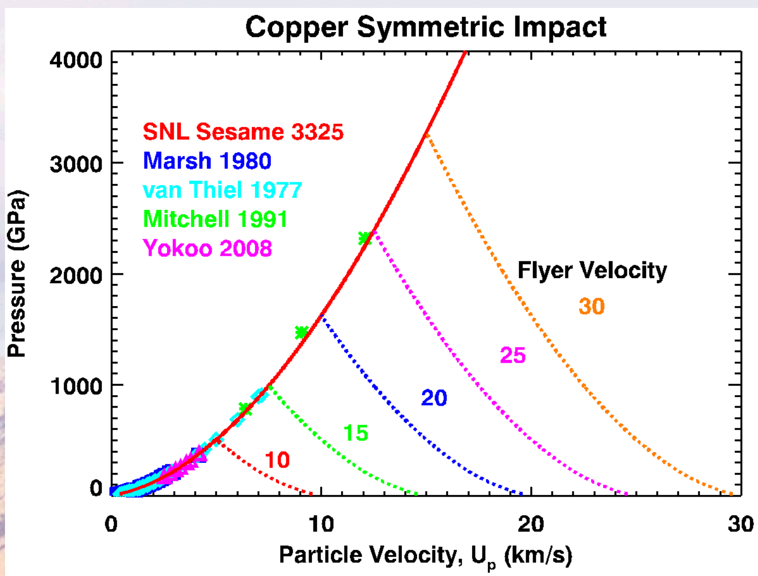

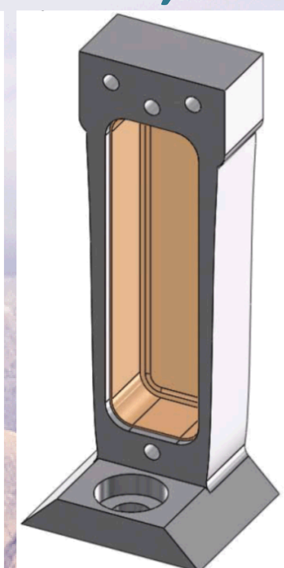

Pulsed Power Sciences Center
Sandia National Laboratories
Albuquerque, NM

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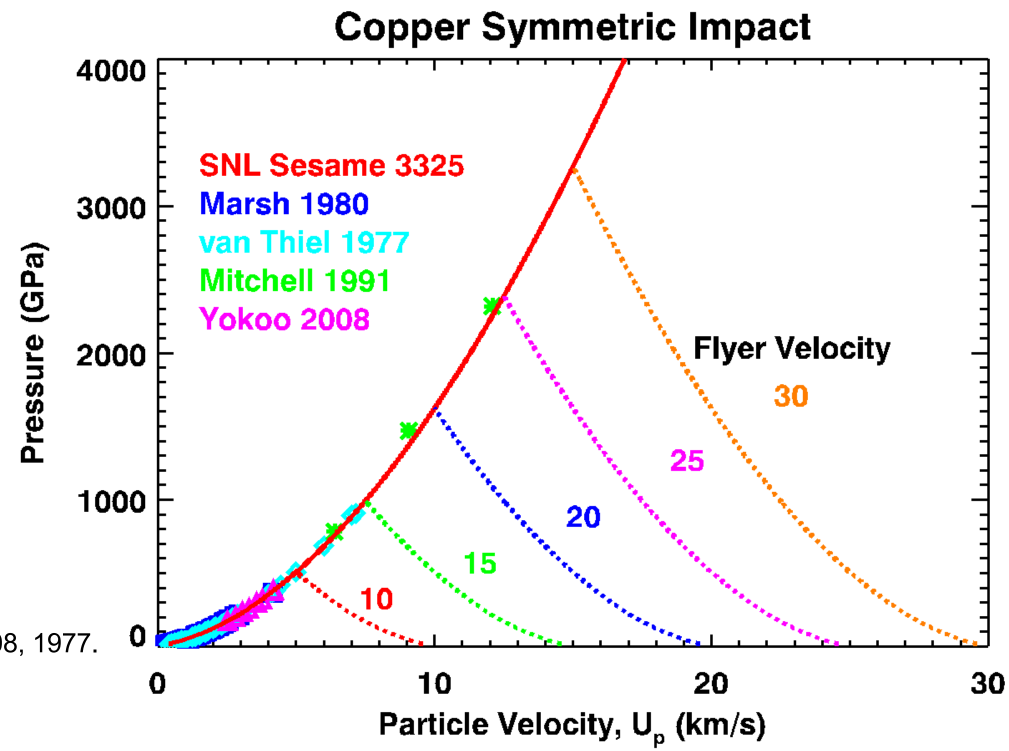
Compression of copper to 30 Mbar using planar impact is motivated by several HEDP applications

