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# VISAR Unfold Analysis of MagLIF Laser Blast Wave Experiments

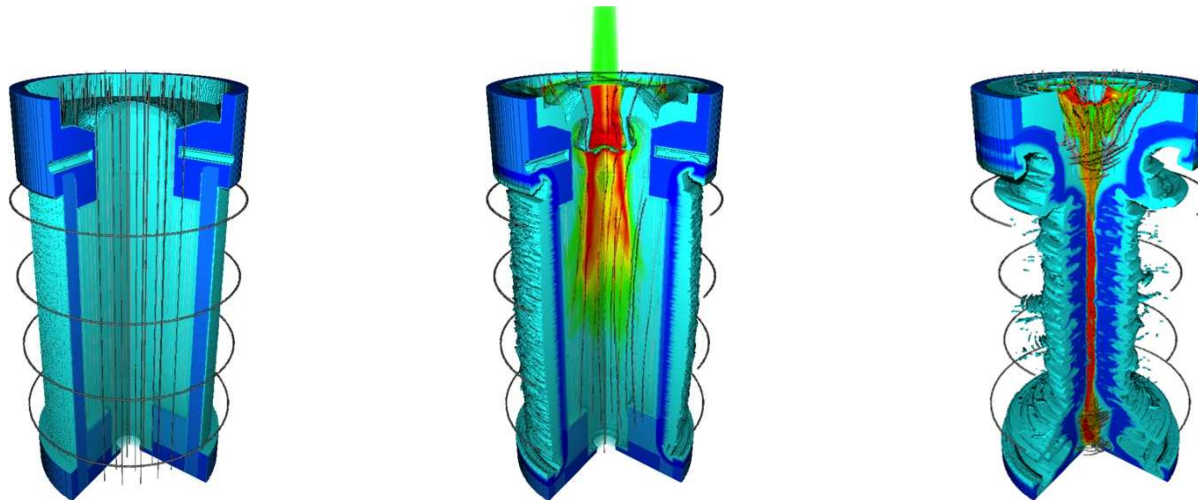
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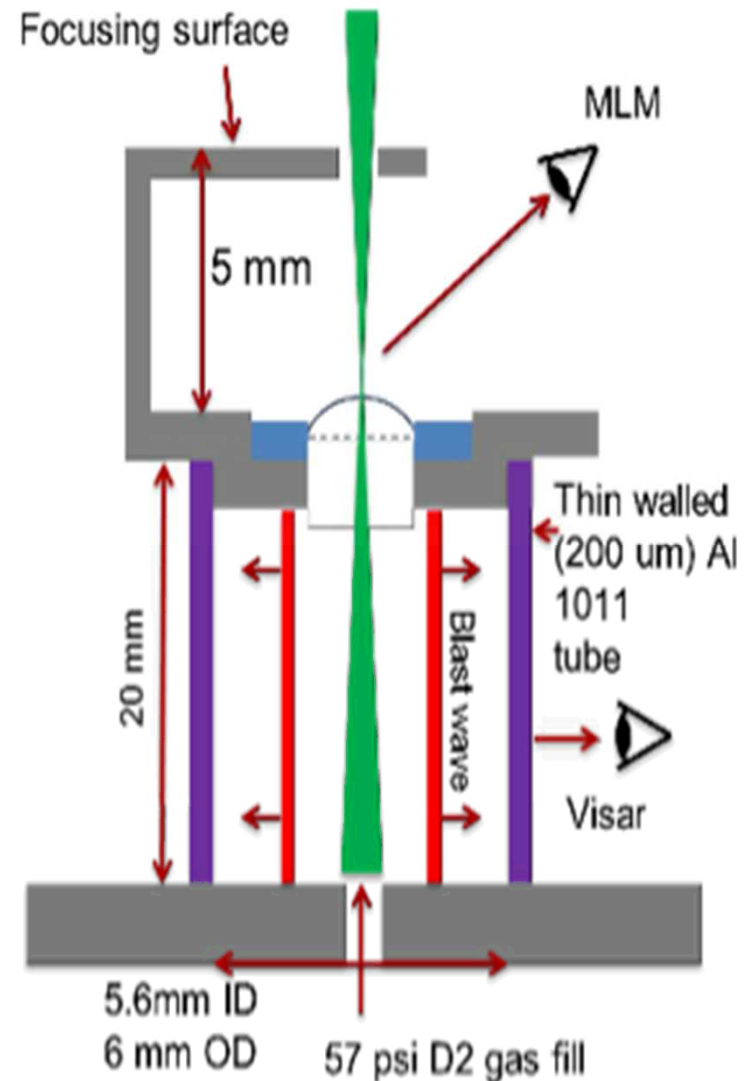
# Motivation

