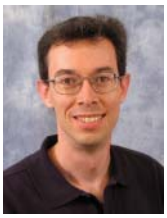
Arc Initiation Modeling for High Explosives



James F. McCarrick
(925) 423-8182
mccarrick1@llnl.gov

Initiation of high explosives (HE) by an electrical arc is a phenomenon with significant impact on the safety of both existing and future nuclear and conventional munitions. Previous work has shown that existing models of HE initiation do not apply to arc initiation and that existing safety-oriented testing of as-built components is insufficient to gain basic understanding. An experimental and modeling infrastructure has been successfully constructed to support a variety of existing and future programmatic efforts.

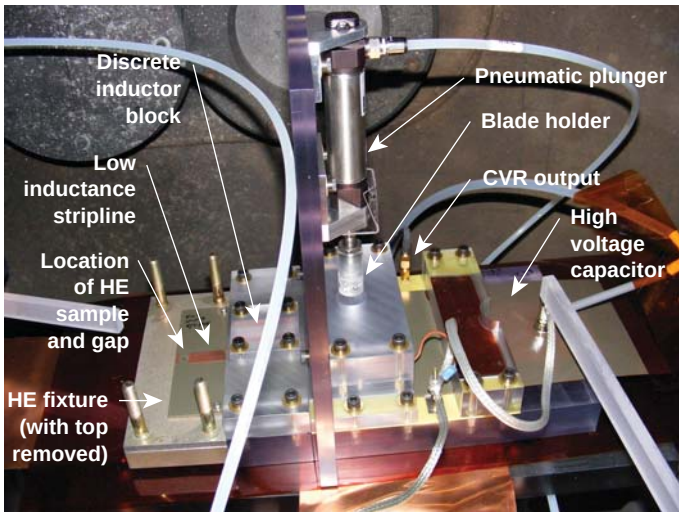


Figure 1. An assembled fireset, shown inside a shot tank. Features visible in this view, from left to right, include the gap in the stripline where the arc is created, the drop-in inductor block, the air-driven blade switch, and the high-voltage capacitor.

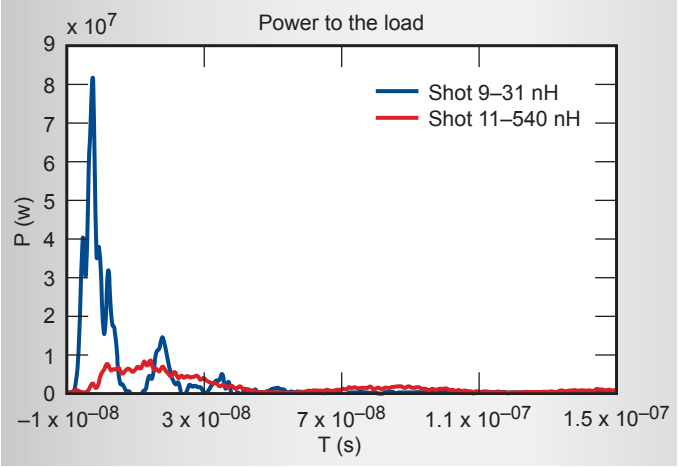


Figure 2. Measured power delivered to the load in high- and low-inductance configurations, at fixed source energy (720 pF and 32 kV).

Project Goals

The goals of this effort are first to construct an arc initiation testing infrastructure with a much broader set of controllable parameters, such as arc path length, air gap, and independently varied power and energy, and with time-resolved diagnostics integrated into the apparatus. A secondary goal is to create a simple modeling tool which allows rapid, flexible exploration of appropriate physics models for high-temperature HE kinetics, arc-to-HE energy transport, and equations of state (EOS), including coupling to output from the Cheetah chemical code.

Relevance to LLNL Mission

Arc initiation appears in multiple LLNL programs in the context of the safety of the existing stockpile, the configuration of future systems as part of the weapons transformation efforts, joint studies of HEs used in DoD munitions, and basic science supporting LLNL's role as an NNSA Center of Excellence for HE.

FY2008 Accomplishments and Results

On the experimental side, our major accomplishment is the creation of a fireset and associated testing protocol specifically for testing the response of HEs to electrical arcs. An assembled

fireset (with the HE fixture removed to show the gap) is shown in Fig. 1. The major characteristics include:

1. a set of easily swappable high-voltage capacitors, successfully operated at up to 35 kV;
2. a set of discrete drop-in inductors that allow independent variation of power and energy delivered to the load;
3. a knife switch and stripline coupling to the load, achieving a source impedance as low as 250 mΩ and 31 nH;
4. integrated diagnostics, including a foil-based current viewing resistor and a capacitive voltage probe that measure the current through and voltage across the arc.

