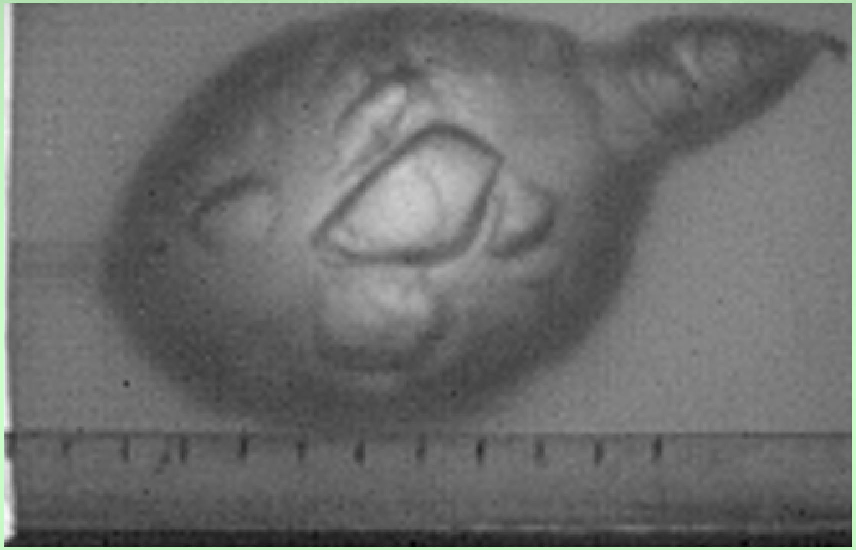
Gelatin Impact Modeling

In support of PM-MAS ES-1A-9000



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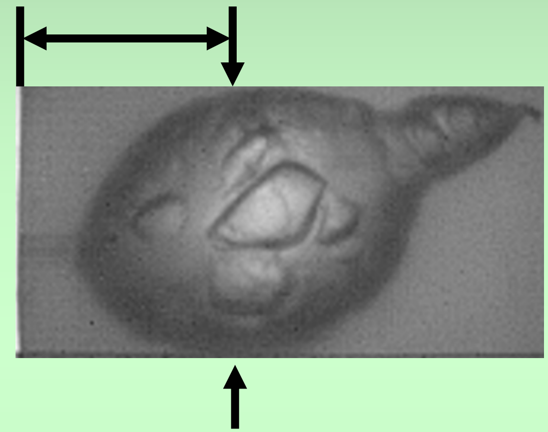
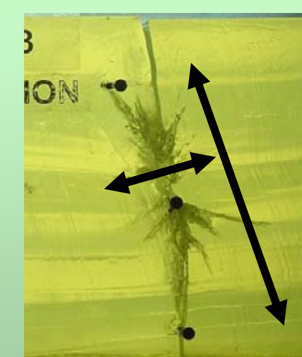
Project Goals

- Create a numerical model capable of predicting the effects on the projectile and the gelatin when struck by M855 ball ammunition at impact velocities applicable to the military



  - Effects on projectile in gelatin
    - Effects of Striking yaw at impact
    - Resulting yaw history in gelatin
      - Velocity decay
      - Final penetration depth
    - Deformation and fragmentation* of projectile
  - Damage to gelatin
    - “Dynamic” cavitations
    - “Static” fractures*; size and location



* Secondary goals with higher risk than the primary

Project Path

1. Code identification

2. Material Model identification

3. Material Property Acquisition

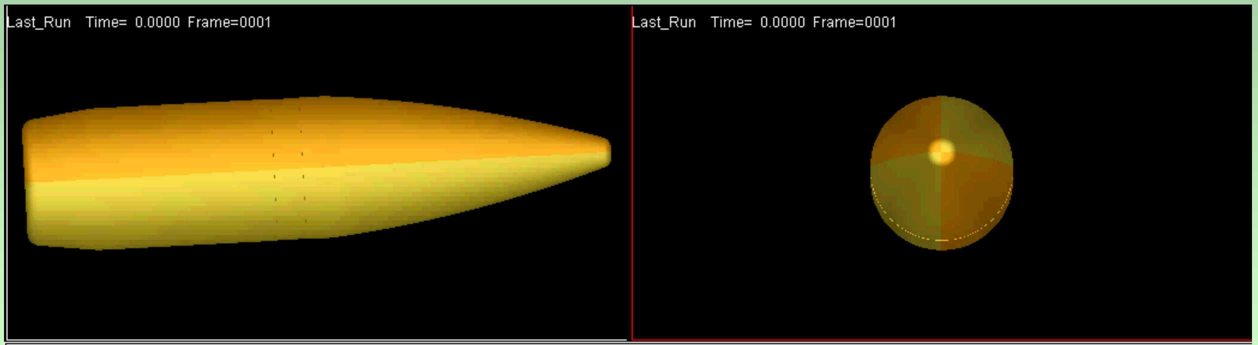
4. **Incremental** Gelatin Impact Simulation Development
    - Rigid Projectile, Low Velocity
    - Rigid Projectile, High Velocity, with Yaw
    - Deformable Projectile, Low Velocity
    - Deformable Projectile, High Velocity

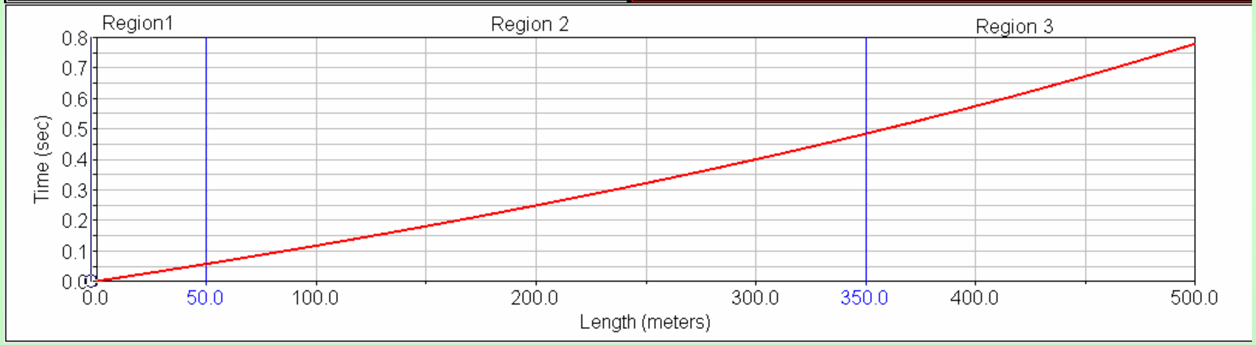
- Hard Targets
    - Steel
    - Bone
    - Glass
    - Wood

* Secondary goals with higher risk than the primary

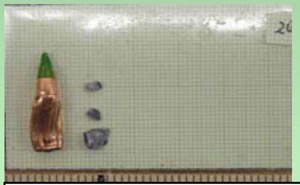
Why FEA?

