Program Manager-Maneuver Ammunition Systems (PA-MAS) Small Caliber Ammunition Program Support at US Army Research Laboratory

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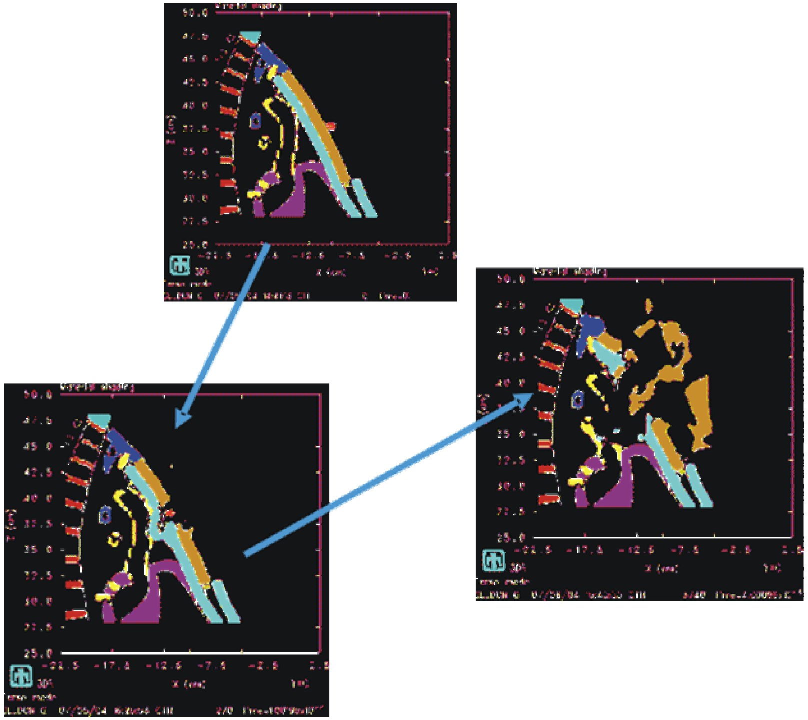
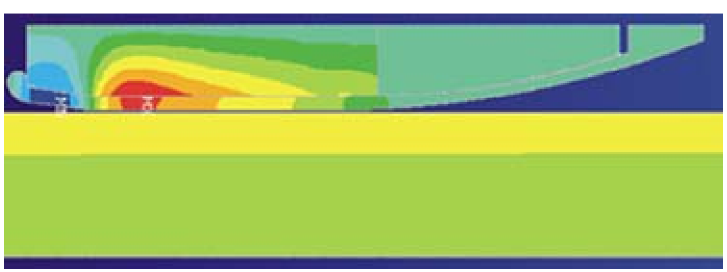
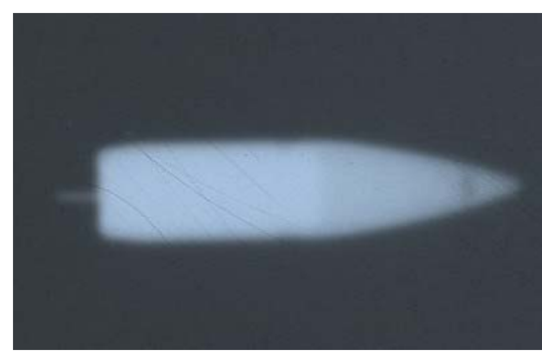


Program Focus

- ***Inject more science into the art of small and medium caliber ammunition systems***
  - Adapt technology developed for other systems to small caliber ammunition
  - Develop a fundamental understanding of the manufacturing of high volume ammunition
  - Develop a fundamental understanding of how and why small caliber munitions works
  - Develop predictive capability, advanced experimental methods, and characterization methods
  - Develop technologies unique to small caliber munitions and weapons
- Provide the insight to improve small caliber munitions
- Build the the small caliber technology toolbox

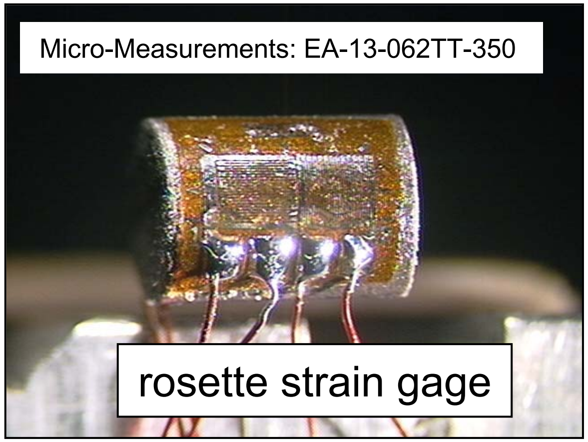
GOAL:
Our role is to develop basic understanding of systems (fill in the holes)

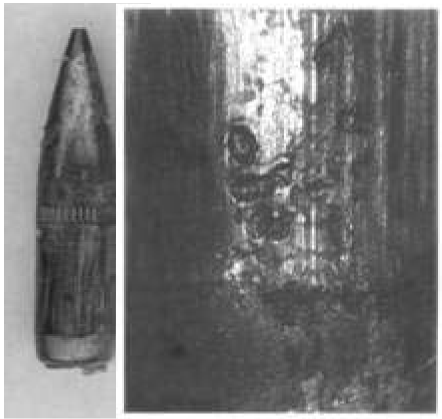




Program Objectives

- We are reaping the benefits of many years of investment in other ballistics systems (such as tank and artillery)
- As a team (MAS/ARDEC/ARL), we have defined the areas of technology that need to be developed along with goals
  - **Interior Ballistics (ignition and combustion)**
  - **Interior Ballistics (launch dynamics -- gun/projectile mechanics/dynamics)**
  - **Exterior Ballistics (aerodynamics)**
  - **Manufacturing Technology**
  - **Terminal Ballistics**
  - **Material Characterization**
  - **System Effectiveness**





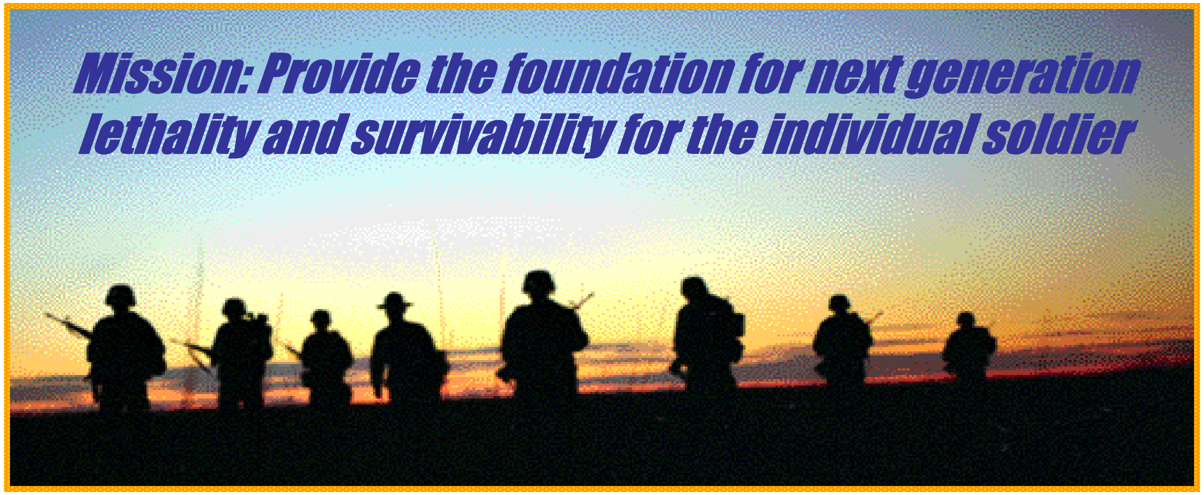
PM-MAS Has Provided Resources For Adaptation Of Current Technology

ARL Is Providing Resources For Development Of New Technology

Linked Laboratory Work Areas

ARL is investing basic research funding to help bridge technology gaps

- Individual Warfighter Technology Work Area
  - Physics of soft targets
  - Understanding of fabrics subjected to ballistics events
  - Improvements in lethality experiments
  - Deeper understanding and improvements in lethality methodology
- Light Weight Ordinance Technology Work Area
  - Lightweight Cases (Polymer)
  - Validation of gun/projectile inbore dynamic simulations with validation
  - Use of simulation/experiments for understanding of accuracy and precision in these weapons

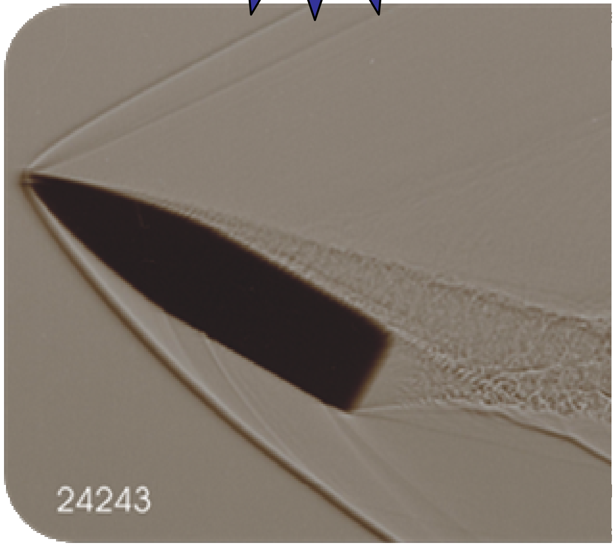


Who is involved?

