SAND2007-3791C

Enhanced Blast Explosives: Research at Sandia National Laboratories

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Work funded jointly by Sandia National Laboratories and the Defense Threat Reduction Agency

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National Nuclear Security Administration

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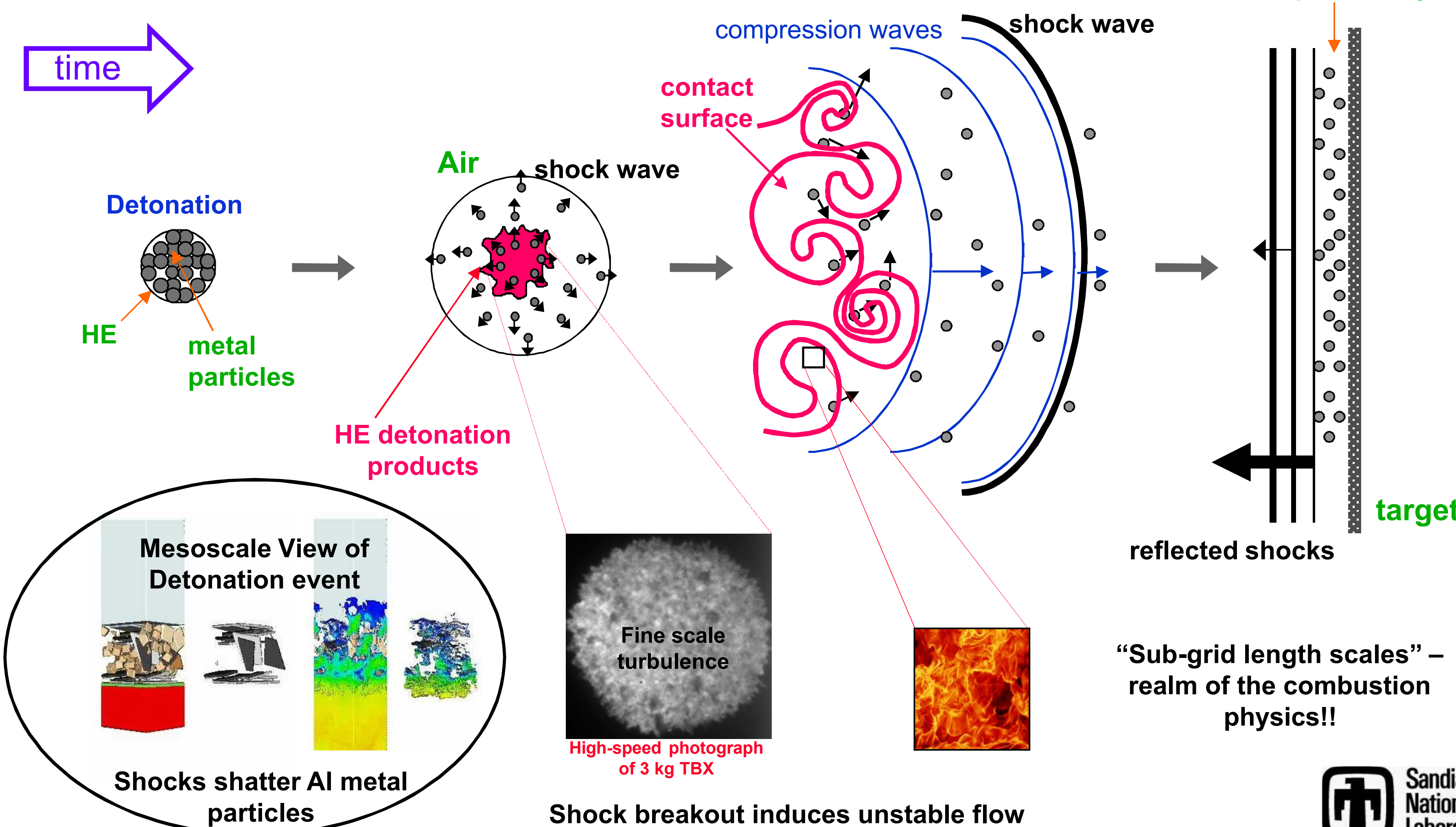
Sequence of "Events"

Flow instabilities induced by expansion / wave interactions and cascade to finer scales



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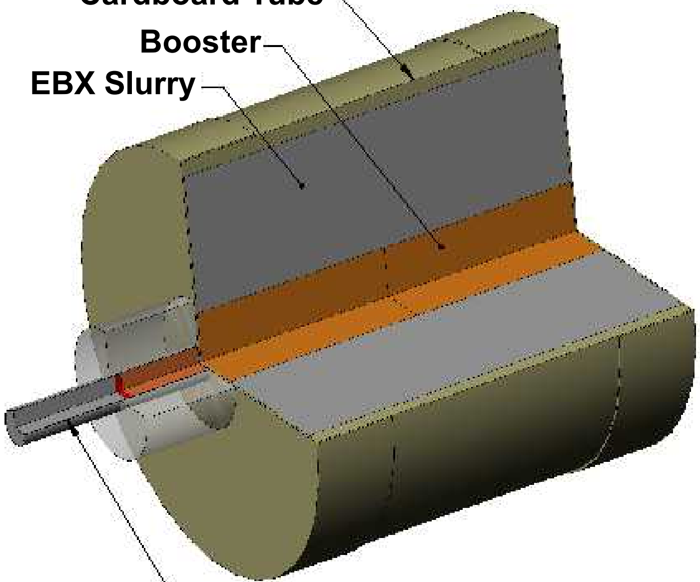
Approach

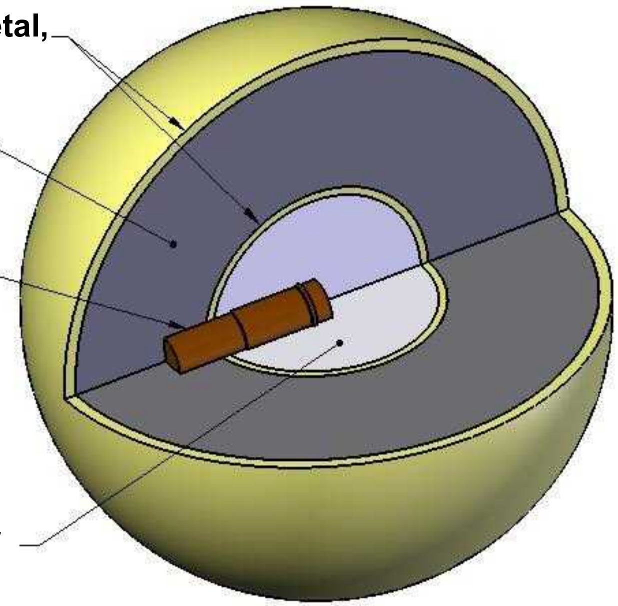
- **Linked modeling-experimental program on enhanced blast explosives (EBX)**
- **Modeling program**
  – CTH (Eulerian shock wave physics code)
  – Goal to develop predictive model of all enhanced-blast "events"
- **Experimental program to**
  – Support model development directly with simple phenomenology studies (charge and containment geometry, single-parameter comparisons, control experiments)
  – Comparative testing of conventional, enhanced blast materials
  – Development of novel diagnostics for evaluating enhanced blast performance and measuring parameters relevant to enhancement
- **Focus of this talk to highlight experimental and modeling capabilities**
  – Charge Description
  – Facilities
    - Chambers (Explosive Components Facility (ECF) Walk-in Chamber, "Big Blue")
    - Firing Areas (Terminal Ballistics Facility (TBF), ECF flash radiography pad)
    - ECF Gas Gun