- A novel fusion concept called MagLIF (Magnetized Liner Inertial Fusion) is currently under development at Sandia.
  - A cylindrical metal liner, e.g. Al or Be, that contains a fuel is initially axially magnetized.
  - The fuel is preheated with a laser.
  - The liner, fuel, and magnetic field are all compressed with high-current magnetic drive, e.g. Z machine, which can lead to fusion relevant conditions in the fuel.
  - The compressed axial magnetic field gives reduced electron thermal heat conduction losses and increased ion confinement.



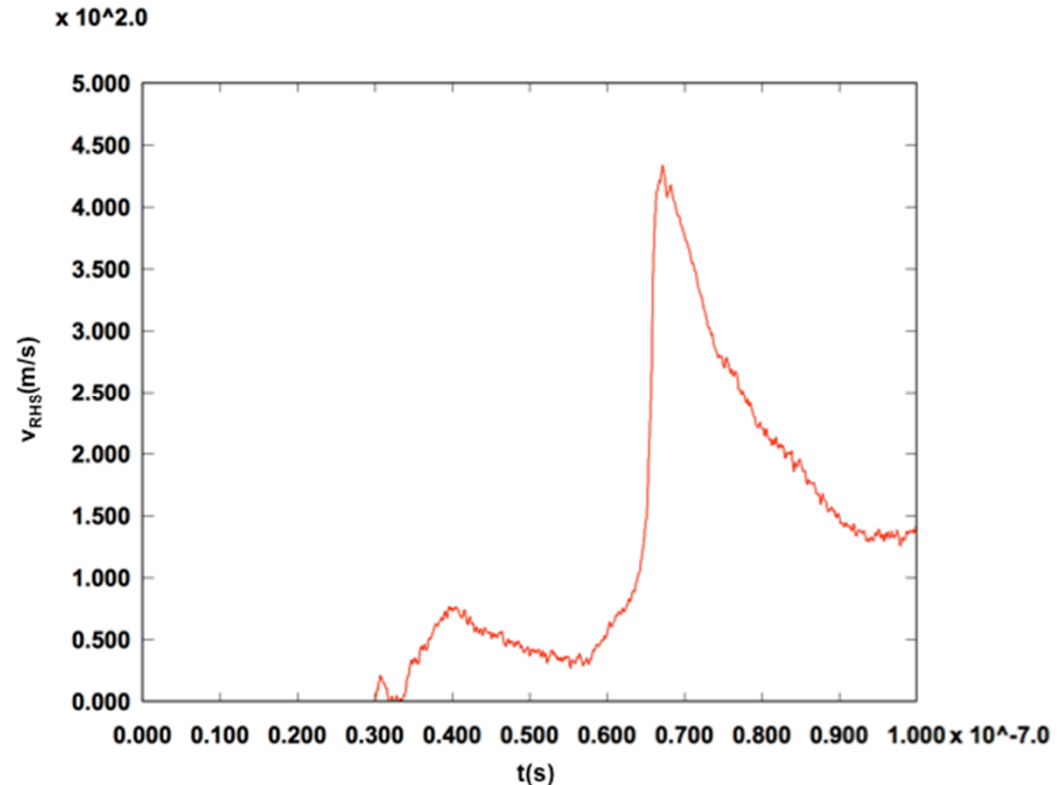
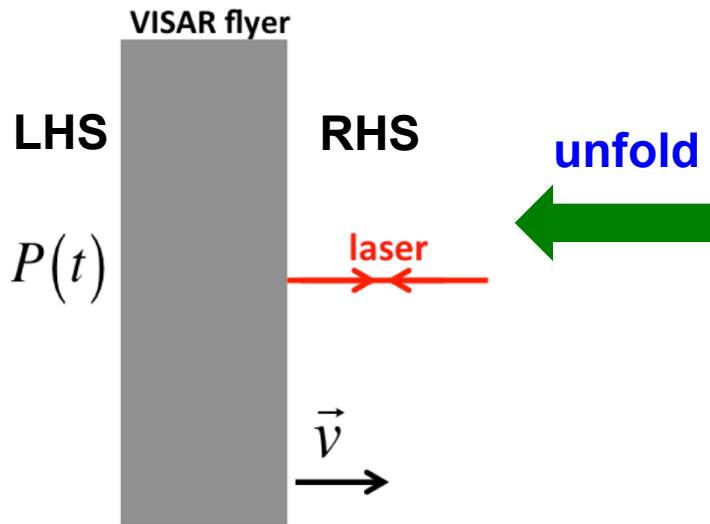
# Laser Blast Wave Experiment

