SAND2014-15647PE

Sandia National Laboratories

July 16th, 2014

15th International Detonation Symposium
San Francisco, CA

Analysis of the Equation of State and Initiation Model for TATB-based LX-17

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Motivation and Objectives

- Successful modeling of explosives and explosives systems requires reliable Unreacted EOS, initiation model, and detonation product EOS
- LX-17 is of interest because of its extreme insensitivity to shock initiation.
- Determine an unreacted EOS for TATB-Based LX17
- Develop a 1D experimental technique to probe the initiation model and detonation product EOS
- Test EOS and initiation models against the experimental data

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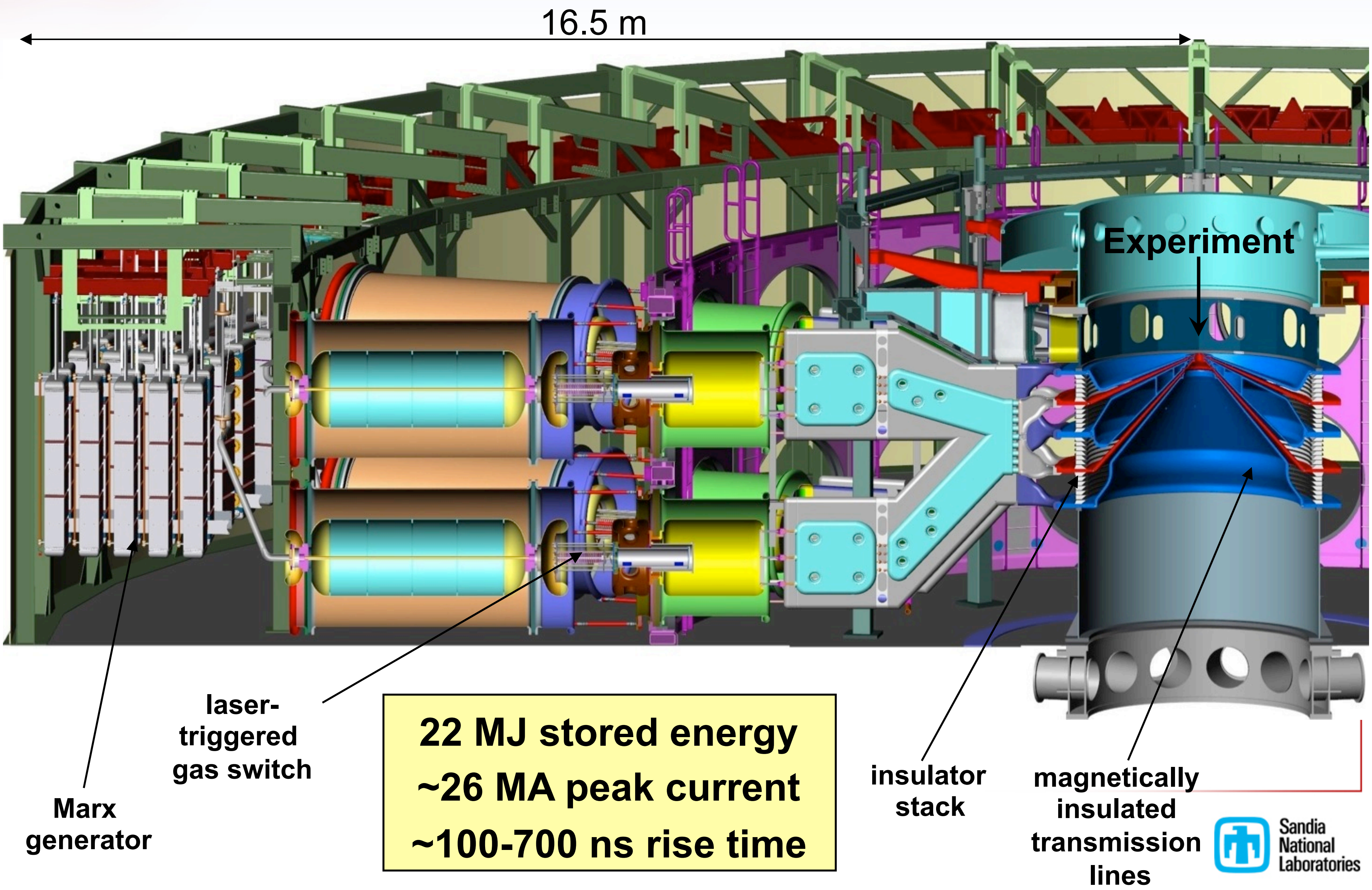
Methods

- Shockless compression experiments using the Sandia ZR-Machine to determine unreacted EOS
- Modified Goranson Metal Plate experiments to provide data for testing initiation and EOS models
- Simulation comparison to experimental VISAR data
- CTH/Dakota optimization methods for determining parameters for the initiation model

Experiments on LX-17:

LX-17-1		92.5 wt% TATB ρ = 1.93 g/cc Mean particle size ~35μm	7.5% Kel-F 800 ρ = 2.017 g/cc	1.90 ± 0.01 g/cc (~1.85 % void)

The Sandia Z Machine



22 MJ stored energy
~26 MA peak current
~100-700 ns rise time

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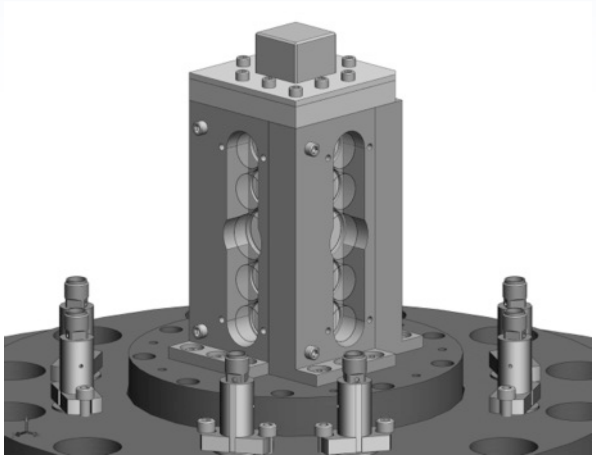
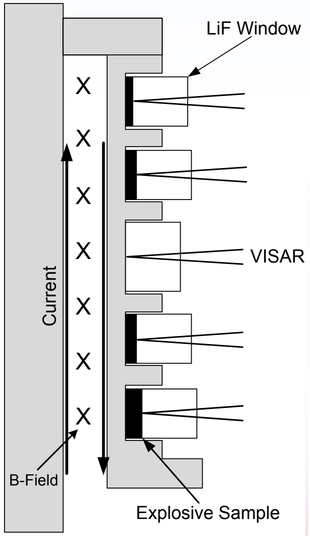
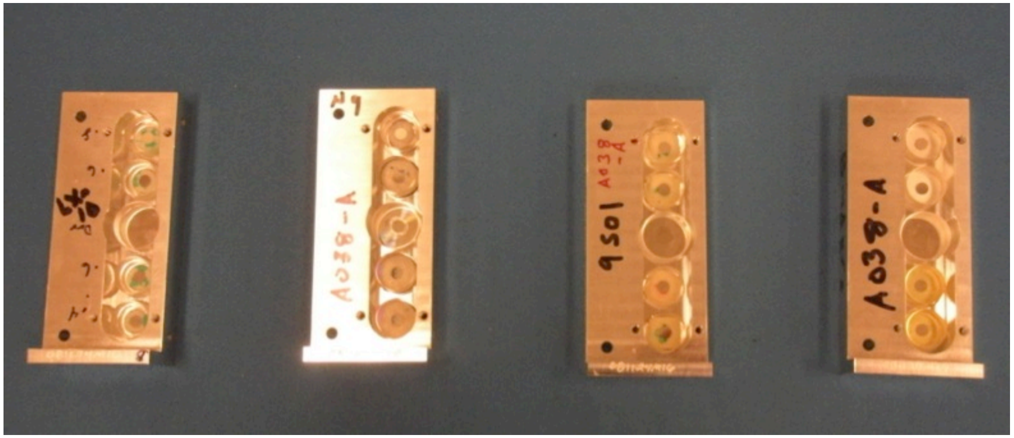
Experimental Setup: Z Shockless Compression

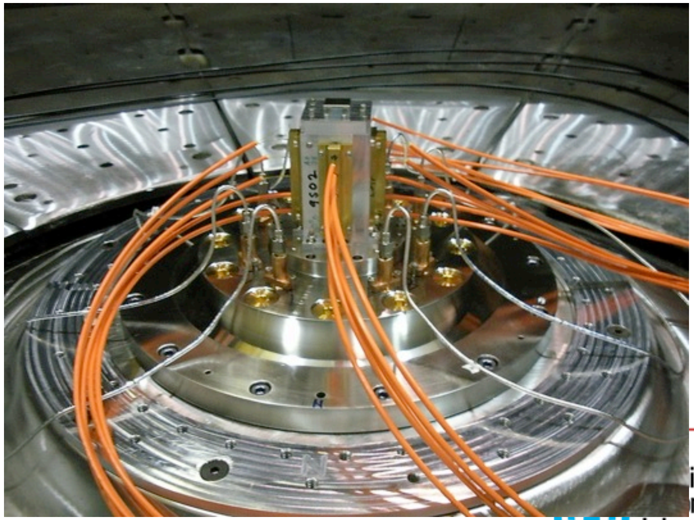
- 4-sided, 6061-T6 Al 'cube'
- Explosive Samples: 0.4 mm, 0.6 mm, 0.8 mm (four samples/panel)
- LiF VISAR windows
- 20 Total VISAR measurements