Complex Projectile yaw motion; Precession / Nutation





M855's taken from 10% gelatin after 5m impacts



MK18 - 2528 fps

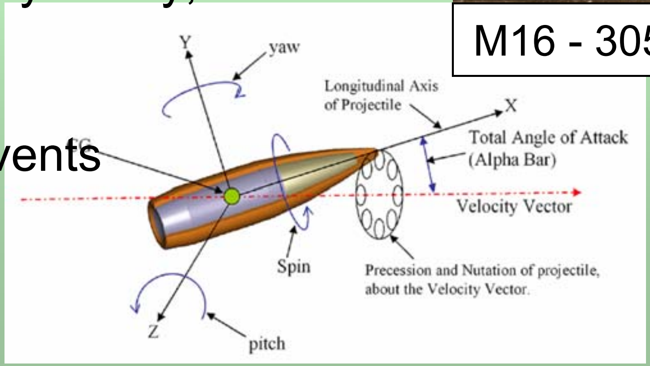
M4 - 2850 fps

M16 - 3052 fps

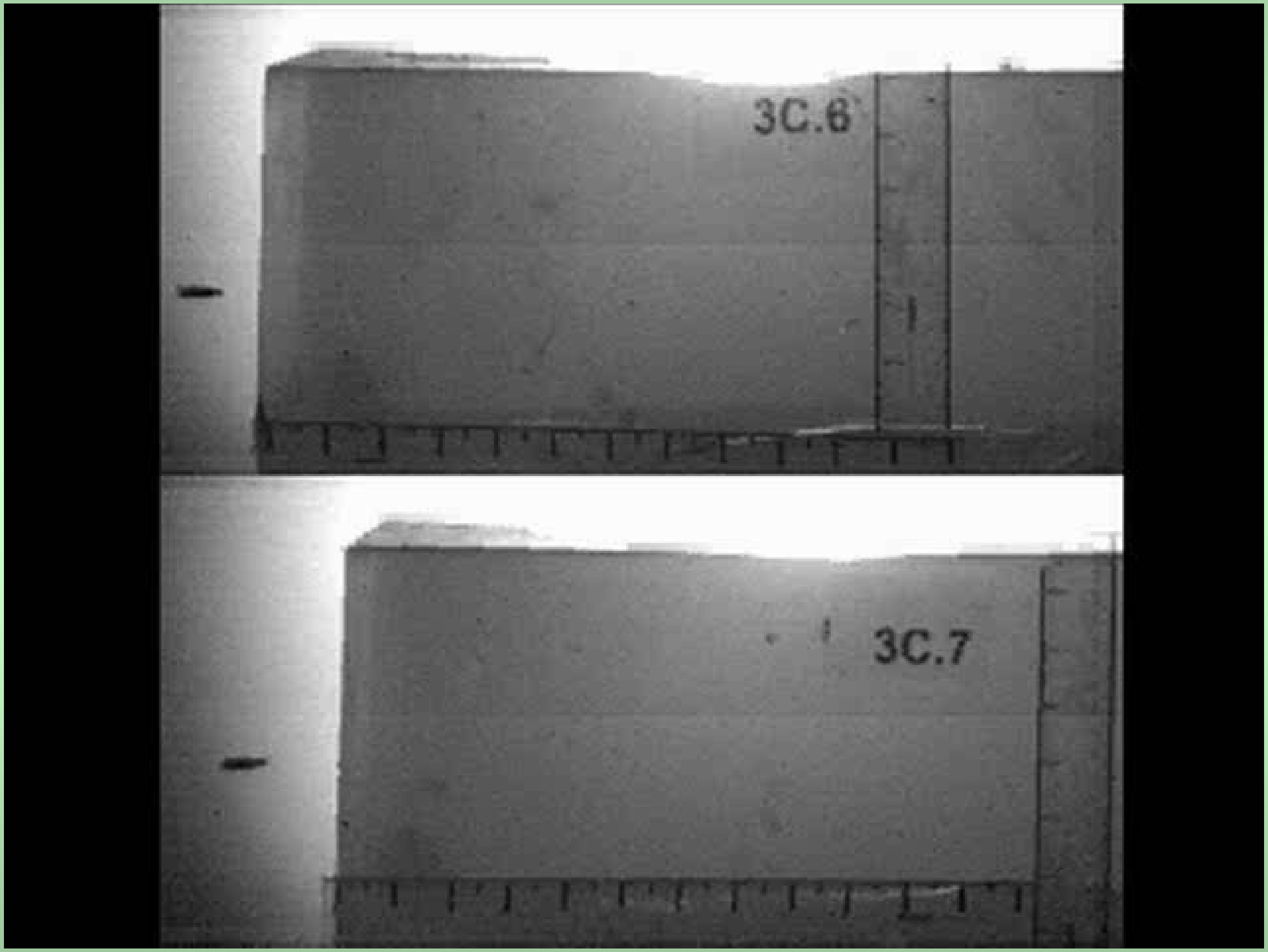
Projectile Deformation and Failure

- Presented Area's contribution to drag, velocity decay, and ultimately damage

- Increased ***Physical Understanding*** of impact events inherent with model development
  - Applying the proper Material models



Angle of Attack at Impact:
Projectile Loading and Fragmentation



Two consecutively recorded M855 fired from an M16 into 10% gelatin at 300m

The Physics; Impact Basics

Validation of physical principles and theories?

Gelatin: A one-way simulant?

