SAND2007-3694P

The Veloce pulsed power generator for isentropic compression experiments

T. Ao[1], J.R. Asay[1,2], R. Hickman[1], C.A. Hall[1], S. Chantrenne[3]

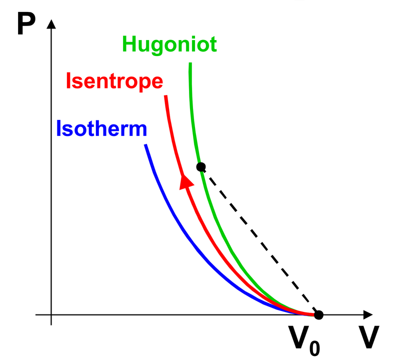
[1]*Sandia National Laboratories, Albuquerque, NM 87185 USA*

[2]*Washington State University, Pullman, WA 99164 USA*

[3]*Ktech Corporation, Albuquerque, NM 87123 USA*

BASIC CONCEPTS OF ISENTROPIC LOADING

Shock experiment yields only the single final *P-V* point on the Hugoniot, an **isentropic experiment** yields a **continuum of points along the isentropic loading path**.



• For simple waves, the flow in an inviscid fluid, where longitudinal stress is equal to hydrostatic pressure, is isentropic ($S=S_0$=constant) the **conservation equations** are given as,

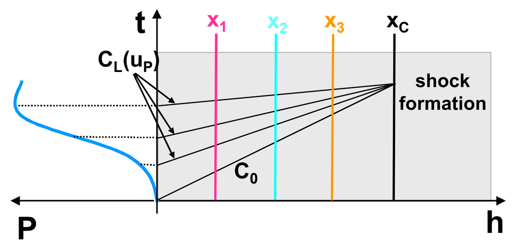
$$d\sigma = \rho_0 C_L du_P$$
$$dV = V_0 du_P / C_L$$
$$dE = -\sigma(S_0)dV$$

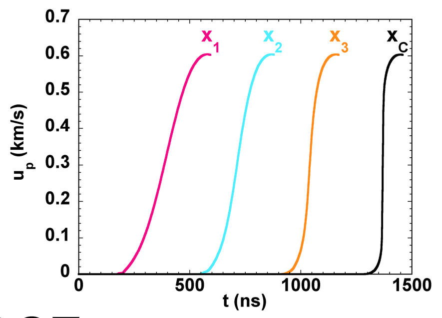
• where $C_L = dh/dt$ is the Lagrangian wave velocity which is approximately related to the $U_S - u_p$ relation as,

$$C_L \approx C_0 + 2su_P$$

Stress-strain loading paths can be determined continuously to peak pressure for most materials.

• The propagation of wave characteristics within sample, and particle velocities at various Lagrangian positions demonstrates resulting ramp wave, and eventual **shock wave formation** at **"critical" location x_C**.