Figure 2 shows how the power to the load is easily varied by an order of magnitude while keeping the total energy fixed. Operation in a fixed-power, variable-energy mode is also possible. This is key in characterizing arc initiation response thresholds, which are expected to show energy and power asymptotes analogous to the James criterion used for shock initiation thresholds. We have also successfully demonstrated batch testing in a single shot-tank purge cycle, allowing a significant increase in shot rate and project efficiency.

On the modeling side, we have created a MATLAB-based simulation tool with "plug and play" elements for the HE kinetics, energy transport models, and EOS. The tool is one-dimensional and easily switched between cylindrical and spherical limits. Prior work has established that the most unique aspect of arc initiation is the extremely high temperature, of order several eV, which is well beyond the range of validity for existing HE kinetics models. There have been promising recent advances in EOS for energetic materials. Therefore, the architecture of the tool was specifically chosen to allow these two aspects to be modified as ongoing studies produce new results; a particularly useful option for the EOS is incorporation of data produced by the Cheetah code.

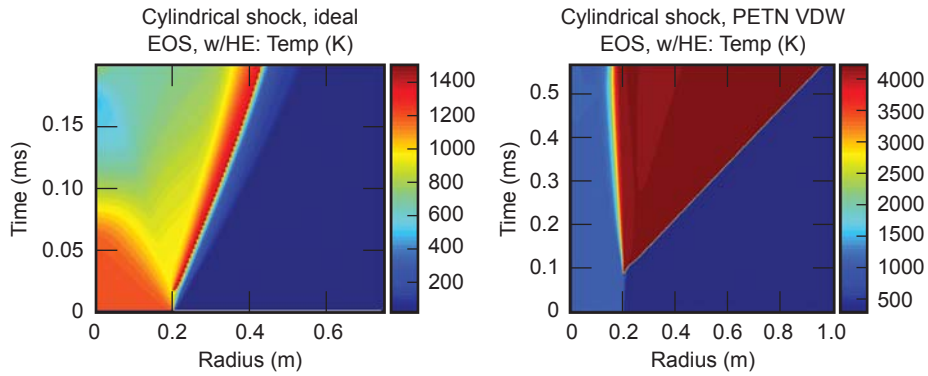


Figure 3. Temperature evolution from a simple MATLAB tool to study various combinations of HE kinetics, transport, and EOS models.

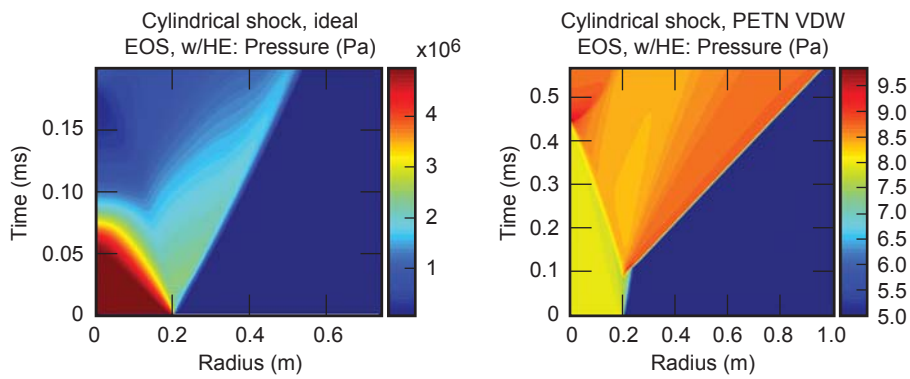


Figure 4. Pressure evolution for the same two cases depicted in Fig. 3.

Figures 3 and 4 show simulated pressure and temperatures for a cylindrical arc in an inert material (representing a surface track on a detonator header) surrounded by a PETN-like HE. The initial conditions are identical but the results change dramatically from subthreshold to detonation depending on choice of EOS.

Related References

1. James, H. R., "An Extension to the Critical Energy Criterion Used to Predict Shock Initiation Thresholds," *Propellants, Explosives, and Pyrotechnics*, **21**, pp. 8–13, 1996.
2. Glaesemann, K. R., and L. E. Fried, "Recent Advances in Modeling Hugoniots with Cheetah," *AIP Conference Proceedings*, **845**, 1, pp. 515–518, 2006.

Project Summary

We have successfully constructed, and tested a flexible fireset configuration with integrated diagnostics and the capability of delivering very high powers to the load. These firesets form a standardized testing infrastructure to study arc initiation of HE in various programmatic contexts. We have also created a simple modeling tool that will be used to explore the basic phenomena of arc initiation as new data and physical insight are obtained. These experimental and modeling tools have been transferred to ongoing and newly started programmatic efforts.