Discovery at the Interface of
Science and Engineering: Science Matters!

Computers and Information Sciences
Computational Shock and Multiphysics

The Power of Simulation: *Unraveling the Mysteries of Electromagnetic Armor*

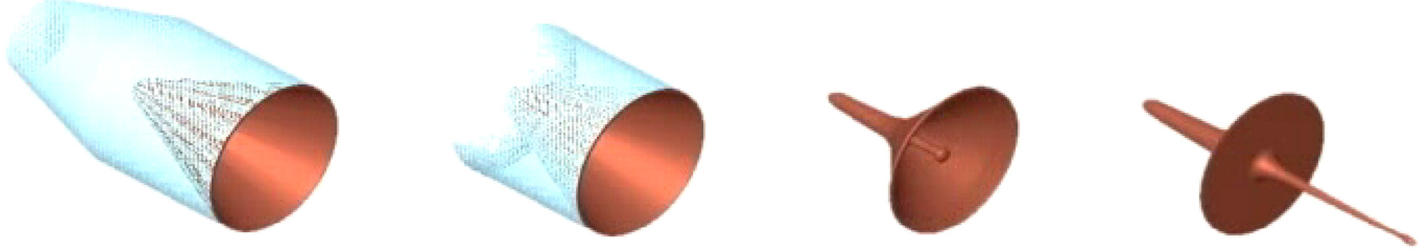

Figure 1: Formation of a shaped charge jet – Explosive (transparent blue) creates a jet of material as it squeezes a cone-shaped copper liner. (Courtesy Dr. Paul Berning, ARL)

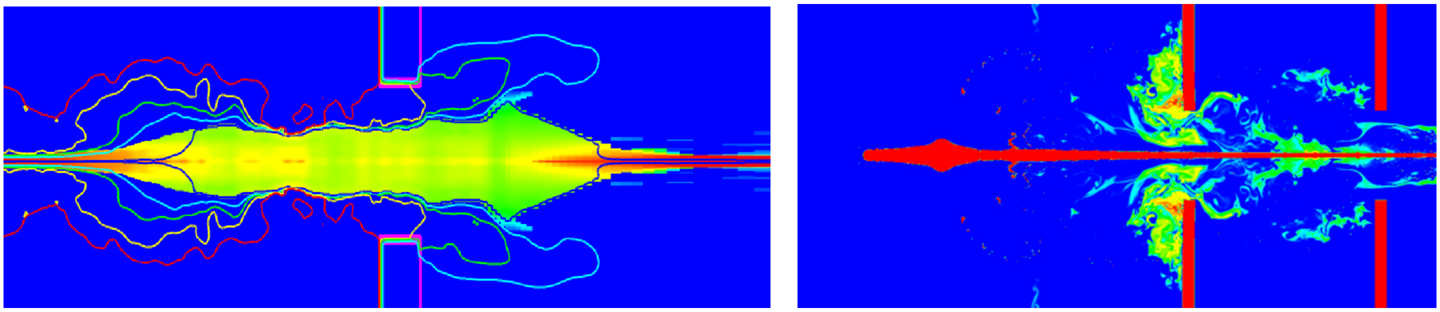

Figure 2: Electromagnetic armor: two example calculations of a shaped charge jet passing between two charged plates with holes. (left): plot of electric current streamlines and material densities for a high-current configuration. (right): plot of electrical conductivities for a low-current configuration.

Simulations are revealing new physics

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American troops have been overwhelmed by the increasingly sophisticated threats used against their vehicles in the recent Middle Eastern wars. Current armor has not been enough to stop the American death toll from rising, and the heavily armored vehicles that can protect against these threats are so heavy that they cannot be airlifted nor drive over ordinary bridges.

The United States Army Research Laboratory (ARL) is addressing these issues by studying many exciting new armor technologies. One promising research area is electromagnetic armor, which can protect against some threats by subjecting the jet from a shaped charge explosive (Figure 1) to high electrical current flows and crushing electromagnetic forces (Figure 2) that substantially decrease its penetrating capability. Some of the phenomena that occur in electromagnetic armor are so complex that ARL scientists have not been able to understand important trends in their experiments. To gain insight, ARL has chosen to enhance Sandia's ALEGRA shock and multiphysics simulation code [1] (originally developed to model experiments on Sandia's Z accelerator [2]) to build a near-first principles simulation capability for the complicated physics in electromagnetic armor. ARL scientists have been working closely with Sandia physicists and computational scientists over the last five years to develop advanced material models, improved numerical formulations of magneto-hydrodynamics, and efficient

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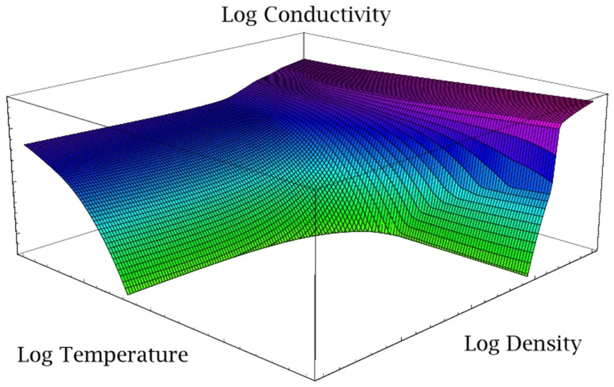

Figure 3: Illustration of an electrical conductivity surface. The conductivities in the original estimates of this surface were off by more than two orders of magnitude in the low-density, high temperature area of phase space.

solvers for massively parallel supercomputers to tackle this ambitious goal.

Scientists at both ARL and Sandia have been amazed by the tremendous differences made by new models for electrical conductivities of key materials. In the early stages of the project, the lack of accuracy in available models was identified as a crucial limiting factor in matching experimental results. For many materials, experimental data were simply not obtainable, and quantum-molecular dynamics simulations [3] were used to calculate conductivities in as-yet unexplored regions of phase space. In one instance, Sandia material scientists, motivated by ARL's experimental results, found differences of two orders of magnitude between existing estimates and their newly developed models (Figure 3).

Advanced numerical methods have also been crucial to the success of the project. Sandia determined that the numerical discretizations employed in the solution of Maxwell's equations must be compatible with the mathematical structure of these differential equations to preserve important characteristics of the magnetic field [4]. Furthermore, the linear solvers that use algebraic multigrid methods (necessary for these very large, difficult problems) required extensive reformulation [5] to obtain reasonable solution times on the thousands of processors required to solve the problems.

The ultimate goal of this work is to deliver a predictive simulation capability for electromagnetic armor. To meet this goal, Sandia is focusing considerable attention on verification of ALEGRA's computational methods. ARL, in turn, continues to run carefully calibrated experiments that provide validation data for the models used. The project will continue to leverage new methods in material modeling and numerical algorithms to make the capability truly predictive.

The future for this work is bright: ARL analysts have been able to reproduce counter-intuitive electromagnetic armor experimental results [6], and the collaboration between the analysts and the experimentalists at ARL has become so strong that ALEGRA is now routinely used to predict experimental trends and important dynamic values (such as inductances) of components in experiments. The strong interaction between simulation and experiment has resulted in a valuable and fruitful partnership between the scientists at ARL and Sandia.

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