Insensitive Munitions Modeling Improvements

S. DeFisher[1], D. Pfau[1], C Dyka[2]
[1] U.S. Army ARDEC
Picatinny Arsenal, NJ
07806-5000

[2] U.S. Naval Warfare Center, NSWC-DD
Dahlgren, VA

Outline

- Background
- Scenario of interest
- Current code use example
- Improvements
  - CTH/SIERRA
  - ALE3D
- Other ongoing work
- Conclusion

Background

- Lack of Insensitive Munitions (IM) compliance has caused the loss of hundreds of lives, millions of $$ of material, and reduced operational capability
- Most warheads behave violently when subject to various external insults such as bullet and fragment impact
- Mil-STD 2105C governs IM related testing
  - 5 levels of severity; Type I Detonation – Type V Burning
- STANAGs supplement Mil-STD 2105C

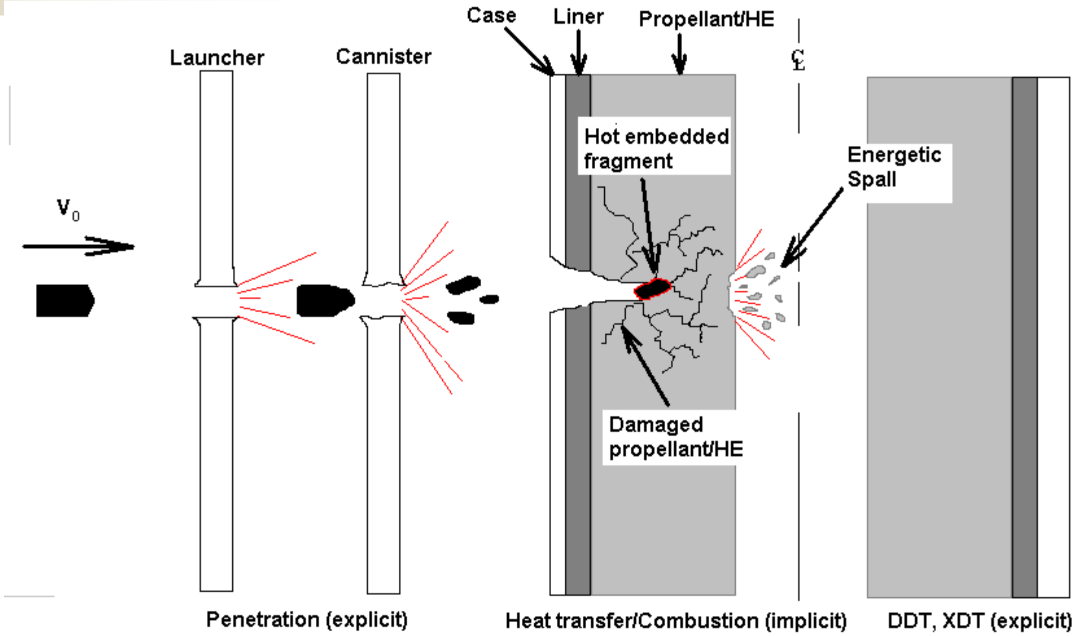
Background continued…

- Improving IM performance through the exclusive application of testing is expensive and takes a lot of time (limited facilities with busy schedules, encroachment, etc.)
- Modeling is often used in conjunction with testing but is far from ideal
  - "Holy Grail" – Type I – Type V delineation between violence and frag velocity, number of fragments, etc.
  - Often used (successfully) for qualitative comparisons
    - Sympathetic detonation (SD)
    - Bullet Impact (BI)
    - Fragment Impact (FI)
  - Also for reaction temperature and time for slow cook-off (SCO)
- If modeling predicted system response more accurately, it could be used more often and earlier in the design cycle saving time and $$

