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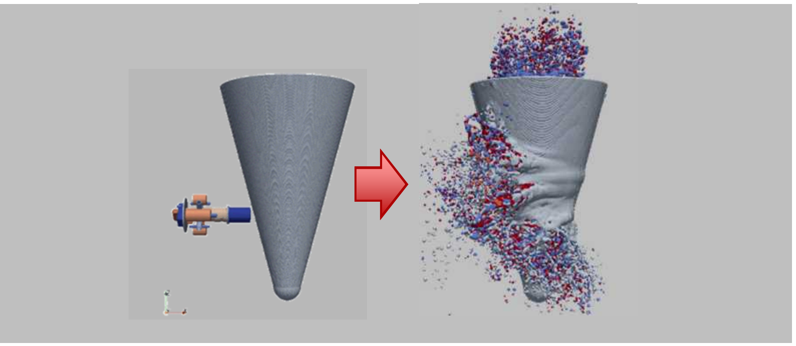

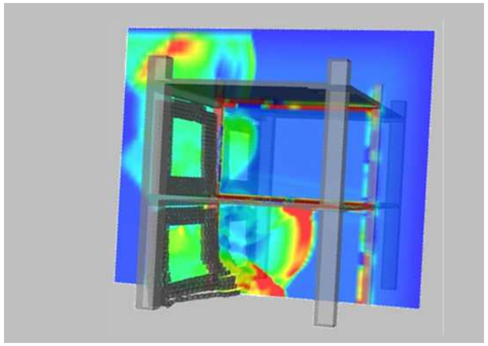

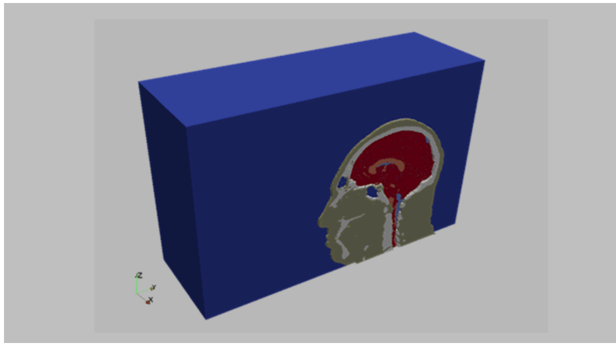

Near-Structure Air Blast Simulations Using Zapotec, A Coupling of CTH and Sierra/SM

Arne Gullerud, Dave Hensinger, Tim Shelton, Edmundo Corona
Sandia National Labs
WCCM, July 23 – July 27, 2018

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Overview of Talk

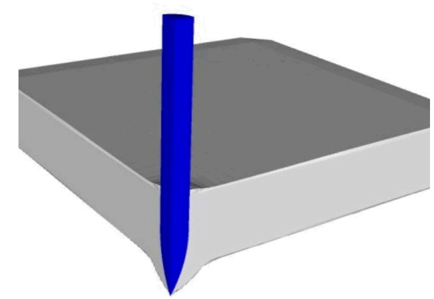
- The Problem of Interest: Structural Response to Nearby Blasts
- Zapotec Overview
- Kinetic Plate Experiments
- Thin Plate Blast Response
- Conclusions

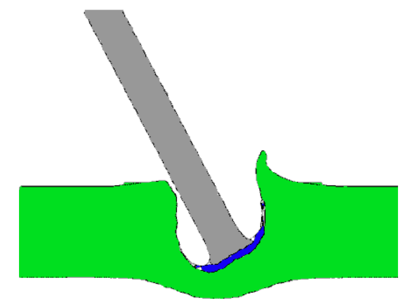
The Problem of Interest: Structural Response to Nearby Blasts

