2014 NDIA Tech Demo

Multifaceted Gun Fluid Flow Modeling and Experimentation at ARDEC

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Name: Robert Carson
Laurie Florio
Daniel Cler
Presenter: Anthony Cannone

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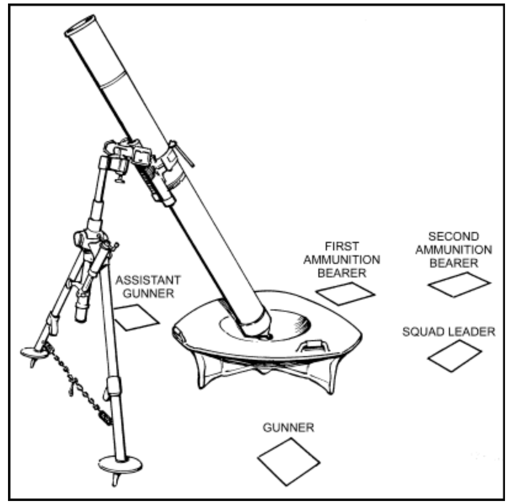
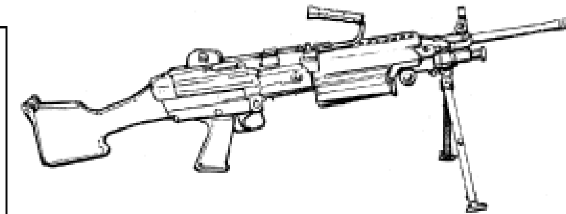
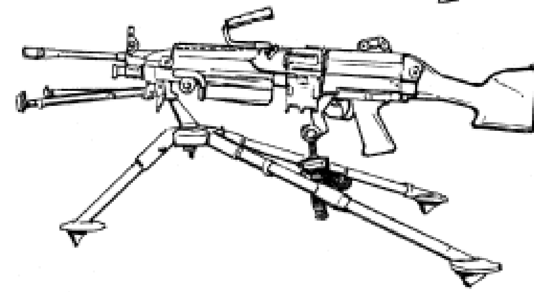
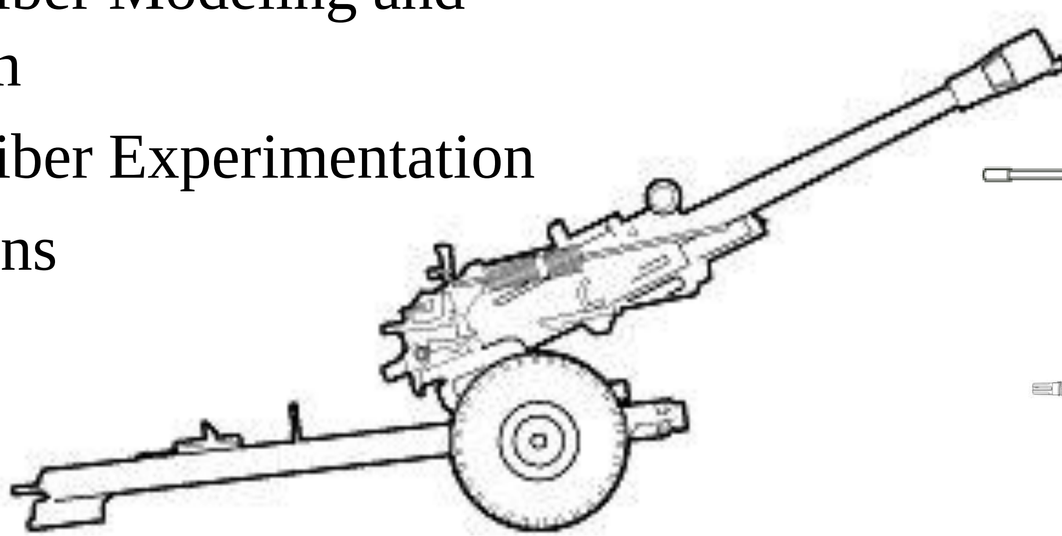
Overview of Presentation

- Numerical codes for fluids modeling utilized at ARDEC
- Small Caliber Modeling and Simulation
- Small Caliber Experimental Testing
- Large Caliber Modeling and Simulation
- Large Caliber Experimentation
- Conclusions









Fluids Modeling
ALE3D

- Arbitrary Lagrangian-Eulerian 3D multiphysics code was developed by Lawrence Livermore National Laboratory.
- Finite Element Based.
- Explicit time integration with non reactive flows.
- Compressible Navier-Stokes equations were solved on an unstructured quadrilateral mesh.
- Two step process:
  - Lagrangian
  - Advection/remap
- Advancing variables at the mesh nodes, and then updating element variables based on the new node variable values.