Background continued…

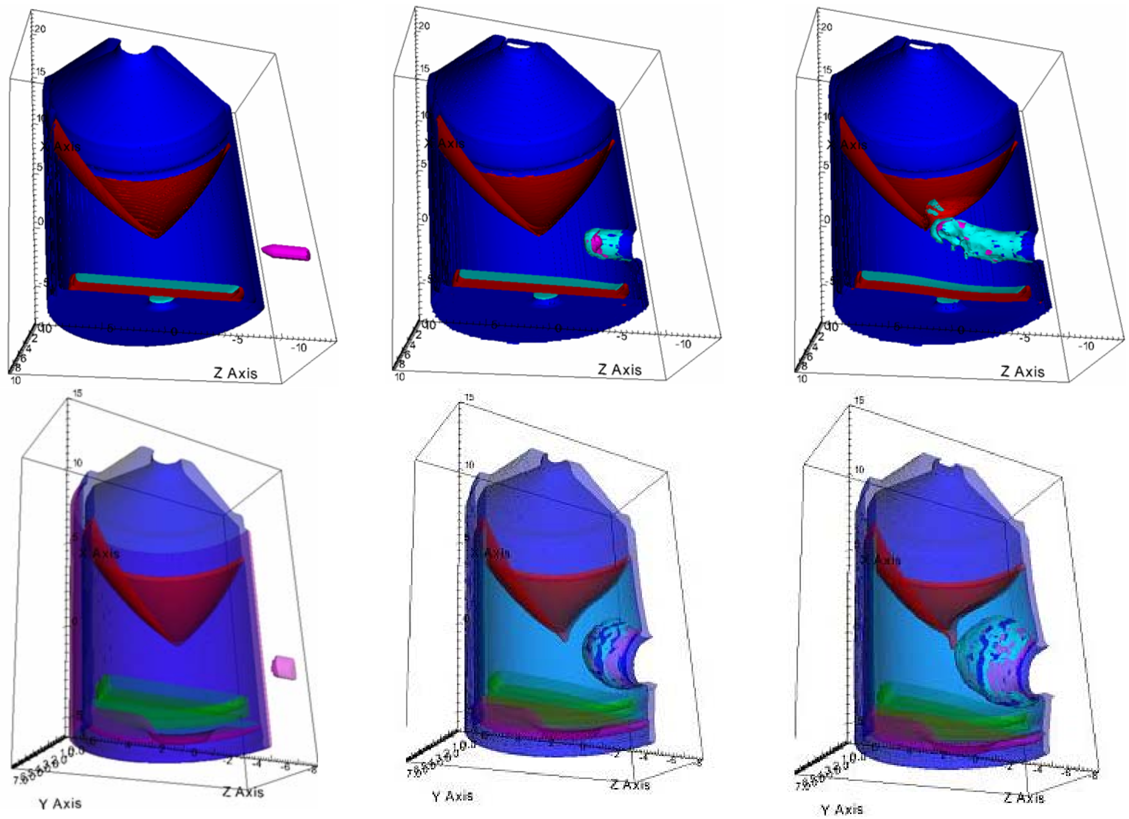
- The U.S. DoD High Performance Computing Modernization Office (HPCMO) recognized this and funded this effort to improve two commonly used codes (numerical implementation only, no testing)
  - CTH/SIERRA
  - ALE3D
- This effort builds on the previous multi-phase flow and target response portfolio (MFT) that developed these capabilities to a rudimentary level. DoD demonstration with DOE code development
- IM related phenomena are often complex and span a variety of length and time scales. To make the problem tractable only bullet and fragment impact (BFI) were chosen with focus on
  - Multi-phase flow
  - Code coupling
  - Particle methods, fragmentation (statistical variation), and transport

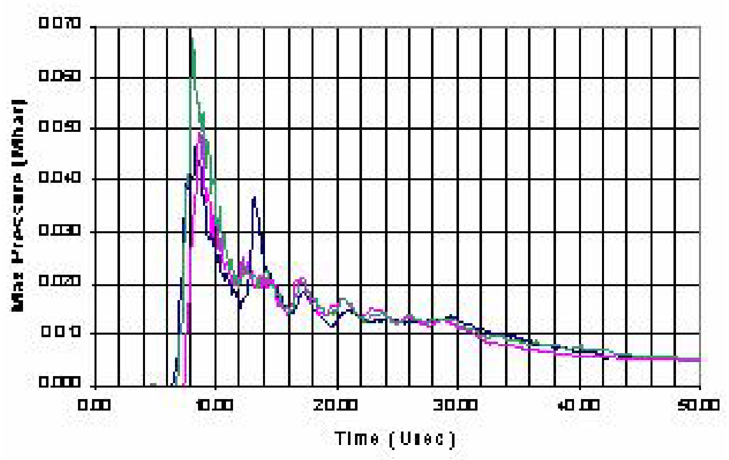
Scenario of Interest



- Physically, geometrically, and numerical complex scenario necessitating a treatment of both explicit and implicit phenomena.
- Penetration, shearing, fracture and debris generation, chemistry (explicit), heat transfer, combustion, multi-phase flow (implicit), shock to detonation transition (SDT) or cook-off like transition to detonation (explicit)
- Made more difficult by incomplete physical understanding (shear initiation eg.), a variety of response levels that vary w/velocity, and inclusion of materials which are non-detonable (not 1.1 Hazard Class)