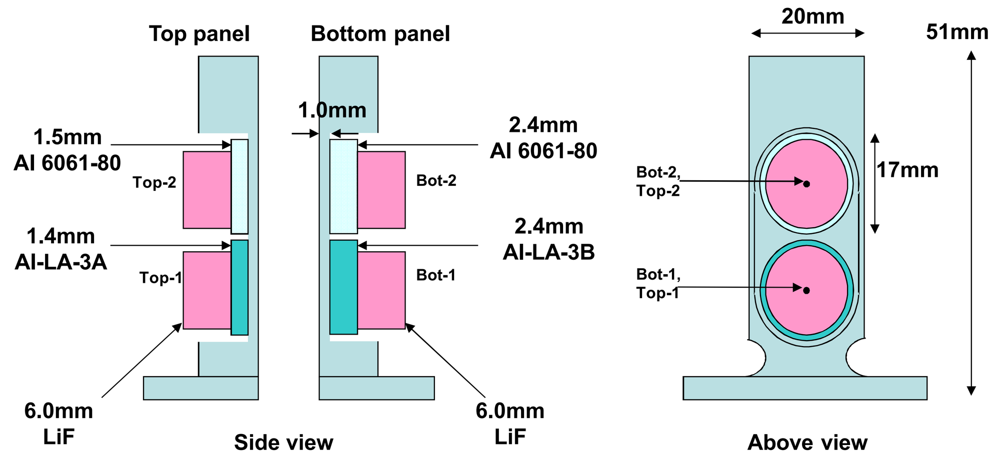
RESEARCH IN PROGRESS ON VELOCE

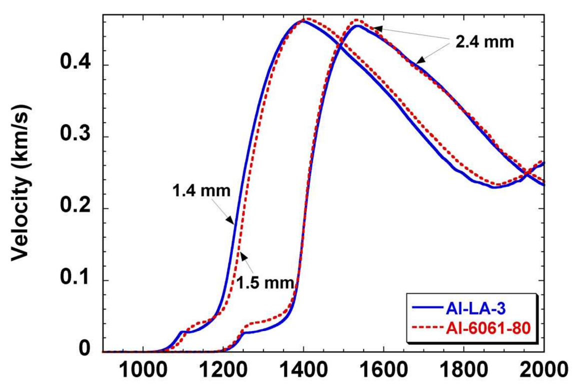
Strength of Aluminum Alloys

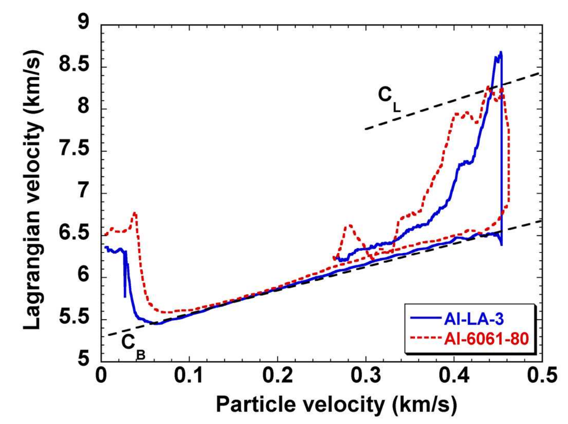
Aluminum materials of various compositions were tested under isentropic compression over the stress range of 7-12 GPa.

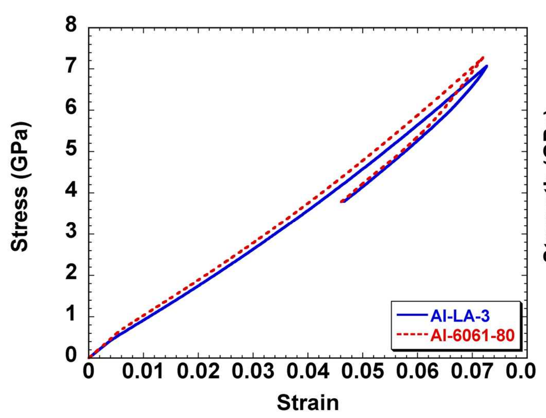
• Eg. Two sets of aluminum specimens with different heat treatments and grains were placed at opposing locations on top and bottom panels.

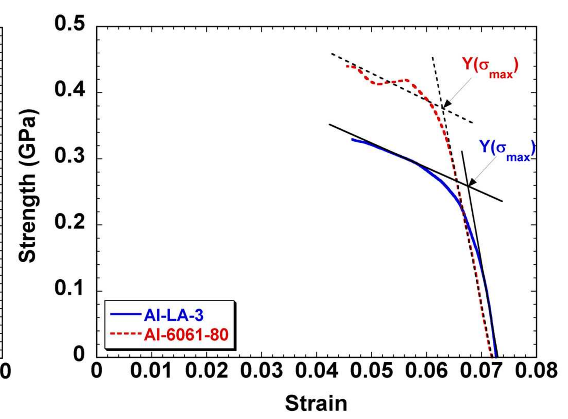
• Using measured velocity profiles, **Lagrangian wave velocities** of aluminum samples during ramp loading and unloading were obtained.