All samples experience similar stress loading path





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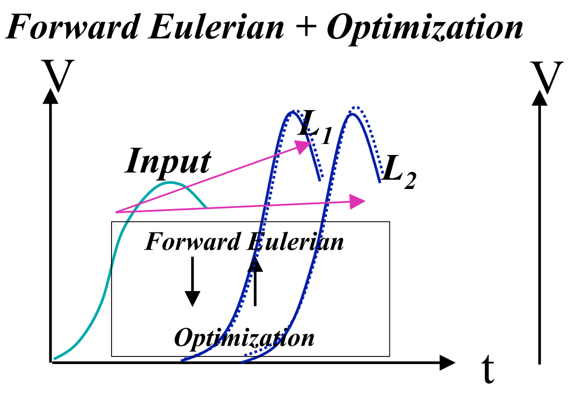
Experimental Results and Analysis

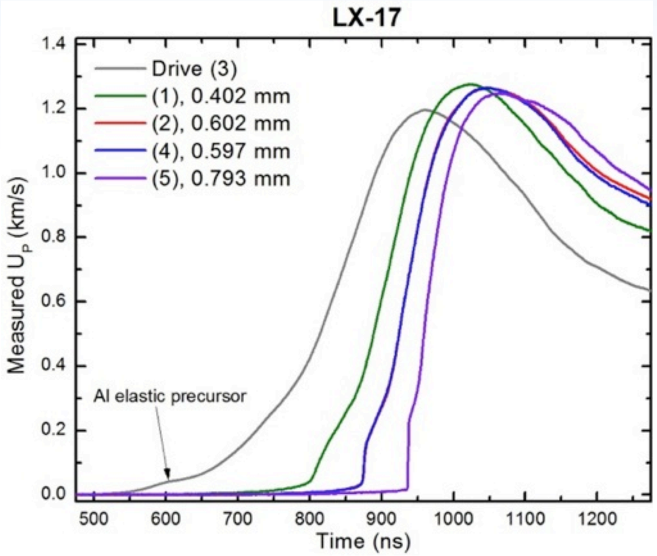
- **No shock formation observed**
- **Data suggests no reactions occurred.**

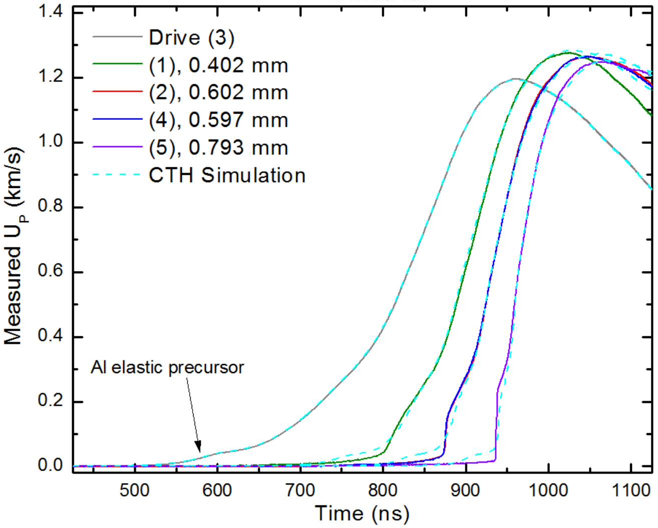


- **Backward Analysis to define input drive**
- **Forward analysis using CTH and DAKOTA to optimize EOS parameters to match experimental data**
- **Quadratic U_S-U_P Mie-Gruneisen EOS for the unreacted LX-17**
- **DAKOTA optimizes C_0, S_1, and S_2**

$$U_S = C_0 + S_1 U_P + \frac{S_2}{C_0} U_P^2$$

c_0=2.411 [mm/µs], s_1=2.177 and s_2=-0.406



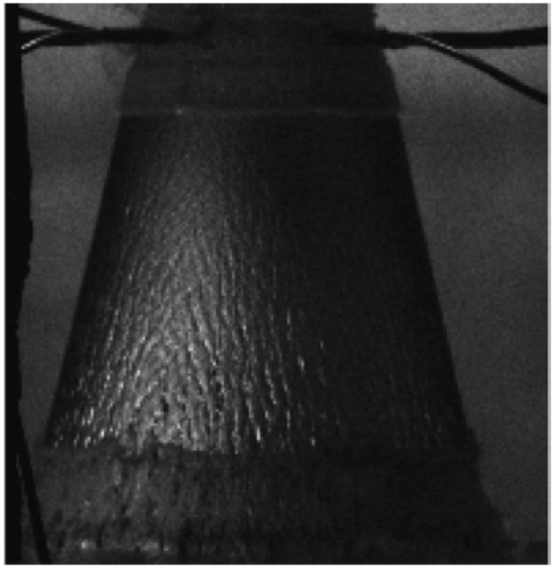


M. R. Baer, S. Root, *et al.*

Detonation Product Equation of State

Cylinder tests:

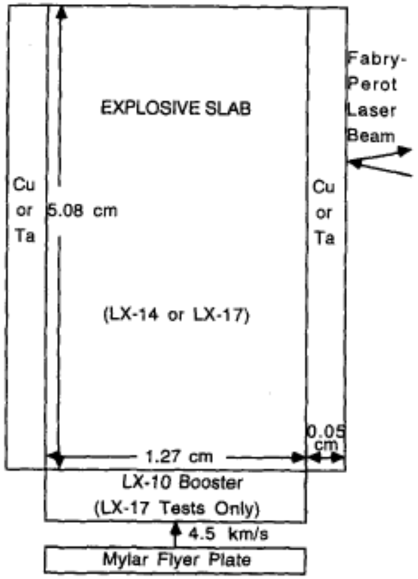
- **Velocity is multi-dimensional**
- **Velocity interferometry on wall sides – tilt corrections**
- **Measurement is not in direction of detonation propagation**
- **Need to account for spall and damage effects in simulations**



Souers *et al.*, Prop. Expl. Pyro. V38, p419, (2013).

Sandwich Plate tests:

- **Velocity is multi-dimensional**
- **Velocity interferometry on wall sides – tilt corrections**
- **Measurement is not in direction of detonation propagation**
- **Need to account for spall and damage effects in the simulations**



Tarver *et al.*, Prop. Expl. Pyro. V21, p238, (1996).

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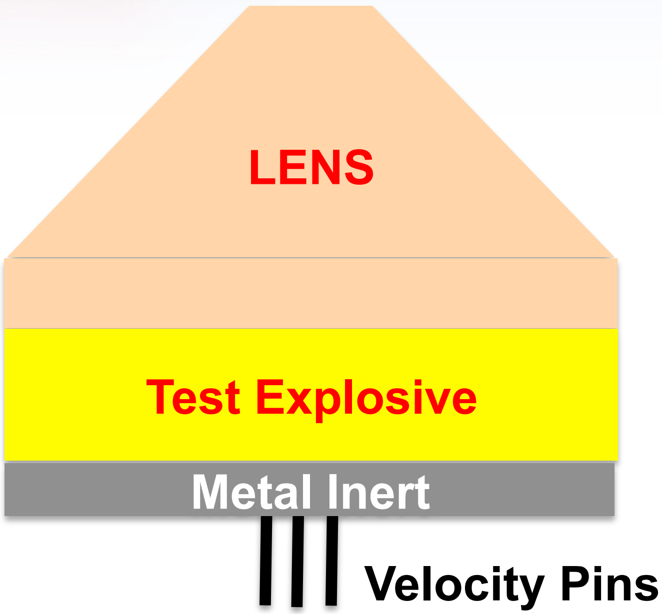
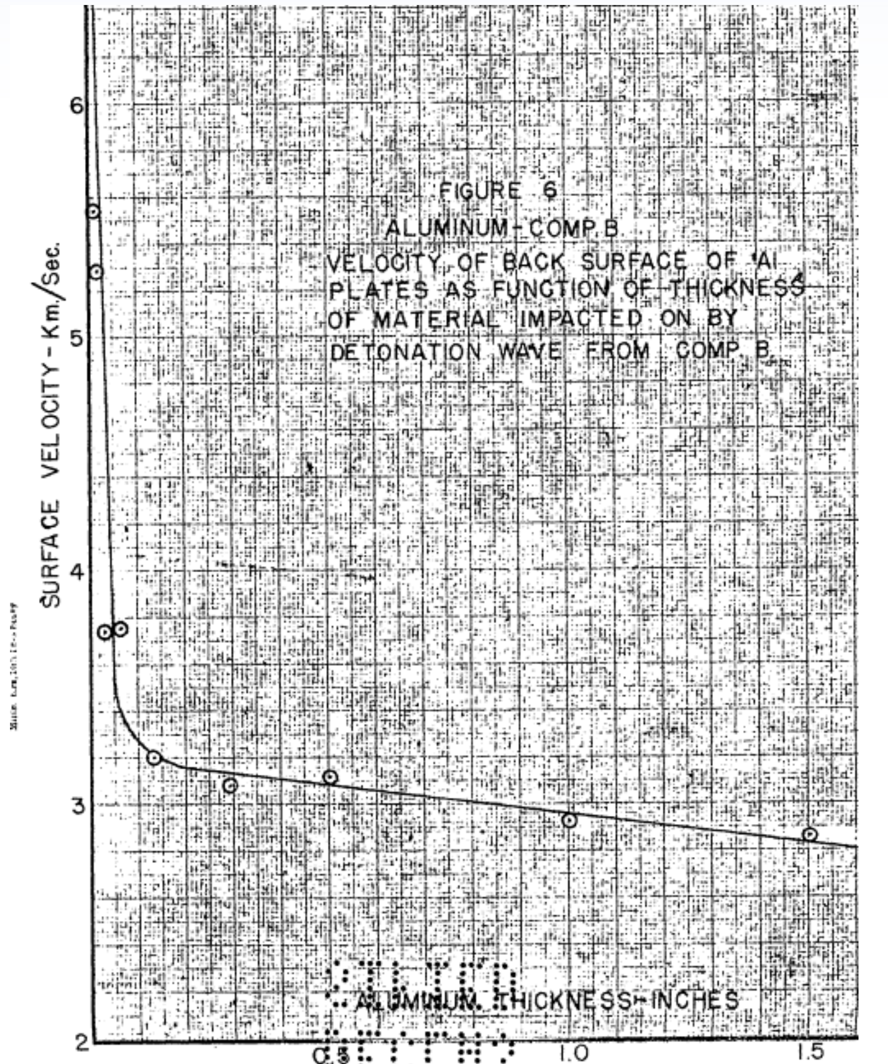
Goranson Test