Projectile Impact KE

→ ***IMPACT***

→ **Drag Force on Projectile**

→ **Deformation of Projectile**

→ **Heat & Sound**

→ **Target Material Motion**

Material Models; ***Metals***

Johnson Cook
Strength Model

$$\sigma = [A + B\varepsilon^{n}]\;[1 + C \ln \dot{\varepsilon}^{*}]\;[1 - T^{*m}]$$

Yield & Strain Hardening — **Strain Rate Effects** — **Thermal Effect**

Johnson Cook
Failure Model

$$\varepsilon_{f} = \left[D_{1} + D_{2}^{D_{3}\sigma^{*}}\right]\left[1 + D_{4}\,\ell n\,\dot{\varepsilon}^{*}\right]\left[1 + D_{5}\,T^{*}\right]$$

Pressure — **Strain Rate Effects** — **Thermal Effect**

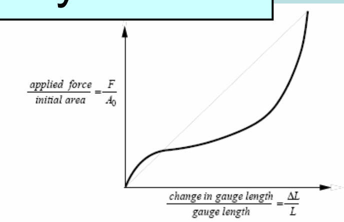
Gruneisen
Equations of State

$$p := \left[\frac{\rho_{o}\cdot C^{2}\cdot\mu\cdot\left[\left[1 + \left(1 - \frac{\gamma_{o}}{2}\right)\cdot\mu - \frac{a}{2}\cdot\mu^{2}\right]\right]}{\left[\left[1 - (S_{1} - 1)\cdot\mu - S_{2}\cdot\frac{\mu^{2}}{\mu + 1} - S_{3}\cdot\frac{\mu^{3}}{(\mu + 1)^{2}}\right]\right]^{2}}\right] + (\gamma_{o} + a\cdot\mu)\cdot E$$

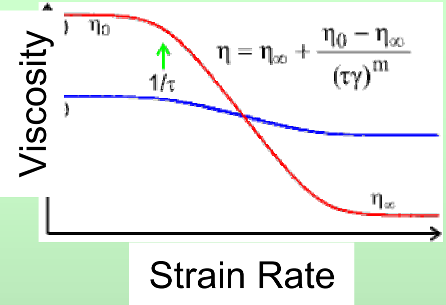
Material Models: ***Gelatin***

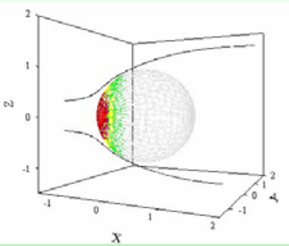
- Poncelet/Peters/Sturdivan
- Forces Involved:
    - ***Inertia***
    - ***Viscous***
    - ***Strength***
- Boundary Layer (Thixotropic)
- Hyper Elastic Solid or Fluid? …***YES***

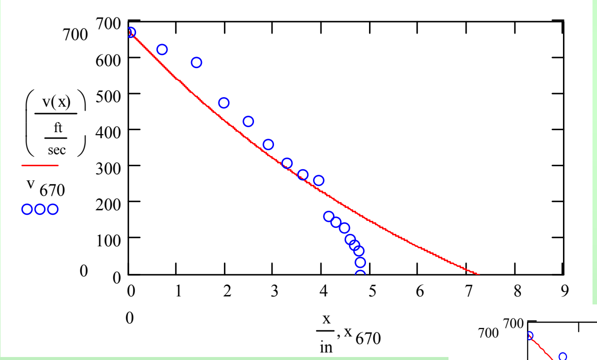
Mooney Rivlen?

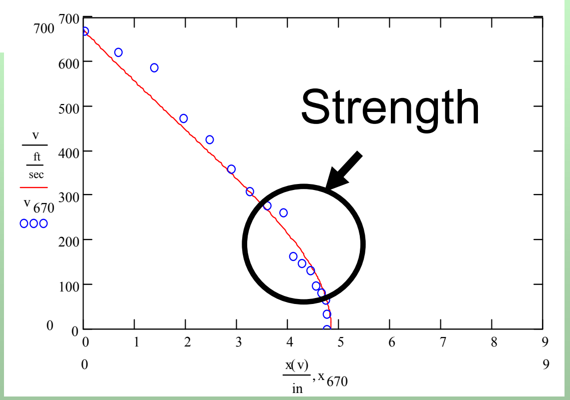


✓Non-linear elasticity
✓Strain rate dependant
•Viscous flow









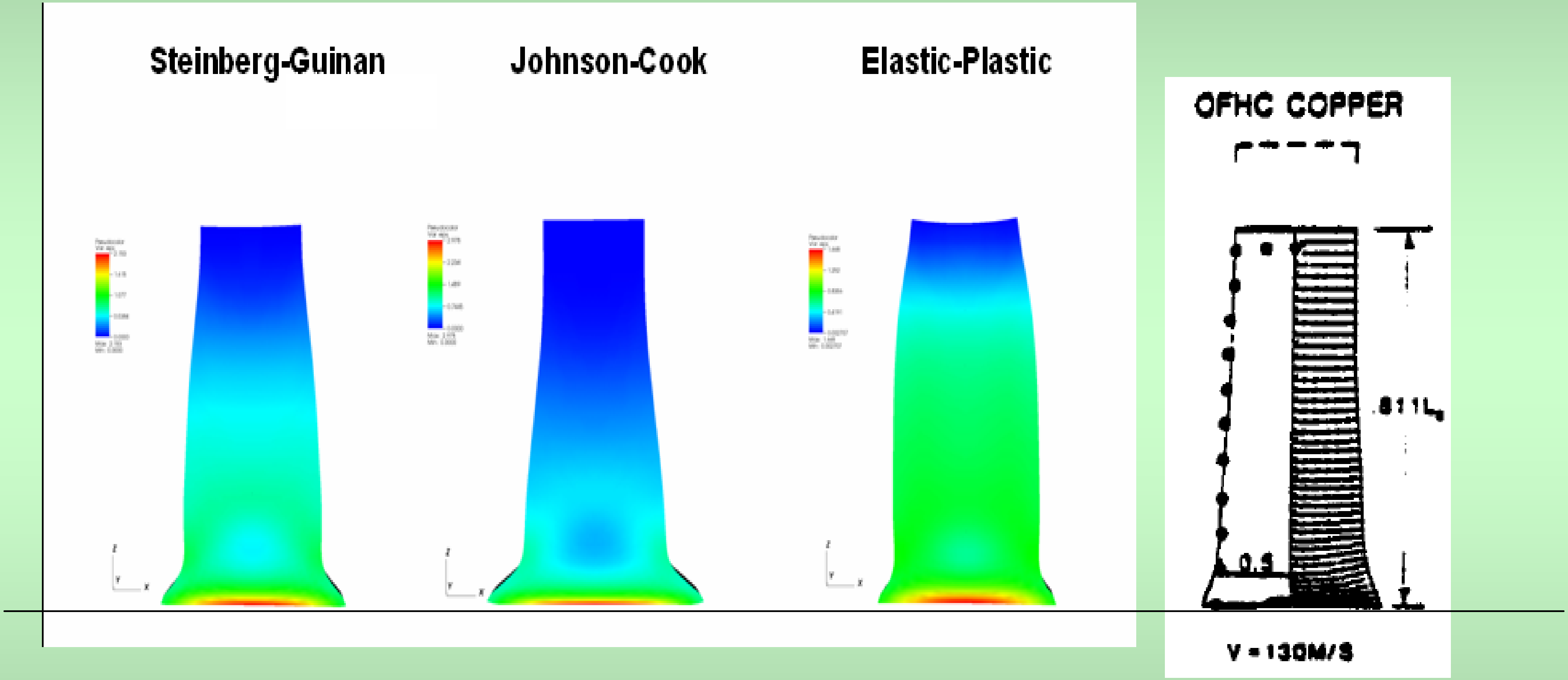
Fluid → Hyper-elastic

Penetrating at High Velocity

Penetrating at Low Velocity

Material Models; choose wisely

Three Lagrangian material models of copper Taylor-bar impact



Test data

Correlate to test data whenever possible

Proper stress/strain accumulation & failure mechanisms

Material Properties

Copper "Gilding Metal"

