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

- Presenting 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

Projectile Deformation and Failure

- M855's taken from 10% gelatin after 5m impacts
  - M4 - 2850 fps
  - M16 - 3052 fps
  - MK18 - 2528 fps

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

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

- Projectile Impact KE
- Validation of physical principles and theories?
- Gelatin: A one-way simulant?
- Impact
- Drag Force on Projectile
- Deformation of Projectile
- Target Material Motion
- Heat & Sound
Material Models; **Metals**

**Johnson Cook Strength Model**

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

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

**Johnson Cook Failure Model**

\[
\varepsilon_f = \left[ D_1 + D_2 \varepsilon_0^* \right] \left[ 1 + D_3 \ln \dot{\varepsilon}^* \right] \left[ 1 + D_4 \ln n \dot{\varepsilon}^* \right] \left[ 1 + D_5 T^* \right]
\]

**Pressure Strain Rate Effects Thermal Effect**

**Gruneisen Equations of State**

\[
p := \frac{\rho_0^2 \cdot C^2 \cdot \mu \cdot \left[ 1 + \left( 1 - \frac{\gamma_o}{2} \right) \mu - \frac{a}{2} \mu^2 \right]}{\left[ 1 - (S_1 - 1) \mu - S_2 \cdot \frac{\mu^2}{\mu + 1} - S_3 \cdot \frac{\mu^3}{(\mu + 1)^2} \right]^2} + (\gamma_o + a \cdot \mu) \cdot E
\]
Material Models: Gelatin

- Poncelet/Peters/Sturdivan
- Forces Involved:
  - \textit{Inertia}
  - \textit{Viscous}
  - \textit{Strength}
- Boundary Layer (Thixotropic)
- Hyper Elastic Solid or Fluid? \ldots \textit{YES}

Mooney Rivlen?

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

- Penetrating at High Velocity
- Penetrating at Low Velocity

\[ \eta(x) = \eta_0 + \frac{\eta_S - \eta_0}{(1 + \gamma x)^n} \]

\[ \eta \]
Material Models; choose wisely

Three Lagrangian material models of copper Taylor-bar impact

- Steinberg-Guinan
- Johnson-Cook
- Elastic-Plastic

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%

Material property characterization (ARDEC/ARL/OGA)

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

True Stress (psi)
True Strain

σ_y  ε_f

2300/s  1/s  0.01/s
ARDEC 2/s  ARDEC 0.001/s  ANSYS

Graph showing material properties under different strain rates.

Graphs and images illustrating material analyses and simulations.
Largest Challenges

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

CONTACT: achieving the correct interfacial mechanics

FLOW

Failure
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
Results of ARDEC work-to-date
Rigid Body, Low Velocity

- Stagnation pressure
- Velocity decay
- Elastic response

Steel BB

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

266 microseconds 1 deg TAOA@impact

TAOA = “Total Angle of Attack”
Deformable Projectiles

0.75 caliber musket ball impacting 20% gelatin at 1028 fps

Lead Ball; LAGR

Deformed Lead 75-cal Ball

Solid Lead Projectile; ALE
Fragmenting Projectiles

M855 impacting 20% gelatin at ~2800 fps

ALE Lead vs. LAGR Steel

- Stagnation pressure
- Velocity decay
- Elastic response

Real-Time Yaw, Deformation, and Fragmentation
Applied What-If’s

• Geometry
  ✓ Cannelure
  • Boat-tail
  • Jacket thickness
  • Core construction

• Materials
  ✓ Hardness
  • Density

• Connectivity
  • Mechanical Interface
  • Bonding
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