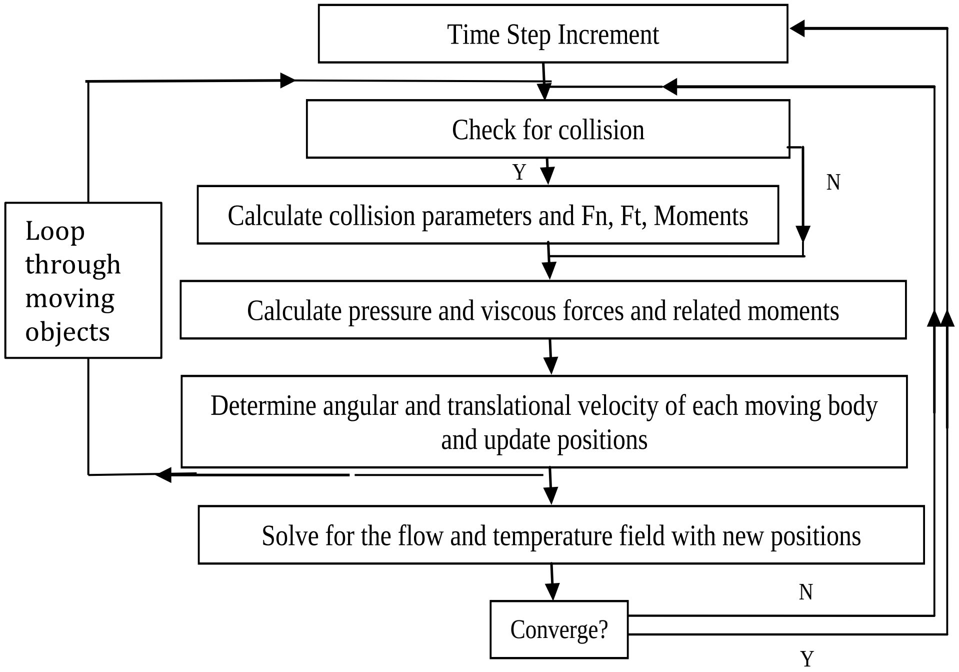
ALE3D High Performance Multi-physics Simulations

1. Calculate the time increment Δt^n.
2. Construct a force at each mesh node.
3. Compute the acceleration at each mesh node.
4. Compute the new velocity at each mesh node.
5. Compute the new position at each mesh node.
6. Update various element variables based on node variables advanced to t^{n+1}.
7. Calculate new artificial viscosity in Q^{n+1}each element.
8. Apply material model properties based on material, volume, etc. in each element.
9. Compute time constraints which will be applied when Δt^{n+1} is calculated for the next step.

Fluids Modeling
ANSYS Fluent

- Commercial code offered through ANSYS, Inc.
- Finite Volume Based.
- Explicit time integration with non-reacting flows/Implicit time integration with multi-body interactions and with chemical reactions
- Compressible Navier-Stokes equations solved in finite volume cells
- Customized real gas material property models, real gas mixture models, and solid body-fluid motion coupling and solid-solid interaction models implemented

ANSYS® FLUENT®

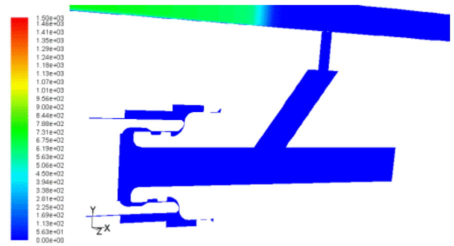


Small Caliber
Modeling and Simulation

Gas Operated Weapon Mechanism Operation and Particle Flow/Erosion

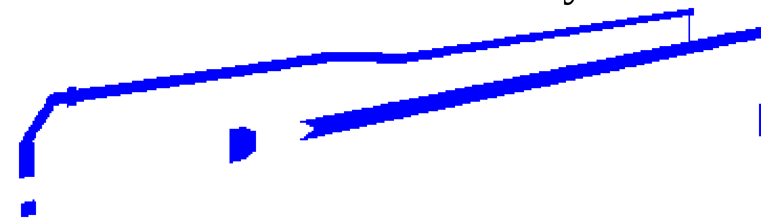
- Capabilities
  - ❑ Simulate and understand the internal gas flow with gas operated weapons and the actuation of weapon mechanisms(bolt unlocking)
  - ❑ Simulate particle flow carried with the gas flow – applications include particle flow carried into gas port and along internal flow paths and particle flow patterns between bolt and upper receiver
  - ❑ Simulate particle impact based erosion along the internal flow paths

- Benefits
  - ❑ Can perform parametric studies to determine impact of changes to geometry, flow conditions, particle material and size
  - ❑ Can capture how the particles collect in or erode gas port area or other areas along the internal gas flow passages to aid in future design