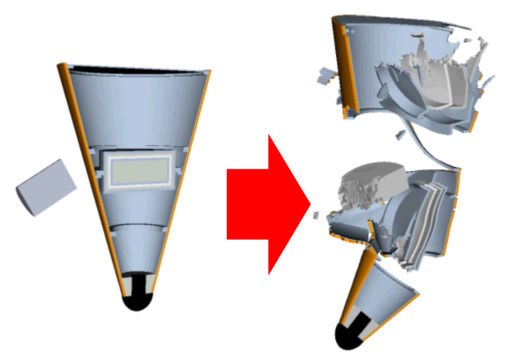
- **Nearby blasts provide a challenging environment for structural stability**
  - **Far-field blasts can be assessed through simplified/analytical techniques such as CONWEP, Friedlander Equations**
  - **Nearby blasts typically involve significant interaction with the structure:**
    - **Shock interaction with structural details**
    - **Penetration of the blast into the structure**
- **Since simplified analytics do not apply well, simulation capabilities are needed**
- **This work aims to evaluate the use of Zapotec for such cases**

Zapotec Overview

- Developed at Sandia National Laboratories
- Coupling between CTH and Sierra/SM (Presto)
- Utilizes a volume coupling approach
- Hex and Shell elements inserted for coupling (others allowed but not coupled)
- CTH AMR is supported
- Eroded Lagrangian elements can be “donated” to CTH to preserve mass/momentum
- Several choices for sampling CTH pressures
  - Solid-on-solid (impact, e.g. penetration)
  - Gas-on-solid (blast)
- Many additional options to assist in a variety of simulation scenarios







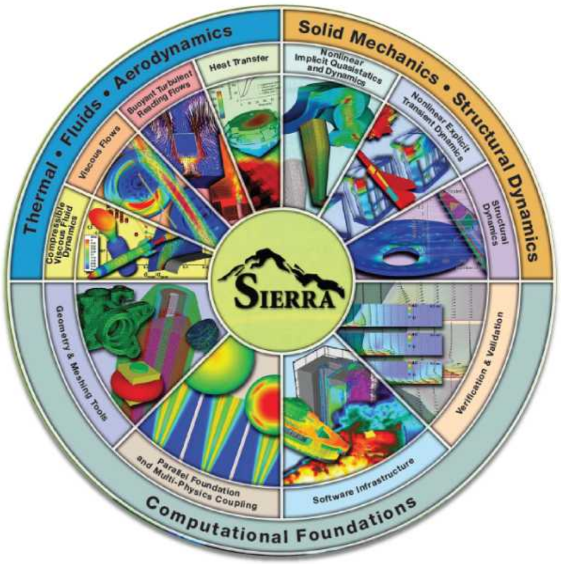
CTH is a massively-parallel structured-mesh shock-physics code that excels at time-to-solution

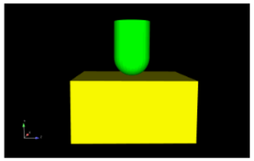
- **Explicit Eulerian shock-physics code (hydrocode)**
  - Solves conservation of mass, momentum, and energy
  - Up to 98 simultaneous materials
  - Gases, fluids, solids, reactive materials
  - Analytic & Tabular Equation-of-State representations
  - Advanced Strength & Fracture models
  - Adaptive Mesh Refinement (AMR)
  - Cradle-to-grave simulation suite
  - Massively parallel (scales on over 1M processors)
  - Ability to import CAD geometries
- **Applications (partial list):**
  - Armor, Anti-Armor, Conventional Munitions, Blast Effects
  - Planetary Science, Asteroid Impact & Planetary Defense
- **CTH licensed to U.S. government agencies and their subcontractors and U.S. academic institutions; heavily used**
  - 1000+ users
  - Most run systems analysis code on the DoD HPC machines
- www.sandia.gov/CTH

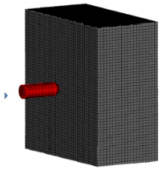
CTH simulation of the Chelybinsk superbolide Boslough (2013)

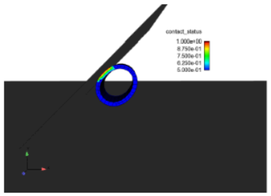
Sierra/SM Explicit (Presto)