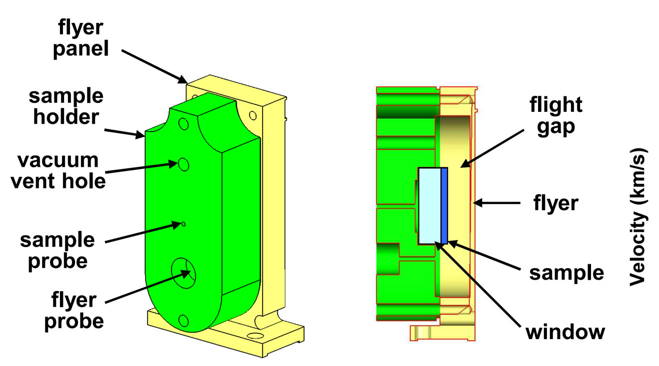


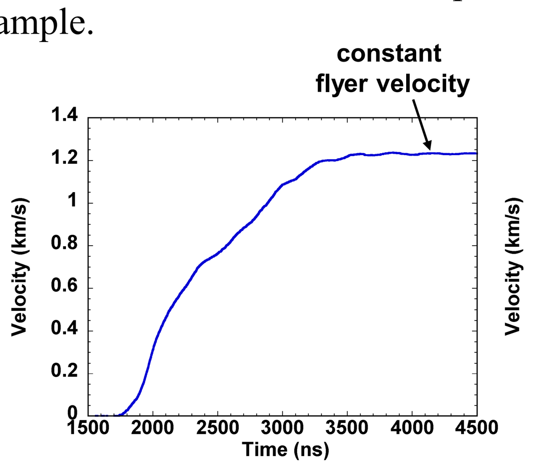
• **Longitudinal stress** and strain were calculated from conservation relationships.

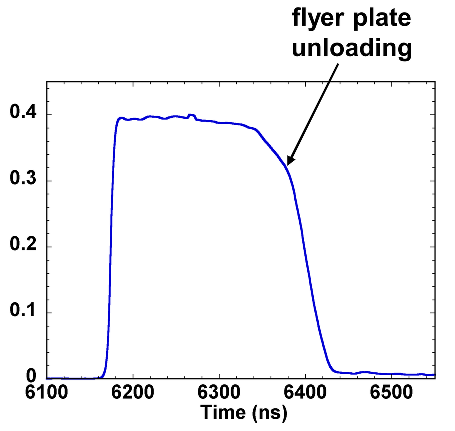
• **Material strength** determined from **difference between loading** and **unloading curves** for a constant strain level.

Launching of flyer plates for shock compression experiments

The load samples are situated at a **flight gap distance** away from the panels. The impulsive pressure produced by ramp loading provides sufficient momentum to launch the panel across the gap at a high velocity **(1-3 km/s)** and impact the load sample.