- **Programmatic motivation:**
  - **Copper is a standard reference to determine the EOS properties of other materials**
  - **High copper conductivity makes it useful as an MHD driver in high current dynamic materials experiments on Z**
  - **Composite aluminum/copper flyer plates increase the dwell time in plate impact experiments by taking advantage of the slower wave speeds in copper**

- **Experimental objectives:**
  - **Reinstate the composite flyer capability on Z**
  - **Extend the range of EOS shock compression data**
  - **Measure Hugoniot data for copper to 30 Mbar using symmetric planar impact**



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2. M. van Thiel, *Compendium of Shock Wave Data*, UCRL 50108, 1977.
3. A.C. Mitchel, et al., J. Appl. Phys, 69 (5) 2981, (1991).
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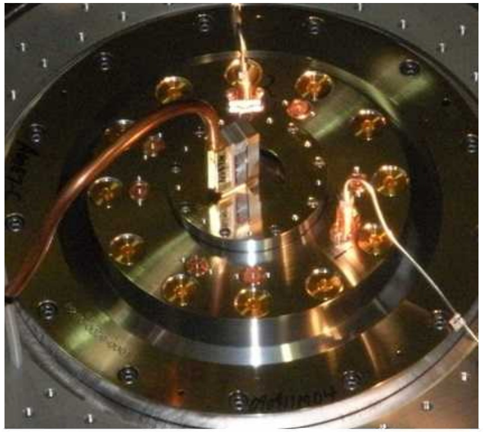
Cu Hugoniot measurement to 30 Mbar is based upon previous shots Z2006 and Z2027 from Oct/Nov 2009

- Z shot 2006 used an Al/Cu composite flyer and reached record velocity of 28 km/s
- Z shot 2027 used an aluminum flyer and reached record velocity of 40 km/s
- Shock data not obtained for Ta sample perhaps due to 90º bends of optical fiber in diagnostic housing
- Thus hardware is updated based upon recent best practices

Z2006



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Magnetically driven hyper-velocity launch capability at the Sandia Z accelerator

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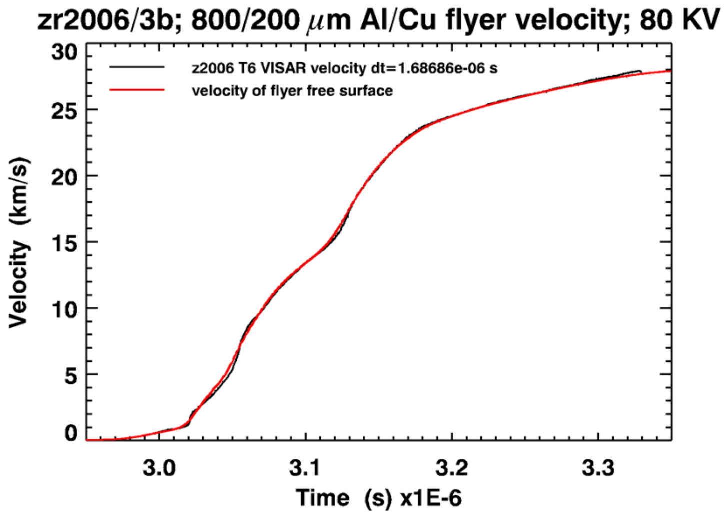