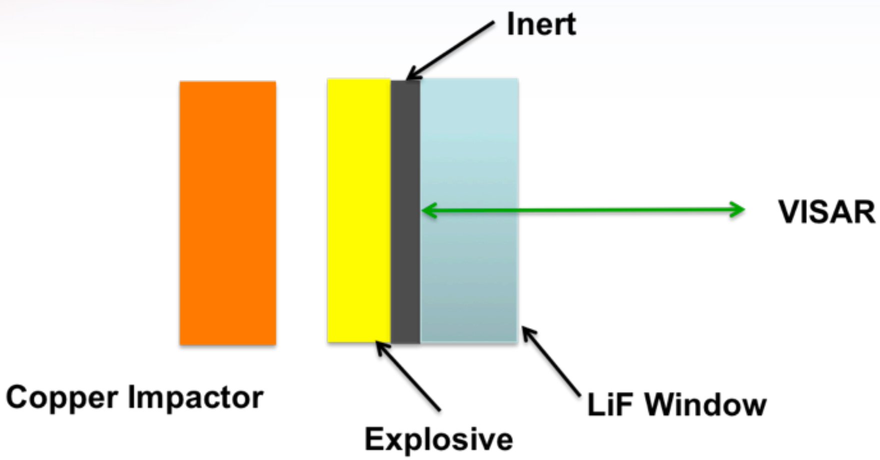


- Goranson Test is 1-D
- Measures free surface velocity of metal inerts of different thicknesses
- Experiments used to determine reaction zone thickness and detonation product EOS

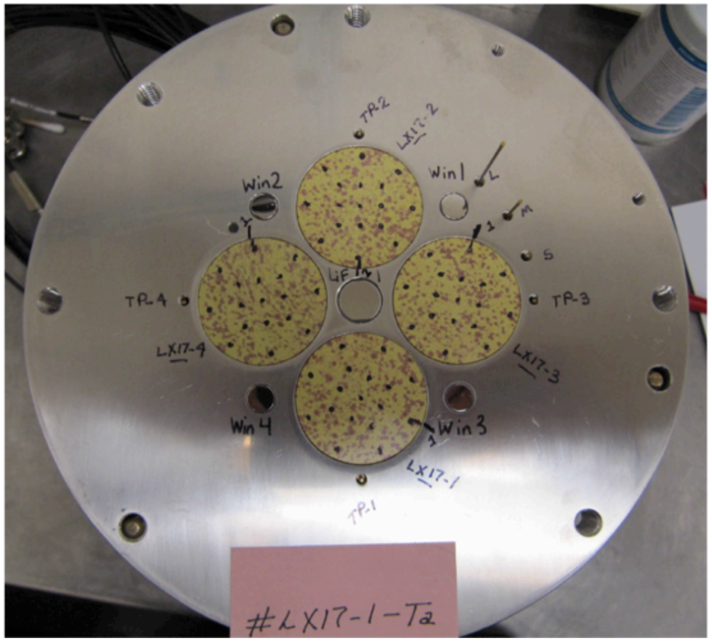


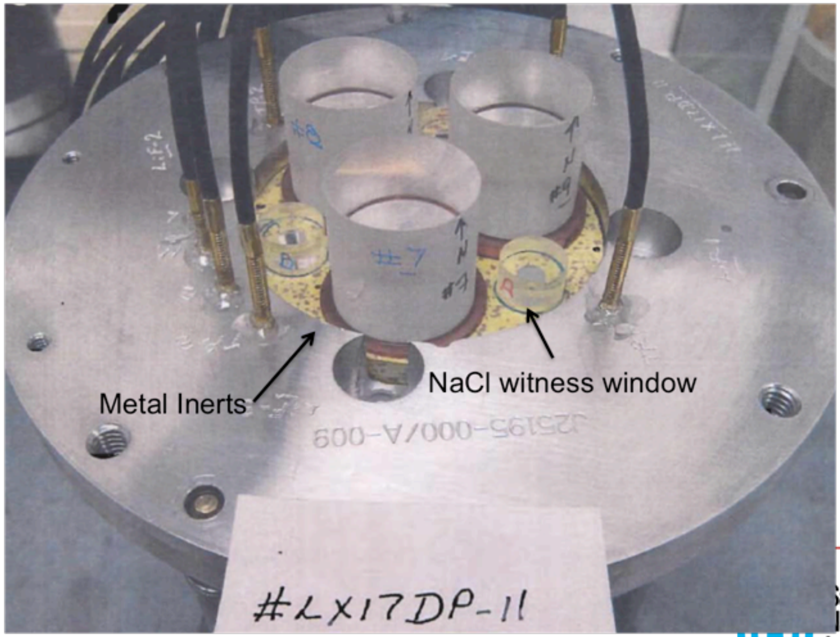
R. W. Goranson, LA-487, (1946)