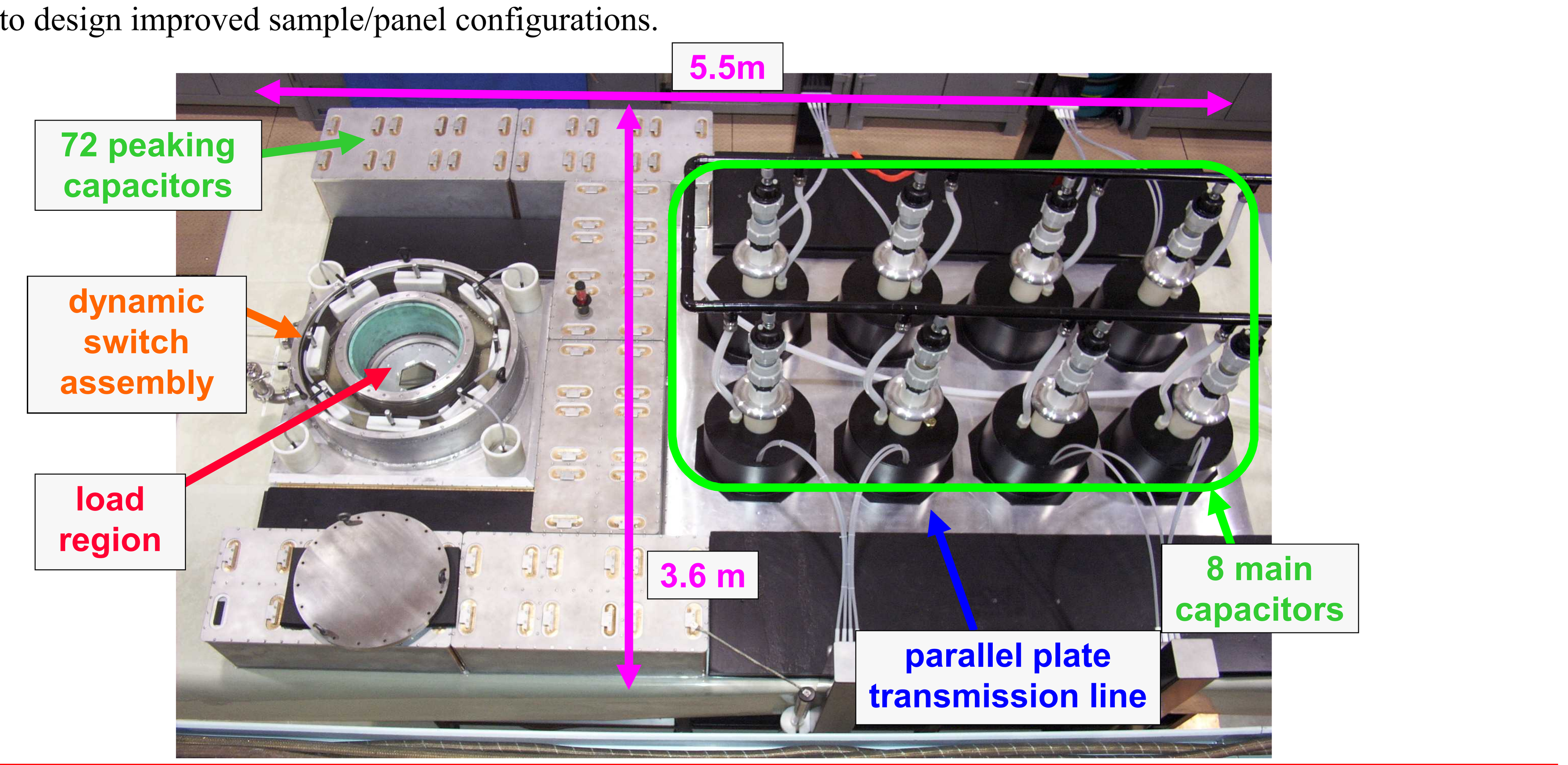


• **Near-ambient density flyer** produces constant pressure drives.

• Measured **free surface velocity** of a 1 mm thick **flyer panel**.

• Measured **particle velocity** of a **shocked sapphire** sample.

Veloce is a medium-voltage, high-current, compact strip-line pulsed power generator developed for isentropic and shock compression experiments. Because of its increased availability and ease of operation, Veloce is well suited for studying isentropic compression experiments (ICE) in much greater detail than previously allowed with larger pulsed power machines such as the Z accelerator. Since the compact pulsed power technology used for dynamic material experiments has not been previously used, it is necessary to examine several key issues to ensure that accurate results are obtained. In the present experiments, issues such as panel and sample preparation, uniformity of loading, and edge effects were extensively examined. In addition, magnetohydrodynamic (MHD) simulations using the ALEGRA code were performed to interpret the experimental results and to design improved sample/panel configurations.



▪ **8, 4-μF Haefely capacitors charged to an absolute maximum voltage of 70 kV.**

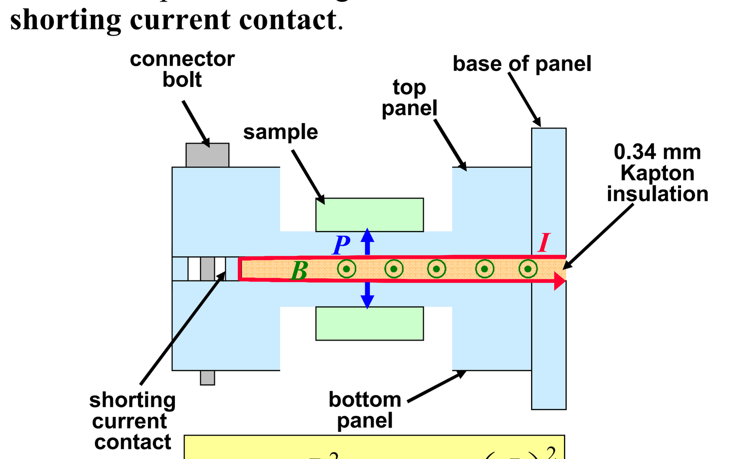
▪ **Maximum current of 3.0 MA in 440-530 ns into a load with magnetic pressures of 50-200 kbar.**

EXPERIMENTAL CONFIGURATION

Current flows from the dynamic switch assembly (DSA) into the load region which is enclosed inside a load chamber filled with N_2 **gas**. On the hex-plate, a set of load panels are attached nearest to the main capacitors for maximum current flow.