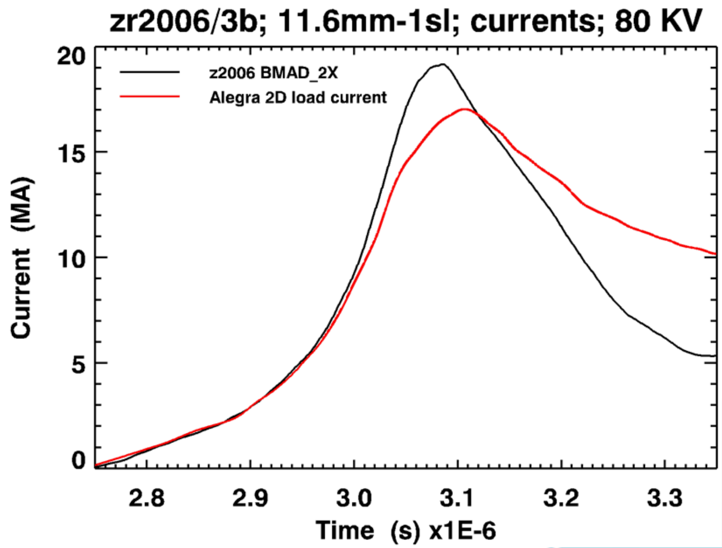

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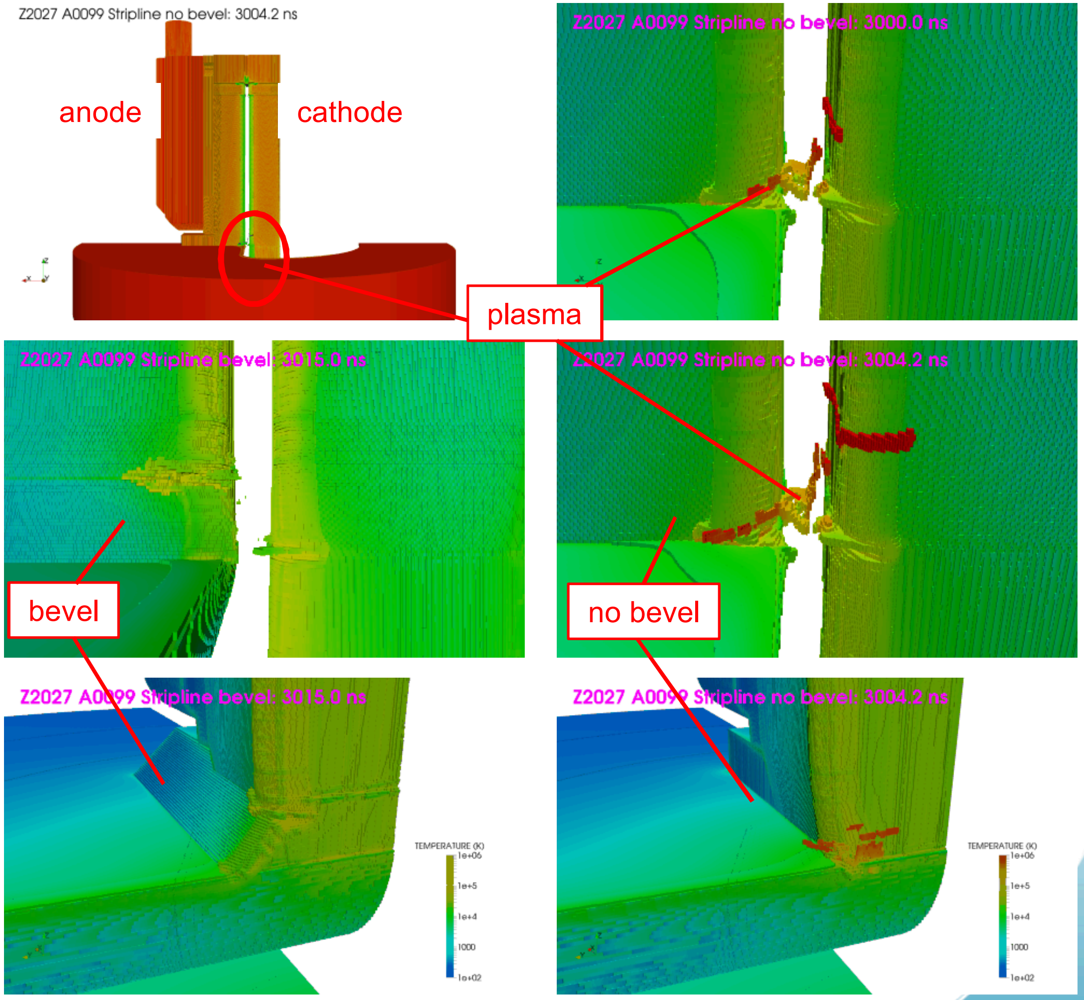
Sandia's Metal Micromachining Team uses a multi-step double zincate process for electroplating Cu onto Al