Lead Antimony

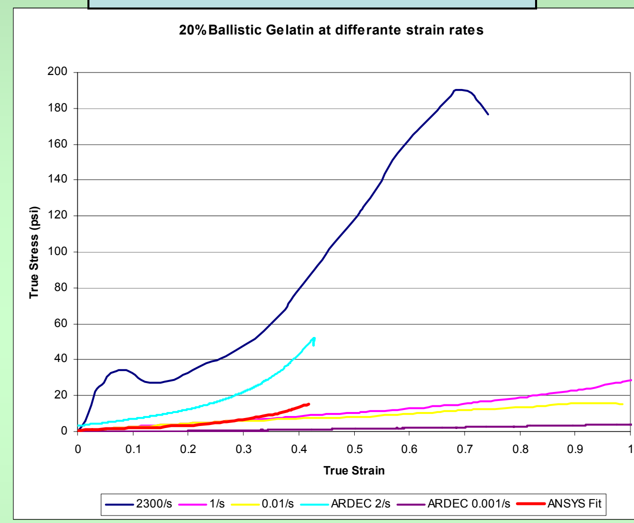
Steel(s)

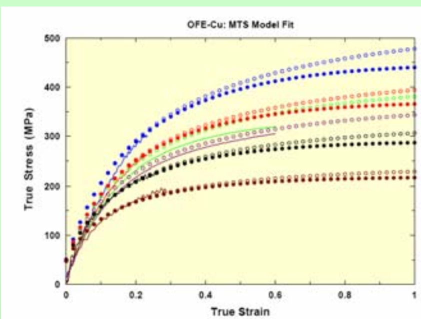
Gelatin; 10% vs. 20%

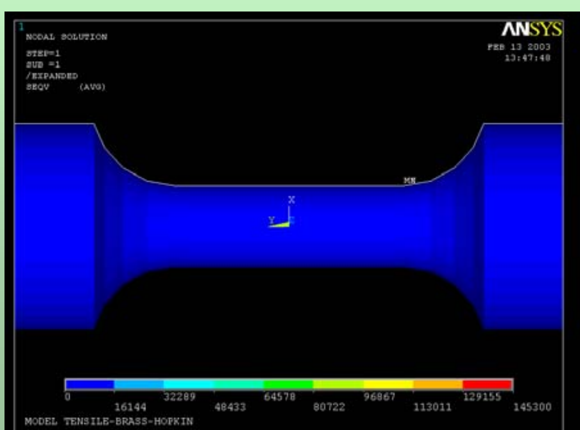
σ_y ε_f

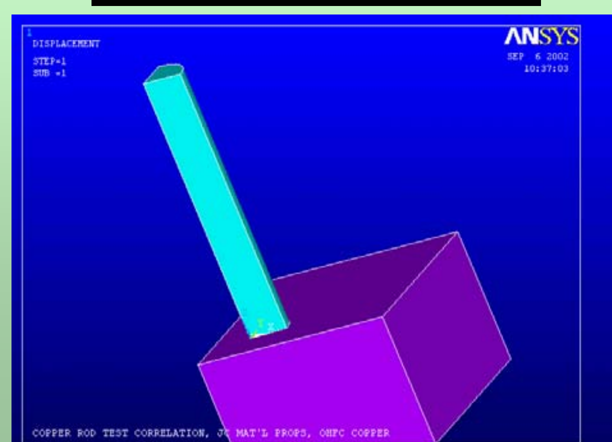
1. Strain Hardening
2. Strain Rate
3. Temperature
4. Pressure
5. Viscosity?

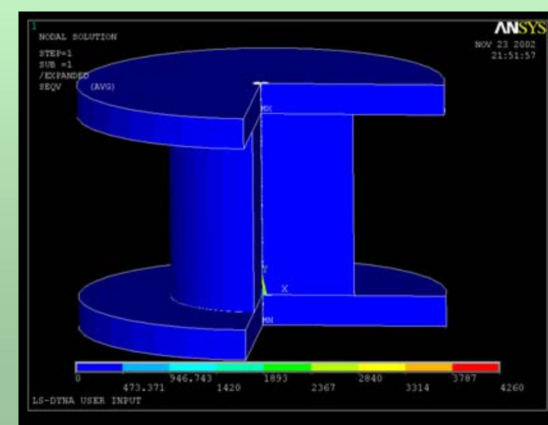
Material property characterization (ARDEC/ARL/OGA)





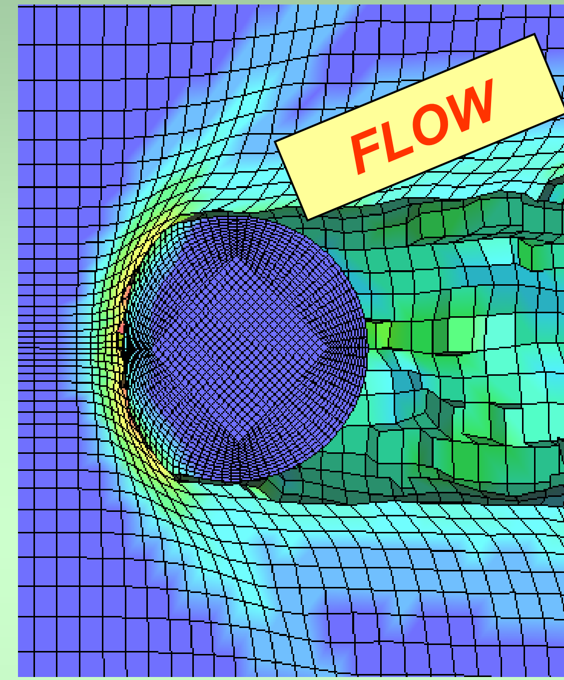




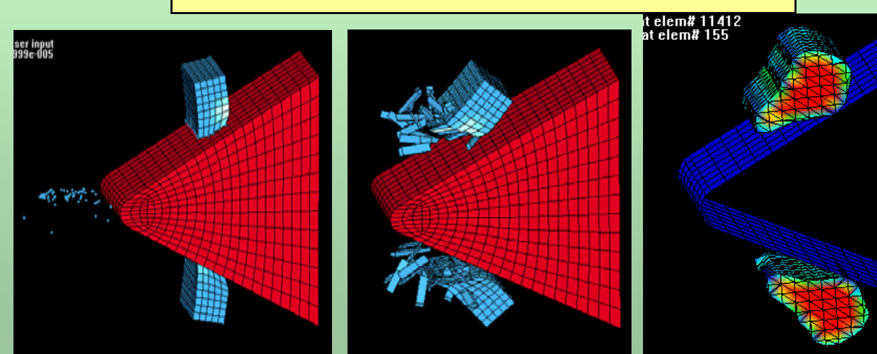


Largest Challenges

- Conservations of Mass
- ***"Conservation of Geometry***"
- Material Failure
- Gelatin; Fluid or Hyper-elastic Solid?
- Time/Displacement



