U.S. ARMY COMBAT CAPABILITIES DEVELOPMENT COMMAND – ARMAMENTS CENTER

SR Barriers for IMX-104 Filled Artillery Projectiles

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OUTLINE

- SR Testing and Phenomenology, Item of Interest
- Logistical Analysis
- Computational Considerations
- Barrier Concepts
- Donor Modeling Considerations
- Acceptor Modeling Considerations
- 2D Plane Strain Models
- Constrained Nonlinear Optimization for 2D Plane Strain
- 3D Models
- SR Testing
- Summary and Conclusions; Future Work

SR TESTING FOR 155MM ARTILLERY PROJECTILES

- Initiation and expansion of donor
- Shock loading and deformation of acceptors
- Various initiation/ignition mechanisms
- Current item of interest: 155mm IMX-104 filled artillery projectiles
- 8 rounds per pallet, multiple pallets
- Projectile known to fail SR in this configuration - Try modeling

LOGISTICAL ANALYSIS

(https://www.armadainternational.com/2021/01/rethinking-resupply-to-the-forward-line/)

- 155mm artillery usually weighs out before it cubes out
- Removing a single pallet provides ample trade space

COMPUTATIONAL CONSIDERATIONS

- Modeling performed in LLNL ALE3D code
- Inert materials: Gruneisen EOS, Johnson-Cook Strength, Johnson-Cook Failure
- Air: Gamma law gas
- Donor explosive: JWLB programmed burn with augmented beta burn
- Acceptor explosive: Lee-Tarver Ignition and Growth

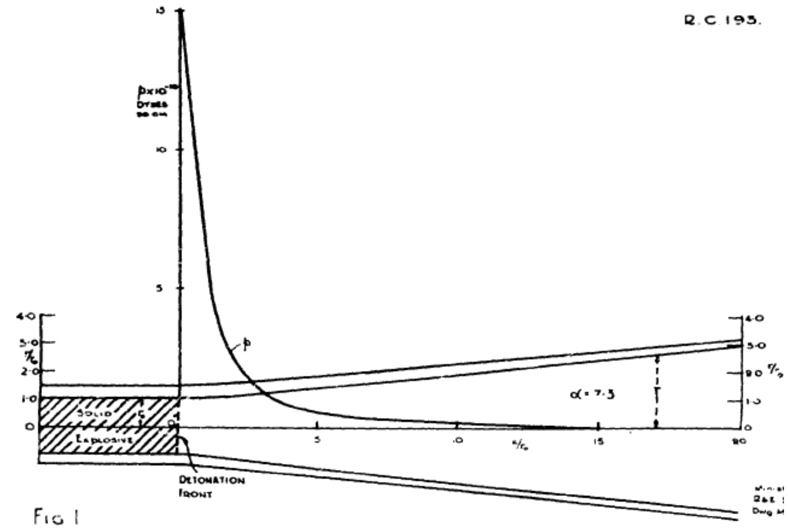
An Arbitrary Lagrange/Eulerian 2D and 3D Code System

BARRIER CONCEPTS

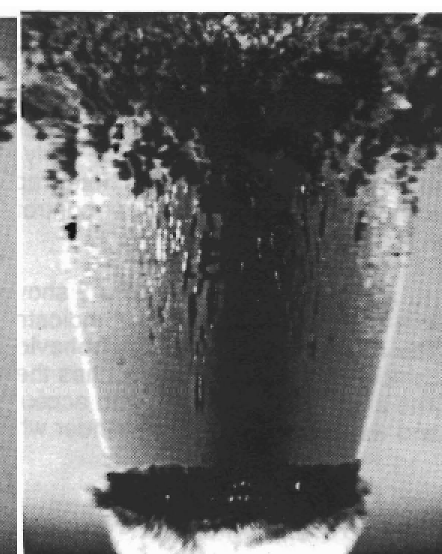
- Standard mitigation methods: Reduced sensitivity fills, more ductile fills, and barriers/buffers
- Barriers widely studied since at least 1970s
- Metals, plastics, foams, geological materials, etc.
- Some easier to model than others
- Geometry: flat panels, tubes, diamond bars, etc.
- Packaging materials are sunk costs
- Polymer buffers frequently used to attenuate shocks – good place to start