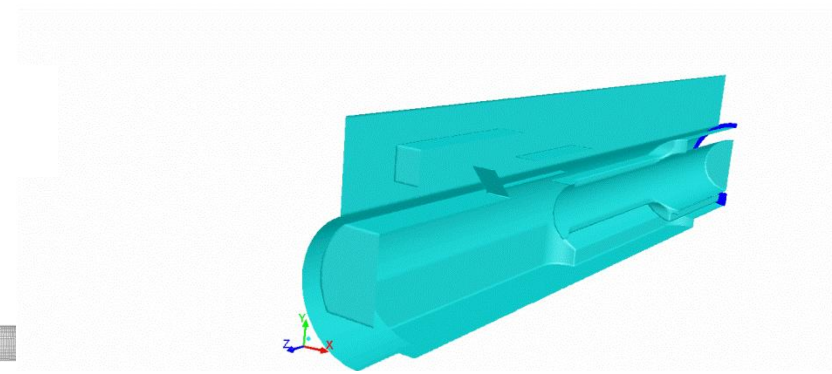


M249- Gas Piston

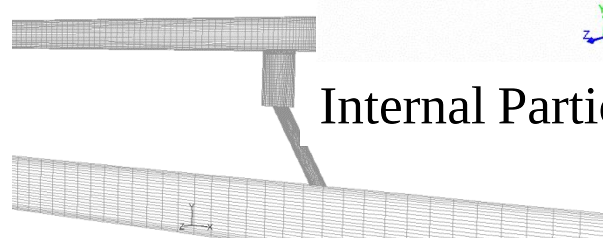
M4 flow into bolt carrier cavity



Internal Gas Flow and Weapon Mech. Actuation



Internal Particle Flow Near Bolt

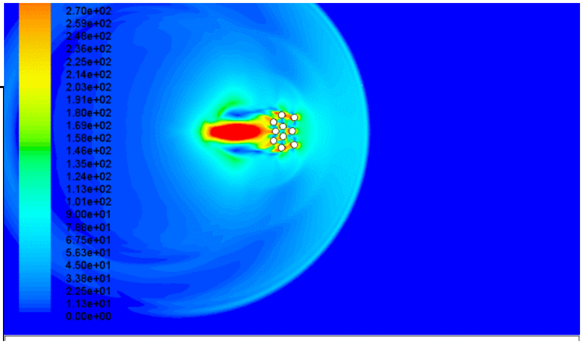


Internal Particle Flow and Erosion Near Port

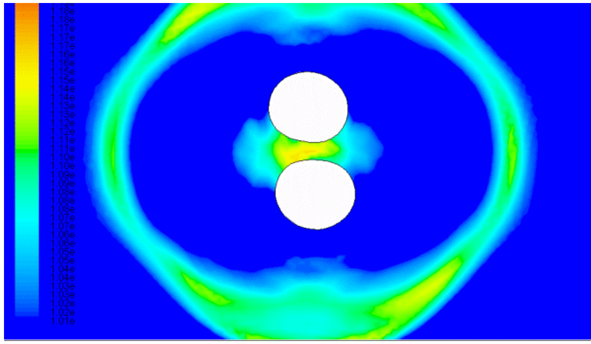
Particulate Flow

- Capabilities
  - ❑ Gun system phenomena operate where particulate flows are NOT dilute so standard built –in Lagrangian models may NOT be applicable
  - ❑ Developed modeling method accounts for particle presence in the flow and particle-particle/particle-other object interactions
  - ❑ Various solid body interaction models developed(spring/damper models, FEA)
- Benefits
  - ❑ Can show effects of particle size, particle material/properties, gas flow conditions on particle motion
  - ❑ Can explore methods to control or alter particle motion
  - ❑ Can be applied to propellant burn
  - ❑ Can eventually be applied to erosion, fouling, chemically reacting particles

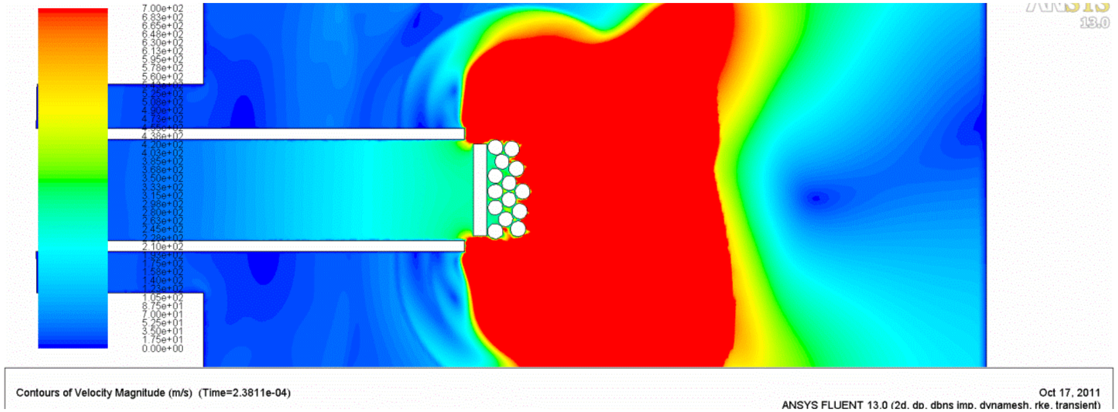
Projectile spread

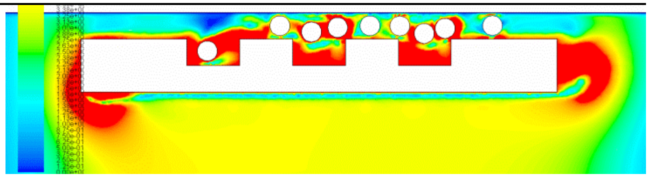


Coupled CFD-FEA model



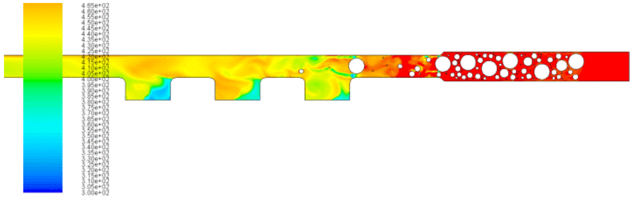
Particulate ejection with elastic/plastic interaction model