Current Code Use Example



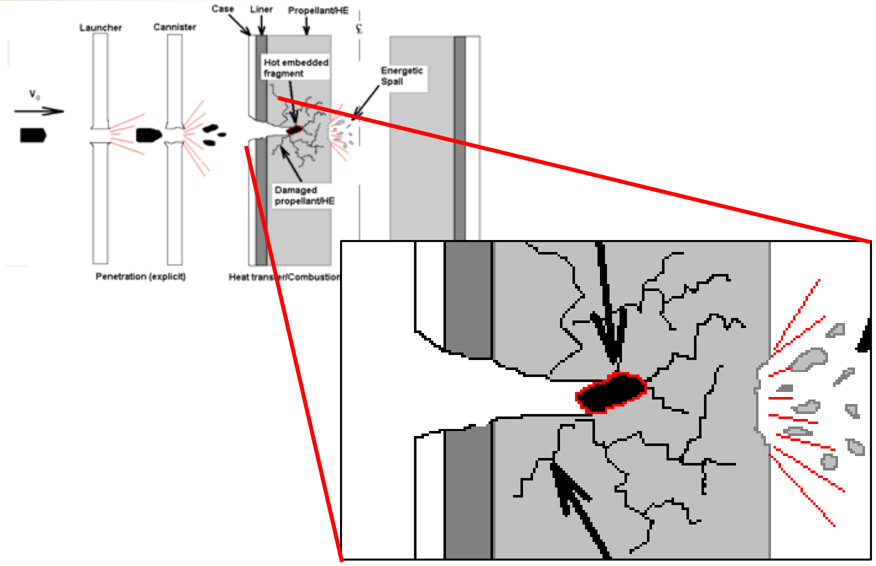


- BI (2789 fps) and FI (6000-8300 fps) are routinely modeled
- Pressure history of the billet is interrogated allowing a designer to *qualitatively* compare one design to the next
- Many aspects of physical behavior simply aren't accounted for thus limiting accuracy of predicting overall response

CTH/SIERRA Background

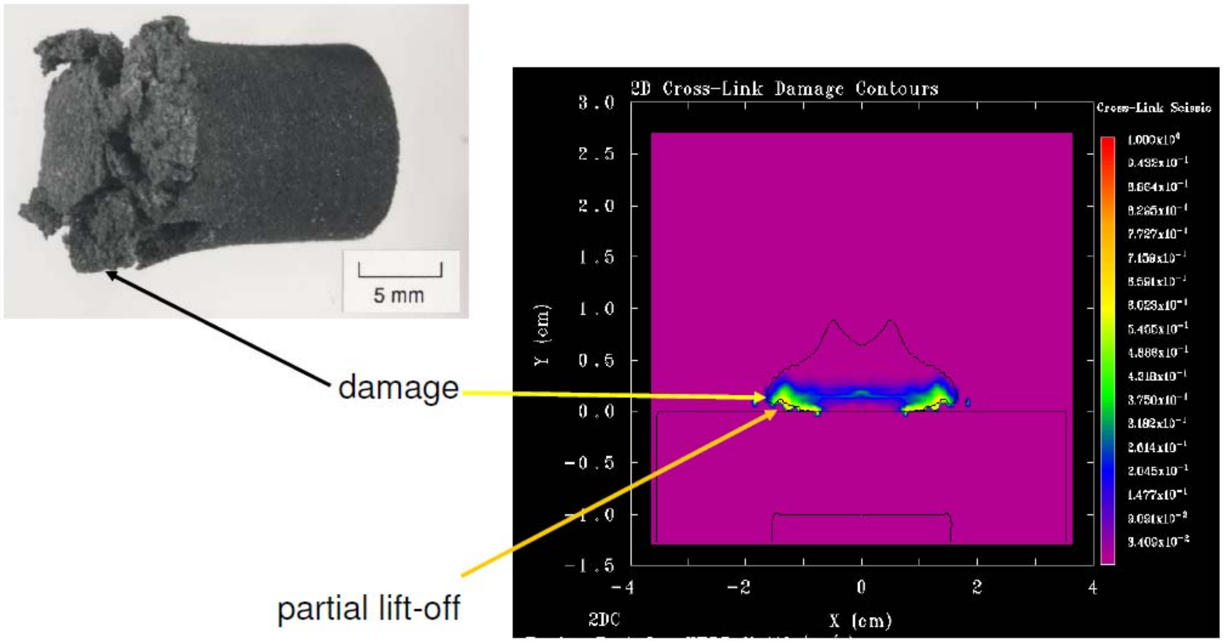
- CTH is Sandia National Laboratory's (SNL) explicit hydrocode and is heavily used by the DoD for various performance models
- It is an explicit Eulerian code which can not be used to solve long time scale (implicit) events and just one code contained in the SIERRA suite
- SNL's philosophy was that individual areas (fluid flow, hydrodynamics, heat transfer, etc.) were each complicated enough to warrant their own code. These approach is different from LLNL's
- SIERRA is the framework that handles all data transfer/coupling between codes (wrapper) and handles/couples a number of codes
  - Aria (implicit, porous flow)
  - Presto (explicit Lagrangian formulation)
  - Adagio (implicit structural analysis)
  - Others