Modified Goranson Test



- Detonation wave propagates into a metal inert
- Experiment is 1D
- Various thicknesses of inert
- LiF VISAR window used to eliminate possible spall effects





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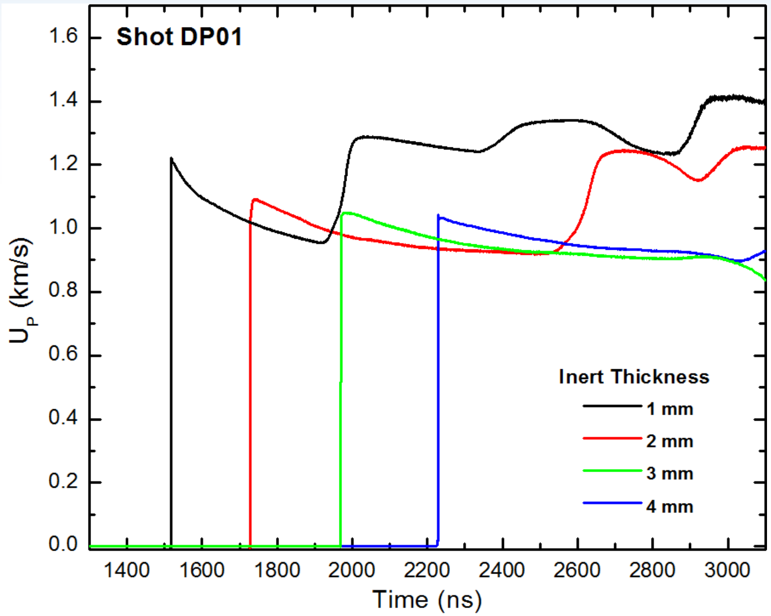
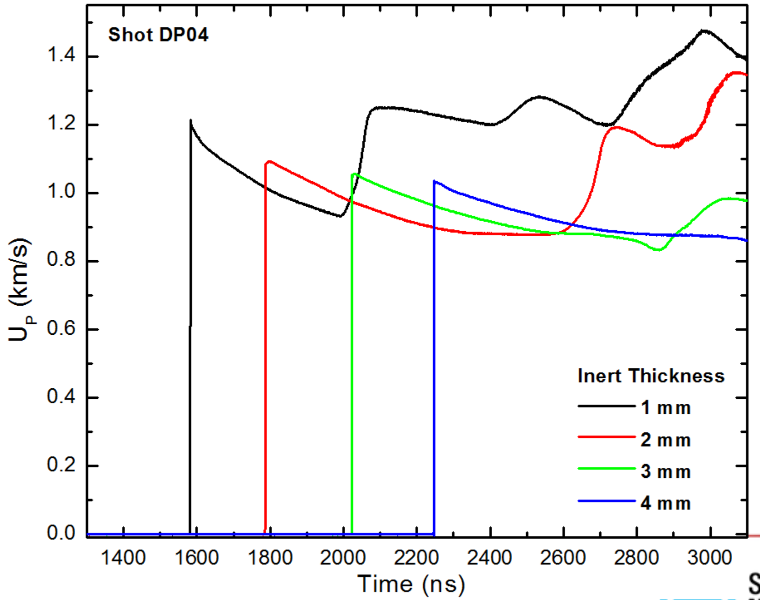
Modified Goranson Test Results

- Copper Impactor: Vf = 2.006 km/s
- LX-17 / Tantalum Stacks:
  - 7.988 mm / 1.017 mm
  - 8.015 mm / 2.004 mm
  - 7.987 mm / 2.978 mm
  - 8.019 mm / 4.002 mm
- LiF Backing Window ~20 mm
- Impact Stress = 16.40 Gpa; Run Dist = 4.15mm



- Copper Impactor: Vf = 1.892 km/s
- LX-17 / Tantalum Stacks:
  - 7.995 mm / 1.022 mm
  - 8.002 mm / 1.977 mm
  - 8.005 mm / 3.016 mm
  - 7.989 mm / 3.990 mm
- LiF Backing Window
- Impact Stress = 15.13 Gpa; Run Dist = 5.38