• Two load panels ("top" and "bottom") are separated by 12 layers of **Kapton polyimide film**.

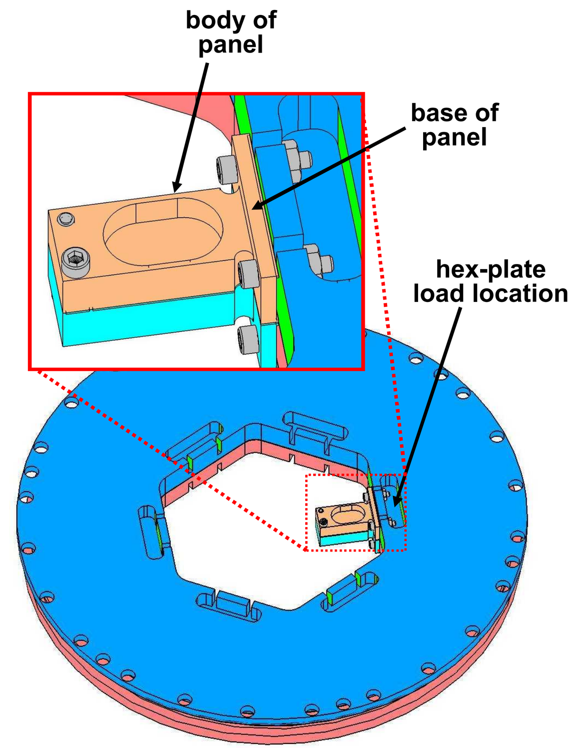
• Insulating Kapton constrains current flow between top and bottom panels to along inner surfaces between via a **shorting current contact**.



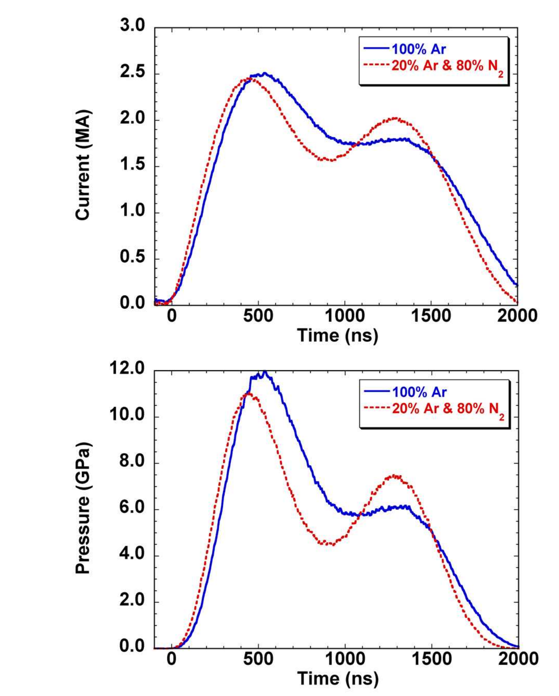
$$P = k_E \frac{B^2}{2\mu_0} = k_E \frac{\mu_0}{2}\left(\frac{I}{w}\right)^2$$

• Cross-section view of load region depicts **J x B force** exerted on load panels and samples.

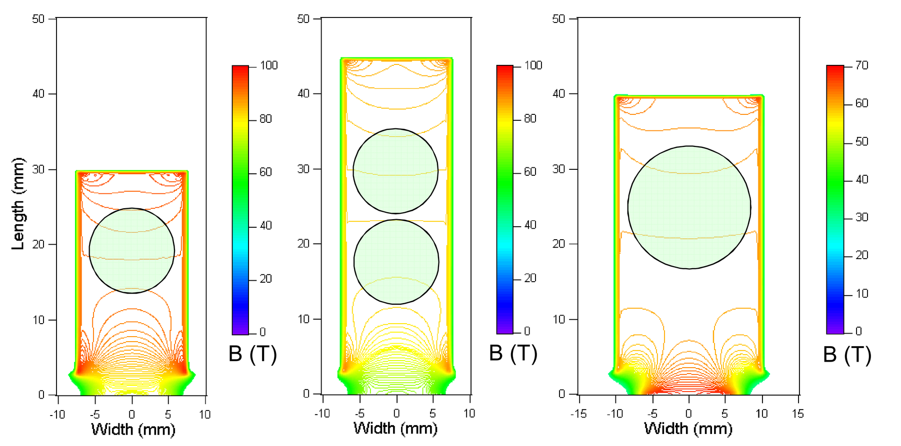
• View of top and bottom load panels attached to top and bottom load hex-plates



• Typical current profiles attained with two gas mixtures in DSA, and resulting pressure pulse at load.