Failure



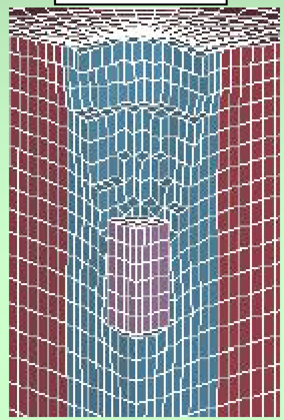
CONTACT:
achieving the correct interfacial mechanics

Lagrangian vs. Eularian vs. Particle

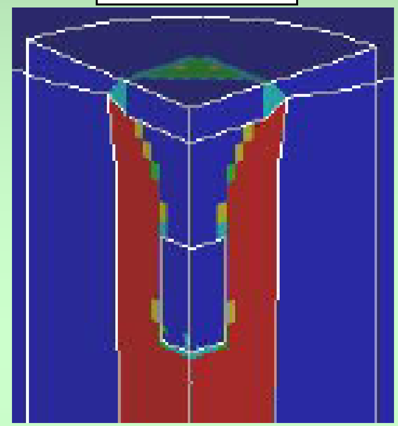
- Pros/Cons
- LAGR, EULER, ALE, SPH
- Connectivity (and lack there of)
- "Conservation of Geometry"

Concrete Penetration Simulations

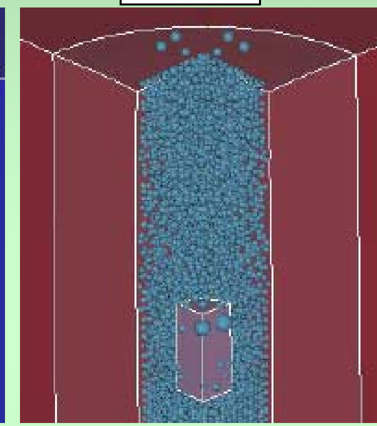
LAGR

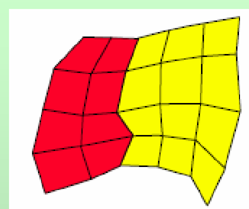


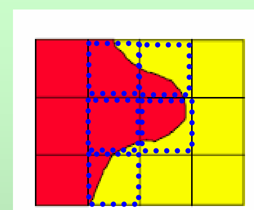
EULER



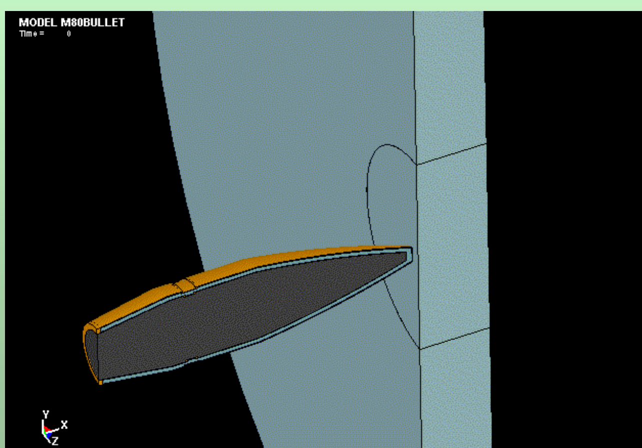
SPH

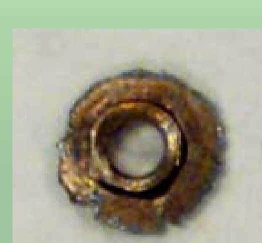