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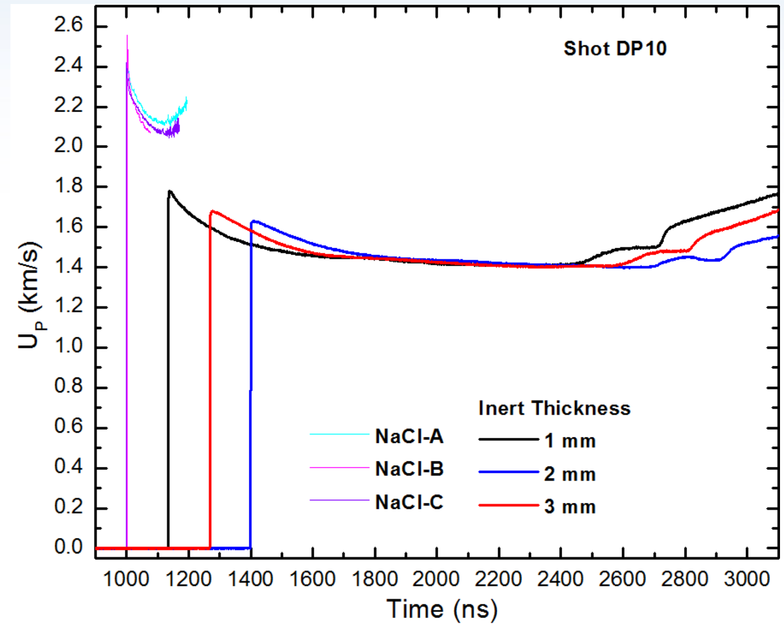
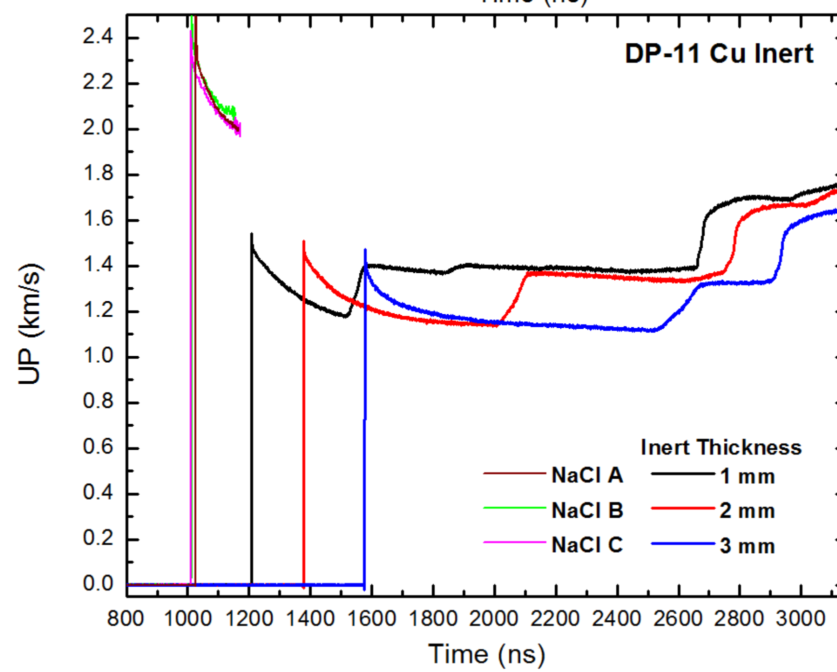
Modified Goranson Test Results

- Copper Impactor: Vf = 2.072 km/s
- LX-17 / Aluminum Stacks:
  - 6.585 mm / 1.003 mm
  - 6.585 mm / 1.995 mm
  - 6.583 mm / 2.989 mm
- LiF Backing Window ~20 mm
- Impact Stress = 17.09 Gpa; Run Dist = 3.63mm



- Copper Impactor: Vf = 2.070 km/s
- LX-17 / Copper Stacks:
  - 6.589 mm / 1.009 mm
  - 6.583 mm / 2.014 mm
  - 6.585 mm / 3.013 mm
- LiF Backing Window ~20 mm
- Impact Stress = 17.05 Gpa; Run Dist = 3.66mm



Simulation Details

- **Linear U_S-U_P Mie-Gruneisen EOS used for the flyer, inert buffers, and the LiF windows**
- **Steinberg-Guinan strength model for the inert materials**

Material	Density (g/cm^3)	C0 (km/s)	S1	Γ
Al	2.703	5.22	1.37	1.97
Cu	8.93	3.94	1.489	1.99
Ta	16.654	3.39	1.22	1.60
LiF	2.638	5.15	1.35	1.69