- **Sierra is a multiphysics simulation environment that provides efficient, scalable computational foundations**
- **A number of simulation tools have been built on top of the framework, designed to address problems in fluid-thermal and structural areas**
- **Zapotec is coupled to the Solid Mechanics module (Sierra/SM), which provides explicit transient finite element capabilities, with**
  - **Large array of finite element types**
  - **Multibody contact**
  - **Range of complex material models**
  - **Extensive capabilities for failure**
  - **Massively-scalable parallelism**









Traditional Zapotec Applications

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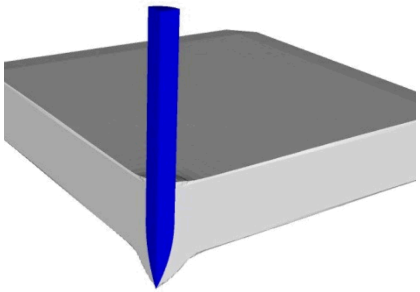
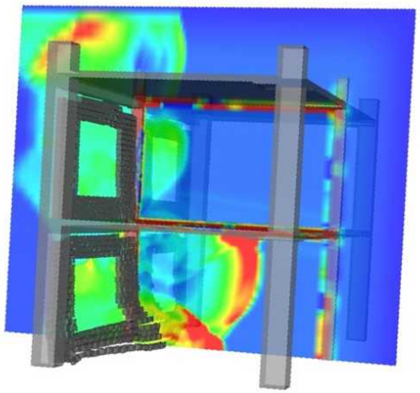
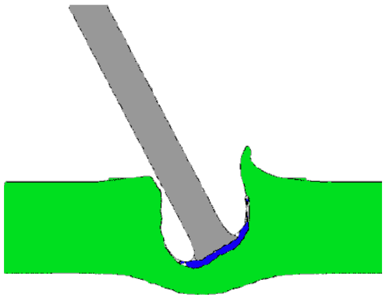


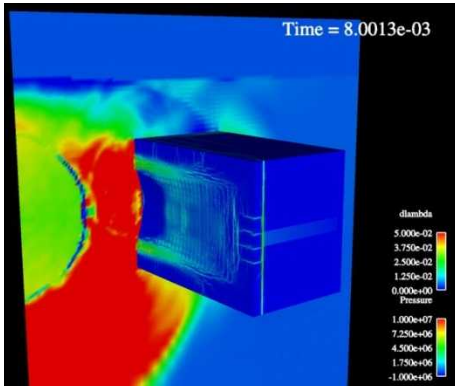
Ballistic Penetration



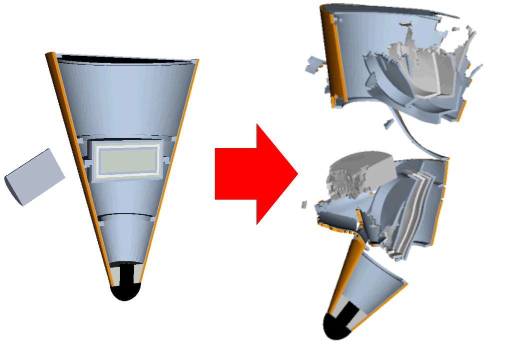
Air Blast on Above Ground Reinforced Concrete (RC) Building with Brick Facade



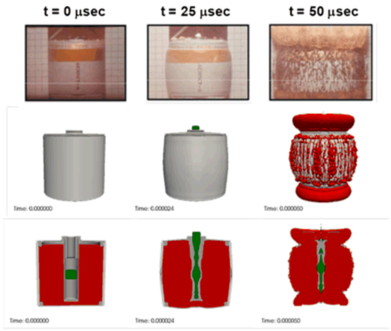
Anti-Armor Applications (Eroding Rods)