EBX Charges

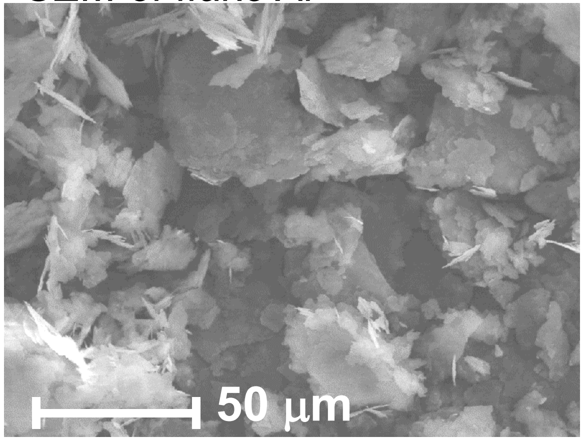
Cylinder (courtesy Rich Lottero, ARL)



Sphere



SEM of flake Al



- Primarily composed of RDX, IPN
- Aluminum particle sizes
  - flake (~100 nm thick, 20 microns across)
  - 120 nm (1.5-2.5 nm oxide layer, 5-15%)
  - 50 nm (1-2 nm oxide layer, 20-30%)

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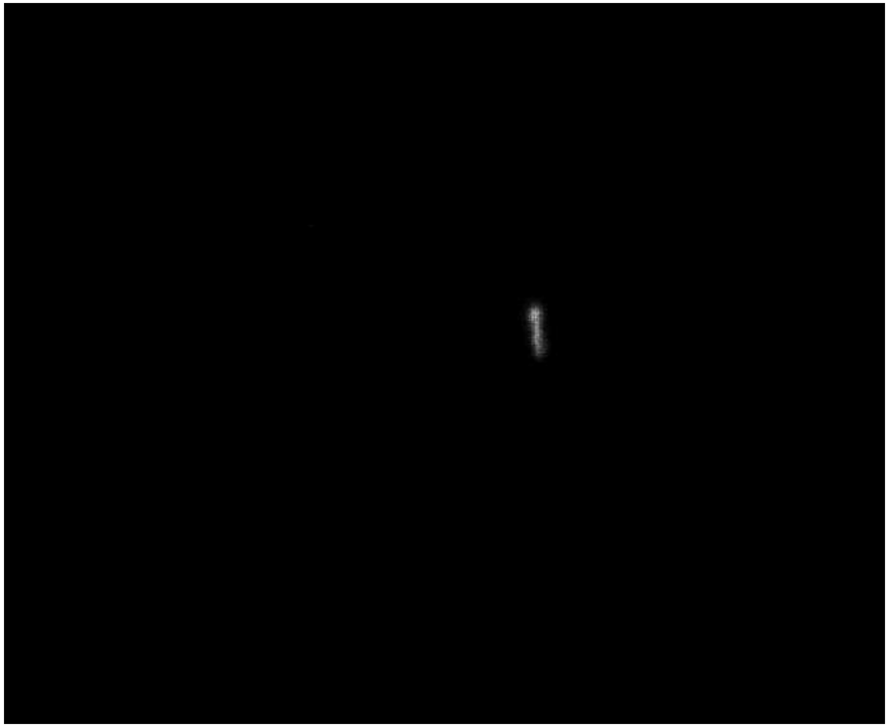
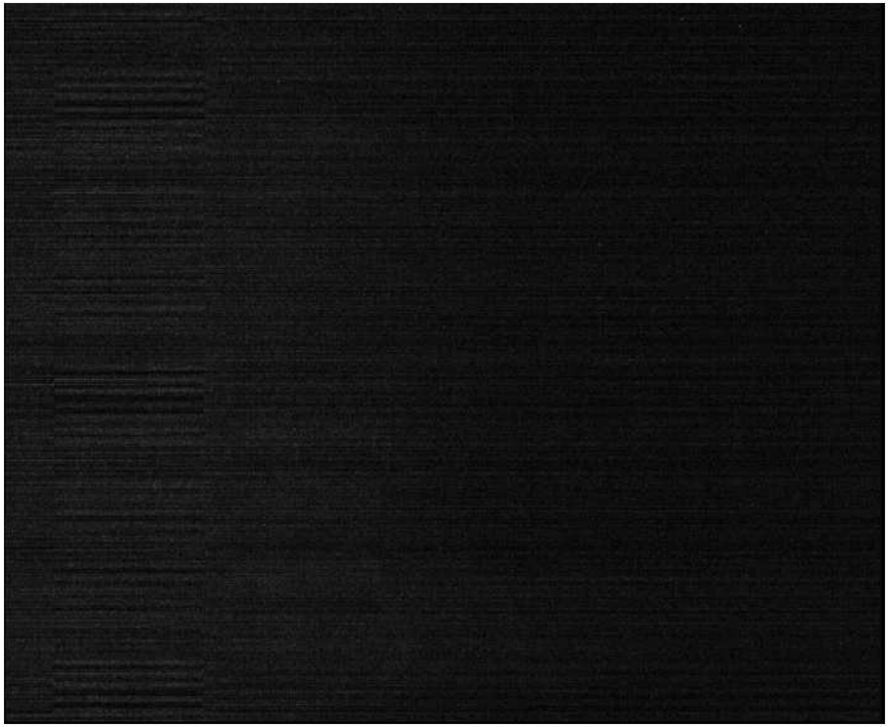
Charge Expansion