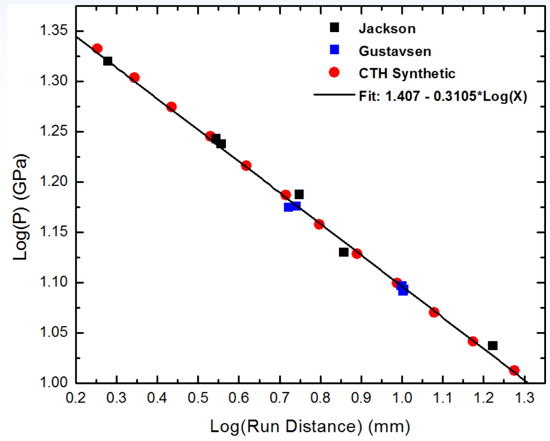
- The quadratic US-UP M-G EOS is used for the unreacted LX-17:

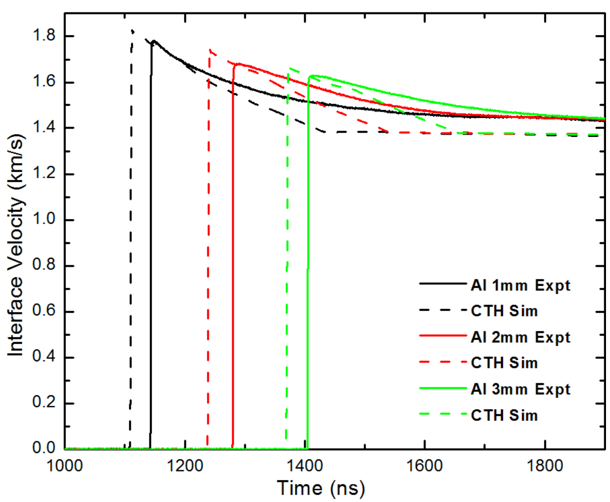
$$U_S = 2.411 + 2.117U_P - \frac{0.406}{2.411}U_P^2;\ \Gamma = 1.1$$

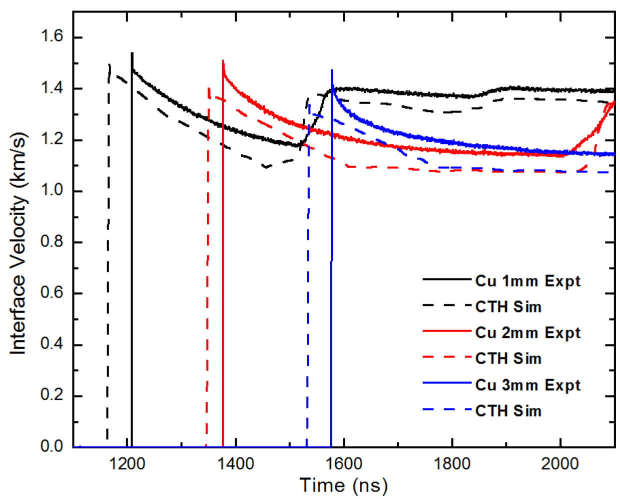
- Detonation Products:
  - Hobbs LX-17 SESAME (in development)
  - The Hobbs SESAME has the correct detonation velocity value compared to the Kerley LX-17 SESAME 8202
- History Variable Reactive Burn for the initiation model
  - HVRB is a 5 parameter model intended to capture Pop-Plot response

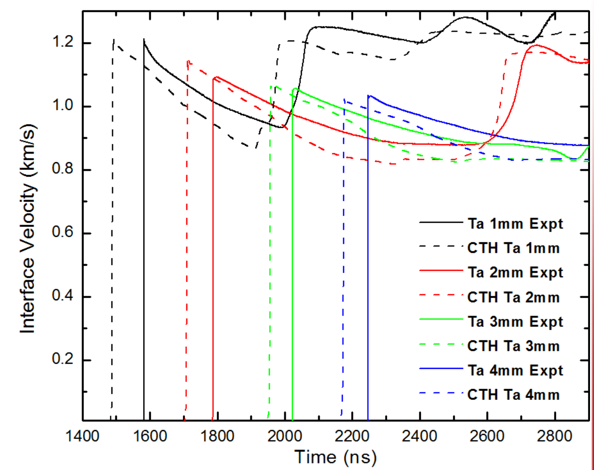
2-Parameter Optimization of HVRB

- Optimization of HVRB to match 1.90 g/cc Pop Plot Data
- Simulations show difference in peak velocity
- Long time velocity is low (up to 7%)
- Timing is always early:
    - ~40 ns for Al and Cu simulations
    - ~70-100 ns for Ta simulations









5 Parameter optimization improves timing, but does not improve velocity profile

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Summary

- Determined an unreacted EOS for LX-17 using shockless compression techniques
- Used a modified Goranson test to examine the initiation model and detonation product EOS
- Optimized the HVRB model to match the Pop-Plot data, but a 2 – Parameter optimization to the nominal Pop-Plot data gives poor results
- Further optimization of the 2 parameters to the less sensitive uncertainty of the Pop-Plot data improves timing
- Comparison to experiment shows that HVRB may not be suited for detailed modeling of non-ideal explosives