Three panel configurations



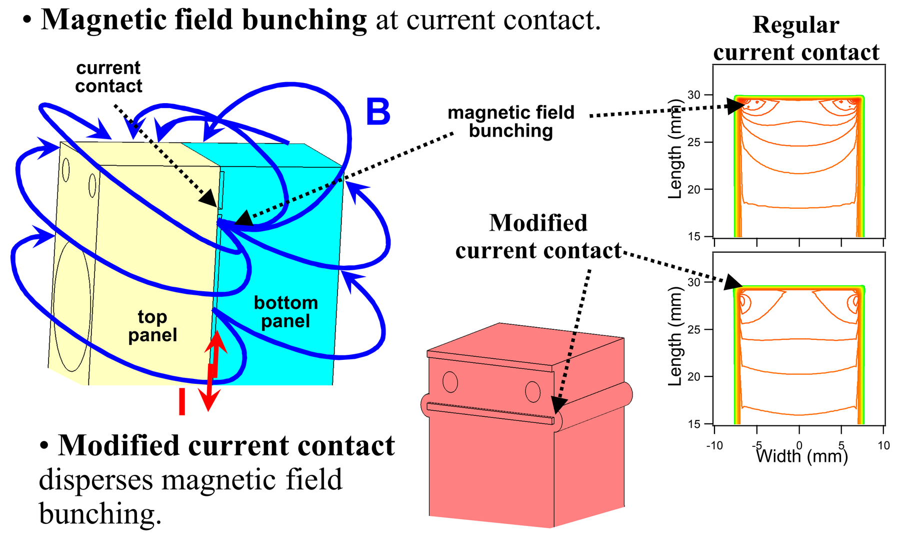
15 x 35 mm panel
One sample,
12 mm diameter

15 x 50 mm panel
Two samples,
12 mm diameter

20 x 45 mm panel
One sample,
17 mm diameter

Panel improvements

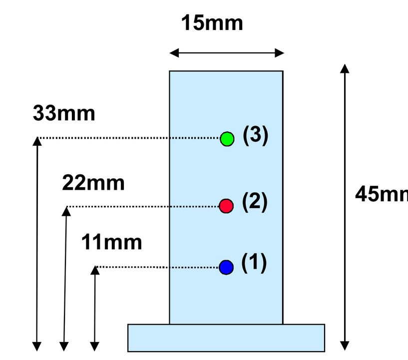
• **Magnetic field bunching** at current contact.

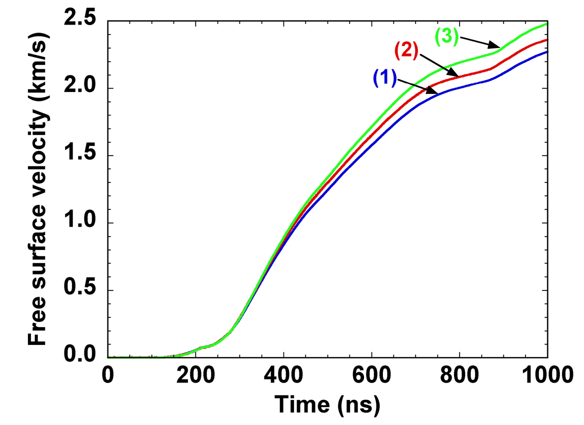


• **Modified current contact** disperses magnetic field bunching.

UNIFORMITY OF LOADING

A **steady increase** in the **measured particle velocity** from the lower panel section to the upper panel section. A **velocity deviation of ~ 5%** was observed between locations (1) & (2), and as much as **10%** between locations (1) & (3).