- **Parts of ARL involved in the program**
  - **Weapons and Materials Research Directorate**
    - **Aerodynamics Branch**
    - **Impact Physics Branch**
    - **Lethal Mechanisms Branch**
    - **Survivability Materials Branch**
    - **Ordnance Materials Branch**
    - **Multifunctional Materials Branch**
    - **Advance Munitions Concept Branch**
    - **Weapons Technology Branch**
    - **Propulsion Science Branch**
  - **Survivability and Lethality Analysis Directorate**
- **U.S. Army Materiel Systems Analysis Activity (AMSAA)**

- **Weapons and Materials Research Directorate is strongly engaged**
  - **All three divisions**
    - **Materials Division**
    - **Ballistic Weapons Concepts Division**
    - **Terminal Effects Division)**
  - **9 Branches**
  - **More than 50 folks involved**

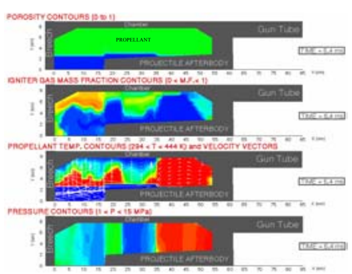
Tap into a wide range of expertise as required by program needs

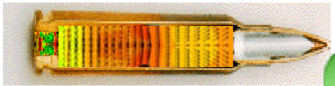


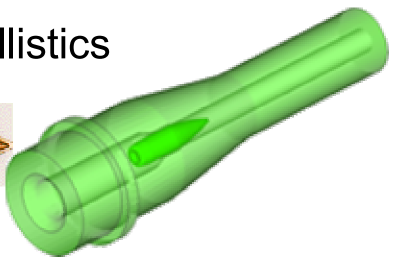
Primary Thrust Areas

- Interior Ballistics (ignition and combustion)
- Interior Ballistics (launch dynamics -- gun/projectile mechanics/dynamics)
- Exterior Ballistics (aerodynamics)
- Manufacturing Technology
- Terminal Ballistics
- Material Characterization
- System Effectiveness

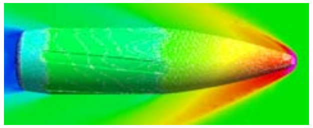
Interior Ballistics



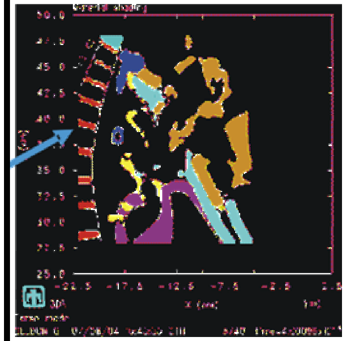




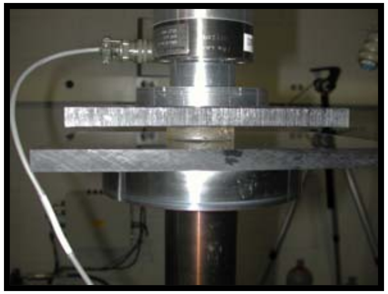
Aerodynamics

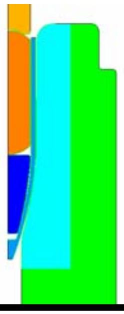


Terminal Effects

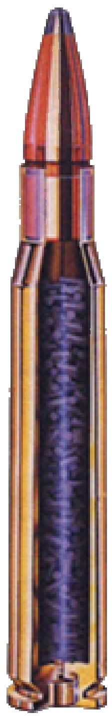


Manufacturing and Characterization





Interior Ballistics
Experimental Characterization and Modeling of Small-Caliber Ammunition



Objective

Develop state-of-the-art physics based interior ballistics (IB) predictive capability

Approach

Experimentally characterize (essential to detailed IB model):

- behavior of neat primer material
- primer output (open-air and confined)
- burn rate of propellant
- pressurization of inert and live propellant beds
- flamespreading through propellant bed

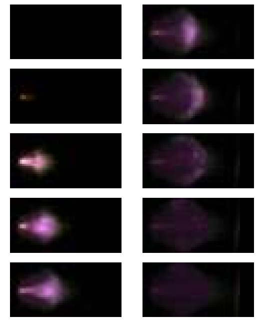
Develop and validate primer sub-model and integrate into existing multi-dimensional IB code

Payoff

Upgraded multi-dimensional IB code enables:

- understanding of fielded ammunition
- analysis of variations in performance
- optimization of components (primer, propellant, projectile)
- tools to maximize performance (maximum velocity at minimum pressure)

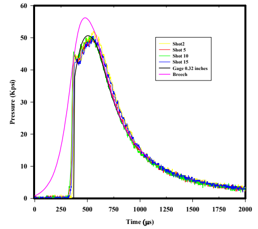
Open-air visualization of small-caliber primer output



3-D drawing of small-caliber ballistic simulator

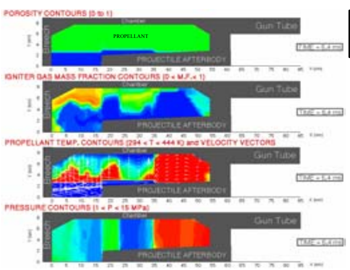
- visualization of flamespreading
- measurement of pressurization during early ignition

Gun firing pressure profiles



Experiments provide understanding of small-caliber interior ballistics Phenomena and validation of IB model

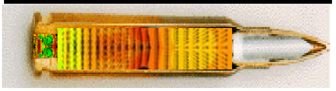
Propulsion characteristics for small-caliber ammunition coupled with existing multi-phase, mulit-dimensional IB modeling capability for large/medium caliber systems



Typical contours generated by ARL-NGEN IB model

ongoing upgrades to model

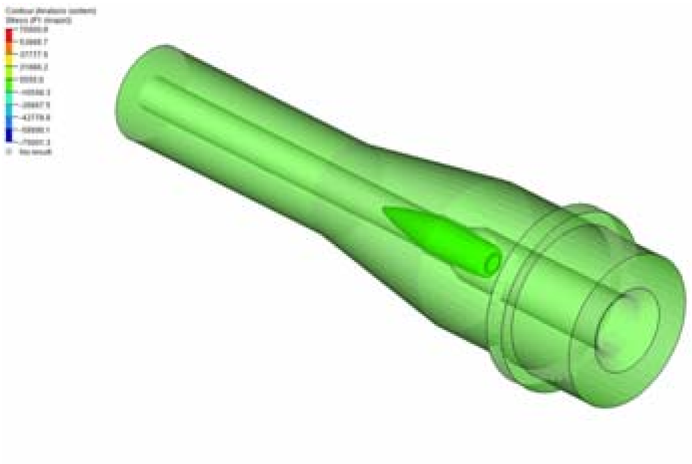
Physics based model for primer of small-caliber ammunition integrated into ARL-NGEN IB model

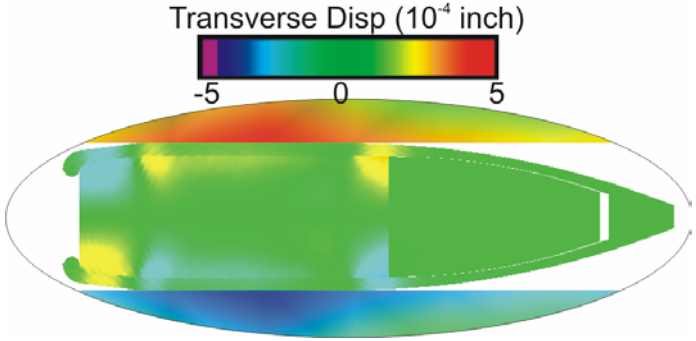


M855 In-bore Gun/Projectile Launch Mechanics and Dynamics

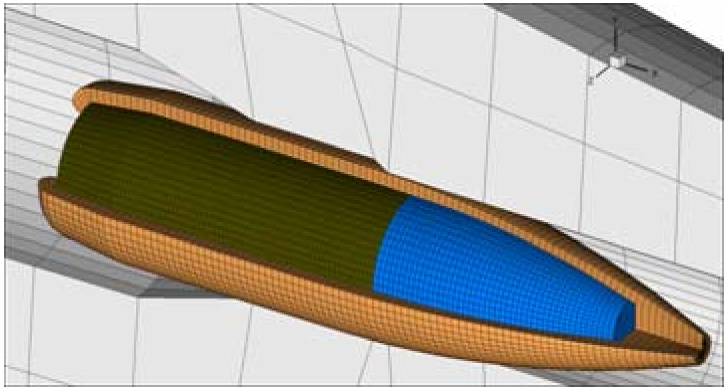
Implicit and Explicit Finite element simulations were used to study the initial portion of launch.

- Smooth bored barrel models were created to evaluate the projectile component interactions.
- Studies showed the rear jacket/slug interface acts a pressure seal.
- During launch the steel core rides freely on the slug.
- Base pressure drives Poisson’s expansion of the slug.
- Displacement along the cylindrical section of the Pb-Sb slug force obturation and engraving.





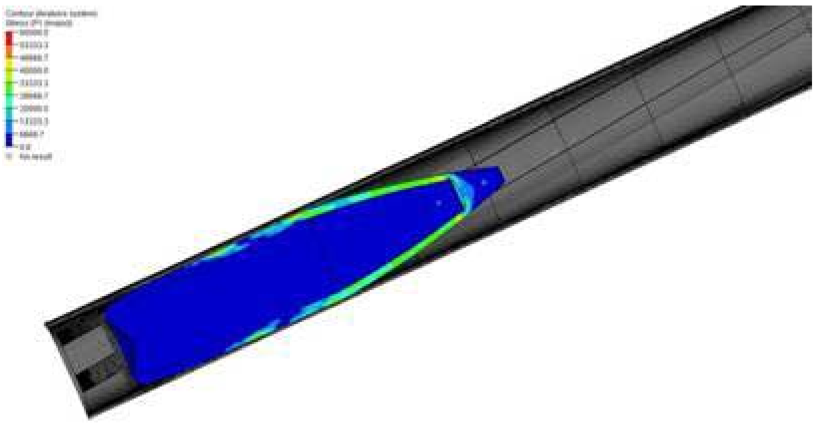
Transverse Displacement of the Projectile at Peak Acceleration



Rifled In-Bore Performance

Explicit Finite element simulations were used to study engraving and projectile motion.

- Full 3D 1 in 7 rifled models evaluate the projectile interaction to rifling..
- Studies show the compression of the jacket during engraving.
- During launch the sides of the projectile must be under pressure in order to engrave.
- Models are being extended in order to evaluate different projectile designs and determine the relationship between bullet location & accuracy.

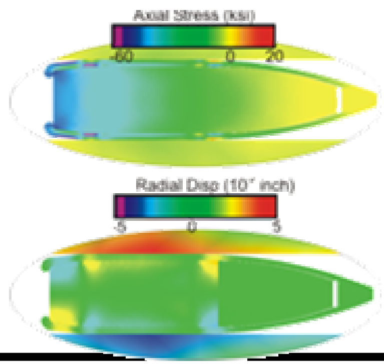


Bullet motion without side support

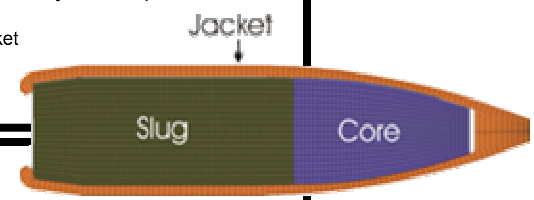
What Happens In-bore

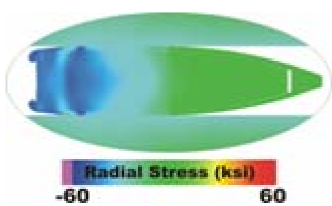
Slug-Penetrator acts Independently of Jacket

	mass (g)	% mass of projectile	force (N)	% force	acceleration (m/s^2)	acceleration (gees)
bullet	4.033		9073.56		2,249,828	229,340
slug/core	2.823	70.0	5996.12	66.1	2,123,765	216,490
jacket	1.210	30.0	3077.43	33.9	2,544,061	259,333



- Jacket tries to accelerates faster than the slug/core
  - Core/Slug represent 70% of mass in projectile, but only experiences 66% of the acceleration force
- Core essentially rides the slug with very little interaction with jacket
- Back end is compressed from pressure loading
- Projectile is compressed as it enters the bore
- Axial stress builds from front of projectile until the end of the cylindrical portion (consistent with base push)
  - penetrator tends to pull away from the front of the jacket