1. Ultrasonic soap clean – ten minutes at 40°C
2. Acetone, ISO, air dry
3. APY-17
4. De-ionized (DI) water rinse
5. Actane 70 etch for 5 minutes
6. DI rinse
7. Actane 70 smut removal for 5 seconds
8. DI rinse
9. Zincate for 45 seconds w/ ferric chloride and Rochelle salt
10. DI rinse
11. 38% HNO_3 dip
12. DI rinse
13. Zincate for 45 seconds
14. DI rinse – extreme agitation with spray and hand agitation
15. Into copper plating bath at 0.9 volts, 40 mA – 30 mA/cm^2

Plating Time (hr)	42.8 - 71.2
Avg Voltage (V)	1.6
Avg Current (mA)	170 – 250
Avg Thickness (μm)	355 - 634
Current Efficiency	26% - 45%

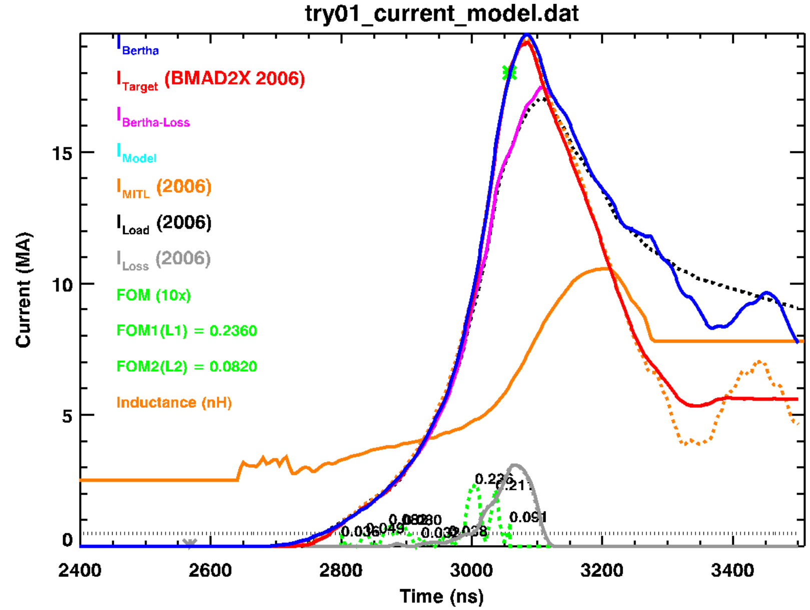
Large-scale 3D ALEGRA MHD simulations on Cielo show plasma generation near base of anode leading to design modifications

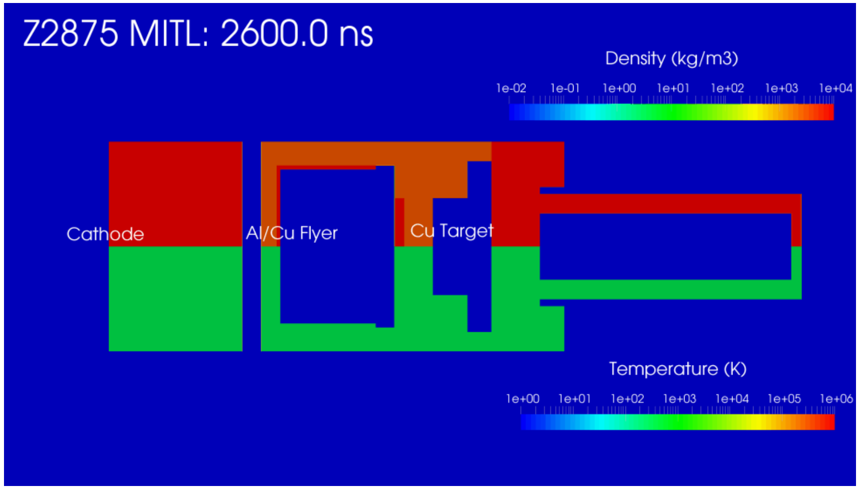
- **Plasma generation is seen near the base of anode**
  - **Not seen in lower resolution simulations**
  - **Traverses the A-K gap to the cathode**
  - **Also is swept upward along the A-K gap**
  - **Plasma may contribute to previously unexplained load current losses**
- **Adding a bevel near the base of the anode panel helps to mitigate plasma generation for up to 15 ns**
- **Simulation parameters:**
  - **87-mm diameter, 66-mm tall mesh**
  - **335.6M elements, 1.006B element edges**
  - **Runs on 2400 nodes (38,400 cores) for 6+ days**
  - **Mesh resolution at the core of the mesh is 40 microns**

