Challenges in the Predictive Capabilities of Fragment Impact of Rocket Motors

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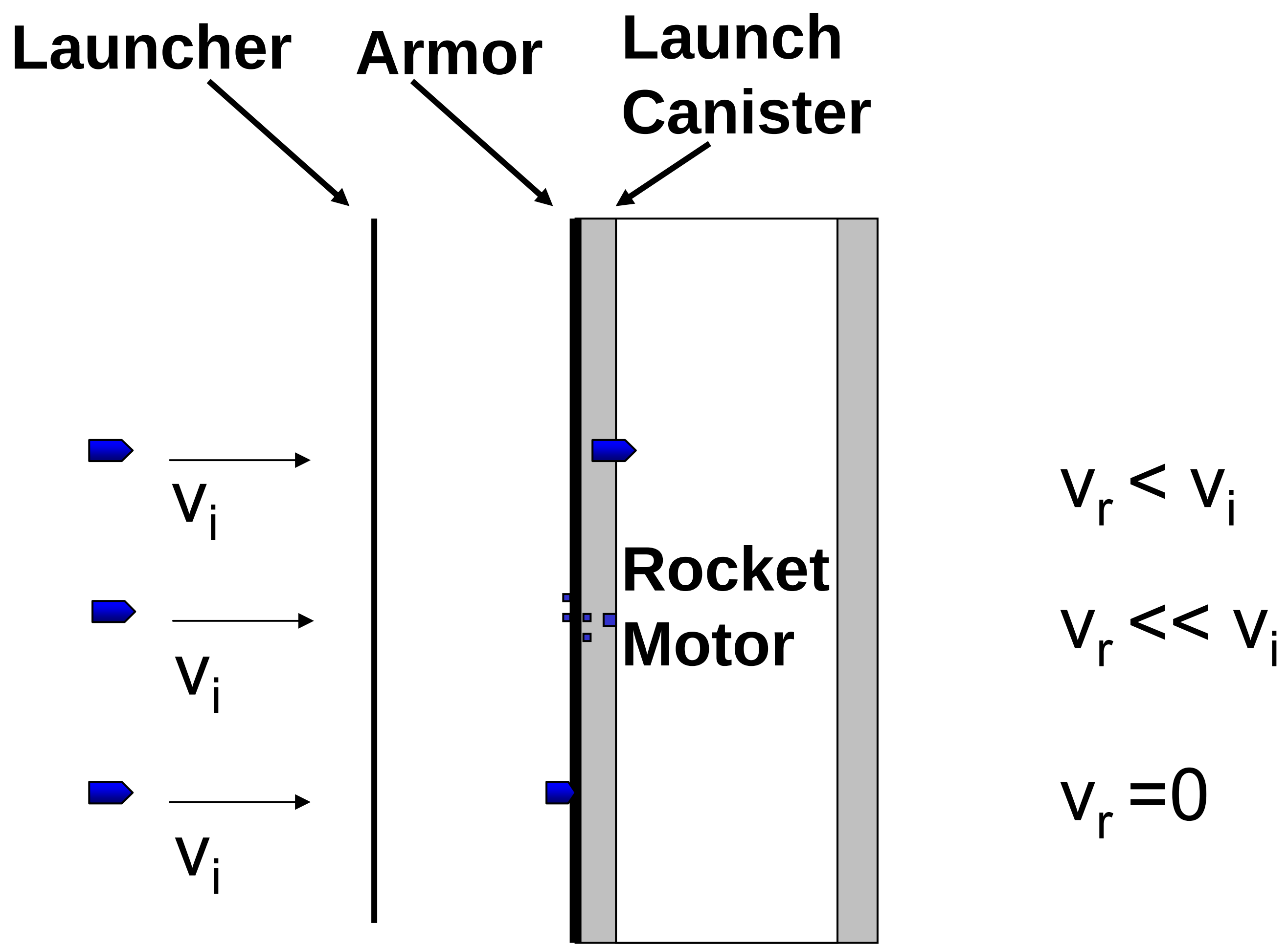
Purpose of this Talk