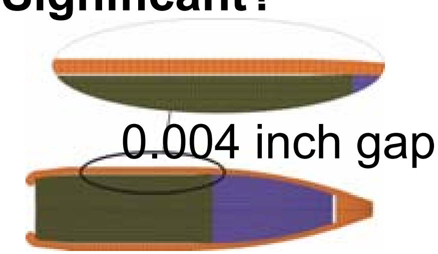


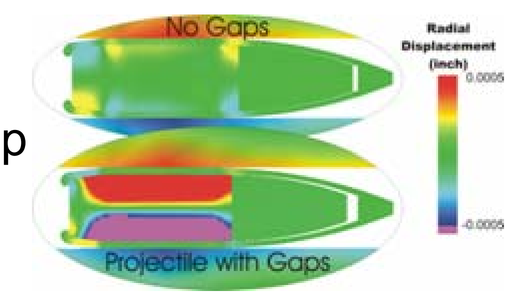


Pressure Seal is Effective

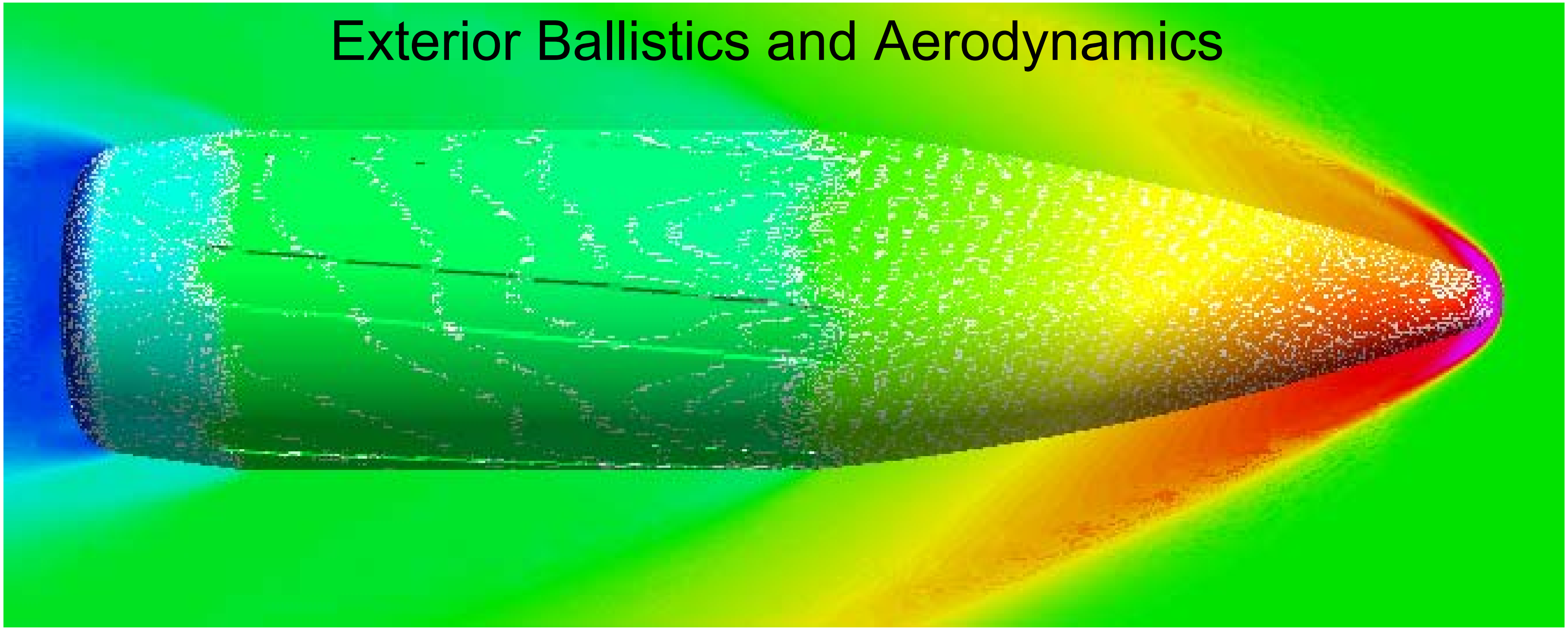
- Since jacket tries to accelerate faster than the slug/core, it is pressed up against the slug
- The back section of the jacket (the boat tail) bends from the pressure
  - The bending reduces the seal (minor effect)
- Seal is important since gas leaking into the projectile can help overcome the gaps

Why are Gaps Significant?



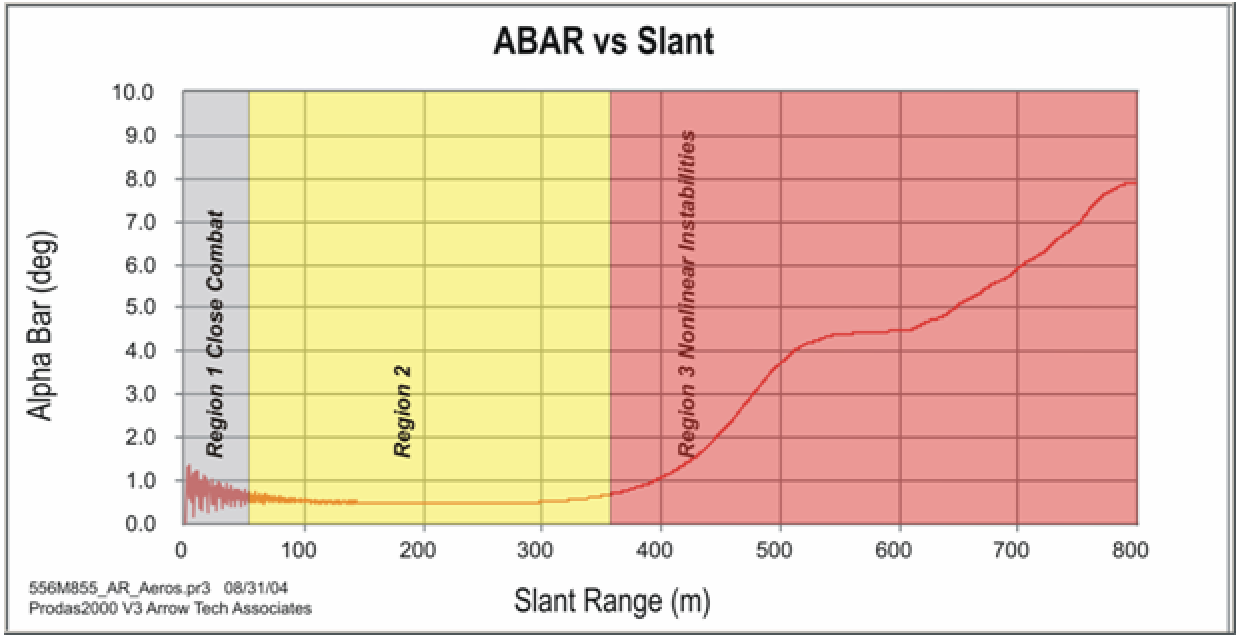


Exterior Ballistics and Aerodynamics



- Use of Computational Fluid Dynamics to predict linear and nonlinear aerodynamics
- Spark range experiments to characterize yaw, validate the codes, and perform diagnostic experiments to help resolve issues

M855 Yaw History
Non-Linear Aerodynamics

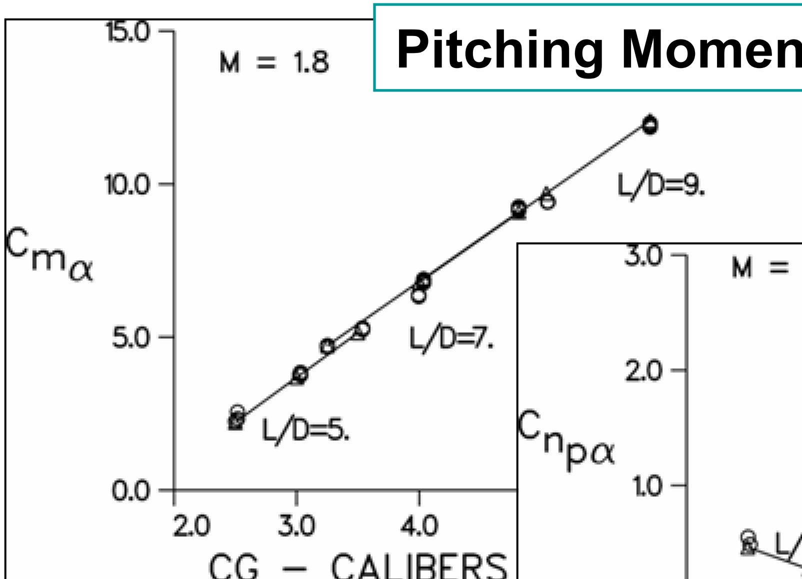


- Three flight regions of interest relevant to terminal events
  - Region 1: Close combat region where the launch yaw is damping
  - Region 2: the round has damped to some trim angle
  - Region 3: The projectile starts showing Magnus instability which results in yaw growth

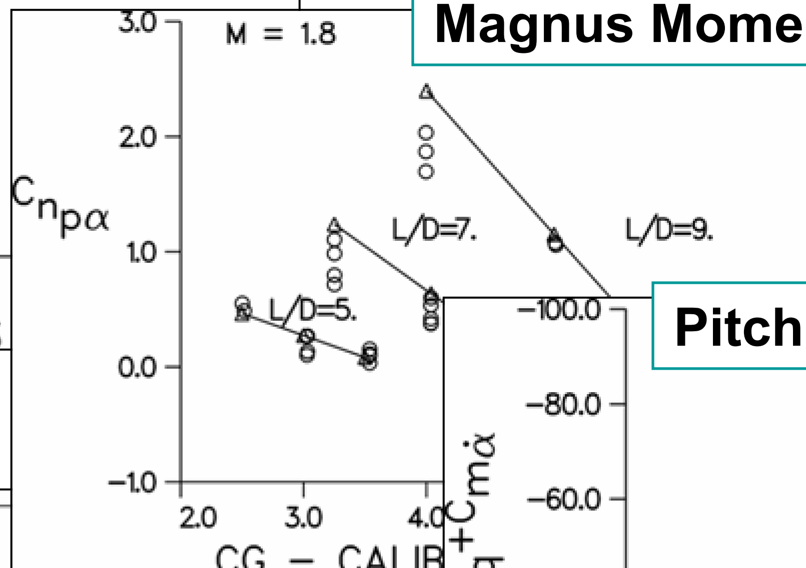
What types of things can be Predicted?