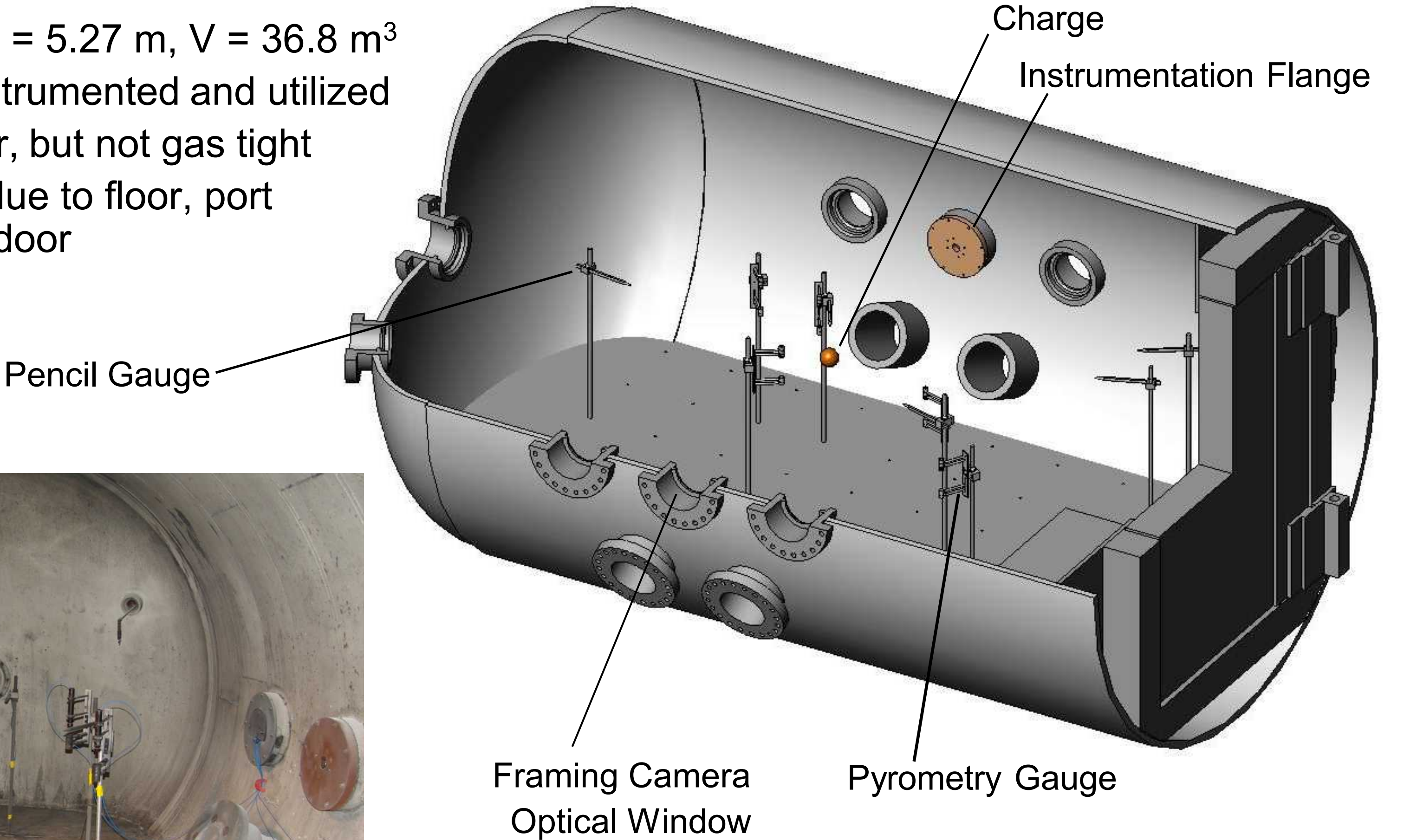




- Hadland Imacon 200
- 4 μs framing rate

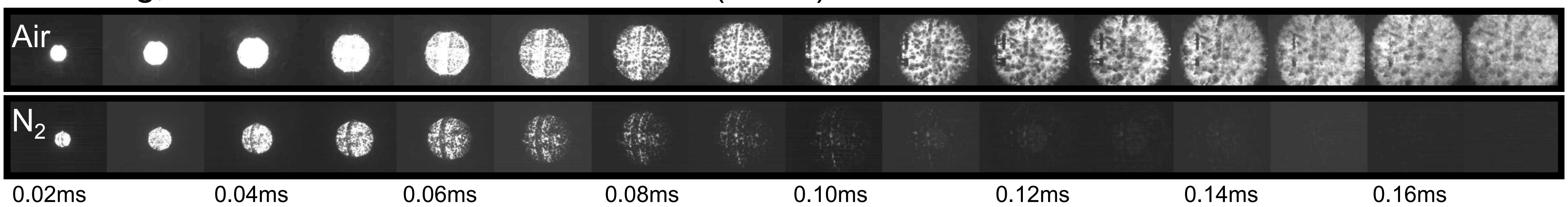
ECF: Walk-in Chamber

- 1 kg TNT limit
- Dia. = 3.35 m, L = 5.27 m, V = 36.8 m^3
- Most heavily instrumented and utilized
- Closed chamber, but not gas tight
- Not symmetric due to floor, port structures, and door