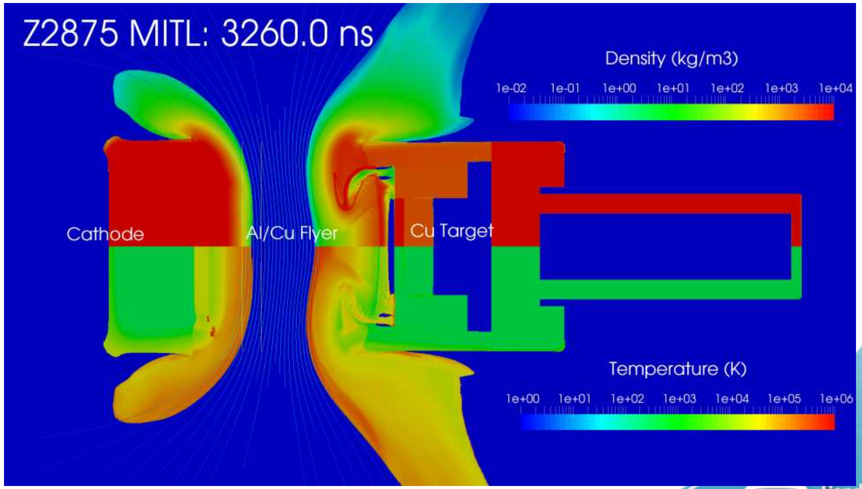


2D ALEGRA MHD simulation are used to design and predict performance of the shot

- New current models begin with configuration from Z2006
- Use unfold of load current to estimate losses for comparison with new design
- 2D MHD simulations provide estimates of:
  - Load inductance
  - Current scaling factors for 1D MHD simulations
- 2D MHD simulation show dynamics of panel deformation



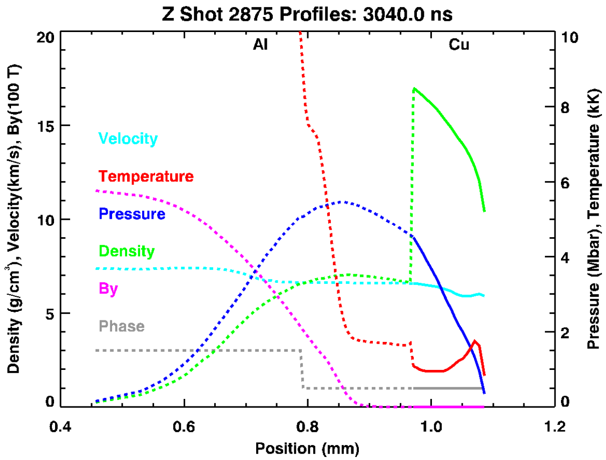


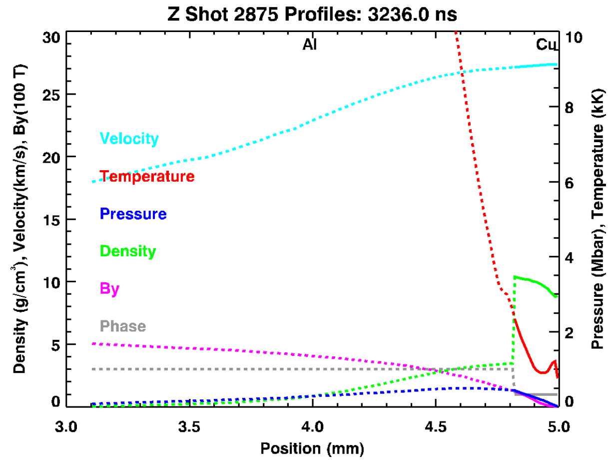


High resolution (10 μm) 1D ALEGRA MHD simulations indicate state of Al/Cu flyer at time of impact

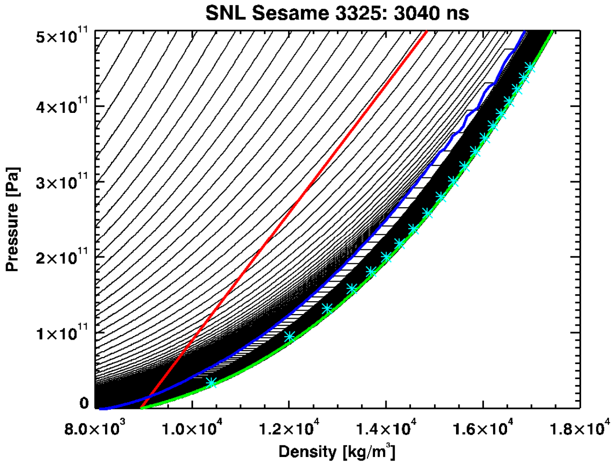
- **Copper of flyer compresses and releases along isentrope at least twice prior to impact**
- **Aluminum burns through due to Joule heating**
- **Copper remains solid**