The capability exists to compute all the aero needed to predict stability and free-flight motion

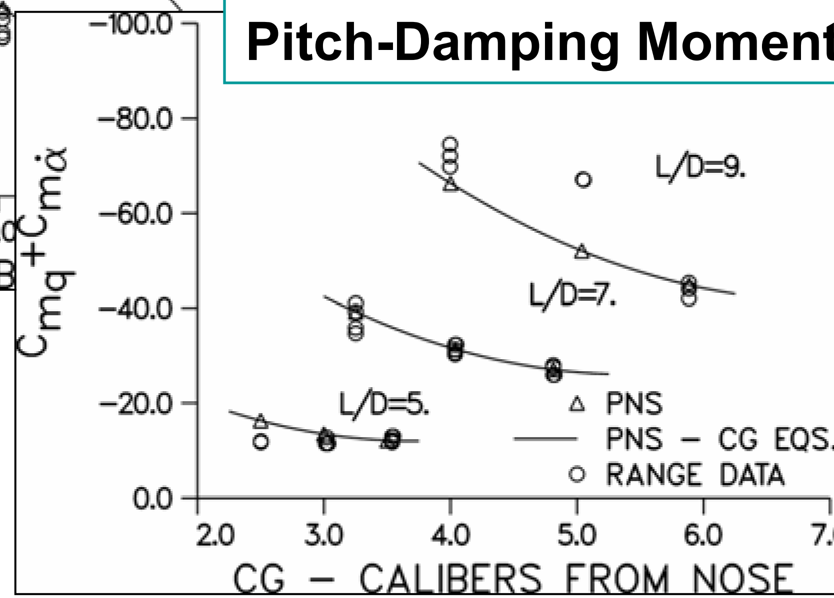
Pitching Moment

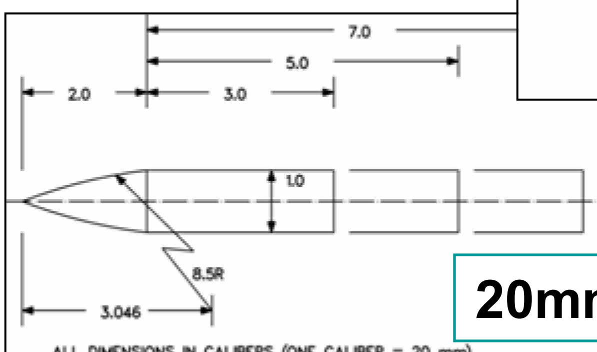


Magnus Moment



Pitch-Damping Moment



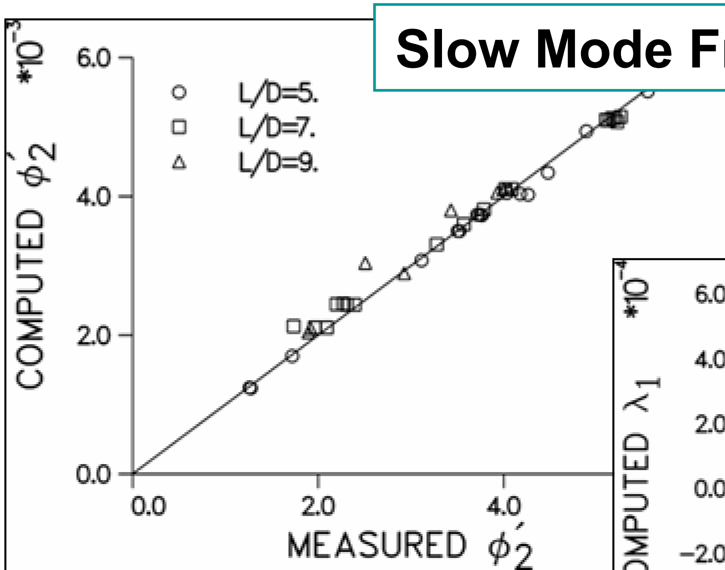


20mm ANSR

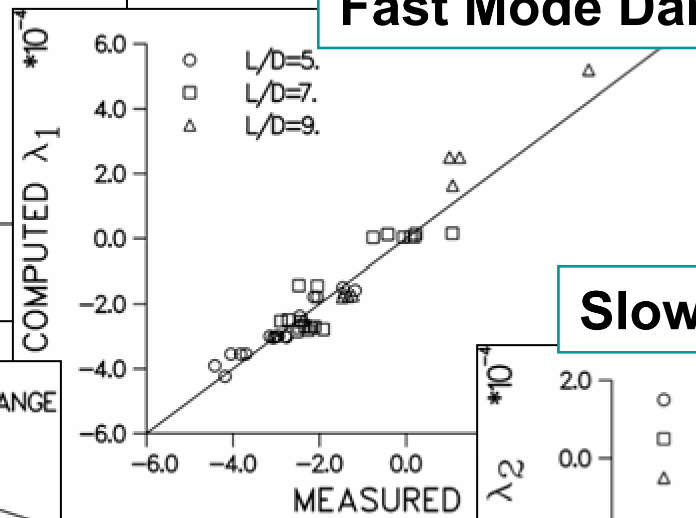
Existing CFD Predictive Capability
Pitching Motion Characteristics

Frequencies, damping rates and pitching/yawing motion well predicted using CFD aero

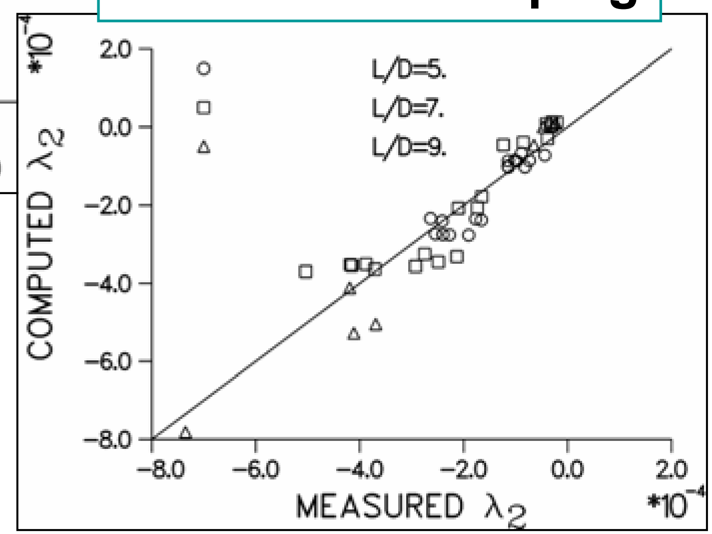
Slow Mode Freq.



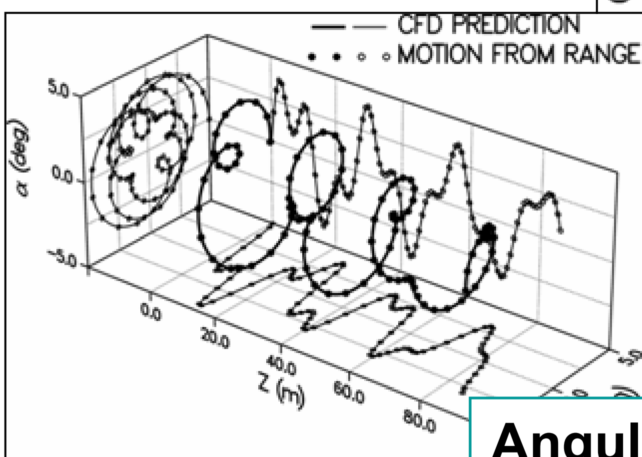
Fast Mode Damping



Slow Mode Damping

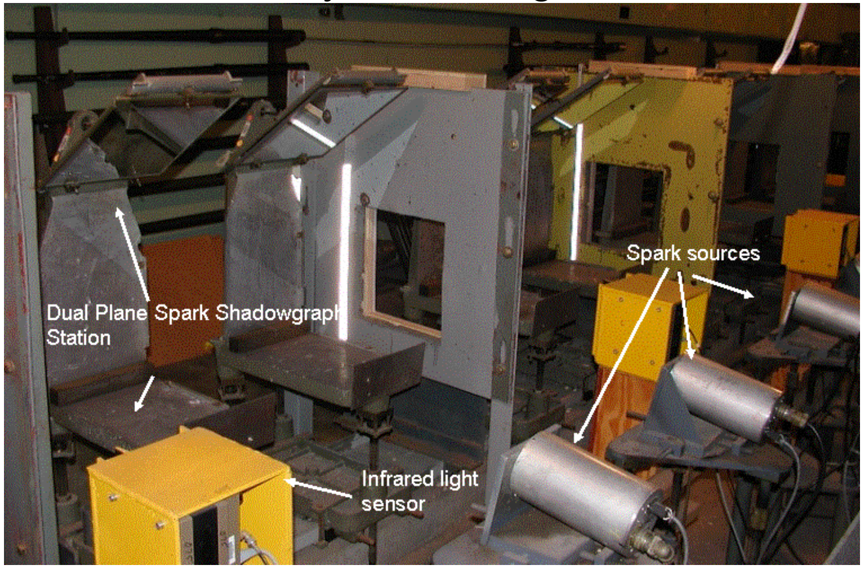


Angular Motion

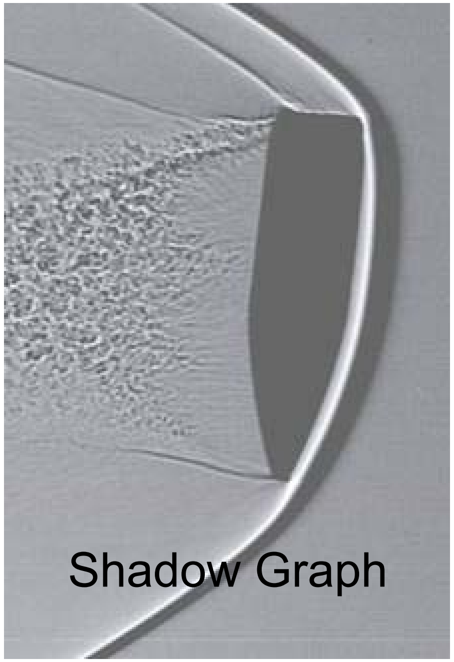


Spark Range Experiments

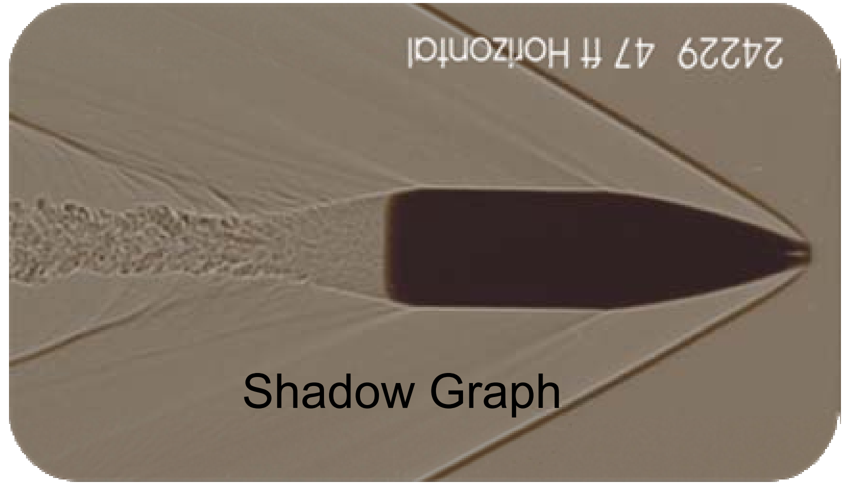
- Aerodynamics of projectiles are obtained in Spark Ranges
- There are three ranges in the US
  - Two at ARL (Aberdeen Proving Ground)
    - small range (up to 40 mm ammunition and 100 m instrumented length)
    - large range (60 mm up to 5 inch or larger and 200 m instrumented length)
  - A medium caliber (Eglin Air Force Base)
    - Medium range (40 mm on up, 200 m instrumented length)
- A spark range take a series orthogonal pictures of the shadow of the projectile over various flight regimes to determine the aerodynamic coefficients
- The aerodynamic range is a national mechanical engineering historic monument