DONOR MODELING CONSIDERATIONS

- Standard mitigation methods: Reduced sensitivity fills, more ductile fills, and barriers/buffers
- Barriers widely studied since at least 1970s
- 2D plane strain: not that physically realistic
- 3D: reactive flow for donor?
- Fragmentation at r/r0 < 1.7, but may behave more like flyer plate in diagonal direction

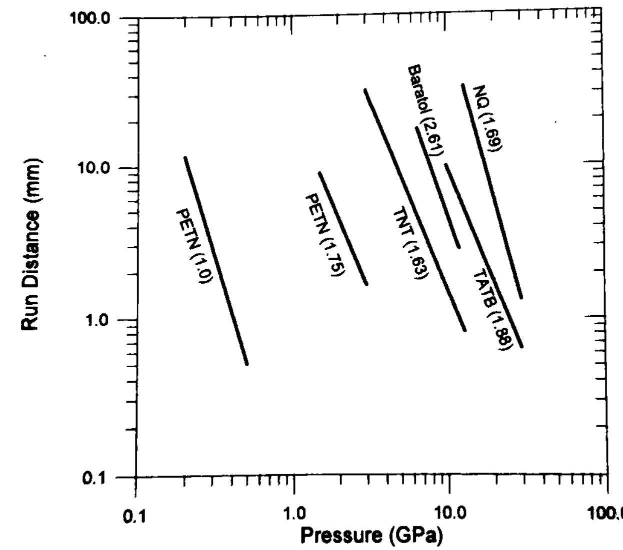


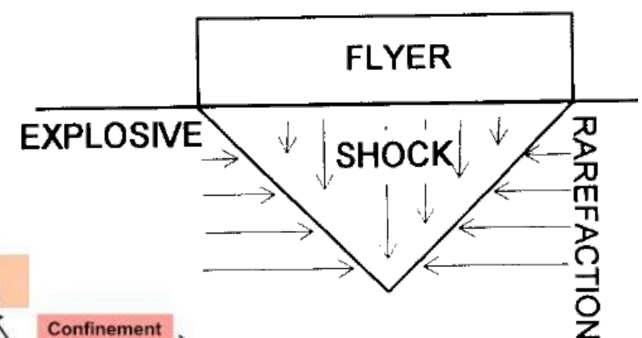

30 µsec

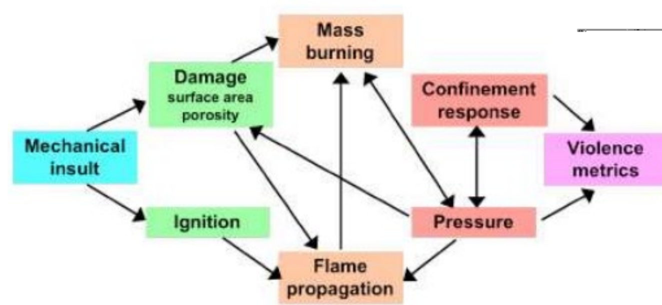

48 µsec

ACCEPTOR MODELING CONSIDERATIONS

- Geometric complexity - need reactive flow modeling
- Lee-Tarver Ignition and Growth
- Rate law; T, P equilibrium for partially reacted states
- Requires very fine zoning (multiple cells through reaction zone)… Try 2D
- Won't address other ignition mechanisms, shock desensitization







2D PLANE STRAIN MODELS

- Constant volume detonation least unrealistic
- Average wall thickness used
- 50 zones/cm, 2.5M zones
- Need to run to ≥ 200us → approx. 2 hrs wall clock
- The baseline configuration mass detonates