- Examine the state of the art in ‘predictive’ continuum modeling capabilities for assessment of fragment impact of rocket motors in engagement systems
- Identify areas for improvement
- Propose where the IM community needs to focus

The Fragment Impact Problem



V_i = initial velocity ; V_r = residual velocity at rocket motor

Relevant Phenomena Involved in Fragment Impact

- Perforation of launcher, armor and launch canister
  - Residual mass and velocity of projectile and debris
- Rocket motor case penetration
  - Case structural response affects combustion
- Propellant penetration
  - Propellant structural response affects combustion
- Propellant initiation
  - SDT, shock induced burn, temperature induced burn
- Propellant burn
  - Stress tensor, cracking

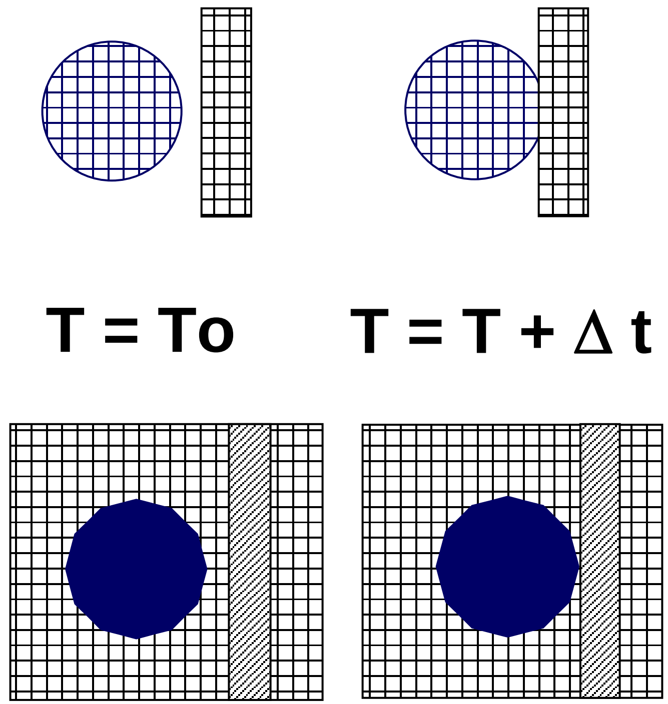
How do models predict IM score?

- Possible outcomes
  - No reaction
    - No fragments thrown
  - Burning
    - Temperature or Pressure Induced
    - Confinement defines distance/size of fragments
  - Detonation
    - Prompt or delayed
    - Natural fragmentation size difficult to predict
    - Fragment speed determined by detonation velocity

Fragment size/distance determine IM score

Numerical Formulations

- Lagrangian
  - Mesh follows the structure
  - Good for strength driven problems
- Eulerian (e.g. CTH)
  - Mesh (grid) independent of structure
  - Media is treated as a fluid with strength
  - Good for very high speed problems
- ALE (e.g. ALE3D)
  - Mesh motion is independent of material motion
  - May be run Lagrangian, Eulerian or ALE