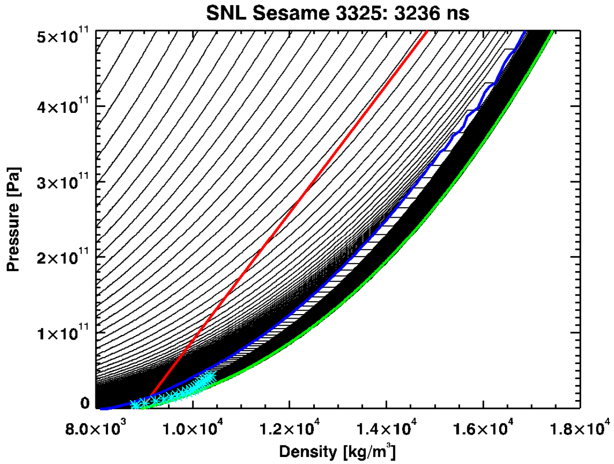
Profiles and material state at peak of flyer pressure at 3240.0 ns





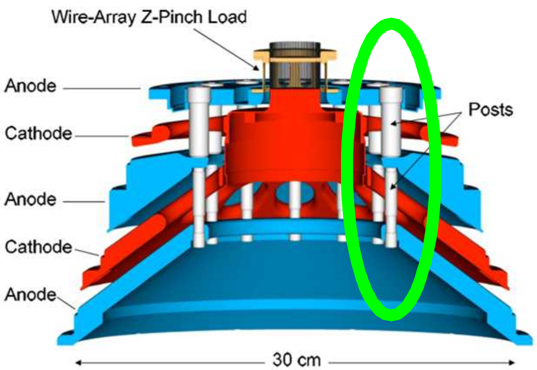
Profiles and material state at target impact of 3236.0 ns



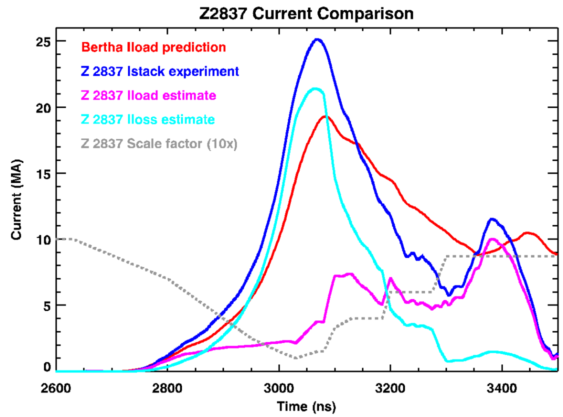


The BAD news! July Z2837 shot experienced a short (zinger) in the DPHC – NO FAVORABLE DATA OBTAINED!

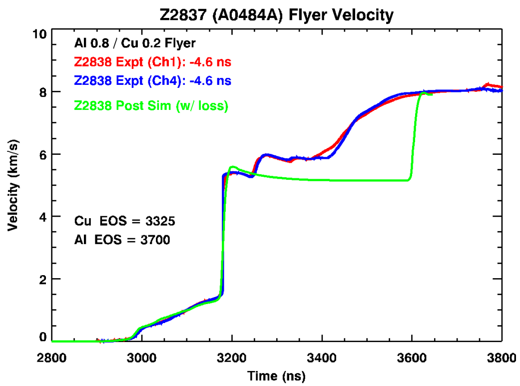
The double post-hole convolute (DPHC) shorted due to plasma generation

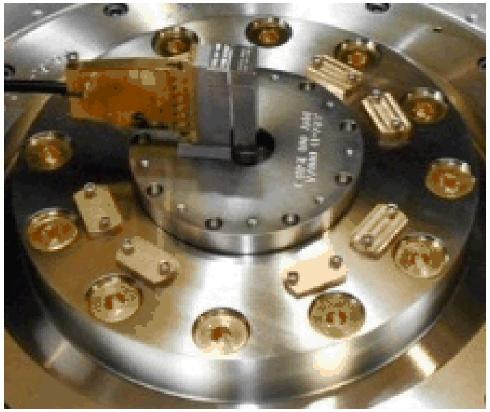


Low inductance current path allows Z to deliver higher current to the DPHC



90% to 70% current loss to the load produces shocks and low ~8 km/s velocity in the flyer