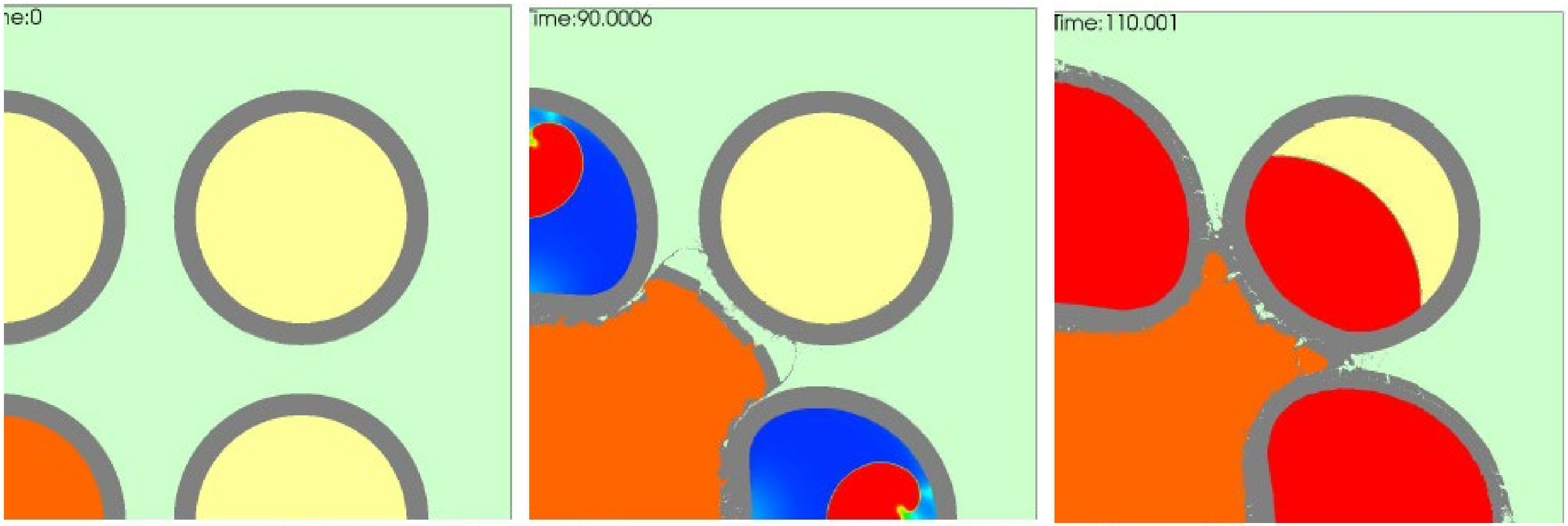
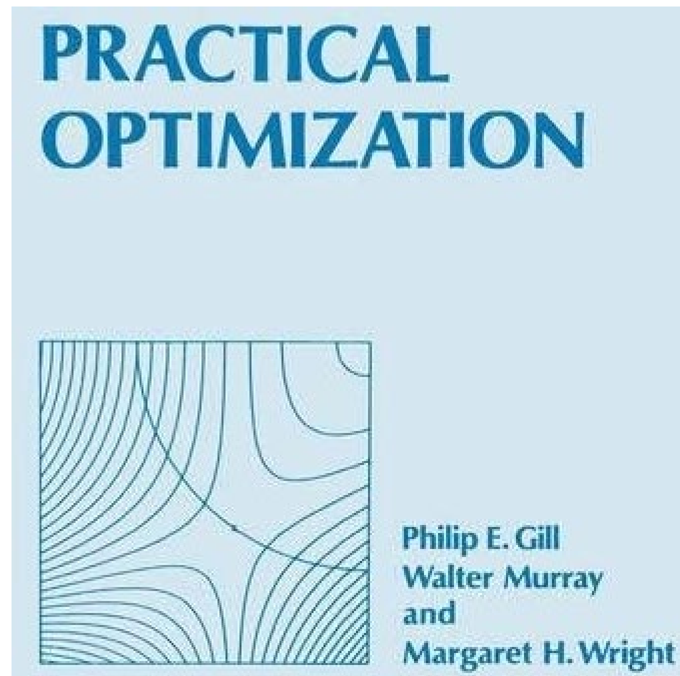


Figure 2. 2D Plane Strain Models – Baseline

2D PLANE STRAIN MODELS – NONLINEAR OPTIMIZATION

- Various barrier models investigated - long run times
- MATLAB fmincon
- Minimize barrier weight (linear function) subject to:
- Bound constraints: non-negative thickness
- Linear inequality constraint: total thickness less than round spacing
- Nonlinear inequality constraint: F comfortably below 1 in IG model
- Piece of cake?

$$
\begin{aligned}
&\underset{x \in \Re^n}{\text{minimize}} && F(x) \\
&\text{subject to} && c_i(x) = 0, \quad i = 1, 2, \ldots, m'; \\
& && c_i(x) \geq 0, \quad i = m' + 1, \ldots, m.
\end{aligned}
$$