- A laser blast wave experiment using the Z Beamlet Laser (not firing Z) to test the preheat component of MagLIF was performed.
- VISAR was fielded at 15 locations: 3 LOS (30 , 150, 280) and 5 axial locations: 3.59 mm, 5.71 mm, 7.84 mm, 9.96 mm, and 12.09 mm from the LEH.



# VISAR Unfolds

- The laser blast wave produces a pressure,  $P(t)$ , as a function of time on the inner liner surface.
- This translates into motion of the outer liner surface that is tracked by the VISAR diagnostic as a  $v(t)$  (velocity vs. time) trace.
- We developed an efficient method for unfolding  $P(t)$  using:
  - each unfold takes about 30 seconds
  - runs on Python script



# New Unfold Method

- The method is decomposed into two parts: low-pressure regime component and a high-pressure regime component

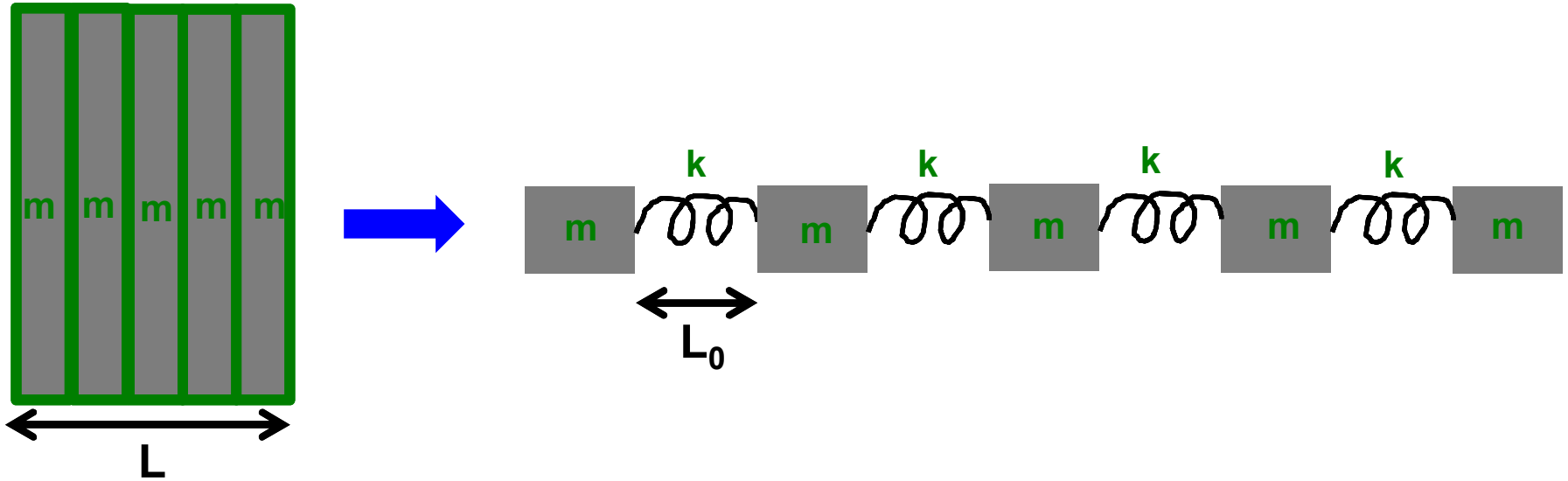
## Low-Pressure Component

- Model flyer as infinite series of mass and springs
- Applicable when  $P \ll \rho c^2$
- Ideal for modeling the low pressure “foot” of the blast wave
- Assume speed of sound,  $c$ , and flyer thickness is constant (pressure is not continuously differentiable at  $P = 0$ )