Blast Loading on a Buried RC Structure



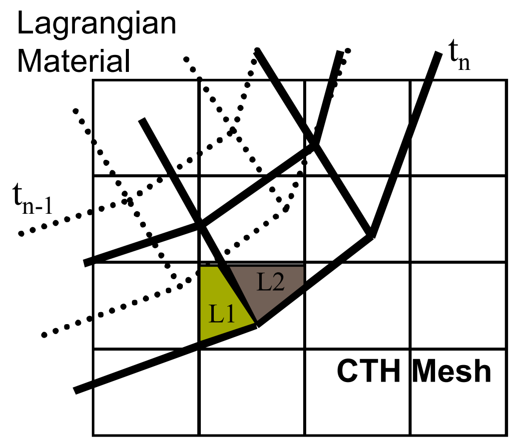
Hypervelocity Impacts

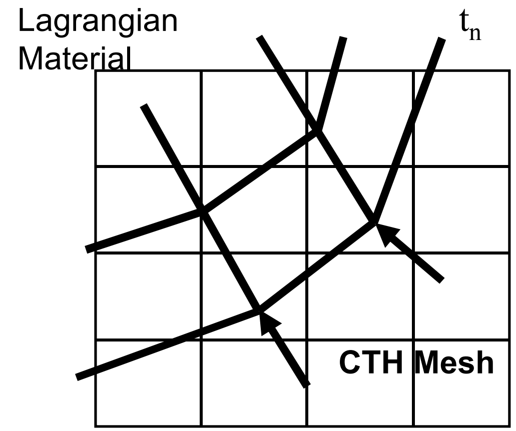


Bomb Fragmentation

Overview of Coupling Algorithm

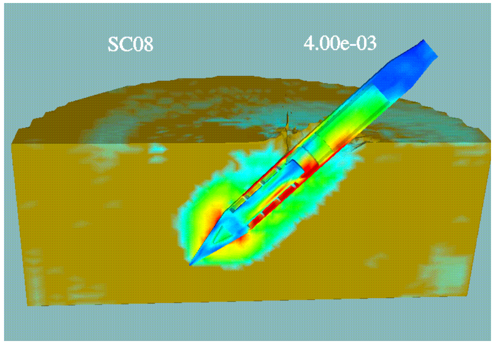
- Zapotec works to make the two code domains consistent
  - CTH: Material Insertion
    - Lagrangian material is inserted into CTH cells
    - Basic information is mapped into CTH (mass, stress state, etc)
  - Lagrangian: Forces computed from CTH domain applied to lagrangian structure
- Codes compute response independently
- Resolution of any differences made in re-insertion of lagrangian material into CTH
  - Solution differences can lead to overfilling of CTH cells
  - Heuristics to deal with overfilled cell can discard mass



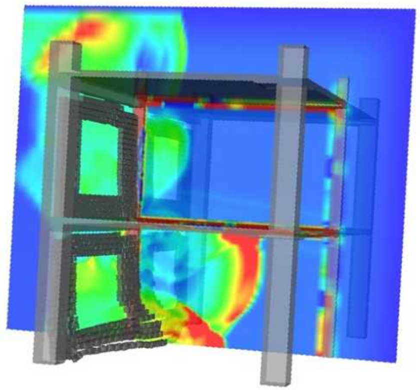


Zapotec History

- **Originally developed as a coupling of CTH with EPIC for penetration problems (Early-Mid 1990s)**
- **Coupling with Pronto3D, parallel architecture (Early-Mid 2000s)**
  - **Used for penetration analyses (Pronto3D for penetrator, CTH for target material)**
  - **Expansion to blast-on-structure (Pronto3D for structure, CTH for explosive and air)**
- **Application shift to hypervelocity impact in late 2000s**
  - **Basis of Confidence Document (in final revision)**
- **Current version; Zapotec 3.0**
  - **Replaces Pronto3D with Sierra/SM**
  - **Improvement/expansion of algorithms**