2D PLANE STRAIN MODELS – NONLINEAR OPTIMIZATION PROOF OF CONCEPT

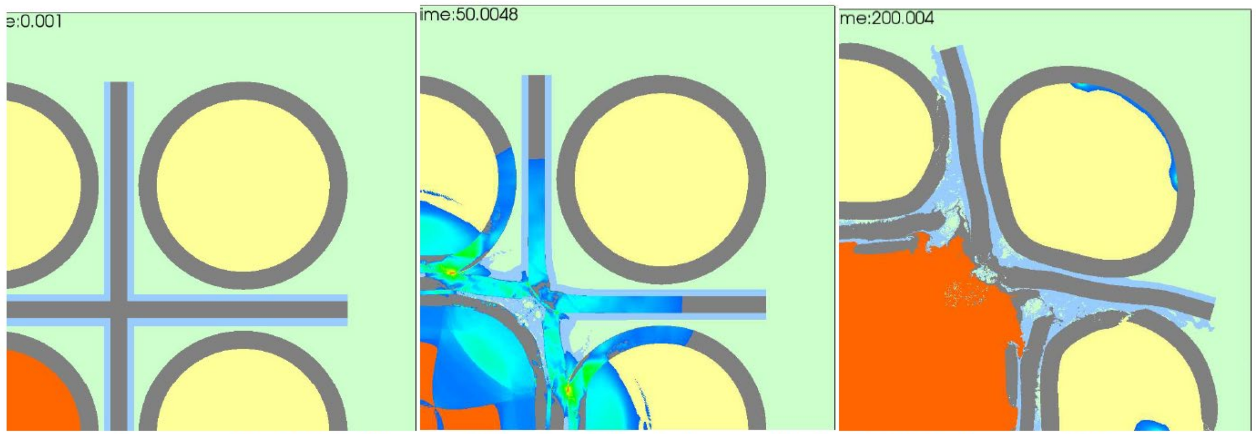


Figure 3. 2D Plane Strain Models – ALE3D Polymer/Steel

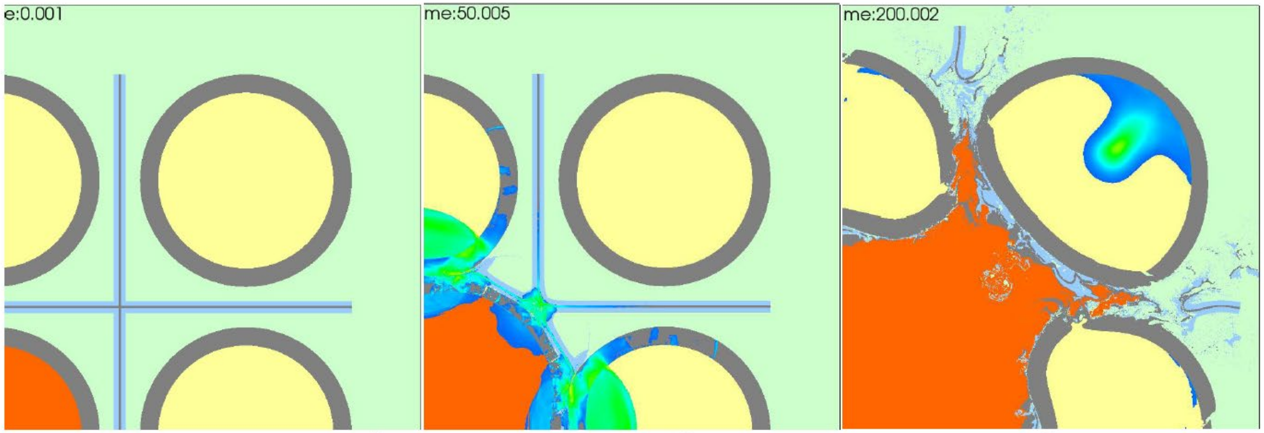


Figure 4. 2D Plane Strain Models – Optimized Polymer/Steel Design

- Initial feasible point, was hard to find
- Looks like a thin plastic buffer will suffice – Try 3D

3D MODELS

- Reactive flow, 7.5 zones/cm, 40M zones, out to 300us
- Appears the baseline configuration mass detonates, polymer tube configuration does not – Try testing