Z2837 load assembly

Top anode plate damage indicates severity of loss

Metal spray coats middle anode plate

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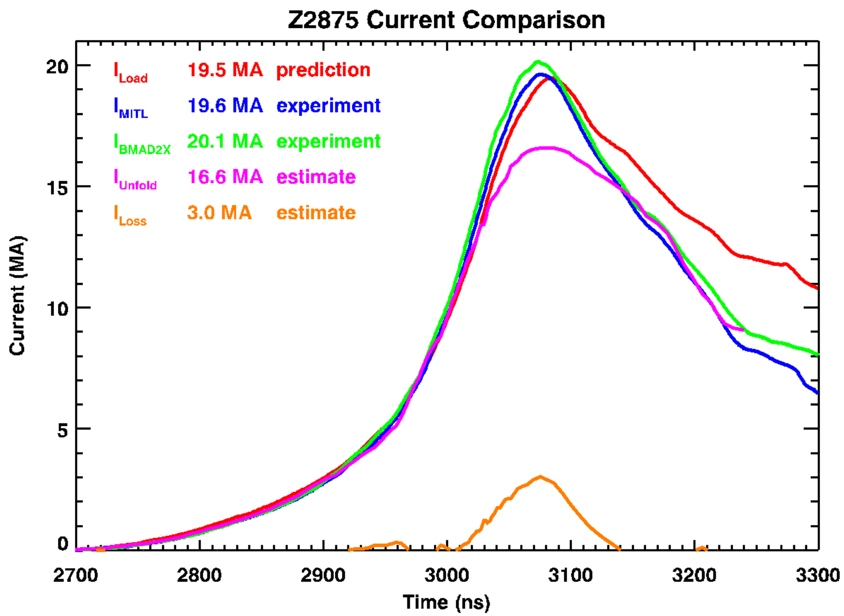
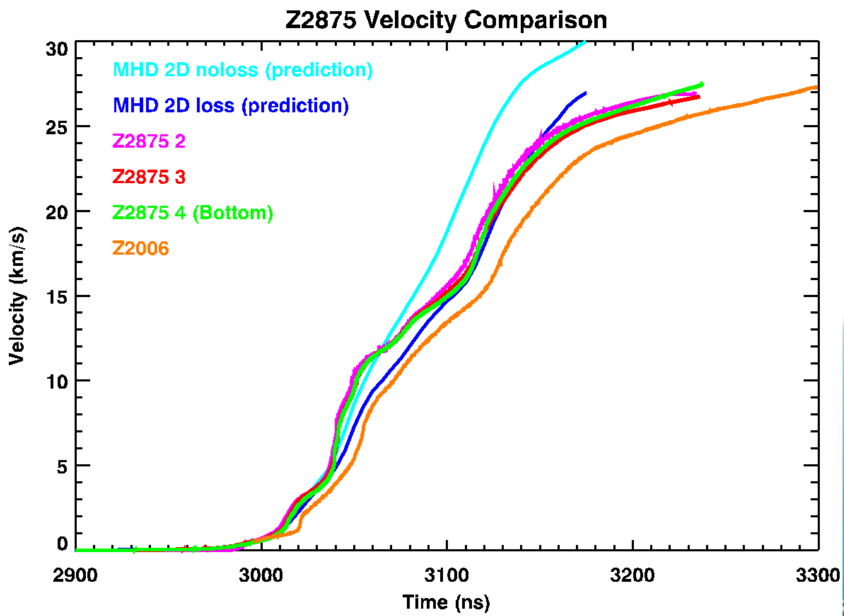
The GOOD news! Preliminary analysis of November Z2875 shot produced excellent data return

- Machine current close to design
- Measured velocity near predictions
- 4 flyer measurements
  - top 1 bad
- 3 sample measurements
  - top 1 bad
- Data analysis is ongoing