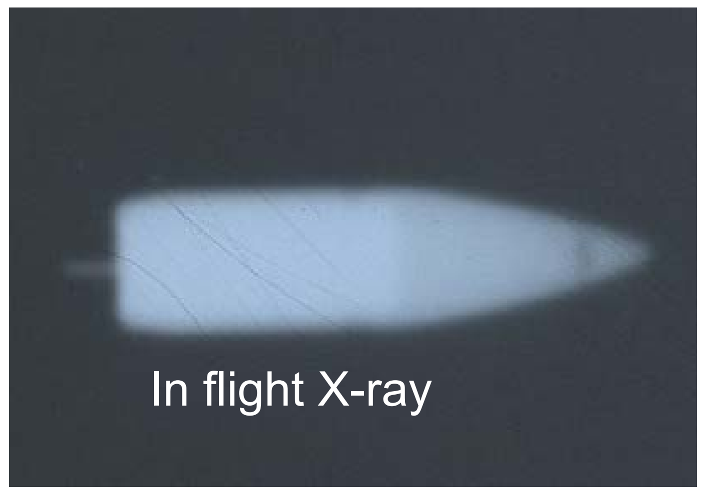
Images from Aerodynamics Ranges

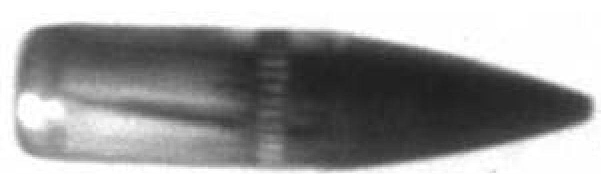

Shadow Graph

Highest yaw ever seen in the range



Shadow Graph

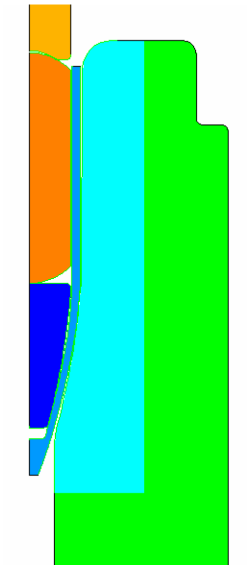

In flight X-ray

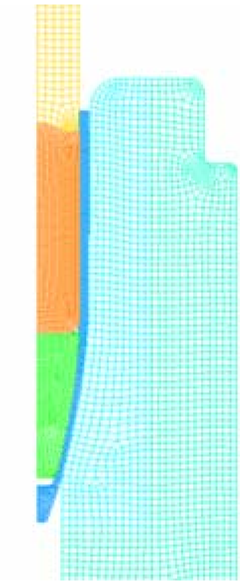

In flight projectile photographs

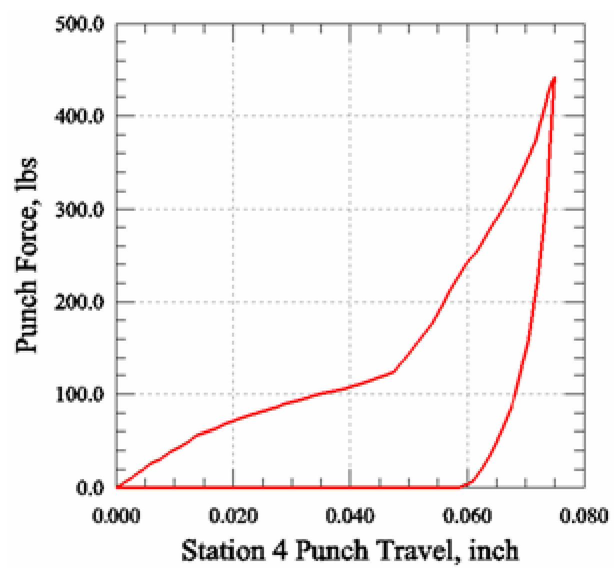
Support for Modeling of Manufacturing Process

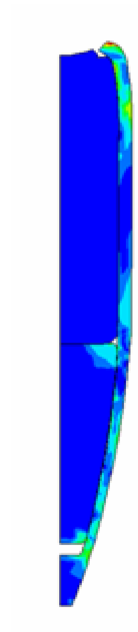
We are supporting ATK with their experiments and modeling of bullet assembly machines (BAMs) to understand the effect of manufacturing process of the bullet forming

- ARL is providing mechanical characterization to support work and large deformation modeling work to compliment Kamdar's (ATK's) work





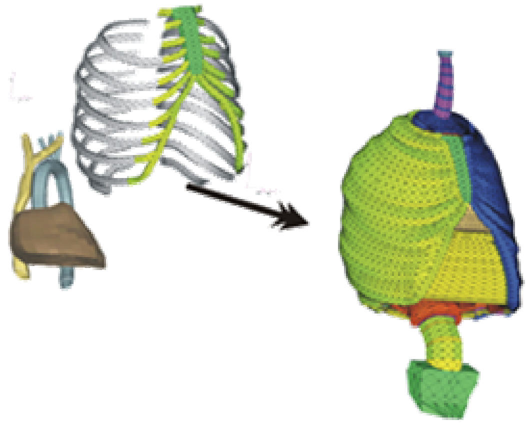


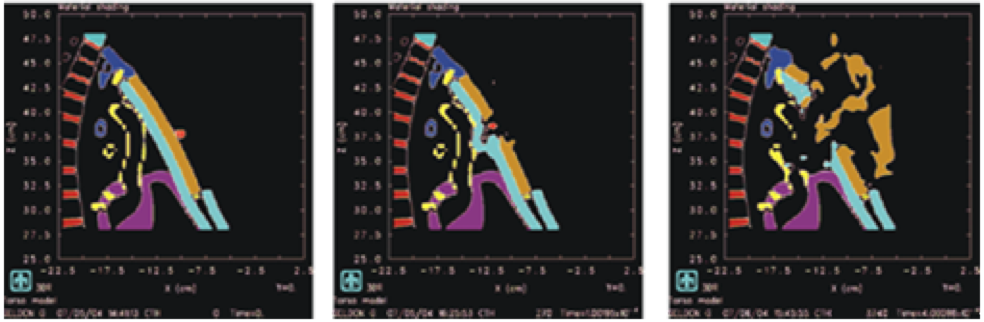


D. Kamdar, Ph.D

ATK OS Systems, Mn 2004

Terminal Effects

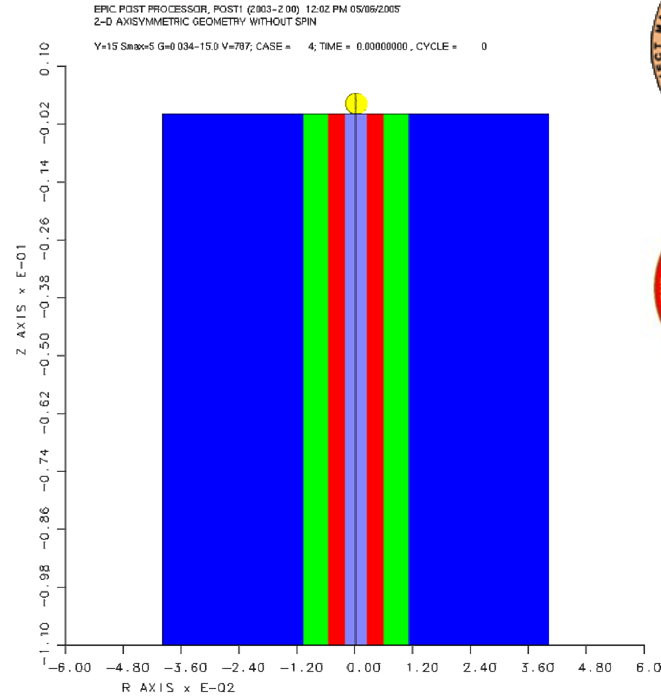




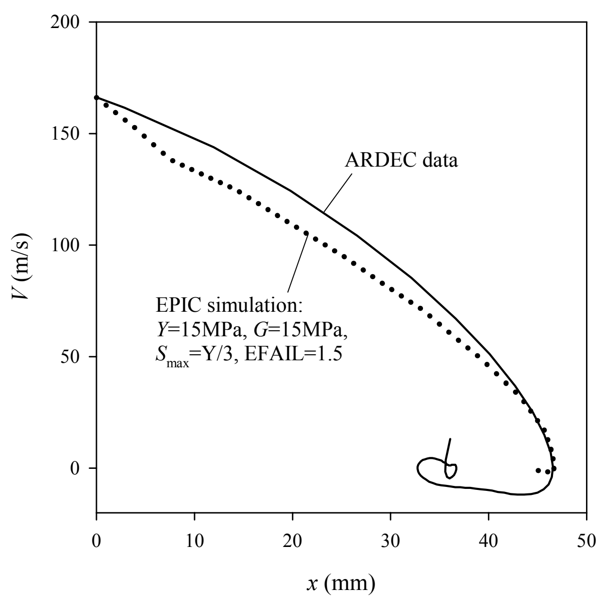
- ARL is pursuing
  - high fidelity physic based simulation capability
  - Methodology support/improvements
  - Experiments on gelatin for M193, M855, and MK262
  - Simulations in support of gelatin work
  - Mechanical Characterization for gelatin work
  - M855 against hard target characterizations

Gelatin Simulation

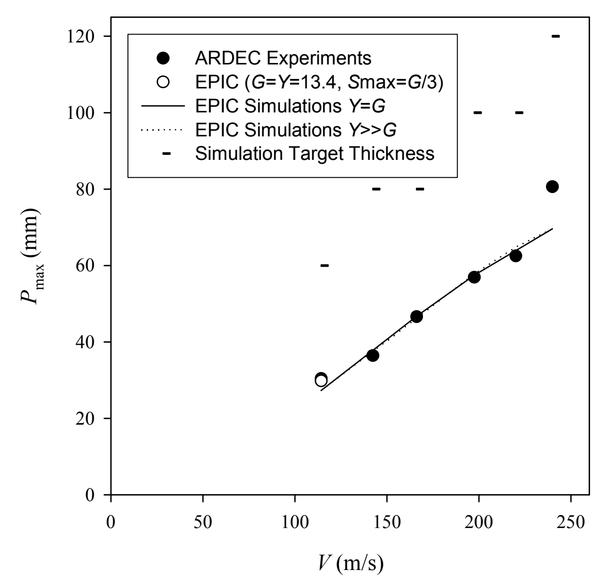
- Working through issues for simple projectiles
- Developing the mechanical properties
- Working through different code approaches
- Developing understanding for what is important
- Validating against experimental data



