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Copper conductivity model validation using flyer plate experiments on Sandia's Z-machine

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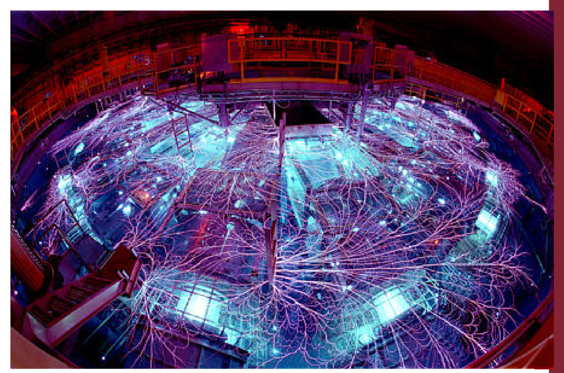
Introduction

Simulations of physical systems involving magnetic fields and a wide range of material states require highly accurate and complete electrical conductivity models. Several such systems important to the study of shock in materials and a new fusion approach, MagLIF, are currently being done at Sandia National Laboratories' (SNL) pulsed power Z-machine.

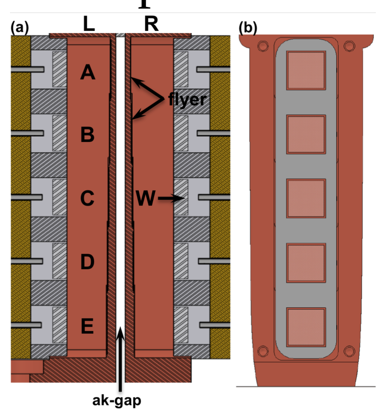
While it is possible to generate conductivity models using a base physics model and density functional theory (DFT)[1-3], there has yet to be solid experimental validation of these models in high energy density regions. We propose such a method, using VISAR data from a Copper flyer plate experiment on the Z-machine matched with simulations done with Sandia's ALEGRA MHD code[4].



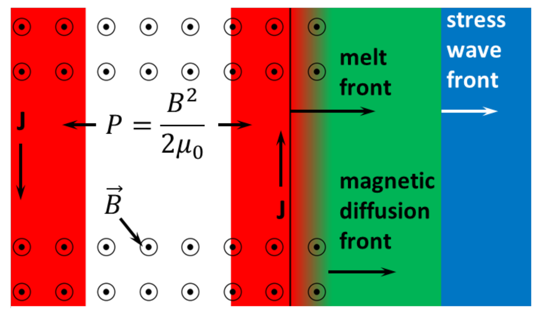
Arcs and Sparks – Sandia's Z-Machine
Photo by Randy Montoya

Experiment

Flyer plates are commonly used in pulsed power experiments to study shock behavior in target material. In this particular experiment, a stripline[5-6] with ten cut-out plates of thicknesses ranging from 500µm-950µm in 50µm increments was placed at the center of the Z-machine. A 1000 T magnetic field created by and combining with 10-20MA of current pulsed through the load in under a microsecond causing a JXB force that sent a pressure wave through the plates, flinging them outward. The first wave is followed by a magnetic field diffusion front and melt through of the material. While it is usually desirable to have solid flyer material left for shock experiments, these plates were allowed to melt entirely through before hitting the target. The data in the next panel shows a distinct bump in the velocity data where the melt front reaches the flyer surface and melted material expands outward before relaxing.

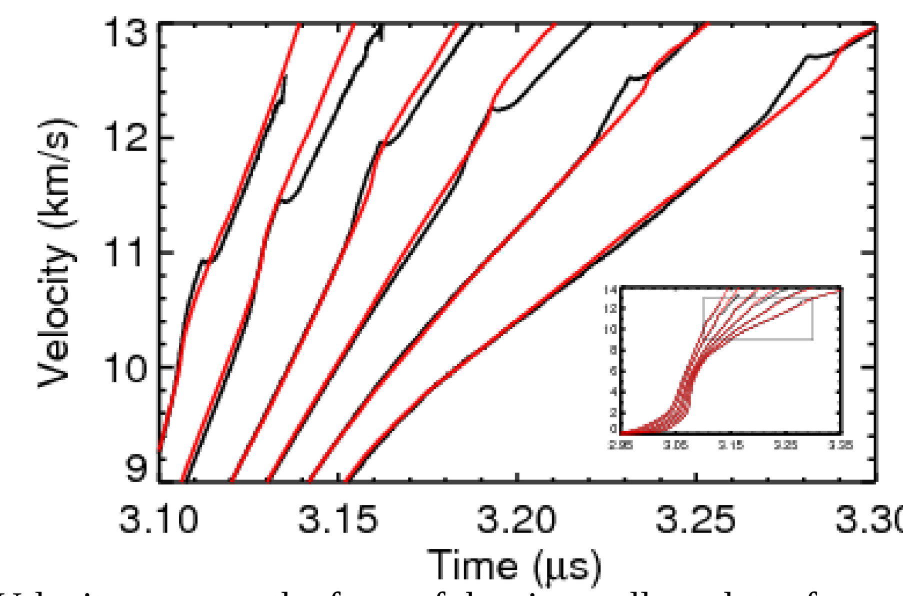


Stripline experimental design



Waves traveling through flyer plate[7]