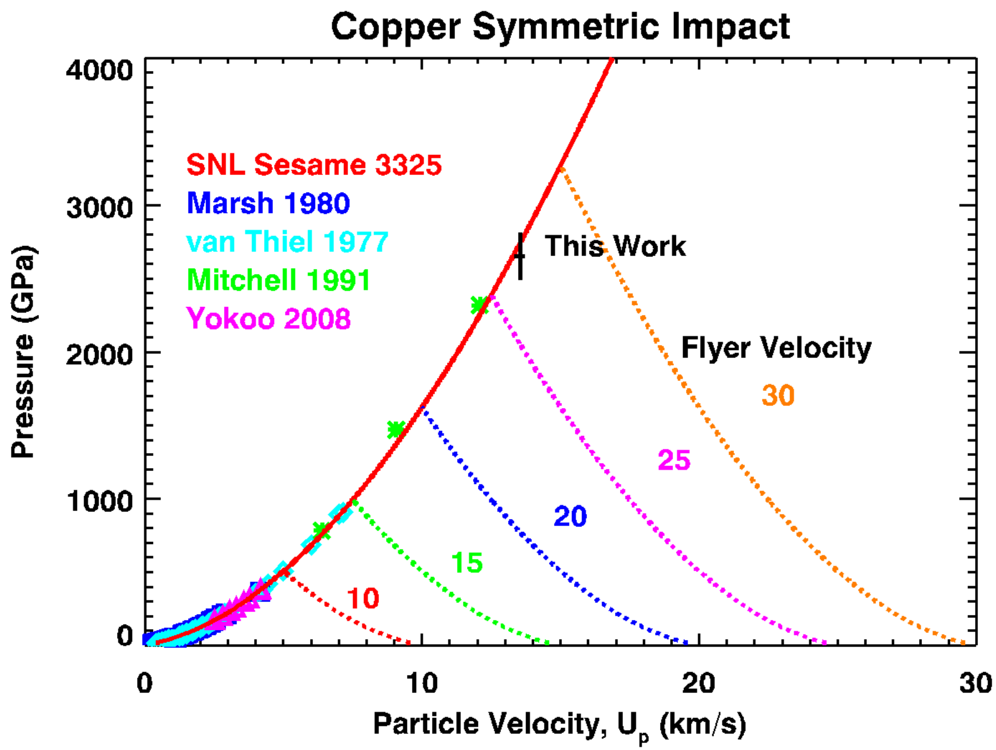
Impact velocity (km/s)	27.1 ± 0.4
Particle velocity (km/s)	13.54 ± 0.2
Shock velocity (km/s)	21.85 ± 1.1
Density (g/cm^3)	23.56 ± 2.0
Pressure (Mbar)	26.5 ± 1.6





Conclusions

- We have:
  - Reinstated the composite flyer capability on Z
  - Extended the range of EOS shock compression data
  - Measured Hugoniot data for copper to 26.5 Mbar using symmetric planar impact



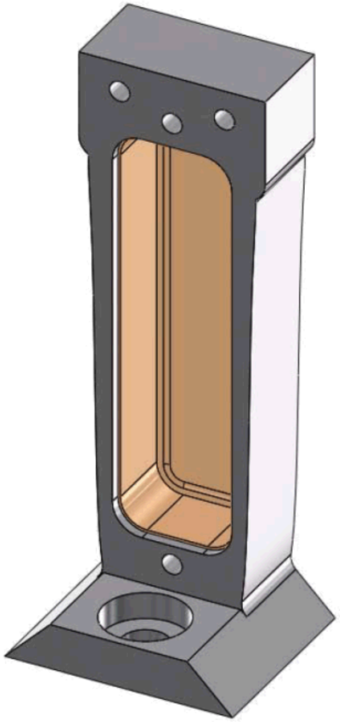
Acknowledgments

- Pulsed Power Center for this opportunity
- Hardware fabrication team
- Z facility crew

Extra viewgraphs

Abstract

- Copper is an important material for a variety of shock and high energy density applications and experiments. Copper is used as a standard reference material to determine the EOS properties of other materials. The high conductivity of copper makes it useful as an MHD driver layer in high current dynamic materials experiments on Sandia National Laboratories' Z machine. Composite aluminum/copper flyer plates increase the dwell time in plate impact experiments by taking advantage of the slower wave speeds in copper.



- This presentation reports on recent efforts to reinstate a composite Al/Cu flyer capability on Z and to extend the range of equation-of-state shock compression data through the use of hyper-velocity composite flyers and symmetric planar impact with copper targets. We present results from multi-dimensional ALEGRA MHD simulations, as well as experimental designs and methods of composite flyer fabrication.

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