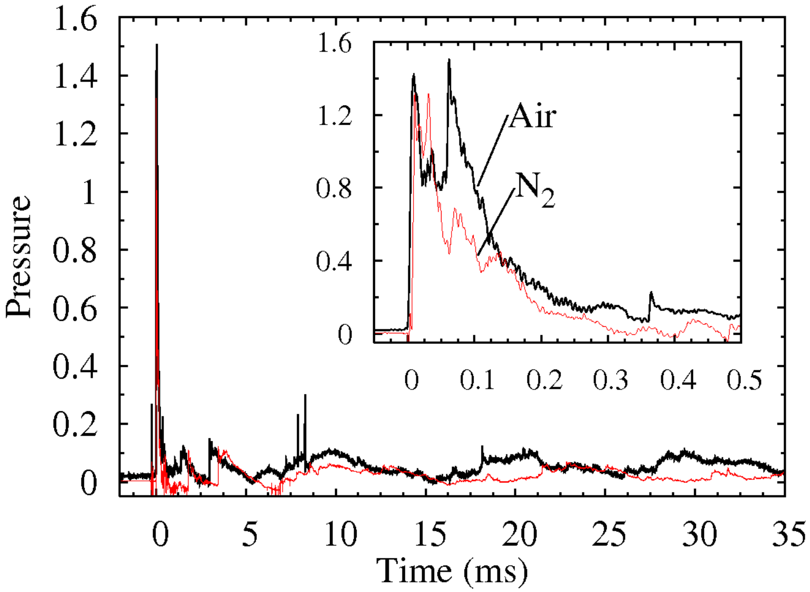


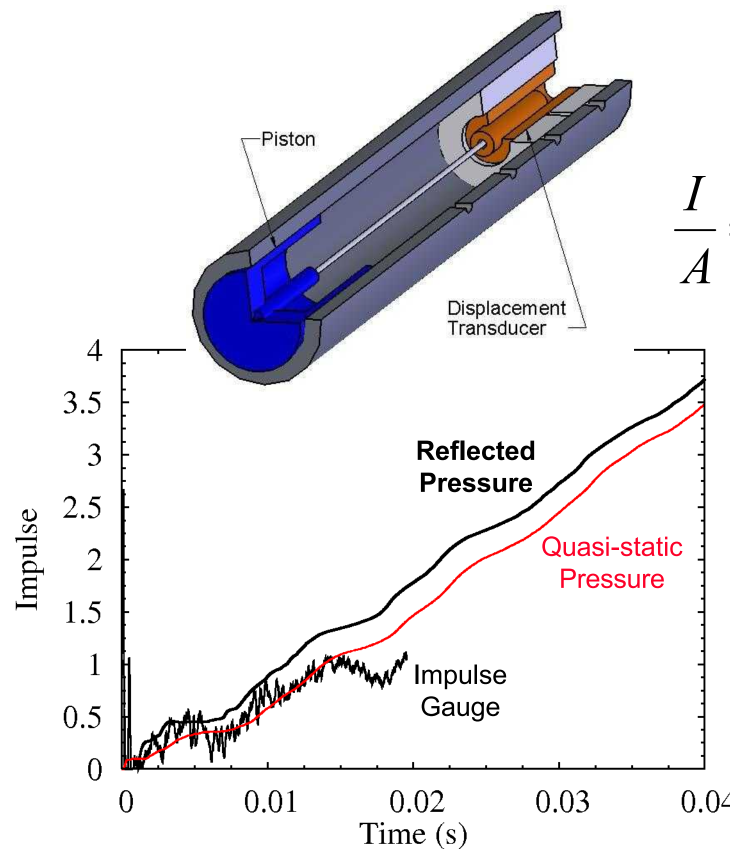
Walk-in Chamber Capabilities

650 g, 50% flake Al / 50% nanometric Al (50nm)



Blast Pressure: d = 76.2 cm





$$\frac{I}{A} = \frac{m \cdot v}{A} = \int P dt$$

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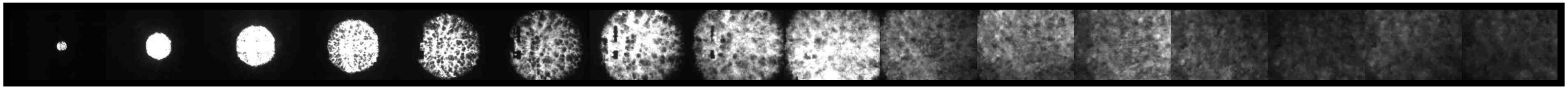
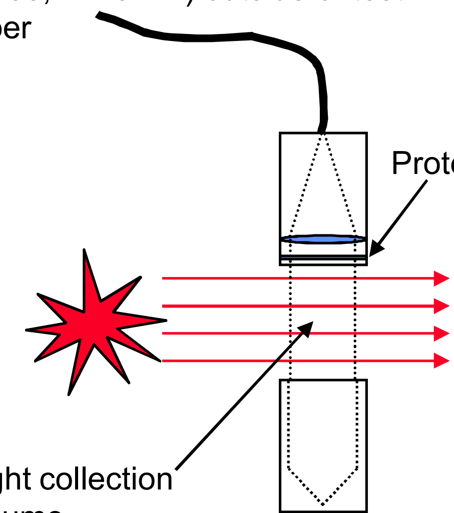
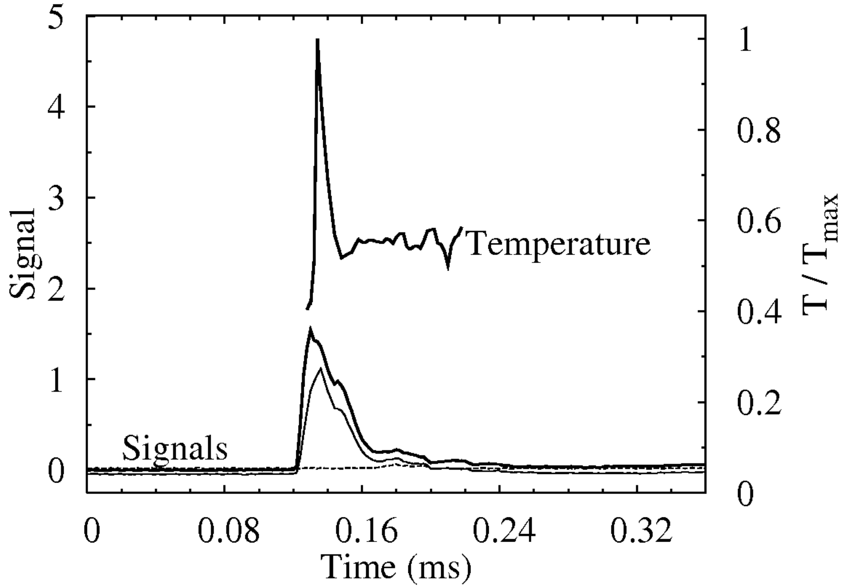
Pyrometry of Expanding EBX Products







R.J. Pahl, M. J. Kaneshige, and S. Snedigar, Post-detonation particulate temperature measurement for aluminized explosives using 3-color pyrometry, *2005 JANNAF Combustion Subcommittee Meeting*, Charleston, SC, June, 2005.

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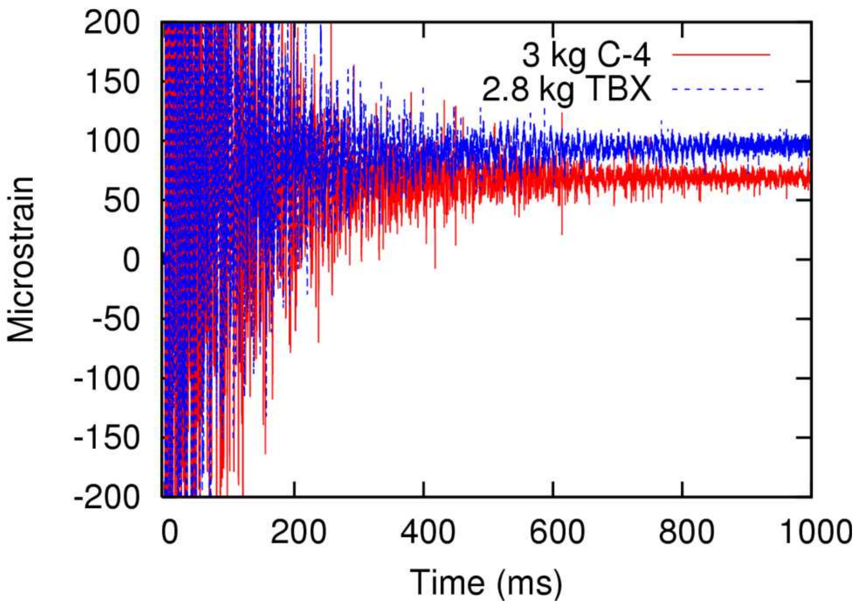
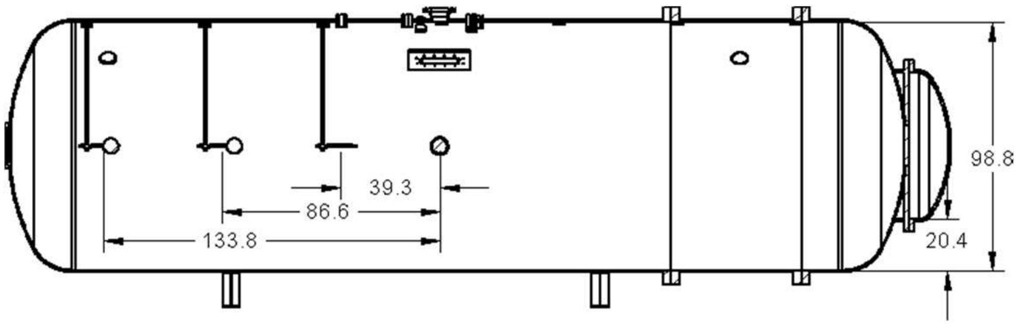
TBF: “Big Blue” Chamber