## High-Pressure Component

- Utilizes EOS tables, e.g. SESAME, to model  $P(\rho)$  and  $c(\rho)$  in flyer
- Utilizes pressure/momentum continuity at both boundaries
- Accounts for time-dependent thickness change of flyer and appropriate time-delay response between LHS and RHS

# Low-Pressure Component



## Mass-Spring Equations:

$$ma_1 = m \frac{d^2 x_1}{dt^2} = -k(x_1 - x_2 - L_0) + F(t)$$

$$ma_j = m \frac{d^2 x_j}{dt^2} = -k(x_j - x_{j+1} - L_0) + k(x_{j-1} - x_j + L_0)$$

$$ma_N = m \frac{d^2 x_N}{dt^2} = k(x_{N-1} - x_N + L_0)$$

## Velocity Response:

$$M = \rho AL \quad P = F/A \quad k = NMc^2/L^2$$

$$v_N \rightarrow v_{RHS}(t) = \sum_{k=0}^{\infty} \frac{2P(t - (2k+1)L/c)}{\rho c}$$

# High-Pressure Component

We assume that the temperature remains small and constant. The pressure and sound speed are functions of density given by the EOS table, e.g. AI 3700/3719.

The density and velocity of the LHS can be found from pressure continuity and momentum conservation at the LHS boundary.

Ignoring density variations due to reflections, momentum conservation yields the VISAR (RHS) velocity in terms of the LHS velocity.

$$P(\rho)$$

$$c(\rho) = \sqrt{dP/d\rho}$$

$$P(\rho_{LHS}) = P_{ext}(t) \Rightarrow \rho_{LHS}(t) = P^{-1}(P_{ext}(t))$$

$$v_{LHS}(t) = \int_0^{P_{ext}(t)} \frac{dP}{\rho_{LHS} c(\rho_{LHS})}$$

$$v_{RHS}(t) = 2v_{LHS} \left( t - \frac{L\rho_0}{c(\rho_{LHS}(t))\rho_{LHS}(t)} \right)$$

# High-Pressure Component

- Given a VISAR velocity data, we want to unfold the time-dependent pressure.

$$v_{RHS}(t) = \rho_{LHS} \left( t - \frac{L\rho_0}{c(\rho_{LHS}(t))\rho_{LHS}(t)} \right) \int_{\rho_0} \frac{2c(\rho)d\rho}{\rho}$$

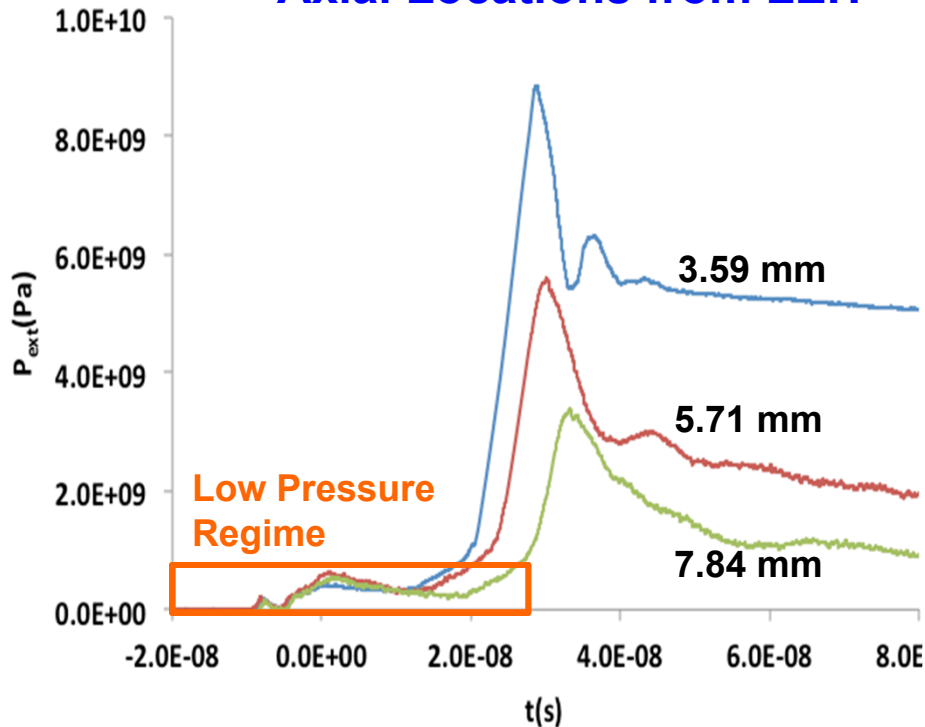
- For each time  $t$ , we numerically integrate the above expression to find  $\rho_{LHS}$ . Then we time shift the LHS density to produce  $\rho_{LHS}(t)$ . The LHS density immediately yields the time-dependent external pressure