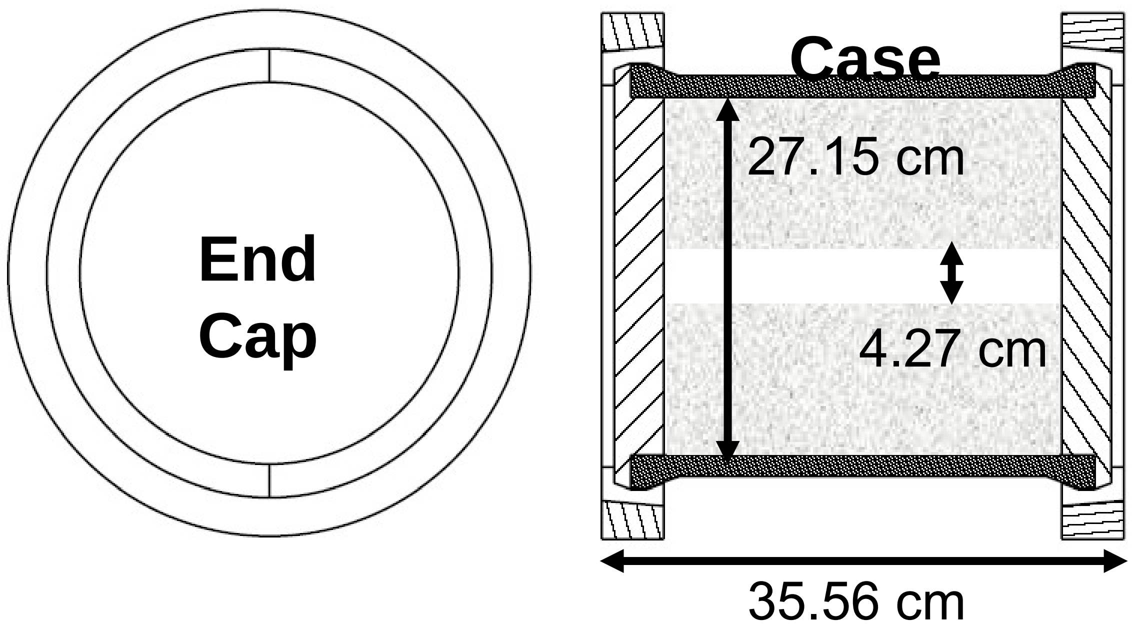


Current Propellant Combustion Models

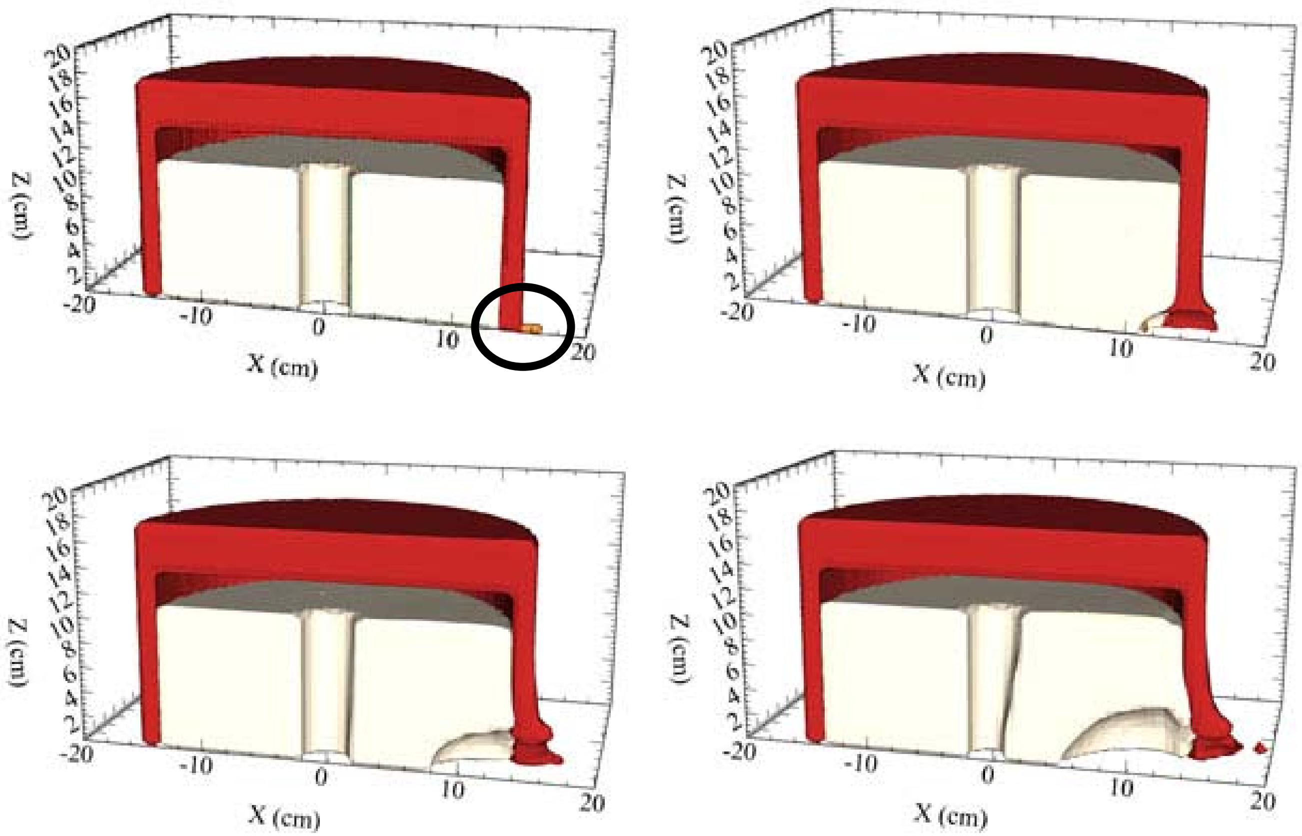
- CTH – **PMOD** (Sandia National Laboratories)
    - Calibrated to shock experiments at varying scales
        - High strain rate regime
        - Treats response like SDT
    - Intended to model shaped charge input
    - Empirical
- ALE3D – **PERMS** (Lawrence Livermore National Laboratory)
    - Developed for rocket motor fallback scenario
    - Calibrated to shotgun and closed bomb experiments
        - Low strain rate regime
        - Treats response like combustion
    - Moderate physics
        - Burn rate is a function of strain rate
        - Cracking based on empirical model