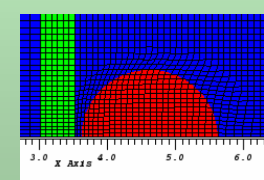


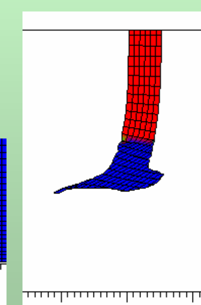
M80 ball at V50





ALE

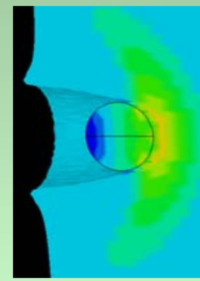




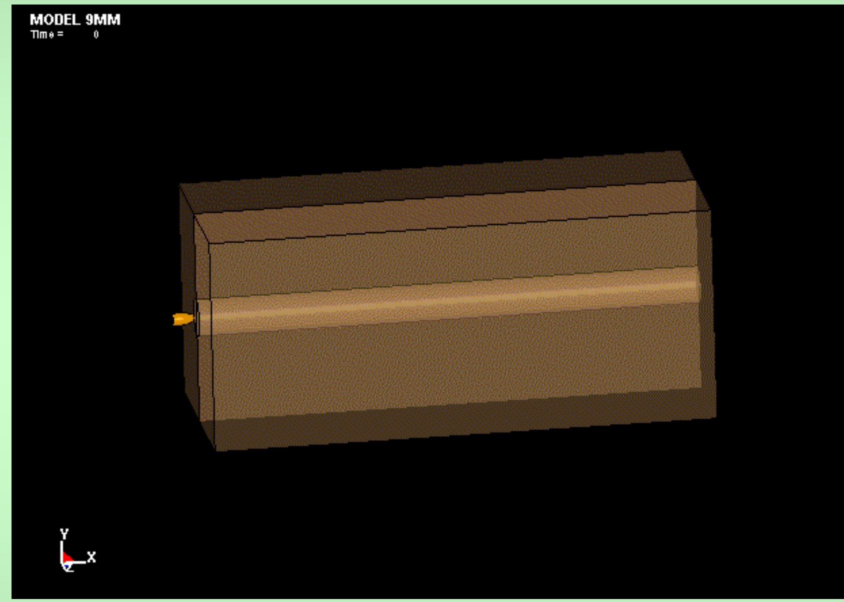
Results of ARDEC work-to-date

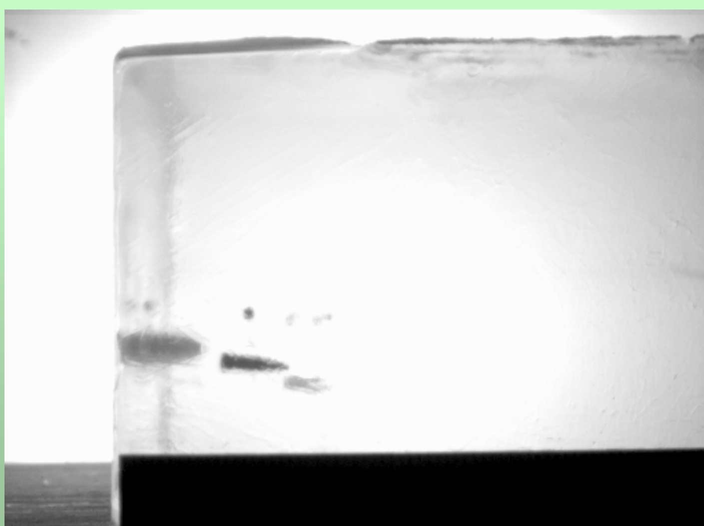
Rigid Body, Low Velocity

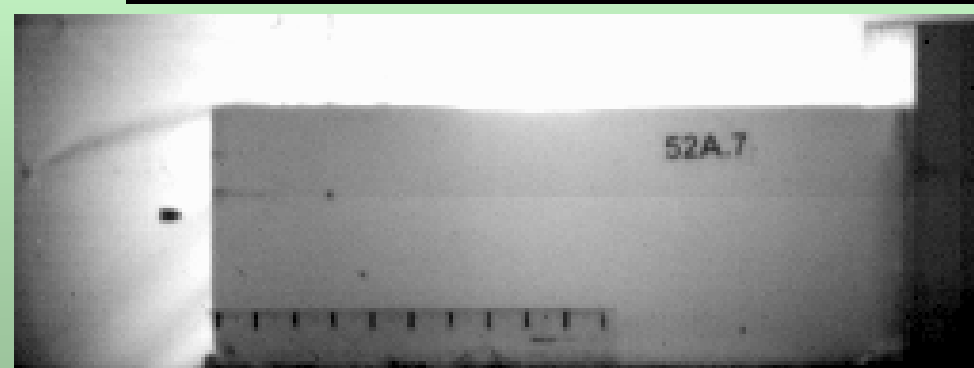
Steel BB



- ✓ Stagnation pressure
- ✓ Velocity decay
- ✓ Elastic response

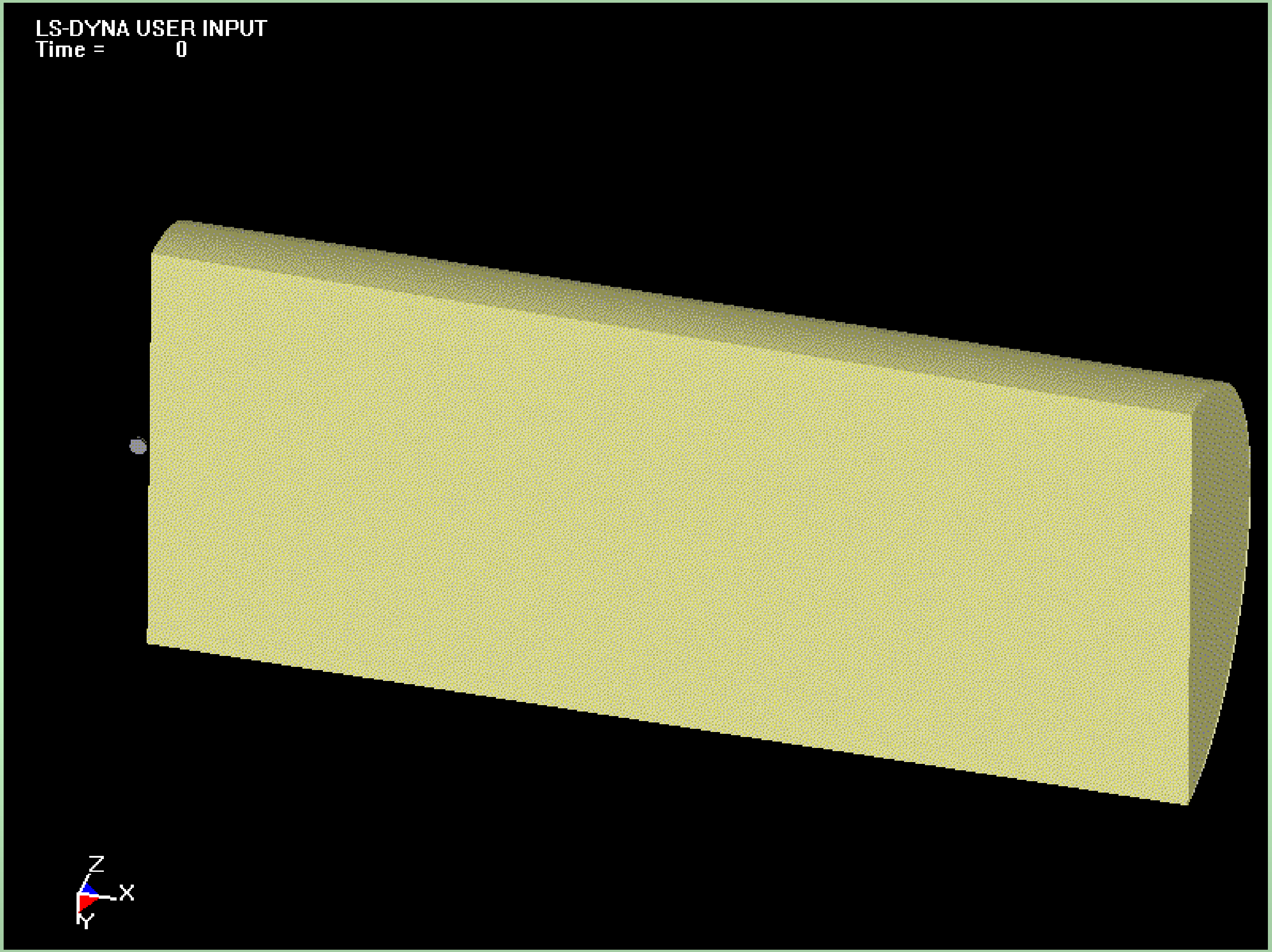






Pistol; FMJ Ball Ammo

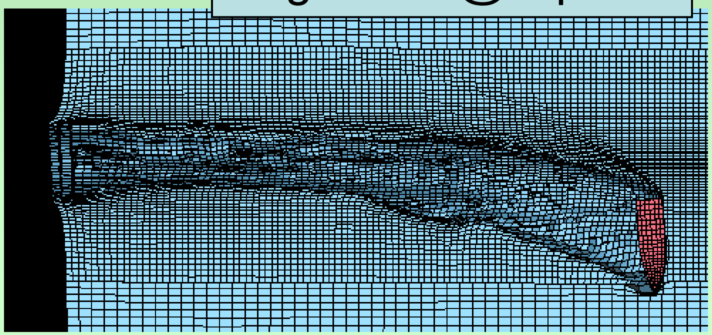