$$P(\rho_{LHS}) = P_{ext}(t)$$

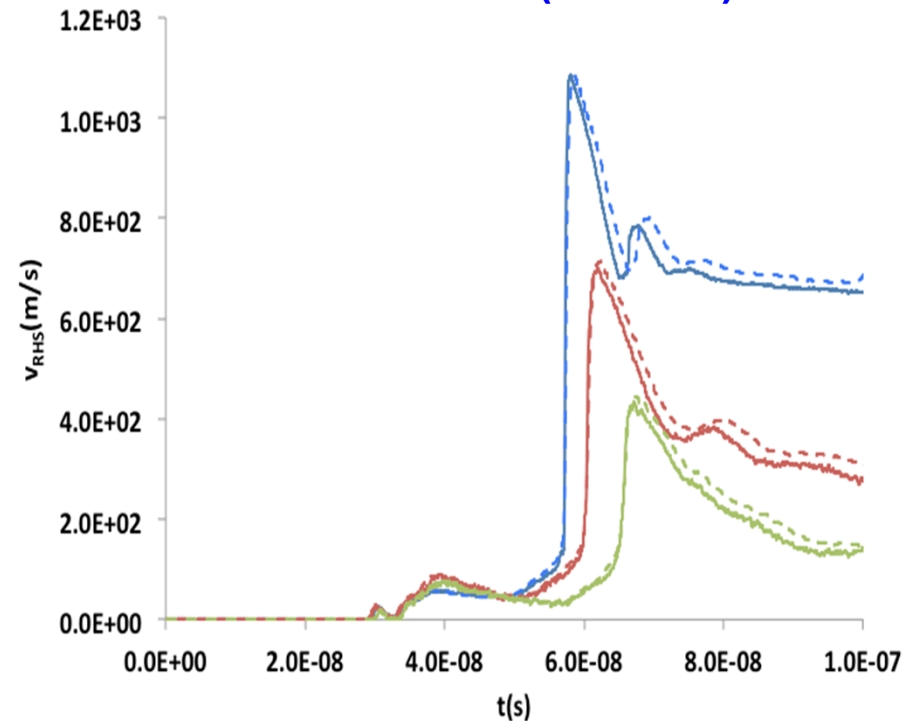
# Laser Blast Wave Unfolds

- The simulated VISAR velocities using the Sandia code ALEGRA\* with the unfolded pressure from our method gives excellent agreement with VISAR data.

**Pressure Unfolds at Different Axial Locations from LEH**



**VISAR Data (solid) vs. ALEGRA\* Simulations (dashed)**



# Current Limitations

- At present, we have not yet included any thermal effects, as well as, material strength models (under development).
- Although the low-pressure component includes the effect of reflections, this has not yet been included in the high-pressure component of the unfold (under development).
- For the laser blast wave experiments, there is the possibility that some material of the inner liner surface could be ablated. This effect is not included in our model.

# Conclusions

- We have a method for efficiently unfolding pressure driven VISAR data, which has been successfully implemented in Python.
- The method incorporates EOS tables, as well as an appropriate time-delay response, to correctly unfold the pressure.
- The model has been utilized to predict the time-dependent pressure of laser blast waves in MagLIF.
  - We are currently working to infer the energy deposition into the MagLIF fuel from the pressure.
- Thank you for your time!