Evaluation of Propellant Models

- Modeled an FI test with a common propellant cylinder using PERMS and PMOD:
  - Compared threshold velocity results
  - “Fragment” was cylindrical with a blunt conical point



CTH Evaluation - Rocket Motor Surrogate



Ignition threshold velocity predicted to be 12000 fps

- Value seems high
- No test data

Material boundary plots from 12000 fps impact
Reacted propellant not shown

Evaluation of PMOD/ CTH for Known FI Test Series

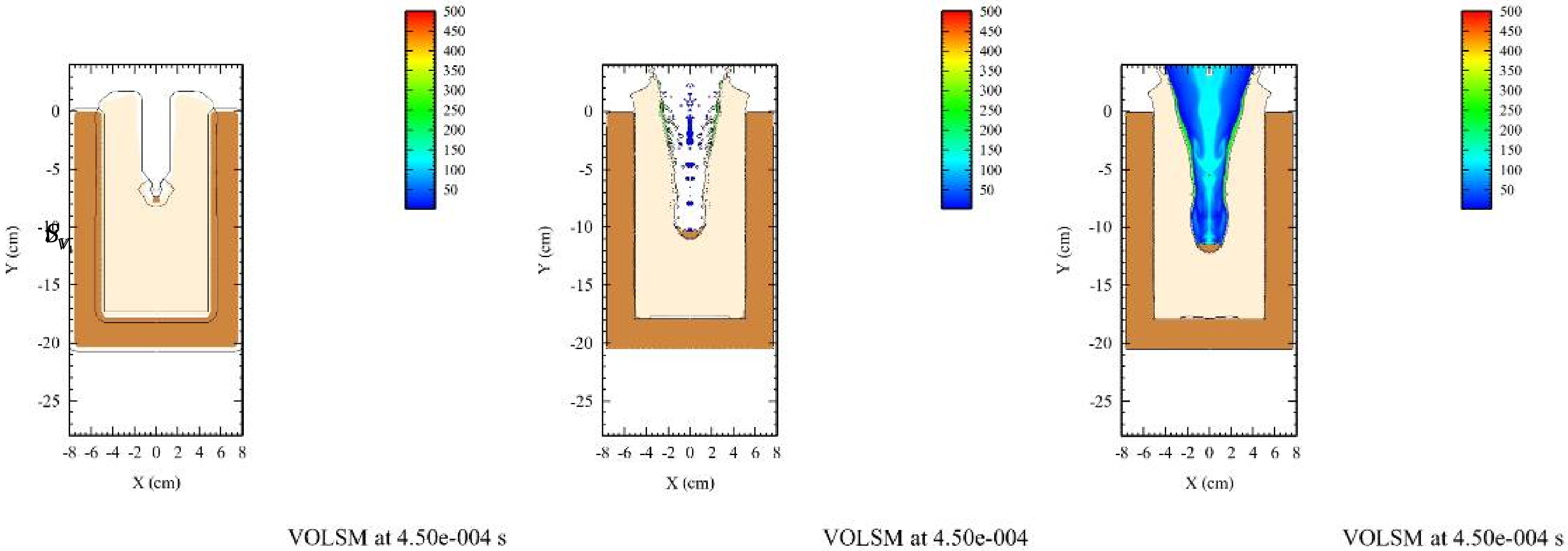
- ARL thin skinned samples- ‘go/no-go’ data
  - Al skin (4 out of the 6 test configurations)
  - Small tungsten fragments
  - AP/Al/HTPB propellant
- 52 tests across 6 test configurations
  - Some overlap in critical velocity values
- Focused modeling on tests over average critical velocity
  - Highest Values Tested
  - Predicted no-go