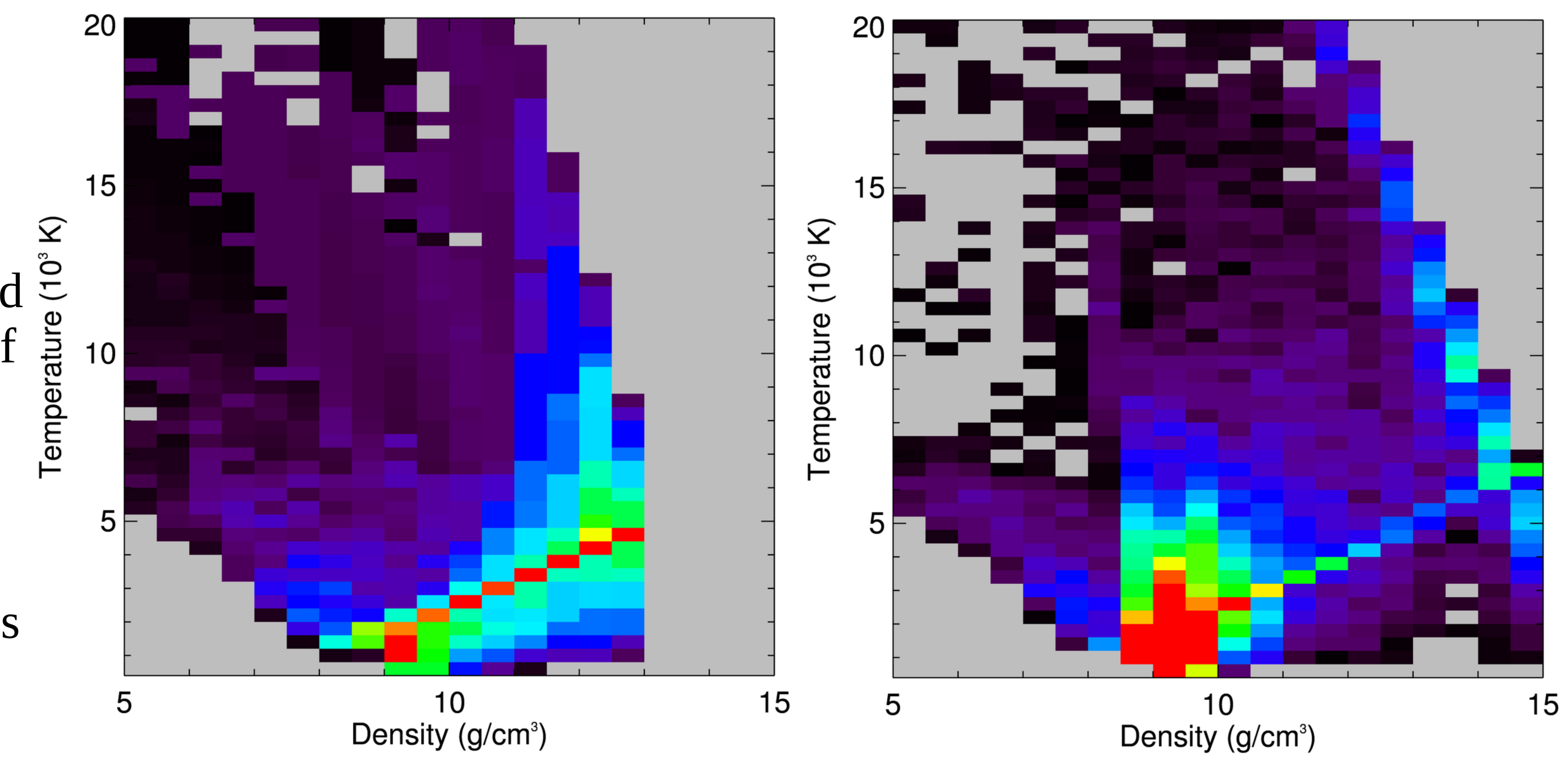
Simulation and Results



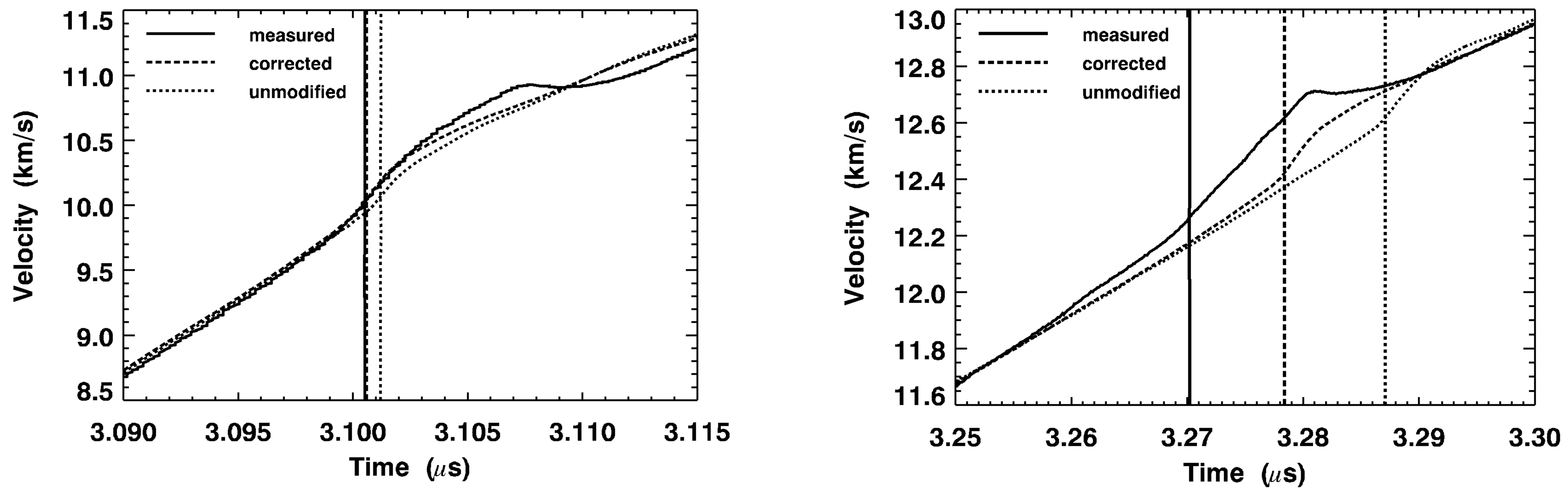
Velocity traces at the front of the six smallest plates from VISAR data (black) and simulation data (red) done using the conductivity model optimized using DFT. The insert shows the full shot.

The VISAR and simulation data agree within 1% for the majority of the shot in all plates that do not reach a shock as the pressure wave travels through. The characteristic bump in velocity shows the melt through reaching the front of the experiment plates at an earlier time than in simulations. Because the melt front follows the magnetic diffusion, it was predicted that a decrease in conductivity at some region would bring the simulation more in agreement with experiment at this bump. Equation of state (EOS) models for copper have previously been validated by experiment, but the conductivity has not.

To handle the large swath of density and temperature space the plates pass through, it was necessary to do a parameter sweep. The "box plots" pictured show the effect on the timing of the velocity bump when that region of temperature and pressure is multiplied by 0.5. Thicker plates reach much higher densities, which explains the larger time difference between experiment and simulation, and greatly reduces our search range.



"Box plots" for the 500 µm (left) and 750 µm (right) plates. Brighter colors indicate a larger change in the timing of the melt front, while grey regions indicate no change at all. Besides showing the thicker plates reaching higher densities, the bright angled line seen in both plots corresponds to the melt line in EOS space, indicating a high sensitivity of the melt front timing to changes in conductivity along the melt line.



The plots above show the results of an iterative conductivity model correction process in the 500 µm (left) and 750 µm (right) plates. The unmodified model referenced is the DFT adjusted version we started the process with. The changes imposed did not alter the already in good agreement results prior to the melt through feature. The box plots guided us to a region that would target the larger error in the thicker plates without overshooting the timing in the thinner plates. The conductivity model has been improved significantly, but there is still room for improvement.

Conclusions

We have demonstrated a technique to validate material conductivity models in high energy density regions of interest to shock and fusion applications.

With copper, we compared VISAR data from a flyer plate experiment with simulation data using a preliminary conductivity model. An educated sweep of the parameter space showed us where in density and temperature space the conductivity is most important to the experiment, and iterative alterations to the model in these regions led to a more accurate model.

The flyer plate experiment described is achievable with a wide range of materials, and may be further optimized to provide even more information with just one Z-Machine shot.

We have made an attempt to automate this process of finding model corrections using a simulated annealing approach, but the coding and proof of validity of this approach has proved non-trivial.

References

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