- Limit: 3 kg C-4?
- Salvaged from surplus and modified for blast experiments
- Axisymmetric, clean interior suited to rapid simulation
- Simple construction supports chamber strain and temperature measurements





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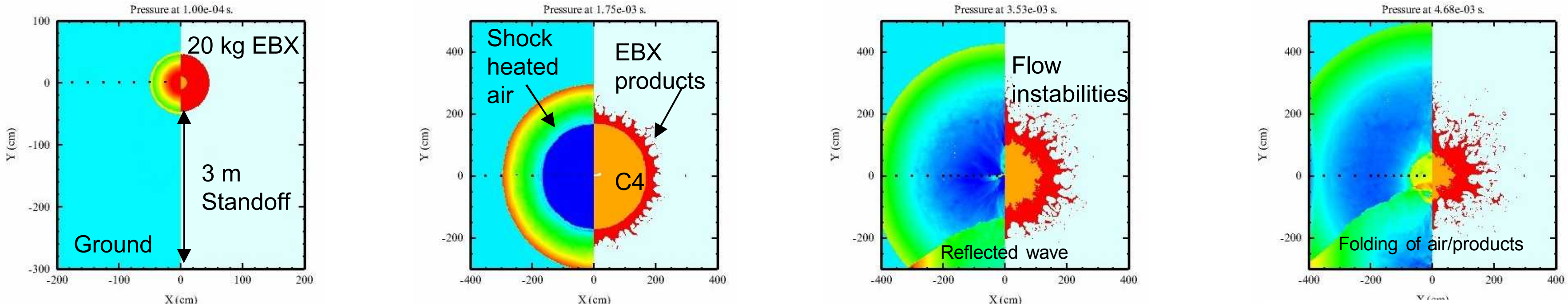
Terminal Ballistics Facility: Free Field

- 3 m height of burst
  - guided by modeling
- 20 kg TBX charge
- 6 pencil gauges
- High-speed cameras and radiometers (at berm in background)
- Identical blast performance of EBX and C-4 in free field shows importance of confinement to enhanced blast performance



- EBX Detonation
- Shock loading of mixture

- Onset of reflection with ground
- Expansion of booster charge

- Booster collapse
- Onset of reflected waves

- Rebound of booster products
- Shock folding of expansion products

TBF Free Field: 20 kg TBX and C-4

- **Different cameras but similar view**
- **TBX charge exhibits clear jetting, not apparent with C-4**
- **Early investigation of scaling from 2-20 kg**

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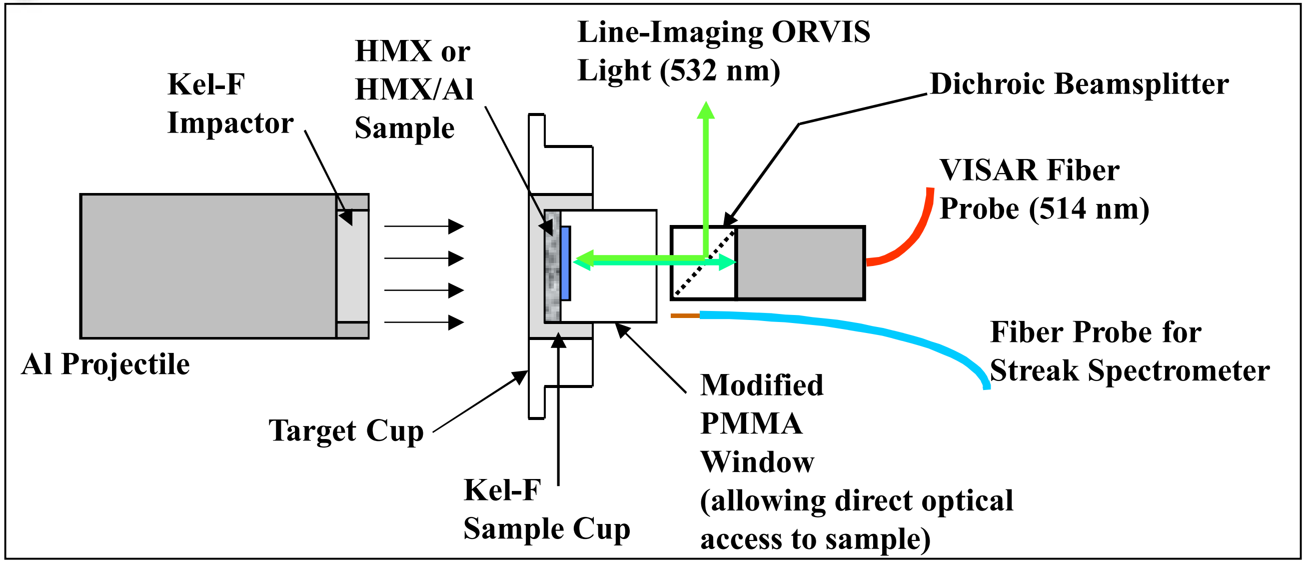
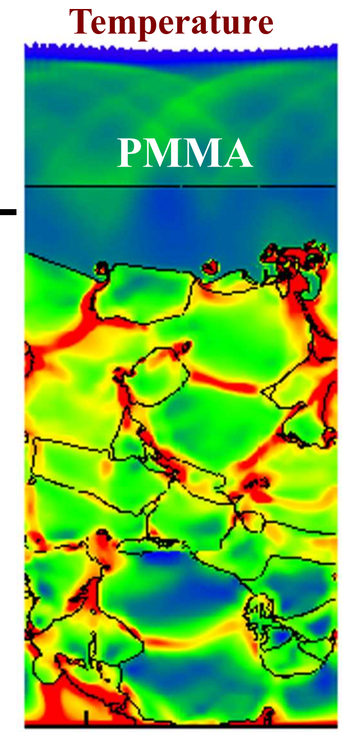
ECF Flash Radiography Firing Pad