PMOD predicts threshold velocity too high (> 20%)

PMOD Reparameterization

- Modeling effort showed that PMOD was very insensitive to FI
- Is there a way to recalibrate the model?
  - Being an empirical model makes this much easier
  - Key to reducing sensitivity is via the pressure due to strain-to-failure model
    - This model is encapsulated in a user parameter
    - Parameter can be changed in tandem with mesh resolution dependent parameter
  - Need a new parameter set which is as effective in modeling the calibration test suite, but yields lower threshold ignition velocities for FI scenarios

Reparameterization Effort

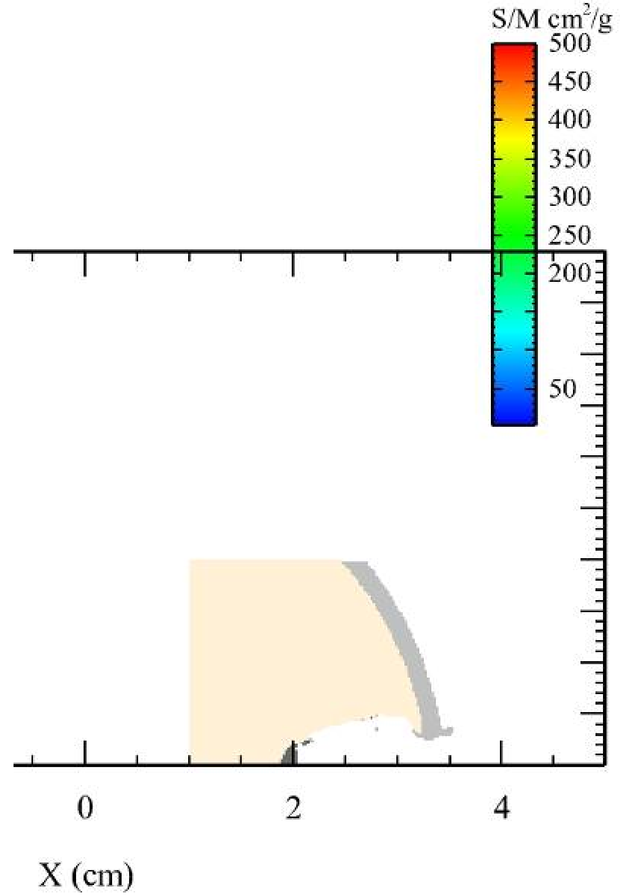


v_V=0.25; S_{v1}=150
Cell resolution = 0.125 cm

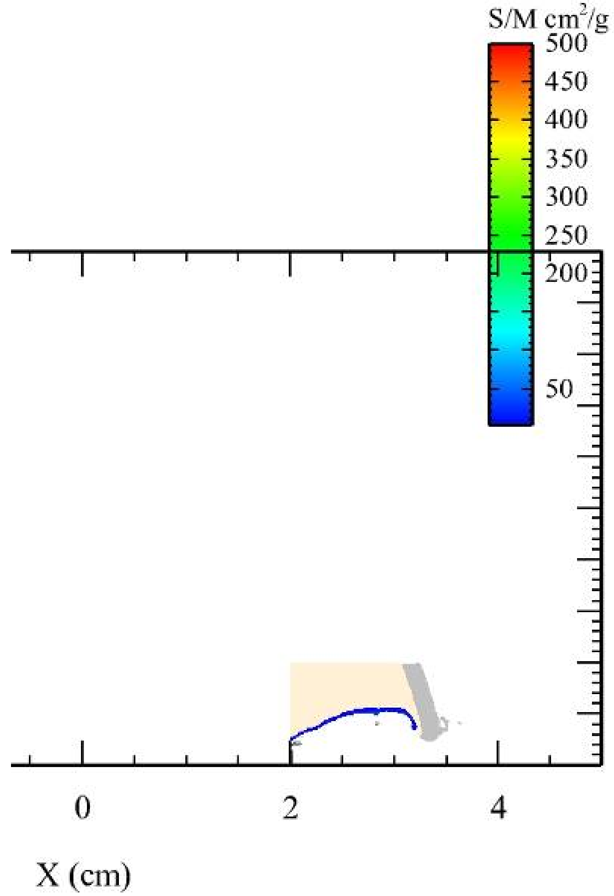
v_V =0.25; S_{v1}=27
Cell resolution = 0.0635 cm