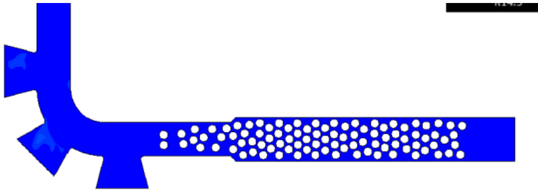




Particle interaction with moving plate

Means to Control Particle Motion



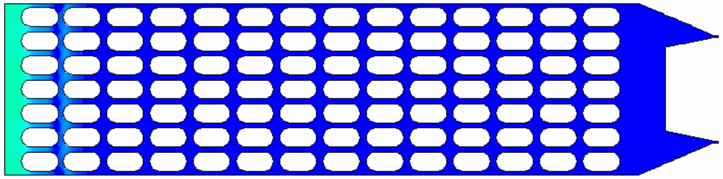


Propellant Burn

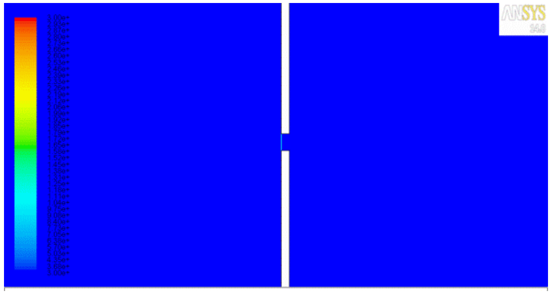
•Capabilities
- High particle concentration conditions typical of propellant burn can be simulated with the application of the particle/flow coupling and interaction modeling methods
- Burn rate based on local surface conditions: first with single species of gas generated, progressing to multiple species and simplified chemistry
- Local surface condition based model assists in study of non-standard geometries
- Customized real gas model and consistent thermo/material properties, real gas chem. equilibrium used in determining gas species output at burn

•Benefits
- Can better understand grain/gas/geometry interaction
- Can improve accuracy of simulations of system operation, can enable study of particle flow based events – erosion, fouling particle reactions

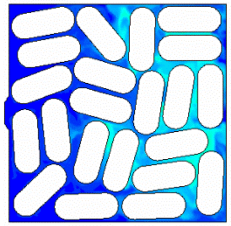
Burning of propellant grains- single gas species generated – Pressure field