Penetration

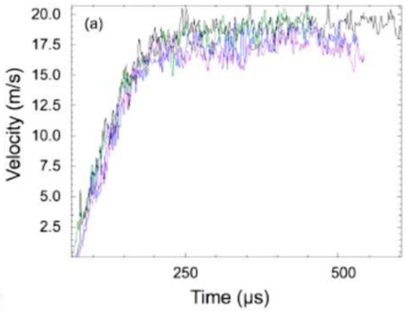


Air Blast on Above Ground Reinforced Concrete (RC) Building with Brick Facade

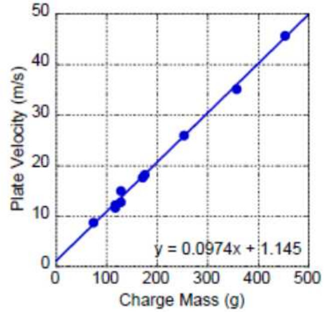
Kinetic Plate

- **Simple test case to explore code use for near-structure blast scenarios**
- **Experiment series conducted by LANL:**
  - **Thick plate loosely suspended in steel fixture (to prevent gas wrap around)**
  - **Explosive charges (c4, various masses) detonated with center 6” from plate**
  - **PDV measurements made of plate speed (4 per test; avg velocity used)**
- **Metric: final velocity of plate**

Experimental Setup[1]



Typical PDV Data[2]



Velocities for C4 Charges[2]

1) Image from Neuscamman SJ, Manner VW, Brown GW and Glascoe, LG. (2014) Numerical simulations of near-field blast efects using kinetic plates. 18th APS-SCCM and 24th AIRAPT. Journal of Physics: Conference Series 500(2014) 052029.
2) Image and data from Manner VW, Pemberton SJ, Brown GW, Tappan BC, Hill LG, Preston DN, Neuscamman SJ, and Glascoe LG. (2014). Measurements of near-field blast effects using kinetic plates. 18th APS-SCCM and 24th AIRAPT. Journal of Physics: Conference Series 500(2014) 052029.

Kinetic Plate

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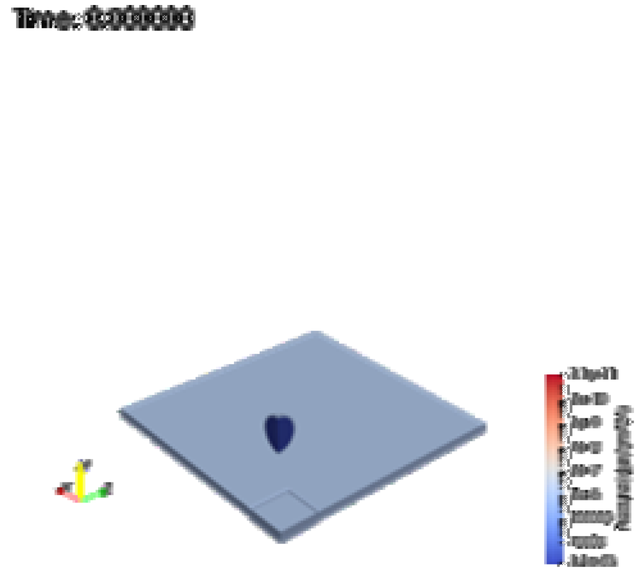
- Zapotec simulations used finite element model of plate and fixture, CTH model of explosive and air – domain configured to be ¼ symmetric
- Simulations correlate well to experiment, show slight under-prediction of velocity



Charge Size (g)	Experimental Velocity (m/s)	Analysis Velocity (m/s)	% Difference
116.2	11.65	11.26	3.3
117.2	12.20	11.35	7.0
174.5	18.26	16.70	8.5
453.2	45.72	42.16	7.7