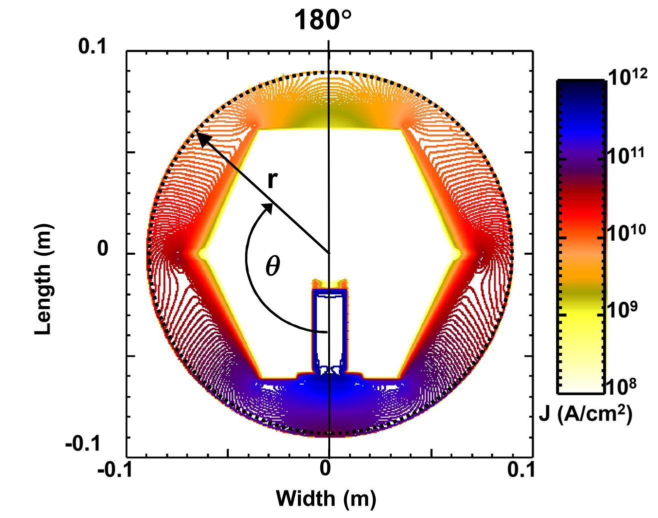
• From 2D hydrocode simulations, in order to produce accurate EOS measurements the input pressure variation across a sample is required to be less than **2%**.

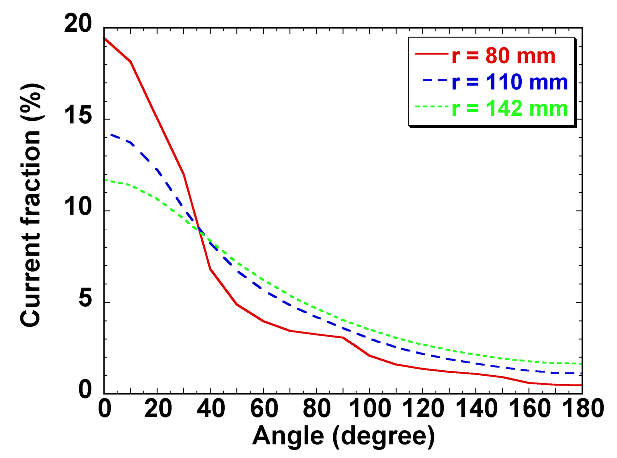
3D MHD ALEGRA calculations

3D MHD simulations were performed with the **ALEGRA** code to understand the cause of the nonuniformity along the panels. The MHD simulations used to optimize configurations that **minimize pressure drive gradients**.

Nonuniform angular current distribution

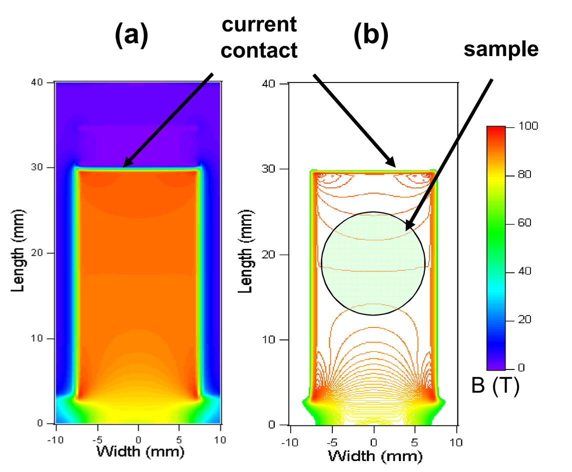
• The current fraction at each angular location is calculated by dividing the current density at that angle (θ = 0-180°) by the total current density within the circular area of radius r = 80, 110, 142 mm.



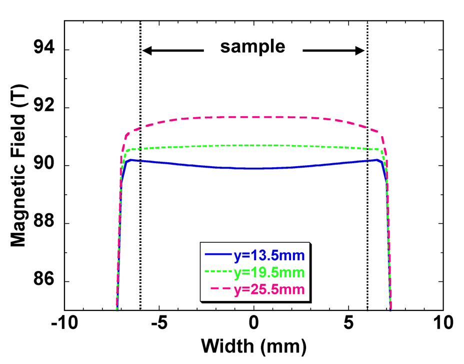


Simulation of 15 mm wide x 35 mm long Al panel

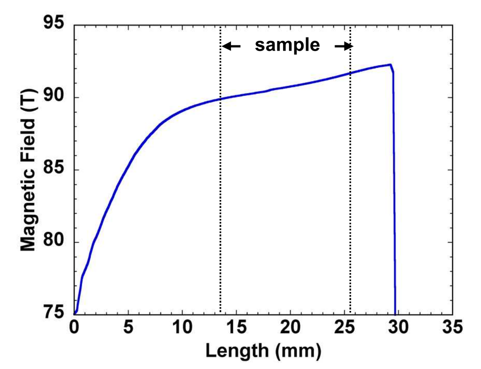
• Magnetic field at inner surface of the panel: (a) false color image, and (b) contour plot; 0.5 T difference between the isolines; with a 12 mm diameter **sample placed at the optimal location**.