Rigid Body, High Velocity

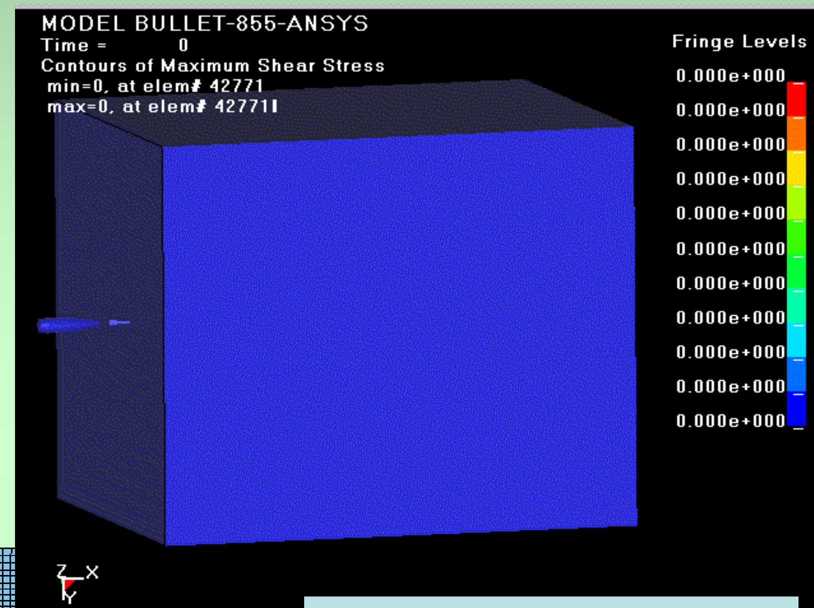


3350 fps Sphere impacting 20% gelatin

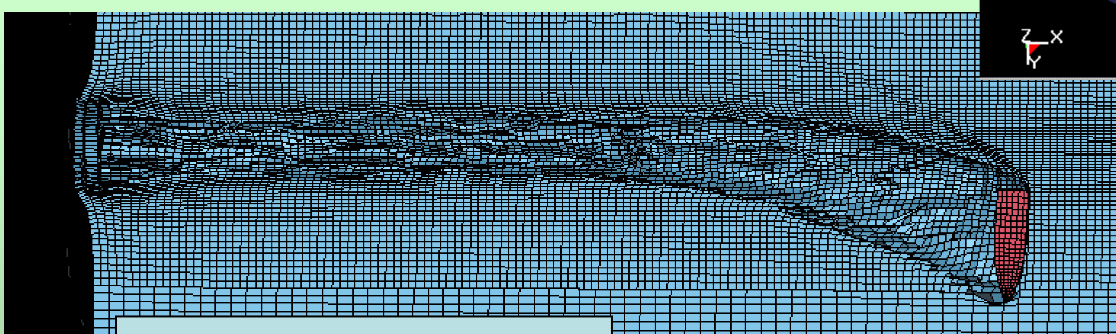
Rigid Body High velocity with Yaw

209 microseconds 4 deg TAOA@impact





Zero TAOA@impact

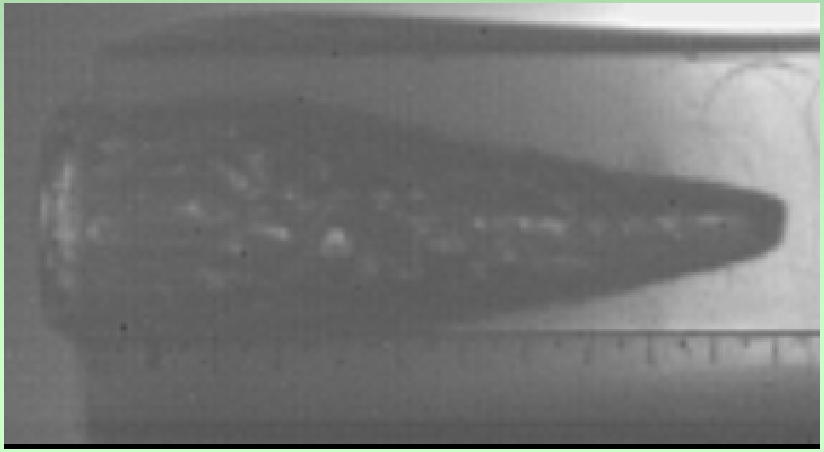


266 microseconds 1 deg TAOA@impact

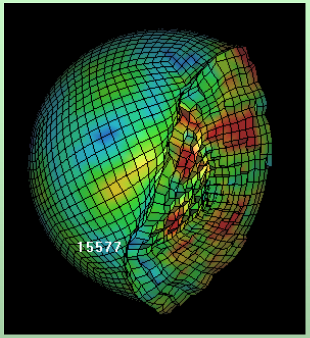
TAOA = “Total Angle of Attack”

Deformable Projectiles

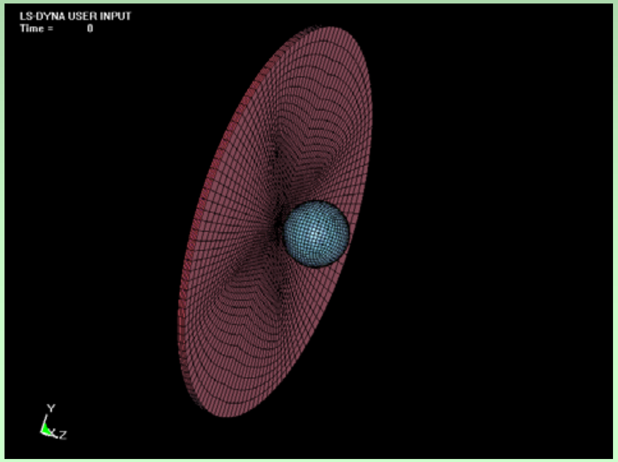
0.75 caliber musket ball impacting 20% gelatin at 1028 fps