CTH/SIERRA Improvements



- SNL focused heavily on this area
  - Multi-phase flow of gaseous-solid interaction required handling multiple EOSs (solid and gaseous) and their use by explicit codes (CTH)
  - Reaction varies heavily with damage (burning eg.) so SNL also implemented a coupled damage reactivity model which closely matched experiments

CTH/SIERRA Improvements continued...



Taylor test coupled damage and reactivity model experiment and numerical prediction

- Code coupling is critical within a framework that uses distinct codes to model specific phenomena
  - Explicit to explicit (CTH to Presto) via shell elements
  - Implicit (Aria) to explicit (CTH)

CTH/SIERRA Improvements continued…

- Statistical variation of fracture now possible (as well as most parameters) within an explicit code
- Because particle routines (SPH) already existed within Presto, other improvements were made including, but not limited to improvements to material models incorporating more advanced thermal, mechanical and chemical behavior

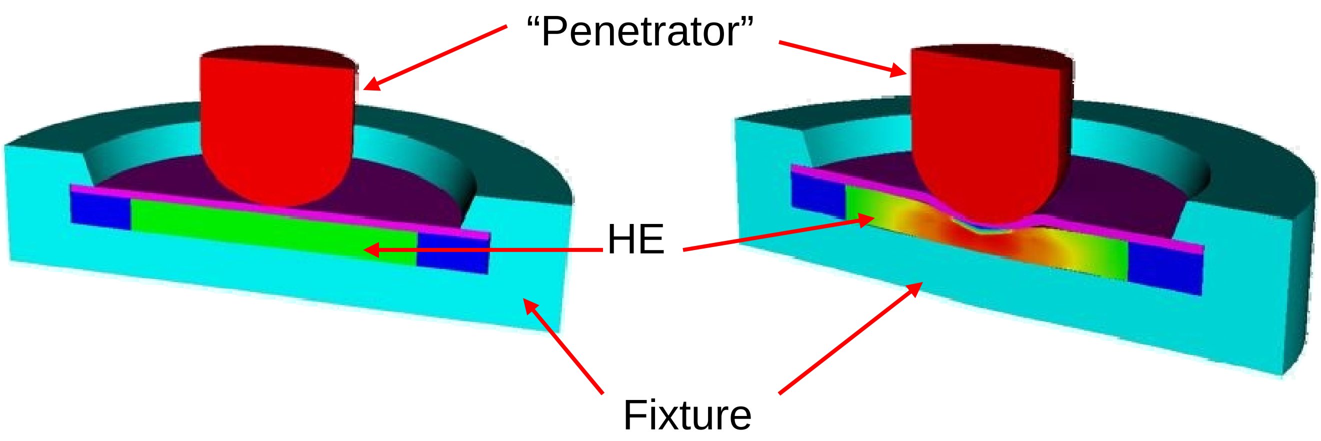
ALE3D Background

- ALE3D is Lawrence Livermore National Laboratory’s (LLNL) multi-physics code
- Unlike CTH, it is an Arbitrary Lagrangian Eulerian (ALE) code. It is monolithic and has the ability to model a variety of phenomena including hydrodynamics, chemistry, heat transfer, fluid flow, and thermal effects and has the ability to transition from explicit to implicit and back within a single code
- Rather than being coupled, like would be required if separate codes were used, the various physical phenomena are merely called or neglected as the designer sees fit. Everything runs from a single deck/single program instance

ALE3D Improvements

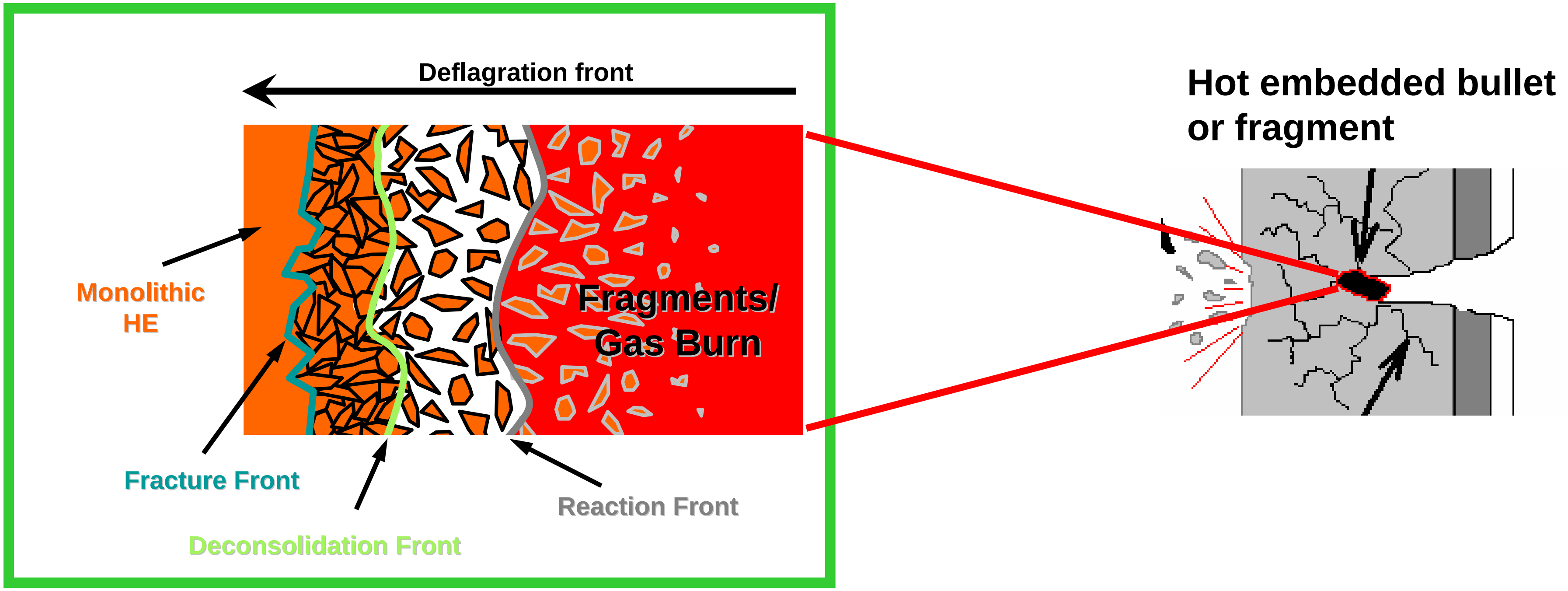
- Multi-phase flow improvements include implementation and enhancing robustness of 3+ phase reactive flow.
- Development and implementation of a sub-grid probability density function (PDF) for enhancement of fracture localization and fragmentation
  - Would like to be able to predict adiabatic shear banding