- 1 kg TNT limit
- Conventional X-rays for detonics
- Experimental mono-energetic soft X-rays for fireball density distribution

- Mono-energetic (Molybdenum) soft X-ray image
- Aluminum particulate cloud in expanding charge

ECF: Gas Gun



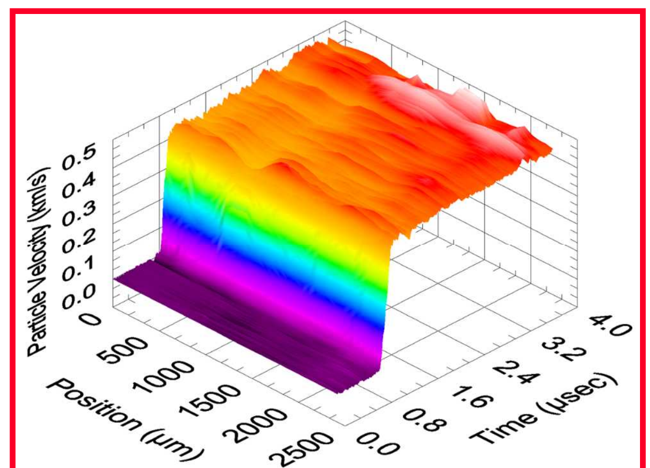


"hot spot" formation correlate with interfacial locations

- Understanding of the timing of Al energy release will aid in better predictive models for formulation design

- Gas gun work with low density HMX and Sugar targets at moderate projectile velocities (~0.4-1.2 km/s) has revealed information about reactive wave growth

- ORVIS diagnostic reveals significant spatial as well as temporal fluctuations



Spatially Resolved Velocity Profile
HMX/2-µm Al; 0.503 km/s

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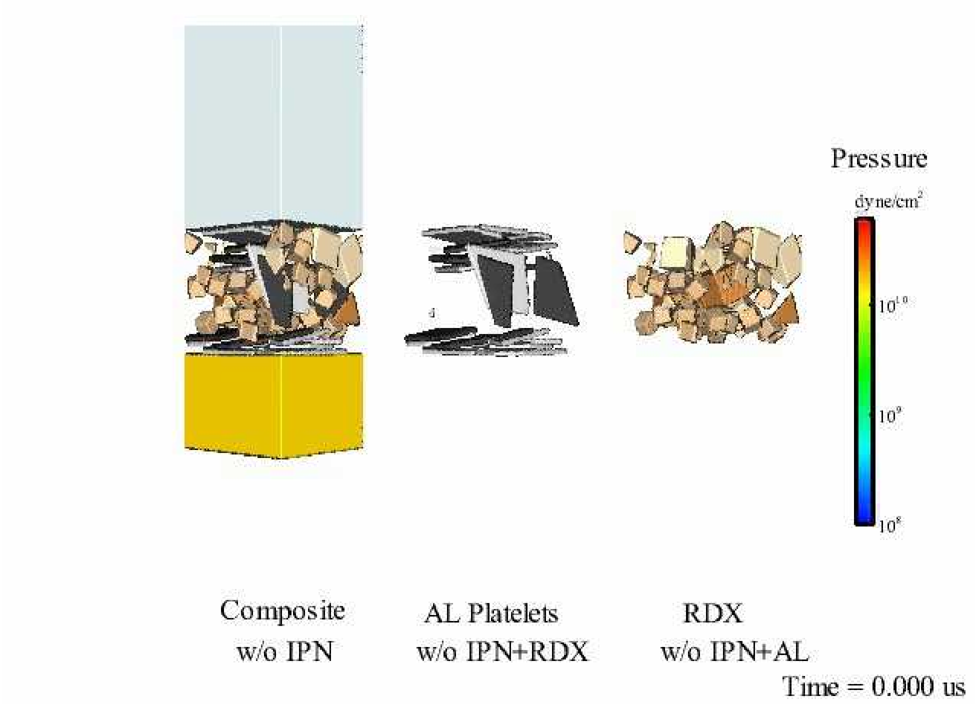
Mesoscale Modeling: Detonics

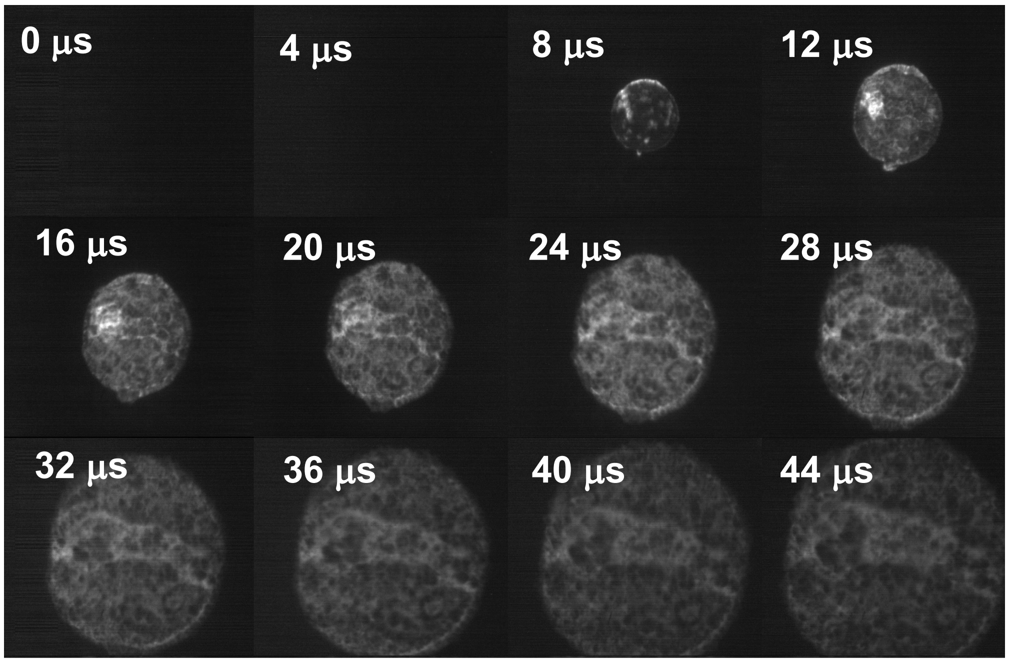
- Nonideal detonation state
  - PVT state + initial KE + how much metal reacts prior to breach of confinement + role of constituents
  - partition of energy and dissipation due to case effects (case breakup, localization jetting effects, etc.)
- Geometry / properties drive the later stages
- *Combustion dictated by the shocked material characteristics*
- *Morphology and specific surface area of dispersed materials likely to be changed during detonation*
- *Predicts early-time expansion rate*