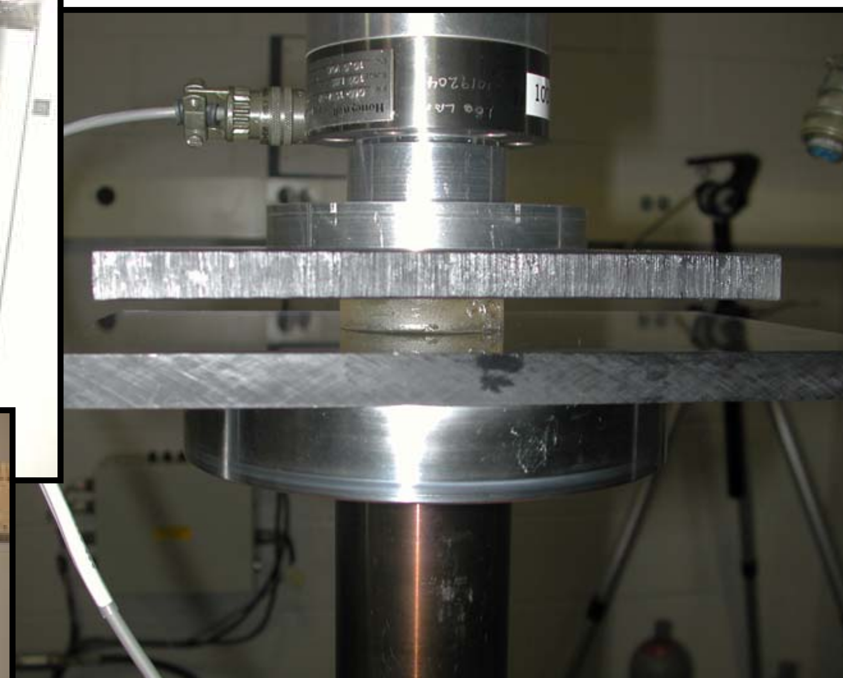
V_s = 545 fps



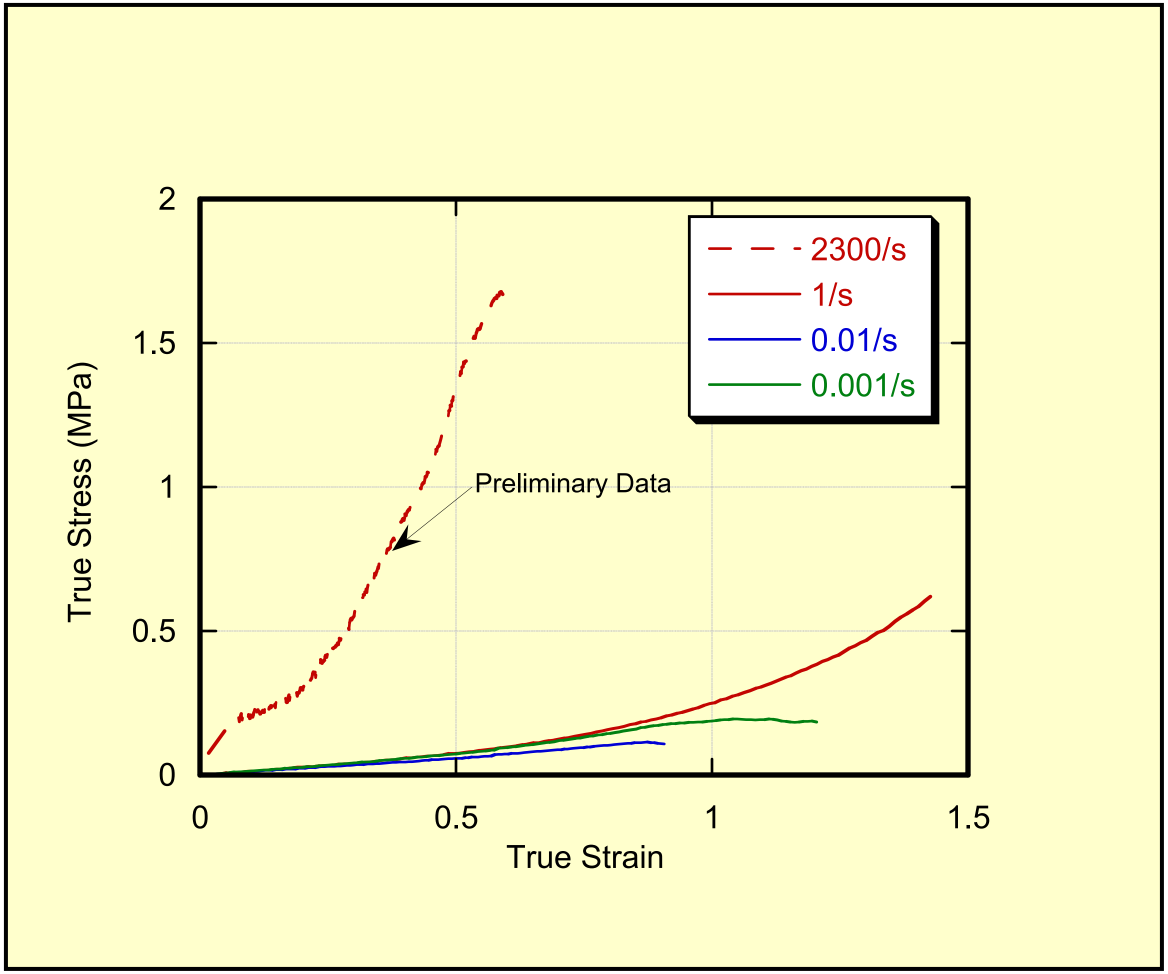
Maximum BB penetration vs. striking velocity
G = 15 MPa, $S_{max} = G/3$



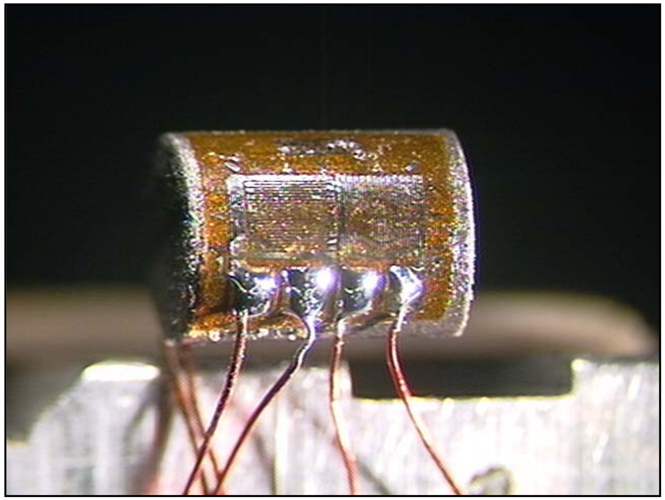
Test Setup for Slow Rate Experiments



Effect of Strain-Rate on Stress-Strain Behavior

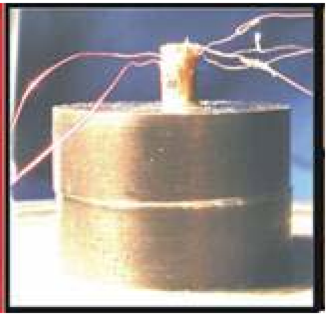


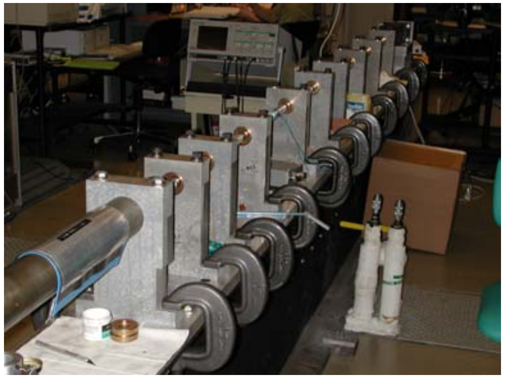
Mechanical and Failure Characterization of Small Projectile Components

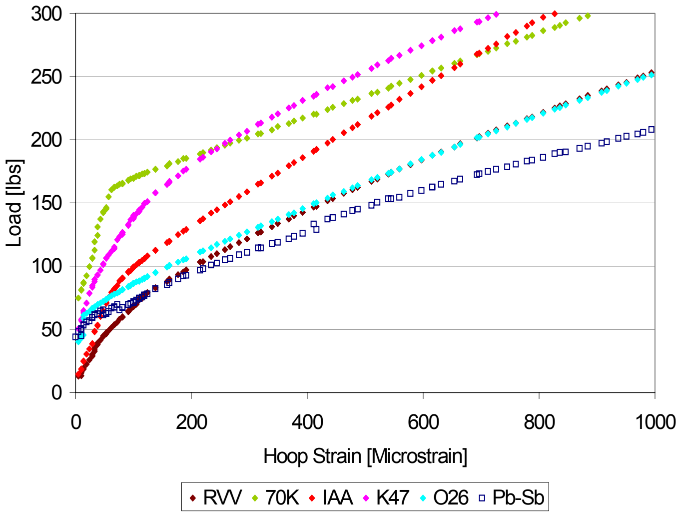


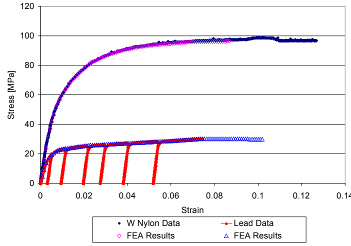
What has been done?