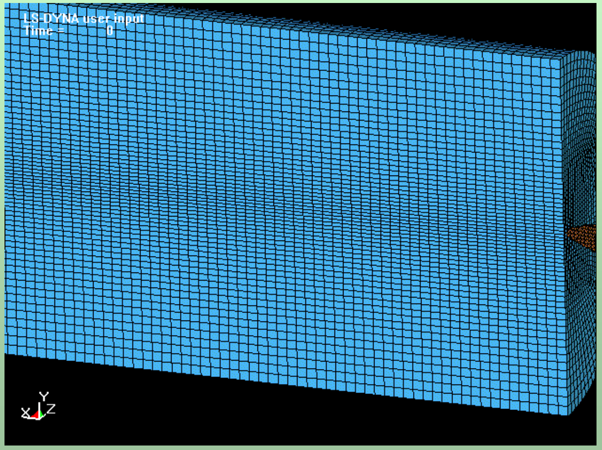
Deformed Lead 75-cal Ball



Lead Ball; LAGR

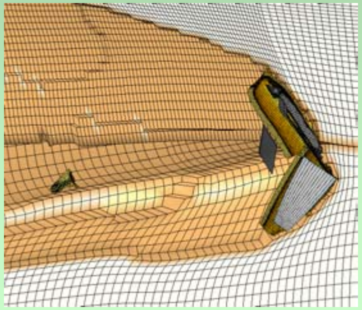


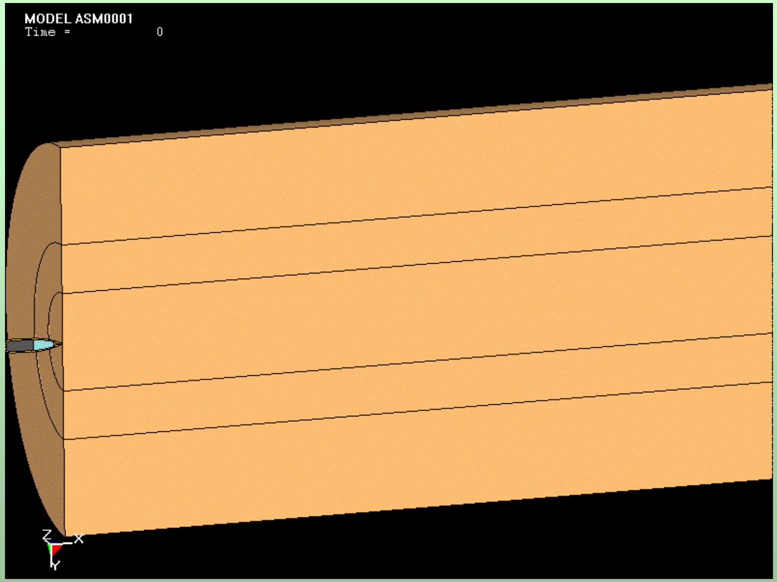
Solid Lead Projectile; ALE



Fragmenting Projectiles

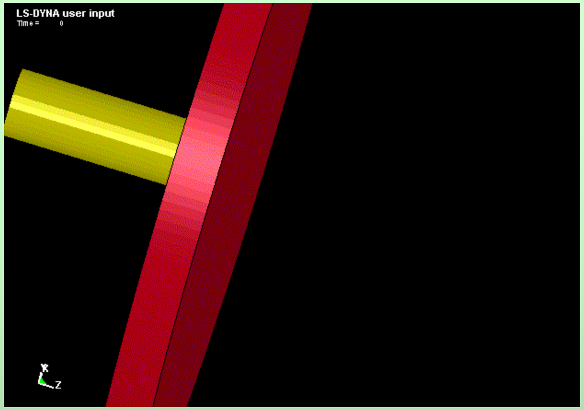
M855 impacting 20% gelatin at ~2800 fps





Real-Time Yaw, Deformation, and Fragmentation

ALE Lead vs. LAGR Steel



- ✓ Stagnation pressure
- ✓ Velocity decay
- ✓ Elastic response

Applied What-If's

- Geometry
    - ✓Cannelure
    - Boat-tail
    - Jacket thickness
    - Core construction
- Materials
    - ✓Hardness
    - Density
- Connectivity
    - Mechanical Interface
    - Bonding

MASS

VELOCITY

CONFIGURATION

Summary & Path Forward

•FEA can be a useful tool for examining the failure mechanisms of projectile impacting both "hard" and "soft" targets

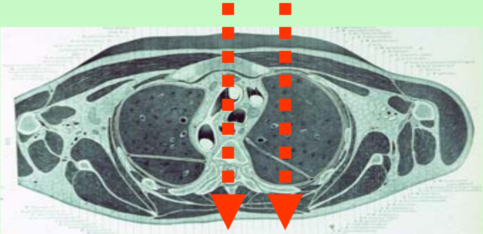
•FEA analysis may be used to augment technically simpler, yet computationally larger "bulk" equation analysis techniques

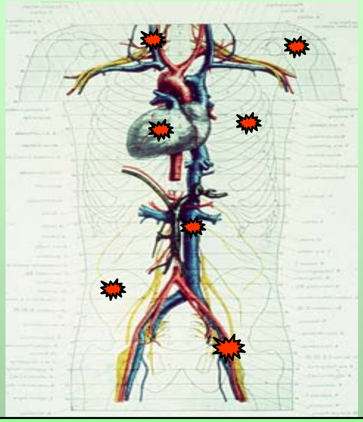
•Physics of the event to be simulated must be understood in order to properly employ material models and constituent parameters.

•Material Model and Material Property research is critical to numerical analysis.

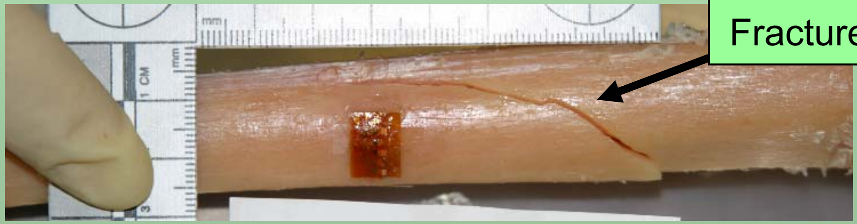
•Continue searching and exercising various codes / models / parameters which best accomplish the missions requiring this level of technical support

Dissimilar Material Properties





Multiple Material Properties on single shot-line



Fracture