ALE3D Improvements continued…



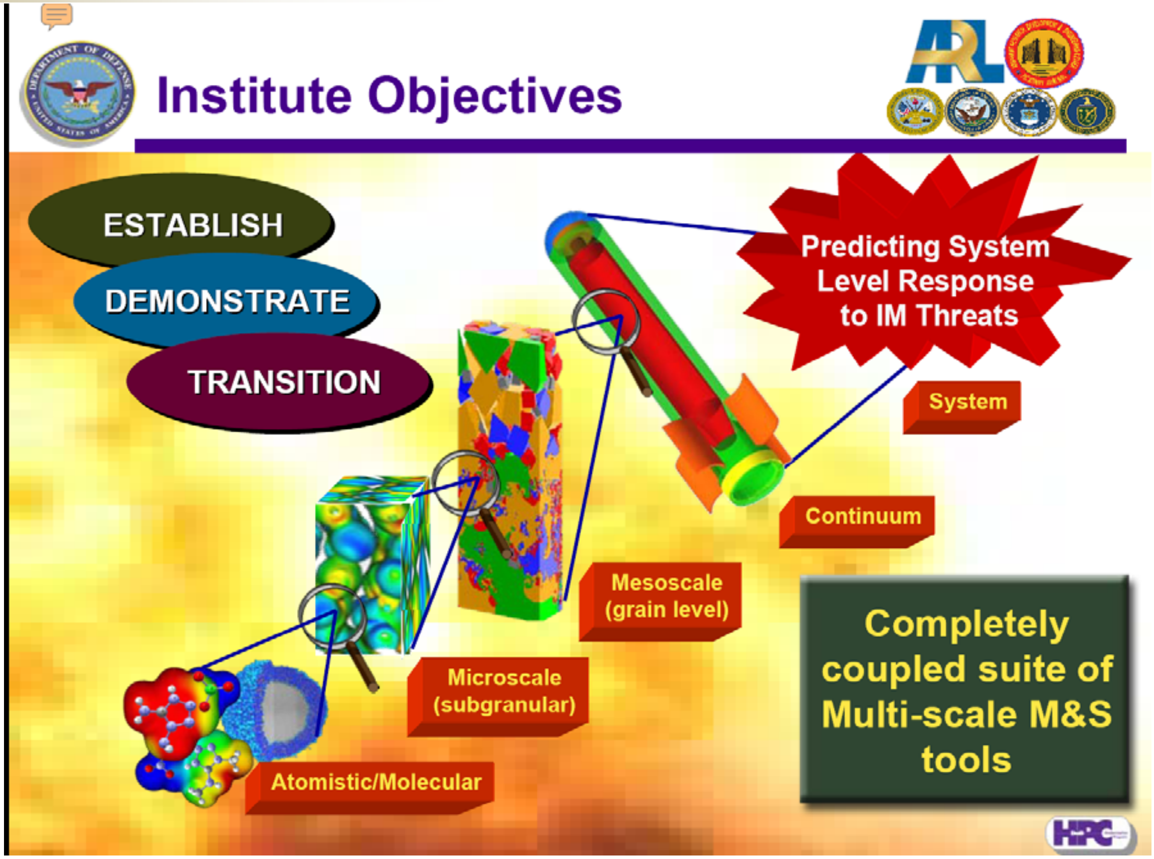
- Since no "code coupling" was required other areas were developed including sub-detonative response
- The simulation above is of a Steven Test and agrees well with the experimental data. It uses a relatively low speed blunt penetrator impacting a heavily confined HE sample. Depending on velocity (10-100m/s) reaction may or may not occur and when it does, it is typically less than a full detonation
- Enhancement of a propellant model, built on the classic Lee-Tarver Ignition and Growth model to model non HE behavior (pressure threshold for ignition) both with and without hot spots

ALE3D Improvements continued…



- Introduction of a method of coupling damage and reaction with a burn rate between laminar and full detonation
- Introduction of rudimentary particle methods (SPH) with more fidelity than element death

Other Ongoing Work



- This effort is not comprehensive. Much more work remains and/or is ongoing
- See Bill Davis' poster for more details about the IM Institute and their work in multi-length scale modeling

Conclusion

- Codes currently used to model BFI are far from ideal but are still used to within their range of validity (being stretched)
- This work was an effort to improve the fidelity with which two codes commonly used by the US DoD can simulate BFI scenarios
- They are useful but require much more development and validation to be truly predictive

Questions?