- Material Characterization
  - Developed new techniques for stress strain measurements of small parts (projectile jackets and slugs)
  - Mechanical characterization of green ammunition configurations (used to help down select the final candidates for green slug replacement program)
  - Unique multi-component expansion testing of complete projectiles
  - High rate material characterization

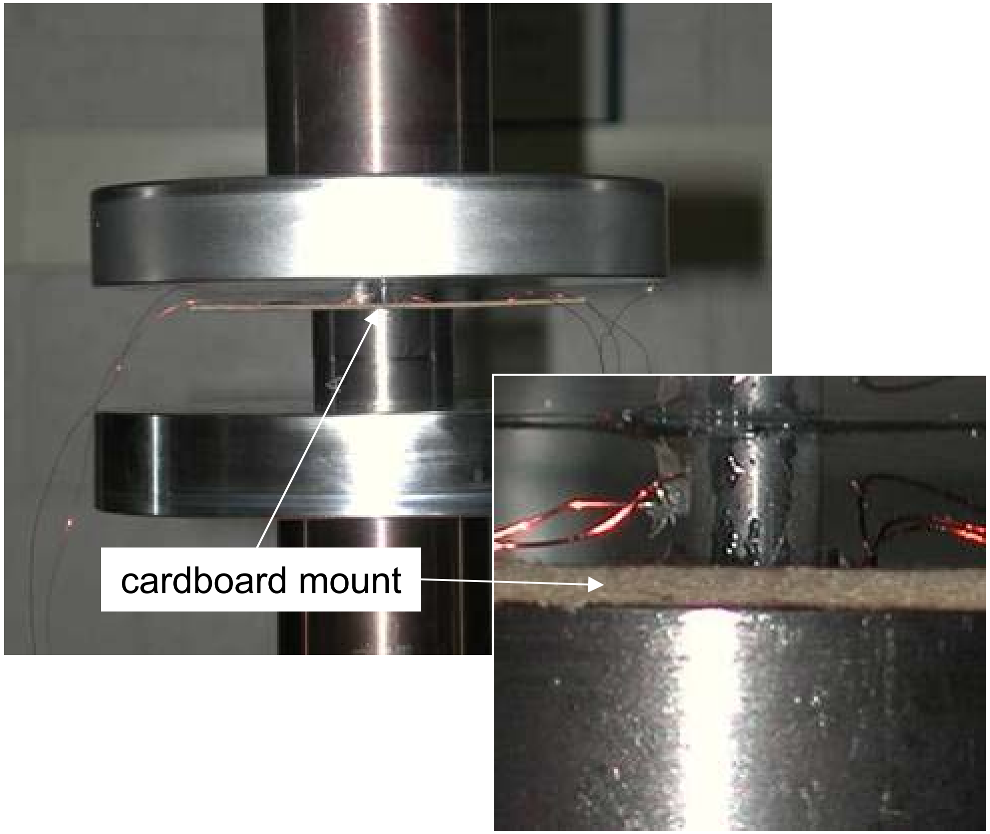


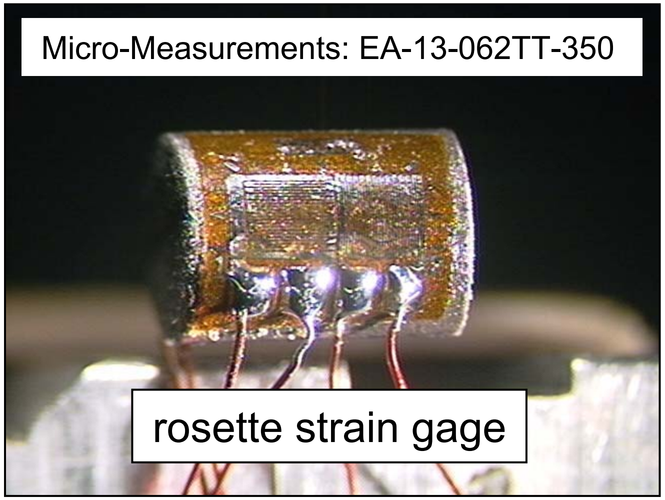


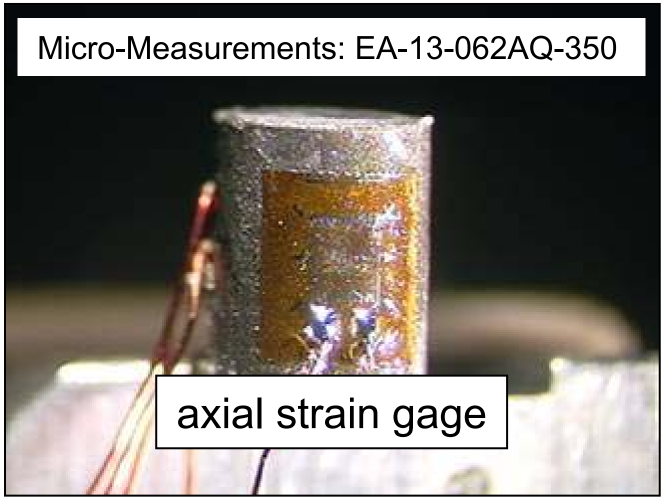




Bullet Core Compression Experiment Setup

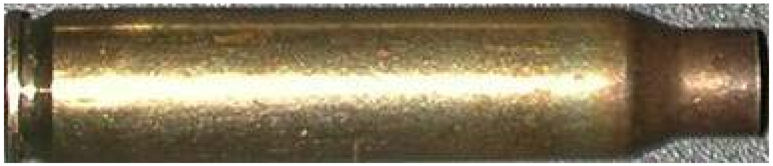


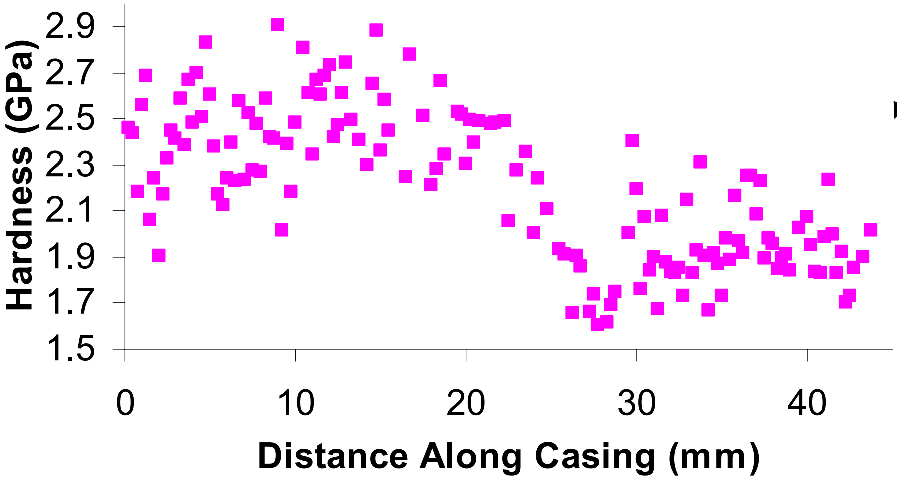




One axial strain gage and one rosette gage were set 180^{o} apart. Cardboard mount were used to ease the handling of the specimen during experiment.

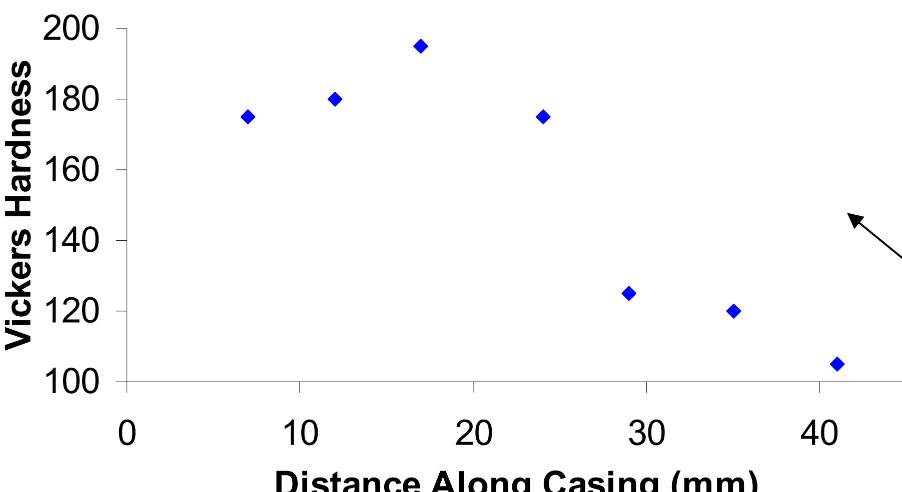
Hardness Measurements on Brass Cartridge Casings





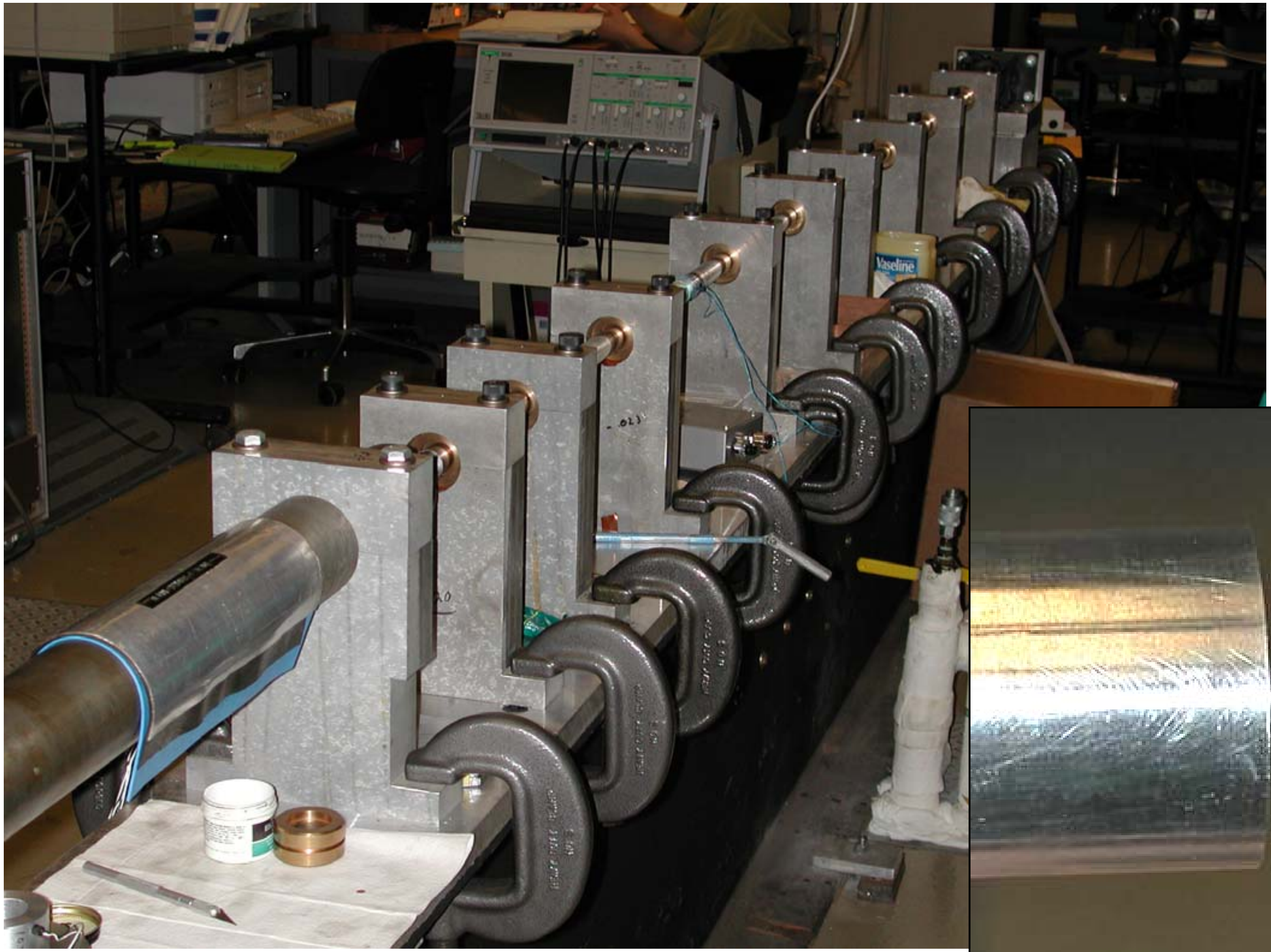
Typical sharp Berkovich indentation data, 500 nm maximum displacement