Kinetic Plate

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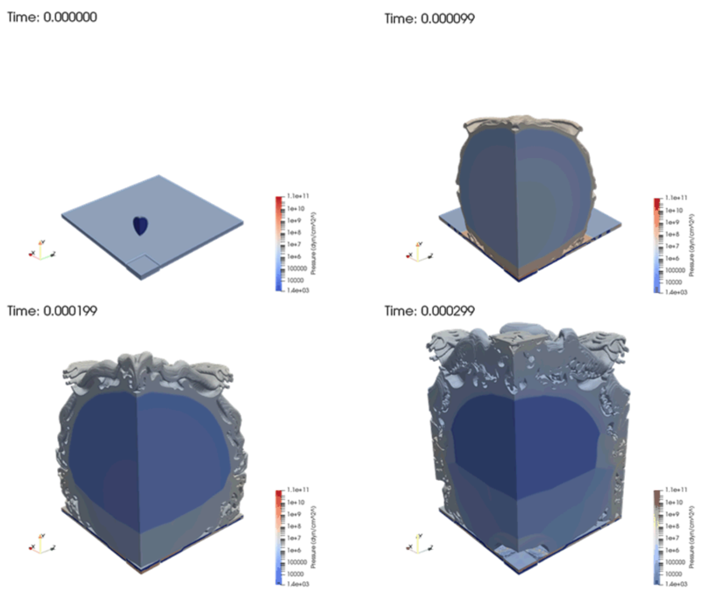

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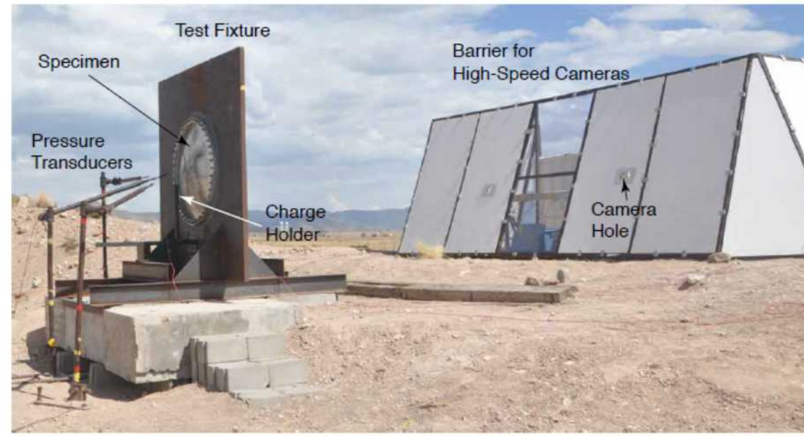
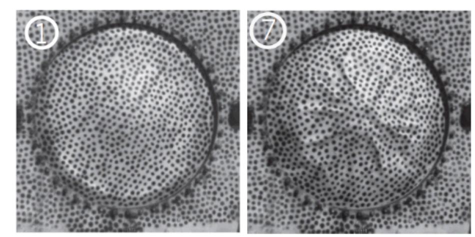
Thin Plate Blast Response

- **More complex test case to explore code use for near-structure blast scenarios**
- **Experimental series conducted by SNL:**
  - **44-inch diameter 0.040 in thick Al 2024-T3 plate held in thick steel holder**
  - **Spherical C4 explosive charge centered on plate, detonated 10” away**
  - **Range of explosive charges used (120-500 g)**
  - **Digital Image Correlation used to measure plate deformation in test**
- **Test series responses ranged from simple bulging of plate to plate breakage**
- **This work focuses on center deformation of plate before failure**