Chemistry model development, Temp H2 escapes

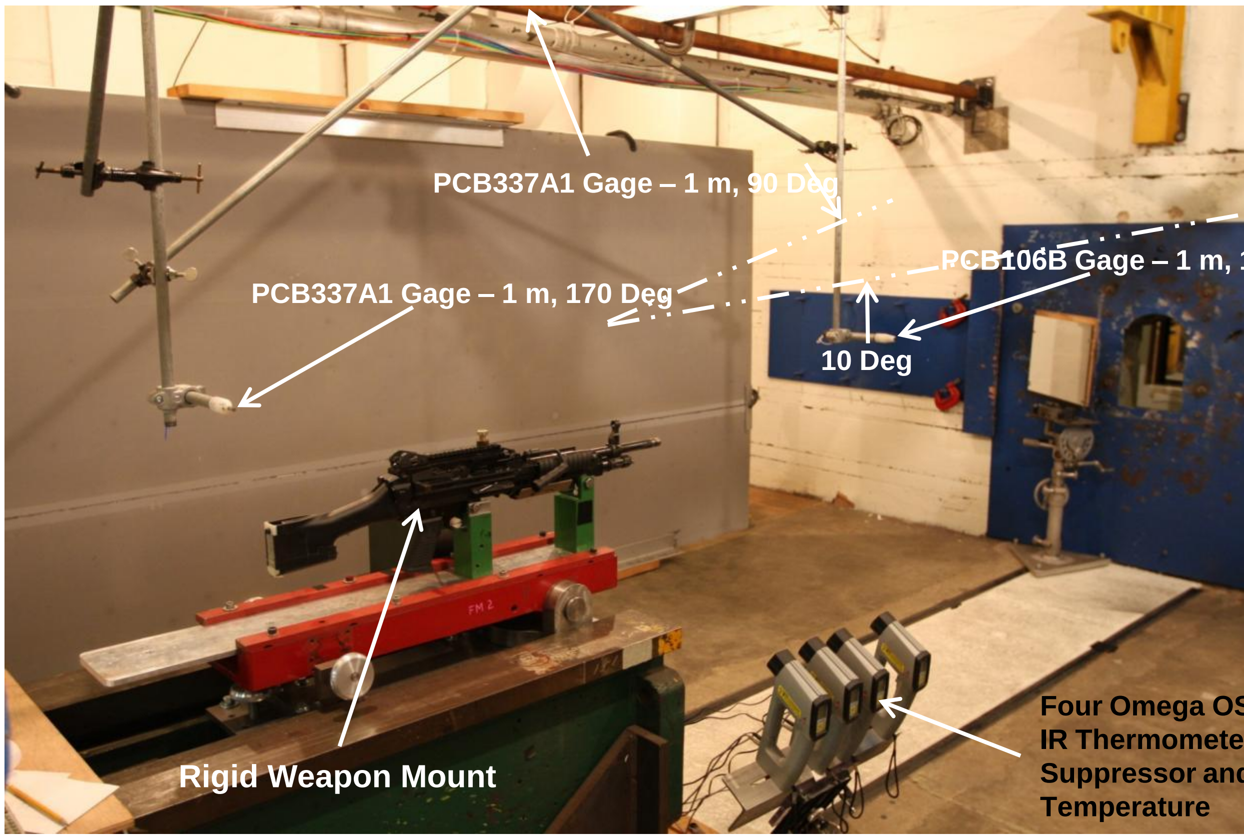


Multiple gas species generated, chemistry, burn based on local conditions- CO_2 mass fraction