v_V=0.10; S_{v1}=27
Cell resolution = 0.0635 cm

Reparameterization Effort for ARL Test



Original PMOD Parameters



Revised PMOD Parameters

New Parameters Resulted in Realistic Results

Evaluation of PMOD/ CTH

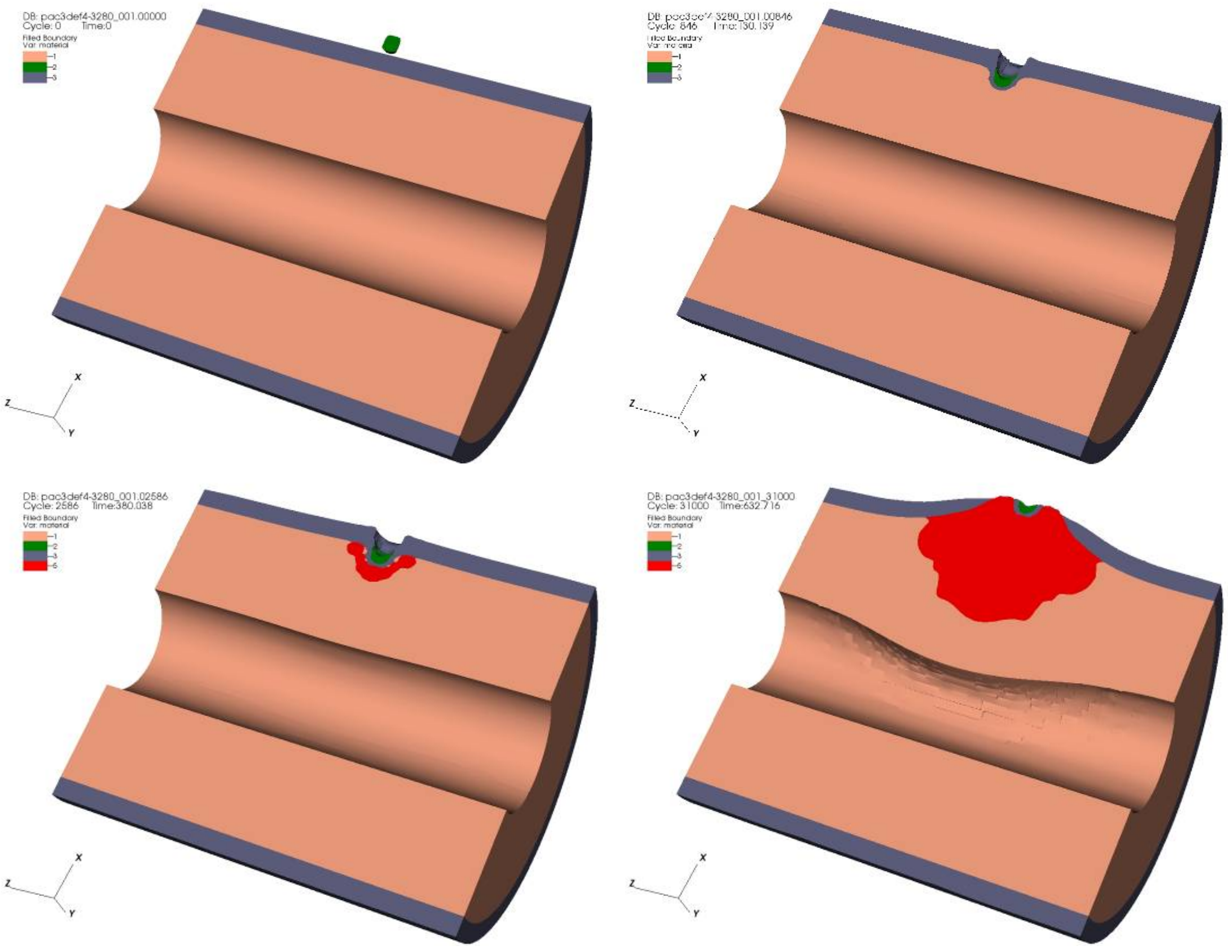
Results

- High threshold velocity predicted for Rocket Motor Surrogate
  - 12000 fps
- Failed to predict any of the FI tests in ARL test series
- Reparameterization effort shows promise

Areas for Improvement

- Ignition threshold
  - Not bounded for pressure
  - Does not allow for shear/thermal ignition
- Empirically based on high strain rate data
  - Order of magnitude higher than fragment impact
- First-order capability until CDAR (also CTH) is finished
  - Reaction chemistry not modeled
  - No deflagration model

ALE3D Evaluation - Rocket Motor Surrogate



- Ignition threshold velocity predicted to be 2000 fps
- Value much lower than PMOD
- No test data
- Qualitative results look good

Material boundary plots from 3280 fps impact

Evaluation of PERMS/ ALE3D

Results

- Low threshold velocity predicted
  - 2000 fps
- ALE3D deflagration model triggered after PERMS event

Areas for Improvement

- Ignition threshold
  - Not bounded for pressure
  - No shear/thermal ignition
- Two part reaction rate
  - Tries to capture some chemical processes
  - Actual chemistry not modeled

Summary on Propellant Modeling

- Two DOE models were exercised for an FI problem involving a rocket motor surrogate
  - Neither model was developed for this problem
  - PERMS designed for fallback (low strain rate regime)