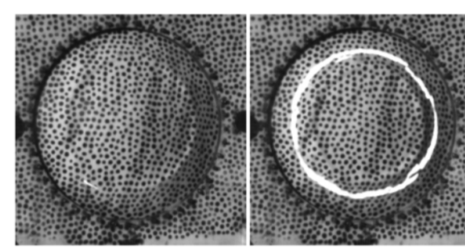


Test Configuration

Deformation for 120g Charge



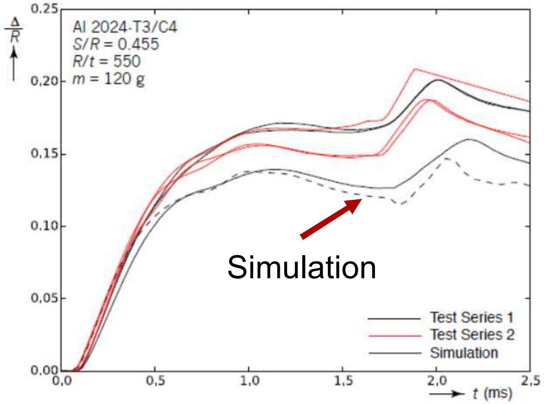
Deformation for 500g Charge



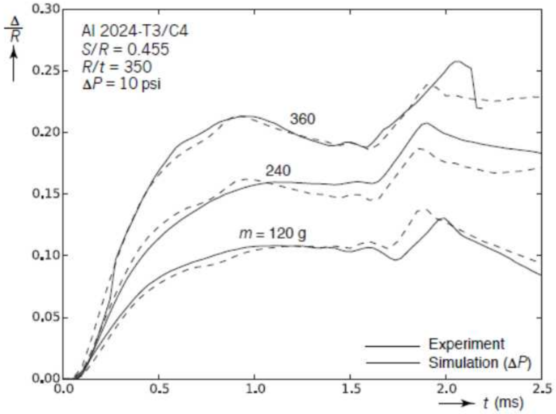
Images and data from Corona E, Gullerud AS, Haulenbeek KK, Reu PL. Ductile Tearing of Thin Aluminum Plates Under Blast Loading: Predictions with Fully Coupled Models and Biaxial Material Response Characterization. Sandia National Laboratories. Report SAND2015-4371

Thin Plate Blast: Zapotec Simulations

- **Initial simulations focused on lowest explosive mass (120 g)**
- **Simulations showed a slight under-prediction on the deformation of the plate**
- **Various computational studies on optional parameters showed little overall effect on underprediction (e.g. coupling approach, JWL parameters, boundary conditions)**
- **By providing a 10 psi additional pressure, simulations matched better; this was applied to higher explosive loads as a calibration factor**
- **Other authors[1] used afterburn models to add the additional pressure needed to match**



Initial Simulations

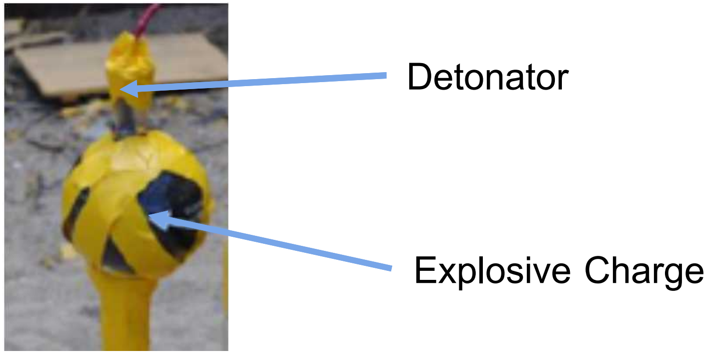


Simulations with Extra 10 Psi

1) Afterburn model used in Alves, S, Glascoe L. and McMichael L. (2012) Modeling of Bare Circular Plate Blast Experiments. NEXESS Center Report 2012-1035, Lawrence Livermore National Laboratories.

Thin Plate Blast: Zapotec Simulations

- **Other work[1] has explored the effect of the detonator geometry on the blast characteristics**
- **The detonator geometry is substantial in comparison to the explosive, especially for 120 gram case**
- **CTH-only 2D simulations show improved comparison in similar problems when detonator details are included**
- **Detonator details have not been included in a Zapotec simulation at this time; work is ongoing**