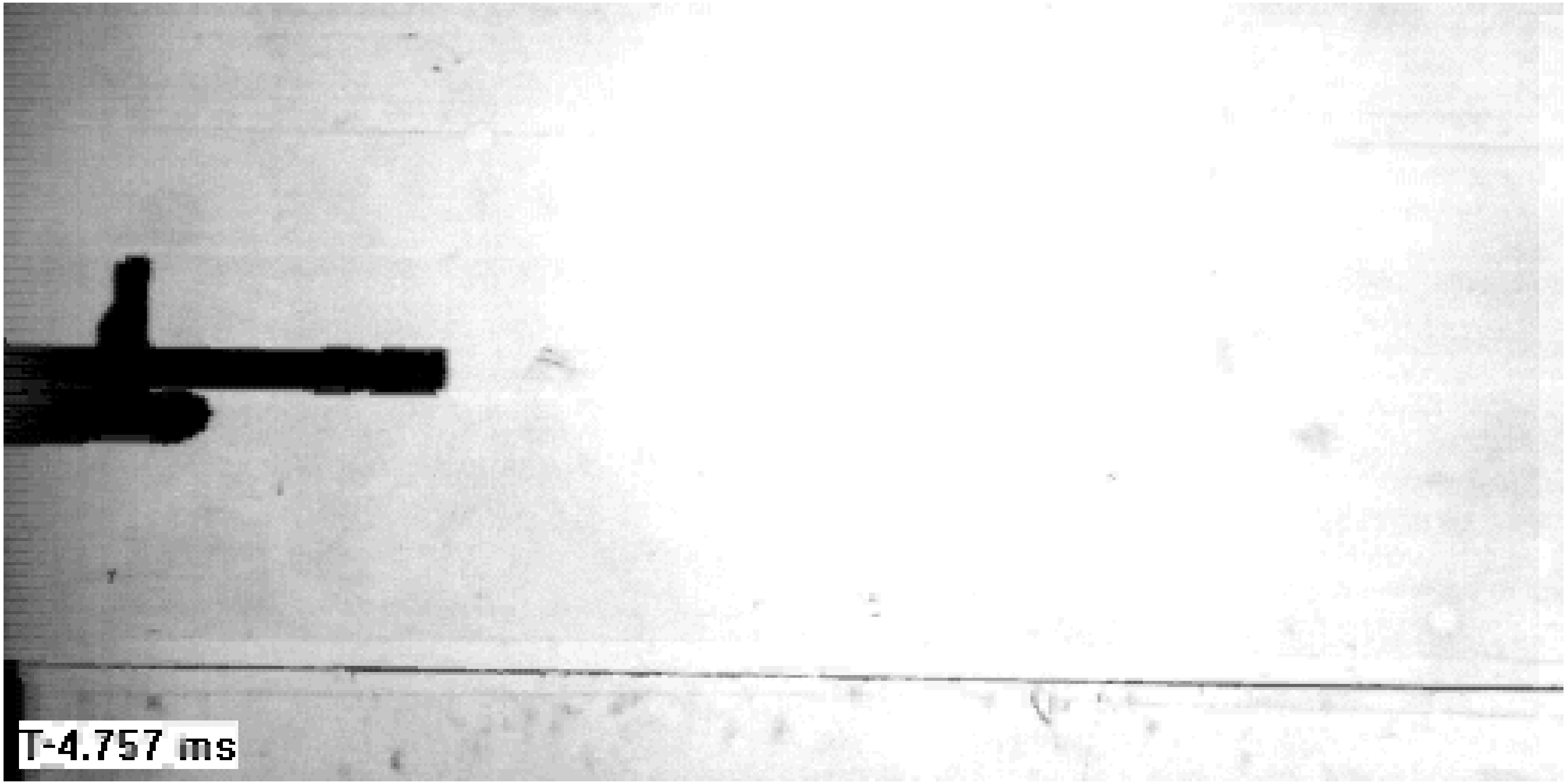


Test Setup – Blast, Flash, Thermal

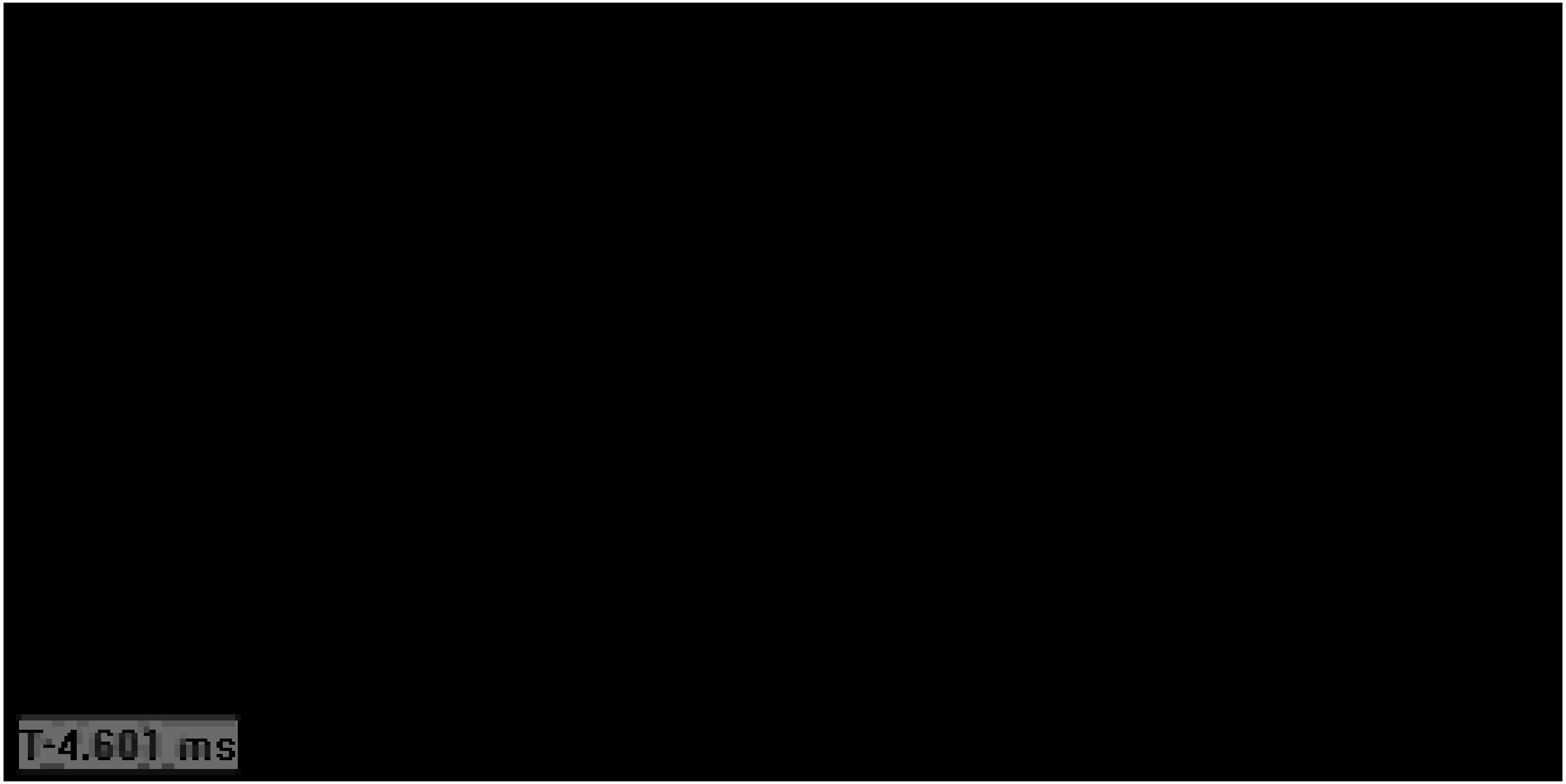
Army Research Lab (ARL) Aerodynamics Experimental Facility (AEF)



High-Speed Shadowgraph