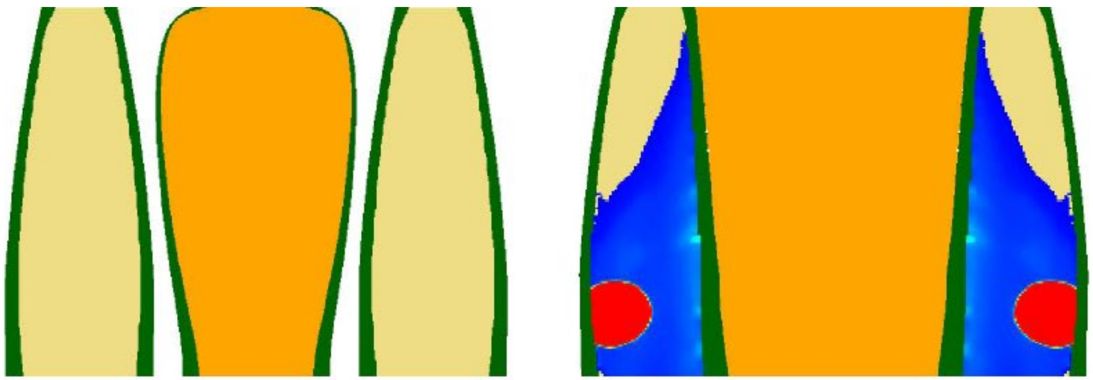


Figure 5. Baseline 3D Model Results

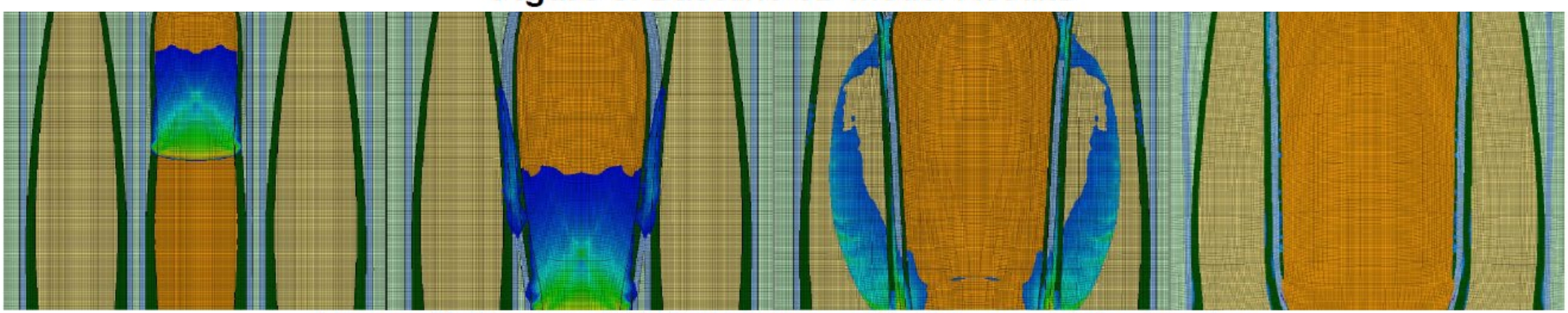


Figure 6. Sample 3D Calculation with Polymer Tube Barrier

SR TESTING - BASELINE

- 2 pallets adjacent to each other (4 rounds x 4 rounds)

SR TESTING – POLYMER TUBE BARRIERS

Configuration	Single Projectile	Unconfined SR	Polymer Tubes SR
Overpressure (Relative)	1.0	6.2	0.7

SR pass produces less overpressure than single round!

SUMMARY AND CONCLUSIONS, FUTURE WORK

- Computationally designed IM barriers to get IMX-104 filled 155mm artillery projectiles to pass SR
- Polymer tube design protects against propagation between pallets and satisfies logistical requirements
    - This design was scored with a passing reaction by the U.S. Army IM Board
    - Stands to be even further optimized!
- Design likely also passes bullet and fragment impact, if any protection needed at all
- Barriers being considered for integration into the packaging
- Other future work – further optimization and demonstration of this and similar concepts, applied to this and similar munitions

QUESTIONS

Distribution Statement A: Approved for public release. Distribution is unlimited.

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