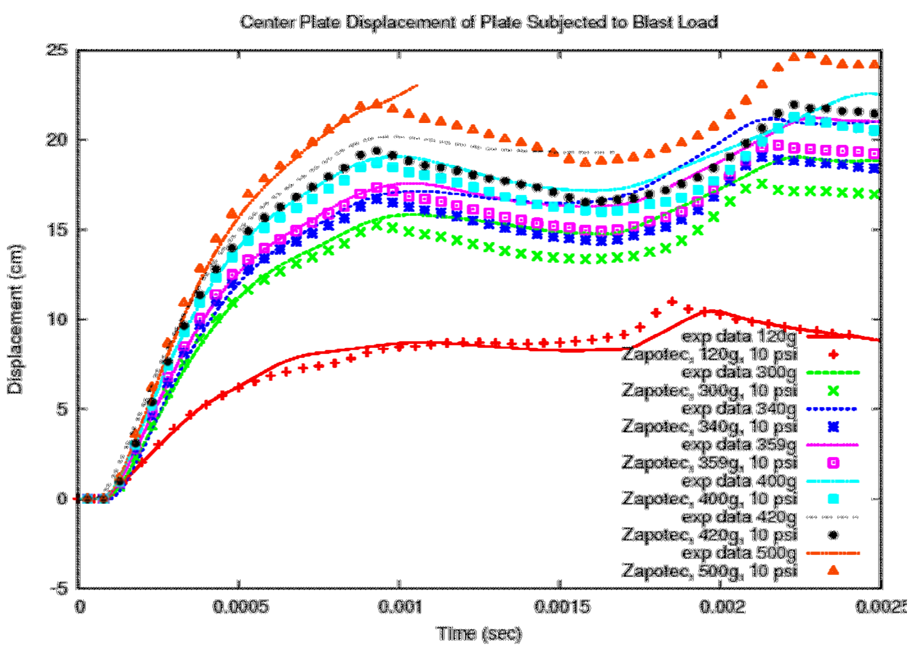


Simulations At Higher Weights

1) Bailey, Molly "Investigation into Late Time Blast Loading of Thin Aluminum Plates", Internal Memo, August 24, 2016

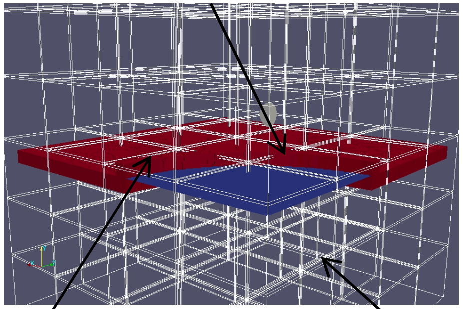
Thin Plate Blast: Zapotec Simulations

- **With extra 10 psi loading, simulation results match experiment well**
- **Work still ongoing to understand the need for extra 10 psi**



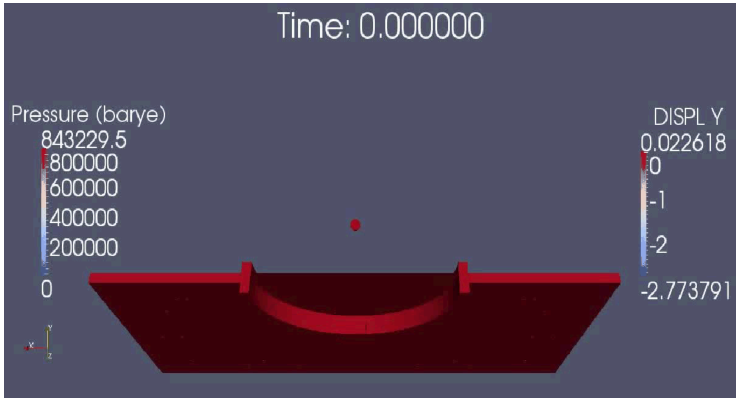
Comparison to Data

Explosive in Eulerian domain (CTH)



Lagrangian Mesh (Pronto)

Eulerian domain (CTH)



Sample Zapotec Simulation

Conclusions

- Zapotec is a coupling between CTH and Sierra/SM; enables use of Lagrangian and Eulerian methods in the same problem
- Zapotec simulations of kinetic and thin plate tests match well to experimental results
- Work ongoin to uncover cause for need for extra pressure in thin plate case
- Zapotec shows significant promise for simulation of near-structure blast scenarios
- Acknowledgements

  - SNL: Kim Haulenbeek, Phillip L. Reu, Bob Schmitt, Dave Crawford, Molly Bailey
  - LANL and LLNL: Experimental/Analysis work