Standard Flash Hider



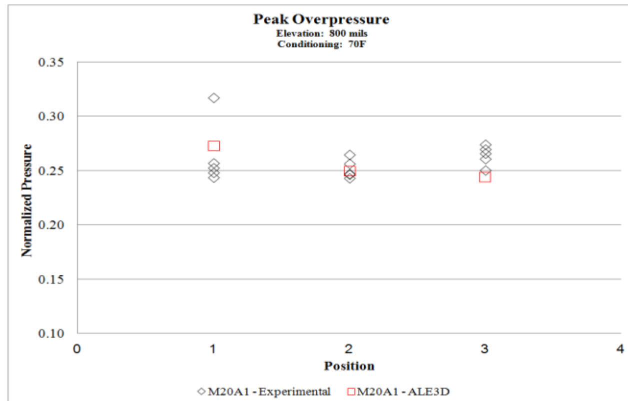
High-Speed Flash Video
Suppressor A



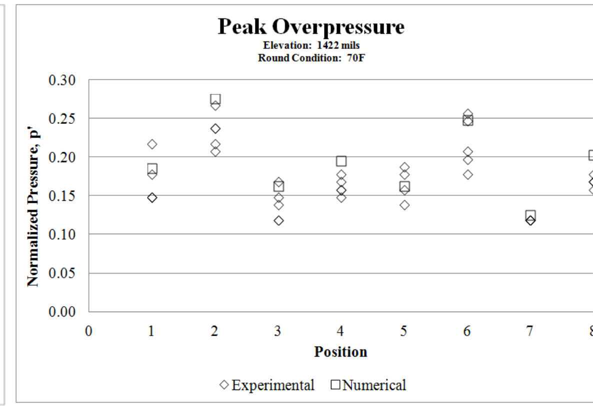
Shock Propagation, Blast Overpressure and Impulse Prediction