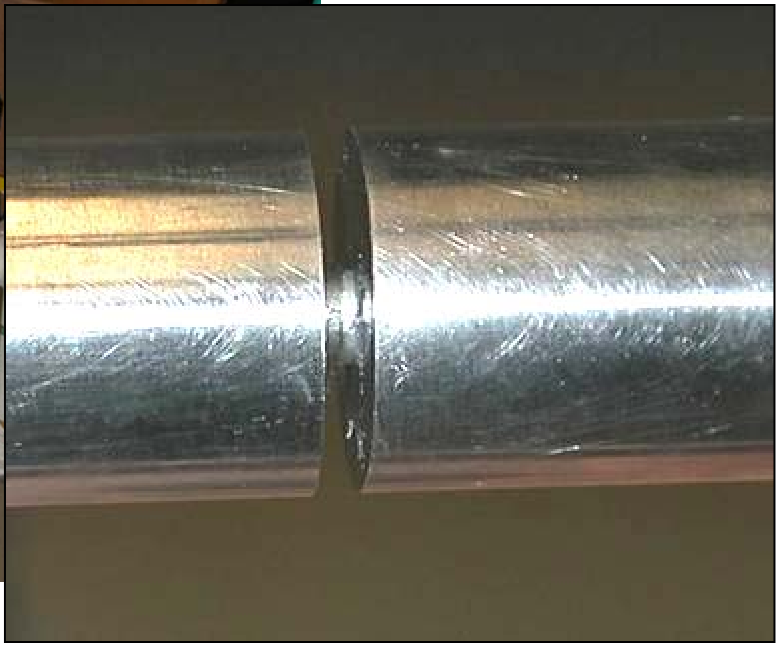
Both depth-sensing and Vickers indentation can produce hardness profiles along the casing cross-sections. Depth-sensing indentation can also gather modulus data as well as measure the hardness from both dynamic measurements during the test and static measurements.



Typical Vickers indentation data

Bullet Core Compression Experiment Setup at High Rates (1000/s)



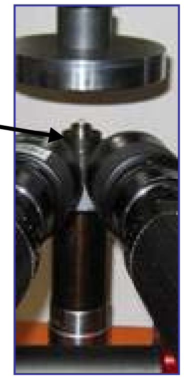


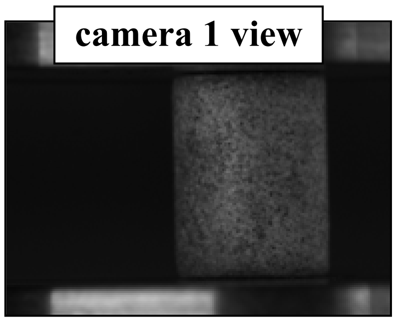
Stress-Strain Behavior

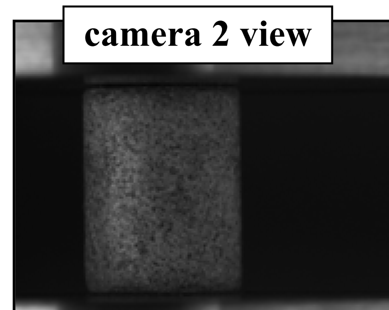
Strain Measurement from DIC

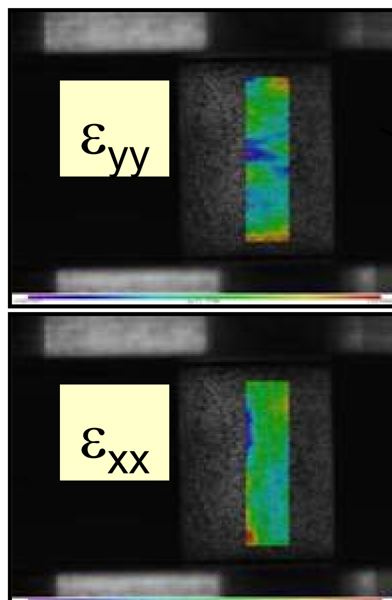
(Digital Image Correlation)

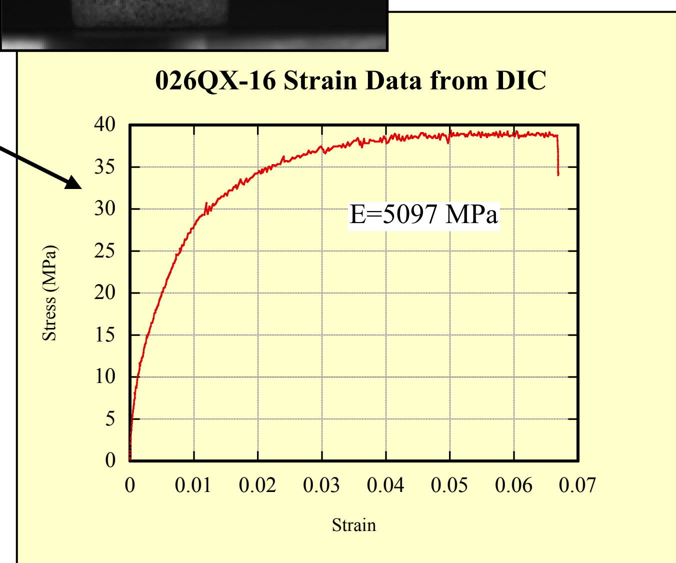
Speckle Pattern painted on Bullet specimen







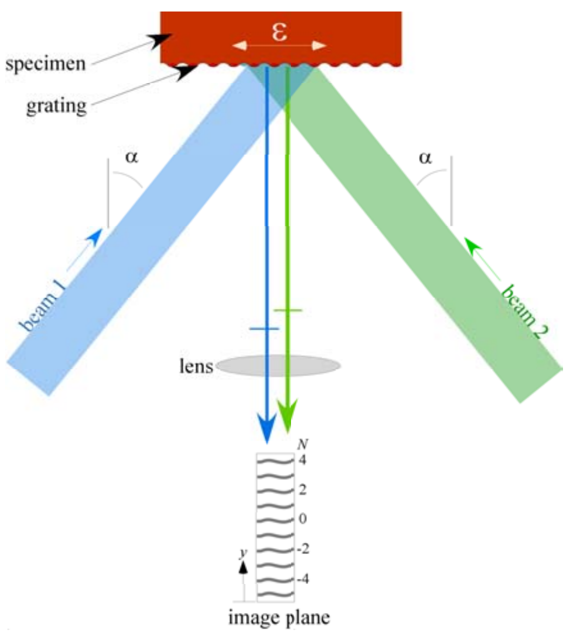


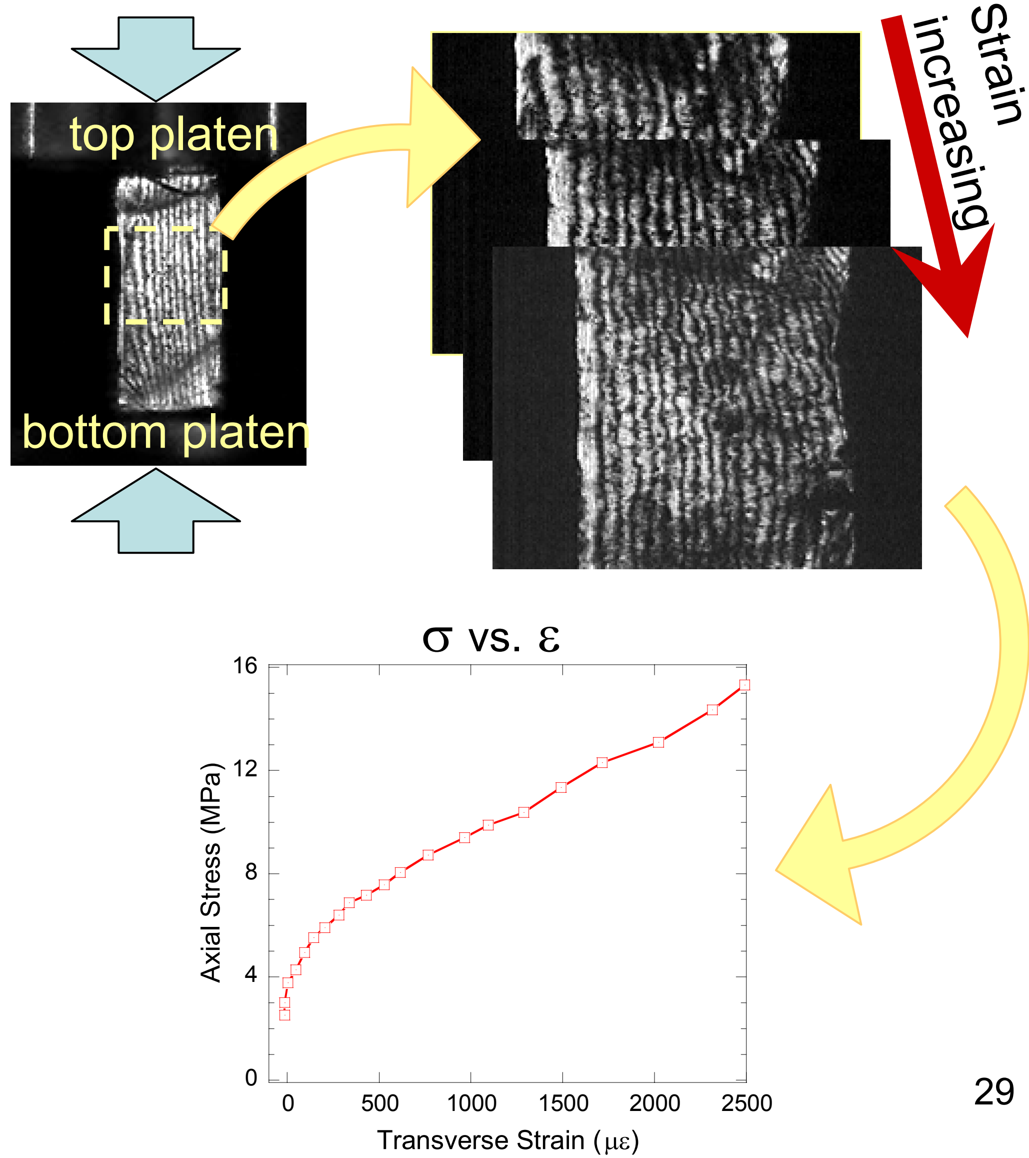


Stress-Strain Behavior

Strain Measurement from Moiré Interferometry

- Beams interact with high frequency grating on sample to produce fringe pattern
- Fringes are contours of constant displacement
- Displacement contours used to calculate transverse strain





Conclusions

- ARL is fully engaged in developing and applying technology to small caliber ammunition
  - A large number of folks working on small caliber systems
  - Investing mission money on relevant technology

- Many types of technology have been and are being adapted and developed
  - interior ballistics
  - in-bore Gun/projectile mechanics/dynamics
  - mechanical properties of small projectile components
  - interior ballistics
  - terminal effects experiments and methodologies