  - PMOD designed for explosive input (high strain rate regime)
- Threshold ignition velocity
  - Low for PERMS model, within ALE3D
  - High for PMOD model, within CTH
- Reparameterization of PMOD appears to improve results
  - More work needed to know if this is viable
  - PMOD not intended to have a future capability in this area

General Areas for Improvement

- Ignition threshold criteria are not well defined
  - Pressure only
  - Need to allow for shear/thermal ignition
- Propellant burn databases
  - Lack of clear test matrix required to calibrate each model
  - No overlap in test matrices
  - Lack of common material model database for multiple codes
- Material models needed (combustion)
  - Non-metallic structural composite (burning)
- Material models needed (strength, damage, fracture)
  - Structural composites
  - Insulators/ liners
  - Propellants

Where does the IM community need to focus?

- Physics
  - Develop 1.3 Propellant (Sub-detonic) Hybrid Ignition Model
  - Functional Evaluation of Next Generation Ignition & Growth Models by Engineering Technical Agents (ETAs) for Propellants
  - Determine areas for improvement for FCO, SCO, SD, SCJ
  - Spiral II Toolset Initial Development
- Common Database Development
  - Mine Existing Propellant Databases
  - Propellant Lab Scale Experiments to Expand Database for DoD Propellants
- Validation
  - ETA Evaluation of Predictive Capability for B/FI for Systems Containing Propellant
- Numerics
  - Numerics and Physics Algorithm Development Identified in Validation Tasks