- Simulate shock propagation (pressure vs. time) at various flowfield points.
- Predict blast overpressure peak levels to match with experimental data.
  - M119 Howitzer
  - M120 Mortar
- Predict impulse (integral of force vs. time) on the cannon system for legacy and new designs.

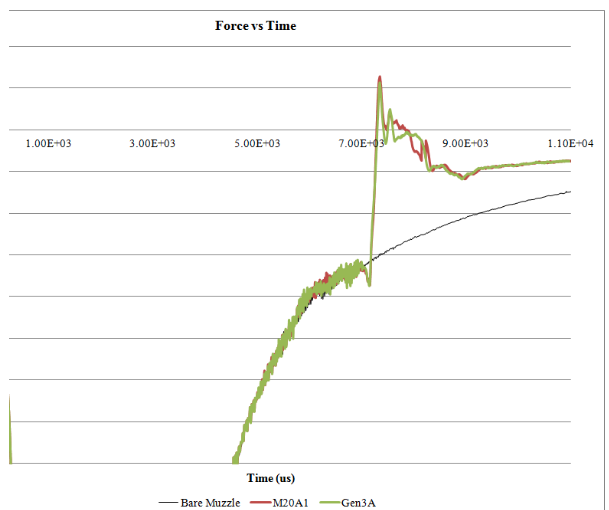
105mm M119 Howitzer



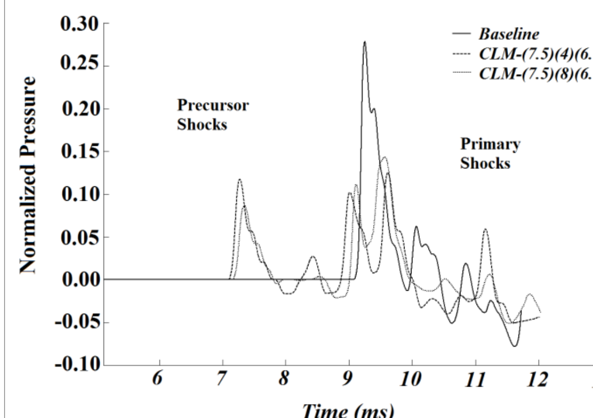
120mm M120 Mortar



105mm M119 Howitzer



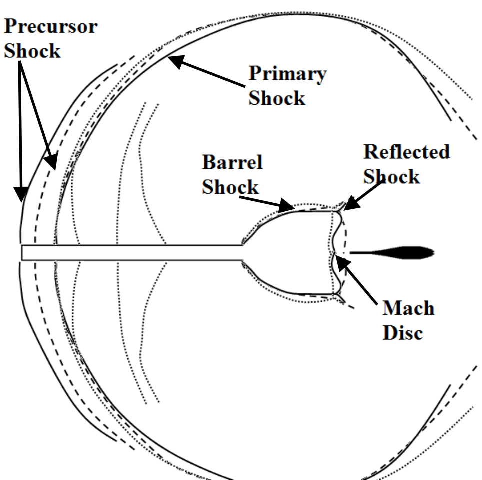
120mm M120 Mortar



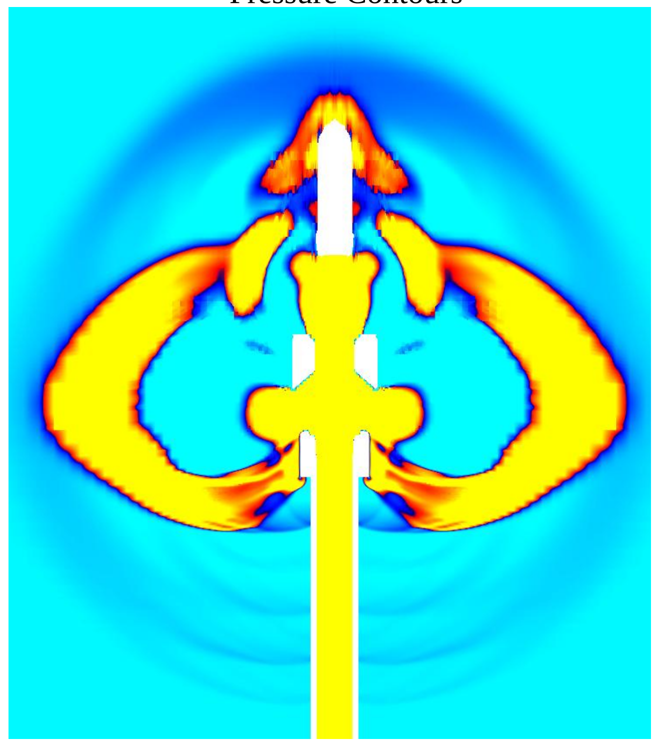
Large Caliber
Modeling and Simulation

Muzzle and Near Field Shock Structure

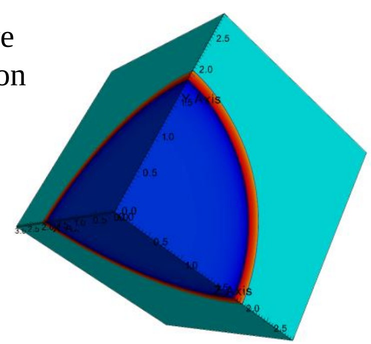
- Understanding of the modification due to the incorporation of a muzzle brake. (M119)
- Prediction of a new flowfield due to intentional leaking of propellant to attenuate blast overpressure (M120 variant "APOLLO").
- Shock propagation of explosives.
- Schematics of shock structure from numerical data.

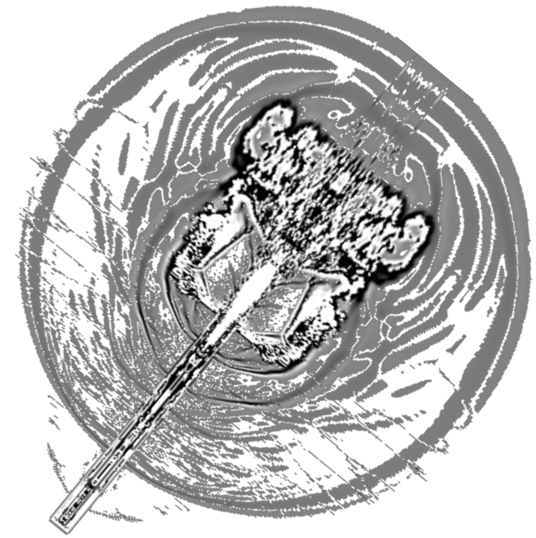


M119 Howitzer
Pressure Contours

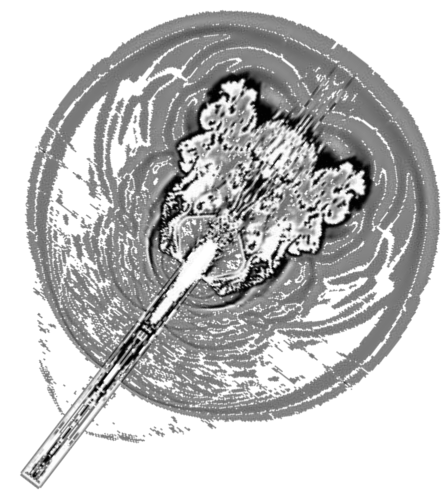


Explosive propagation





M120 Mortar Leak Attenuator
("Shadowgraph")
APOLLO



Large Caliber
Experimental Testing

- Testing at various US Army proving grounds (APG or YPG)
- Monitor blast overpressure and impulse.
- Ensure correlation to numerical models.





Conclusions

- Two primary numerical codes are utilized for fluids modeling at ARDEC.
  - ANSYS Fluent
  - ALE3D
- Small Caliber Numerical Analysis
  - Gas operated weapon mechanism operation and particle flow/erosion
  - Particulate flow
  - Propellant burn and muzzle flow
- Large Caliber Numerical Analysis
  - Shock propagation, blast overpressure and impulse prediction
  - Muzzle and near field shock structure
- Small & Large Caliber Experimental Testing
  - Multiple facilities and capabilities including blast, flash, and thermal

Recent or Upcoming Publications

- Carson, R.A. and Sahni, O., "Plume-in-Plume Blast Attenuator," *Proceedings of the 27th International Symposium on Ballistics*, April 2013.
- Carson, R.A. and Sahni, O., "Numerical Investigation of Propellant Leak Methods in Large Caliber Cannons for Blast Overpressure Attenuation," *Shock Waves*, (Accepted April 2014).
- Carson, R.A. and Sahni, O., "Numerical Investigation of Channel Leak Geometry for Blast Overpressure Attenuation in a Muzzle Loaded Large Caliber Cannon," *J. of Fluids Engineering*, (Submitted March 2014).
- Carson, R.A. and Sahni, O., "Cannon Blast Scaling Utilizing a Propellant Channel Leak Method Blast Attenuator," (In Process).
- Carson, R.A. and Sahni, O., "Numerical Investigation of the Effect of Length of the Channel Leak Method on Blast Overpressure Attenuation for Cannons," *Proceedings of the 28th International Symposium on Ballistics*, September 2014.
- Cler, D.L., "Experimental Flow Diagnostics Investigations of the 25-mm, M4A1, Special Forces Combat Assault Rifle Heavy, and Bare Muzzle Suppressed Flash and Blast Characteristics," Technical Report ARWSE-TR-12003, US Army ARDEC, Nov. 2013.


Questions?