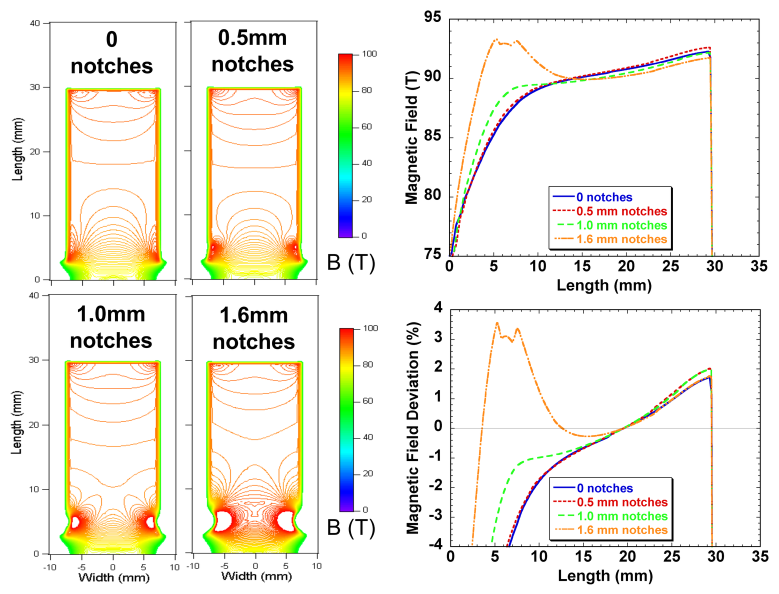
• Horizontal lineouts of the magnetic field at y = 13.5, 19.5, and 25.5 mm.



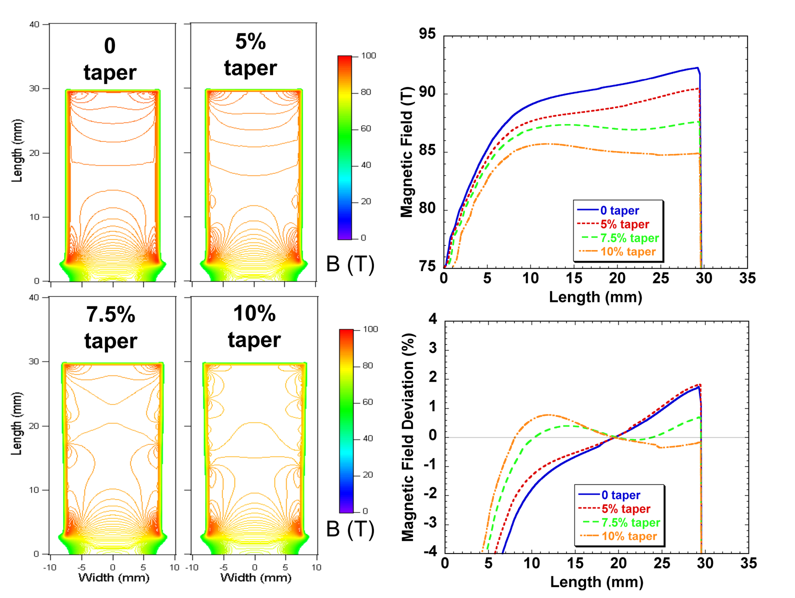
• A lineout of the magnetic field along the panel's central axis (x=0).



• The effect of **notches on panel**: 0, 0.5, 1.0, and 1.6 mm notches radii. Lineouts along the central axis of the panel.



• The effect of **tapering panel**: 0, 5, 7.5, and 10% tapers. Lineouts along the central axis of the panel.



National Nuclear Security Administration

Sandia is a multi-program laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Sandia National Laboratories