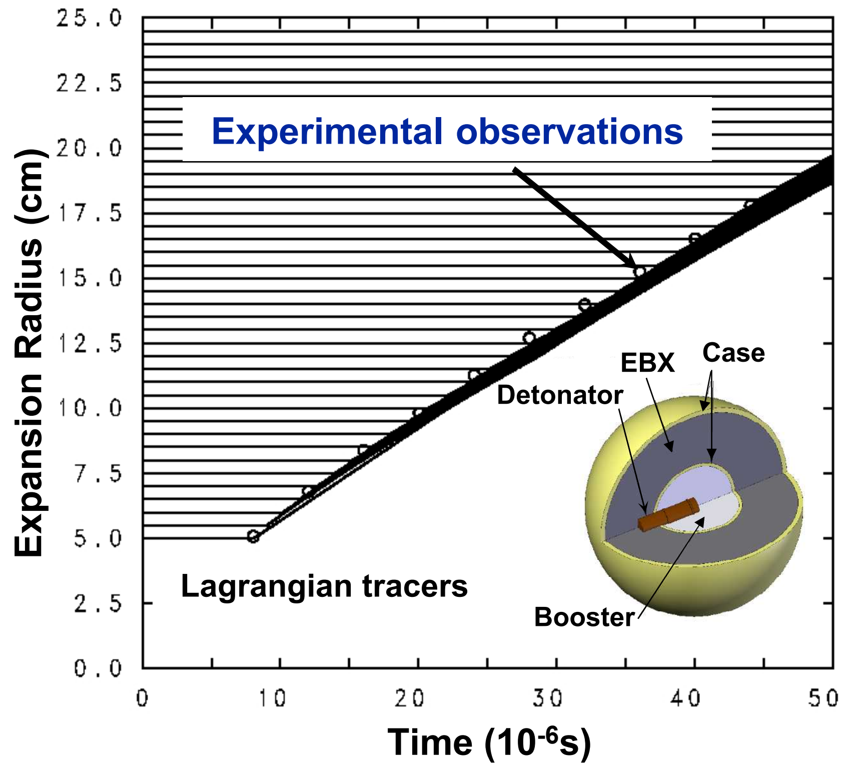
- Mixture of IPN/RDX/Al, typical composite explosive
  - Al plates 200 μm x 200 μm x 10 μm (segregated during packing; inert)
  - RDX 50 μm and 100 μm random blend
- Shock-induced reaction rates determined by impact testing

Spherical Charge Expansion

High speed photography of spherical expansion

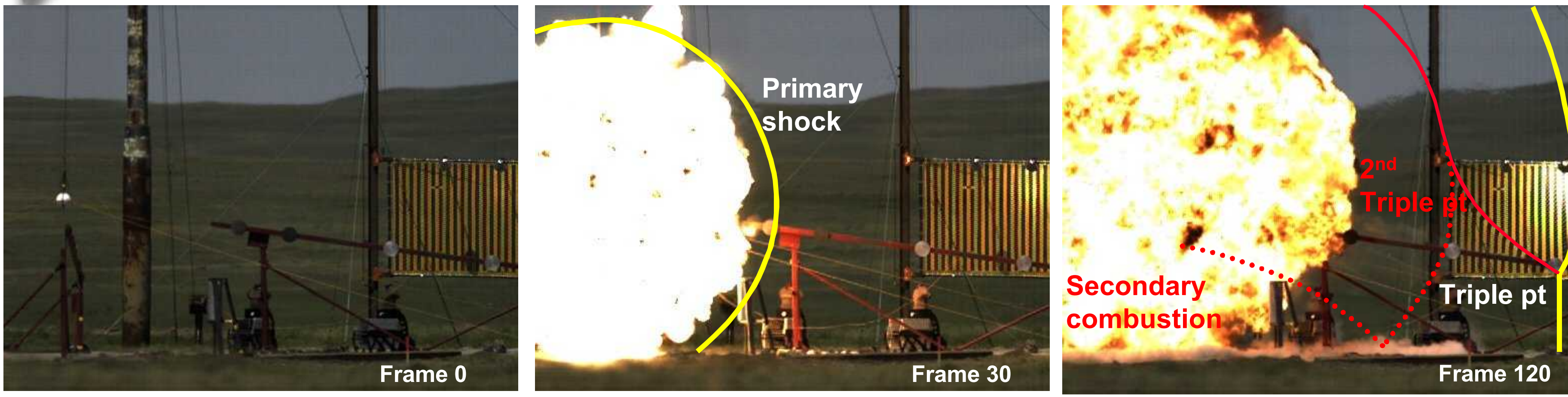


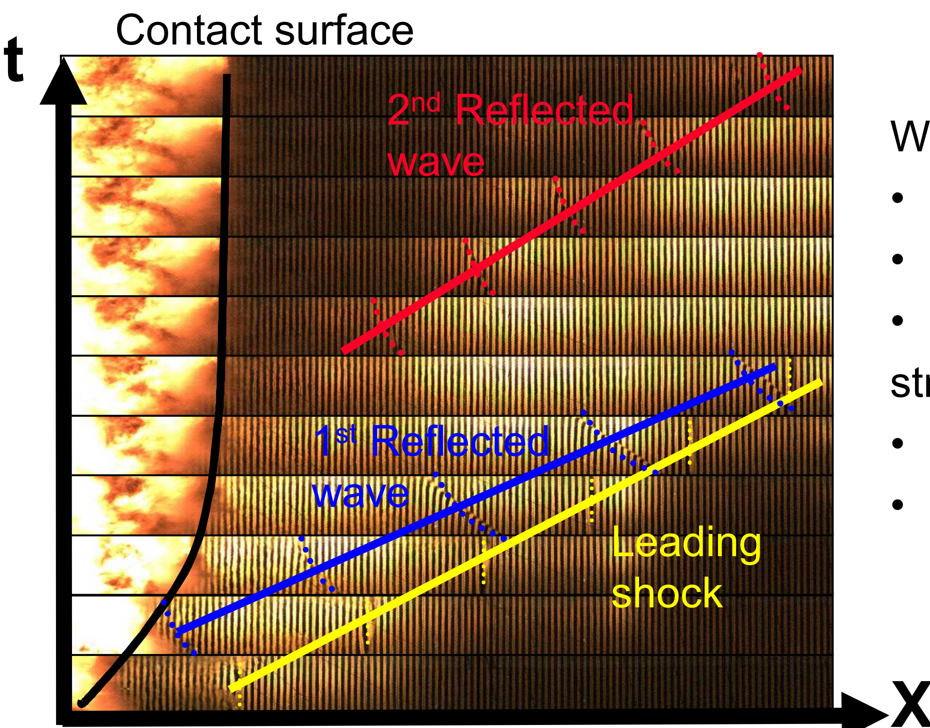
CTH calculation



Detonation modeling predicts early expansion

Current Modeling Efforts: Secondary Combustion





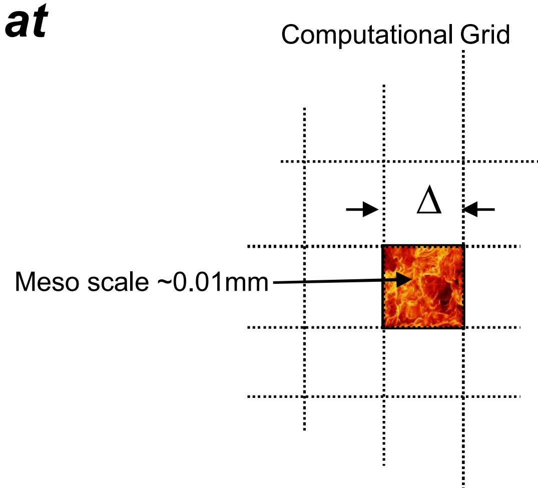
Wave Features:

- Deceleration of gas expansion products
- Separation of dispersed phase materials
- Formation of large scale jets and turbulent structures
- Heat transfer and reactions with entrained air
- Formation of secondary shocks

Turbulent Combustion Modeling
PDF formalism

- ***Central idea: define an "averaging" method that extracts relevant combustion physics (occurring at small scales) that can be applied to the practical computational scales***

"The devil is in the details!"



- A "point" means a distribution of states

- *i.e.* $\langle \psi \rangle = \int_{\Omega_\psi} f_\psi \psi \, d\Omega_\psi$

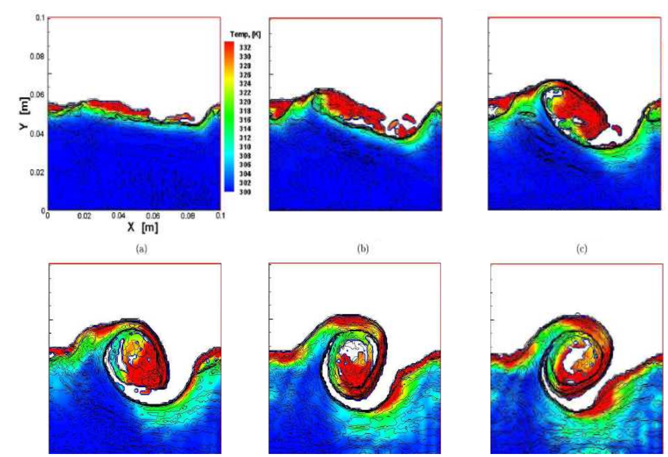
where f_ψ is the probability of the state Ψ in the space $d\Omega_\psi$ such that: $\int_{\Omega_\psi} f_\psi d\Omega_\psi = 1$

- Includes species transport and reaction, *i.e.:*

$$\left\langle \frac{\partial \rho Y_i}{\partial t} + \nabla \cdot (\rho Y_i \vec{u}) = \nabla \cdot (\rho D \nabla Y_i) + \dot{m}_i''' \right\rangle$$

Key aspect is defining f_ψ

Extension of PDF formalism using the "conservative scalar approach" already in place in CTH



Marginal PDF formalism demonstration

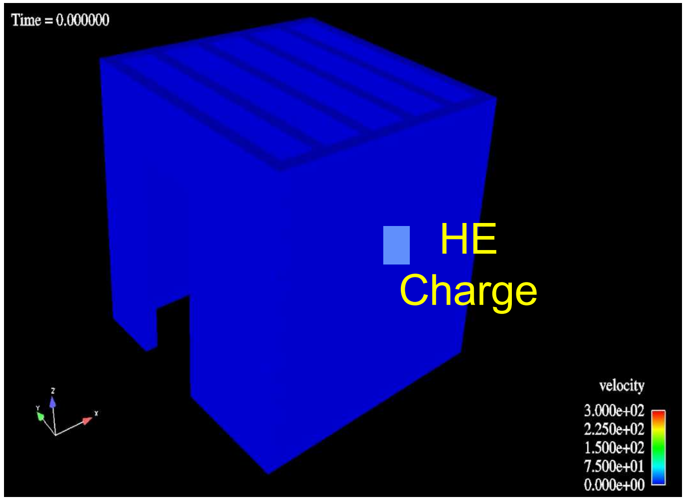
- Multiphase PDF transport equation derived (Carrara, M. D. and DesJardin, P. E., "A Probabilistic Approach to Modeling Separated Two-Phase Flows Using LES I: Mathematical Formulation," *Int. J. Multiphase Flow*, 2005)

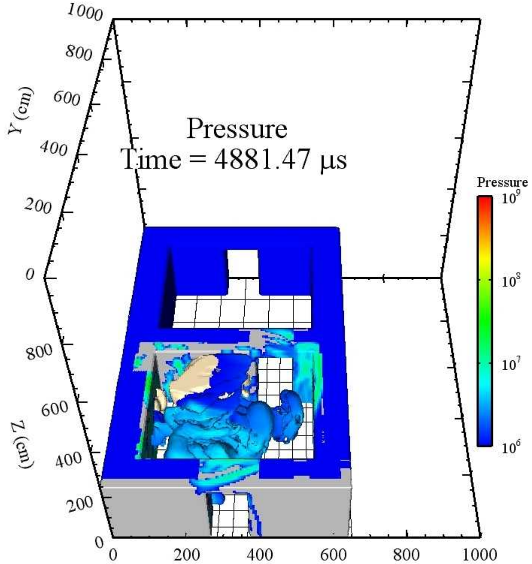
Coupling to Structural Analysis

PRESTO

- Fully Three-Dimensional
  - Massively Parallel
    - Thousands of processors
  - Nonlinear
    - Complicated material response
    - Large deformations
    - Complex interaction of components in contact
  - Solution Method
    - Explicit central-difference integrator
    - Durations of interest: ms

Blast onto single room structure





- Target Modeling
  - Expansion of particle methods (GPA, HPM)
  - Element-to-particle conversion
  - EPIC material models
- Explosive Modeling: CTH
- Coupling Strategies:
  - One-way transfer of pressures from CTH to PRESTO
  - Two-way coupling

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Conclusions

- Multiple experimental facilities and diagnostics enabling scientific study of EBX "events"
  - Indoor and outdoor test facilities (large and small scale)
  - Range of high-fidelity diagnostics and video imaging
- Ongoing, collaborative modeling efforts:
  - Mesoscale simulations
  - Models guiding experiments & experiments feeding models
  - State-of-the-art turbulence modeling of secondary combustion

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Recommendations for Future Work

- Aluminum's role
  - Particle morphology and characterization (pre- & post-detonation; overall performance)
  - Aerobic/anerobic burning, associated time scales and particle histories
  - Does agglomeration cause jetting?
  - Need evidence of "bootstrapping"

- Continue PDF implementation for modeling of secondary combustion – fundamental combustion studies needed that study nonpassivated, highly strained metal additive.

- Case effects and charge scale