U.S. ARMY COMBAT CAPABILITIES DEVELOPMENT COMMAND – ARMAMENTS CENTER

Energetics and Munitions Suitability for Gun Launch

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BACKGROUND

- **Gun launched munitions undergo extreme loading conditions during ballistic cycle**
- **Sufficient heating due to defects can lead to the unintended ignition and cause a premature reaction of the item**
- **There is a knowledge gap in understanding the environment and the cause of a reaction occurring**
- **Existing test methodology does not address influence and safety criteria from defects found in energetic materials.**

BACKGROUND

- **A working group has been setup under NATO AC326 SG/A**

- **Consists of engineers & scientists from different laboratories and nations**

- **Goals**
  - Identify topic areas that are related to issue
  - Review available relevant information
  - Determine level of understanding
  - Begin developing future standard

CURRENT RELEVANT STANDARDS

- **AOP-7 Data Requirements and Tests for the Qualification of Explosive Materials**
  - Guidance on requirements for type of energetic material
  - Provides test methods to assess sensitivity, thermal, physical, performance, aging

- **AOP-4170 Principles and Methodology for the Qualification of Explosive Materials for Military Use**
  - Establish explosive qualification requirements
  - Ensure materials are characterized sufficiently

- **STANAG 4224 Large Caliber Artillery and Naval Gun Ammunition Greater Than 40mm, Safety Suitability for Service Evaluation**
  - Defines test series such as propulsion charge, strength of design, environmental conditioning, worn barrel, projectile safety,
  - “there shall be no significant voids, cracks, HE dust, bonding failures or other unacceptable features in the condition of the projectile, and where appropriate, sub munition filling”
  - “where there is evidence of these features, the significance of these shall be explained by the developing nation”

CAUSES LEADING TO IGNITION

- **Unintended ignition such as an inbore is related to damage to defects during the launch**

- **Mechanisms attributed to heating are believed to be**
  - Adiabatic compression of gas
  - Shear flow
  - Frictional heating
  - Pore Jetting

- **Numerous past work efforts have studied the effects**

- **However their role and contribution are not well defined**

DEFECTS IN MUNITIONS

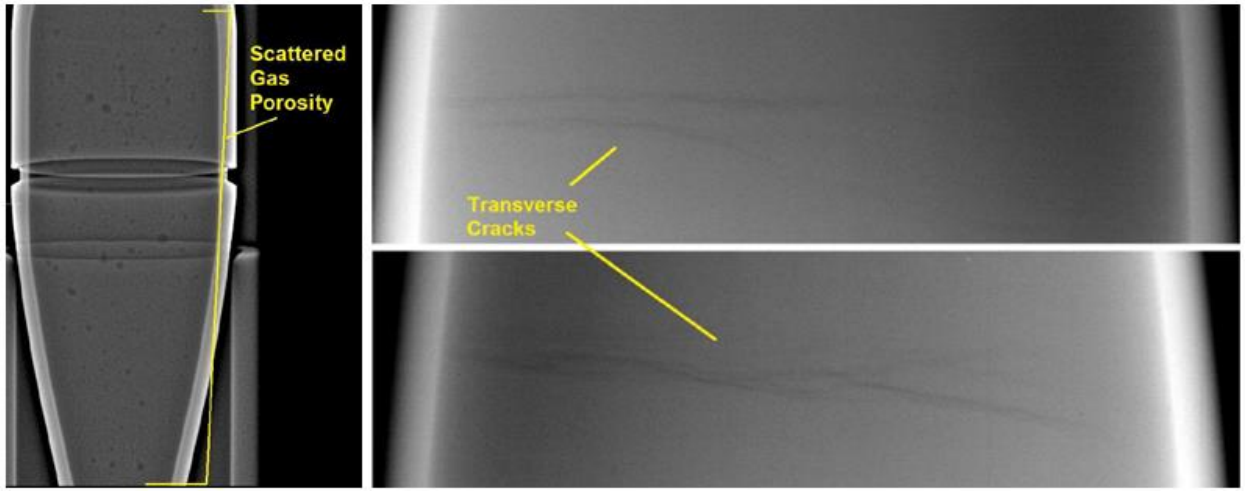
- **Formation of defects occur in energetics due to**
  - Type of formulation (Cast Cure, Pressed, Melt Pour)
  - Manufacturing loading process
  - Aging of the material during storage

- **Common Types of Defects**
  - Cracks
  - Voids
  - Porosity
  - Piping
  - Base Gaps
  - Exudation
  - Migration

INSPECTION OF DEFECTS

- **X-ray (non-destructive)**
  - Influence from multiple defects, requires multiple orientations
  - Does not detect exposed crystals, migration, or exudation
- **Sectioning Loaded Projectiles**
  - Cutting operation may cause further damage to defects
  - Apparent size may reduce with shavings
- **Are we measuring the correct parameters?**
  - Surface area
  - Volume

Sectioned projectile showing defects



X-rays showing defects such as gas porosity (left) and cracks(right) in projectiles

DYNAMIC LAUNCH ENVIRONMENT

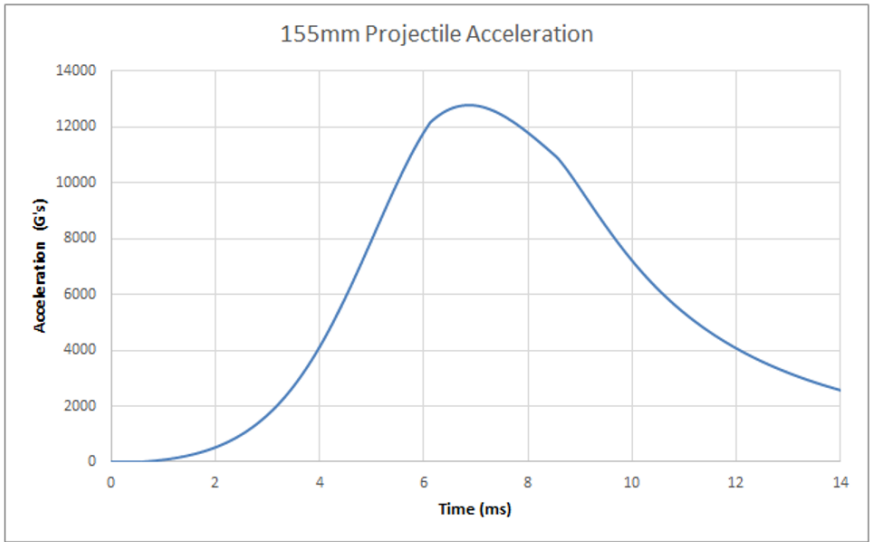
- **Internal ballistics calculations for the launch environment**

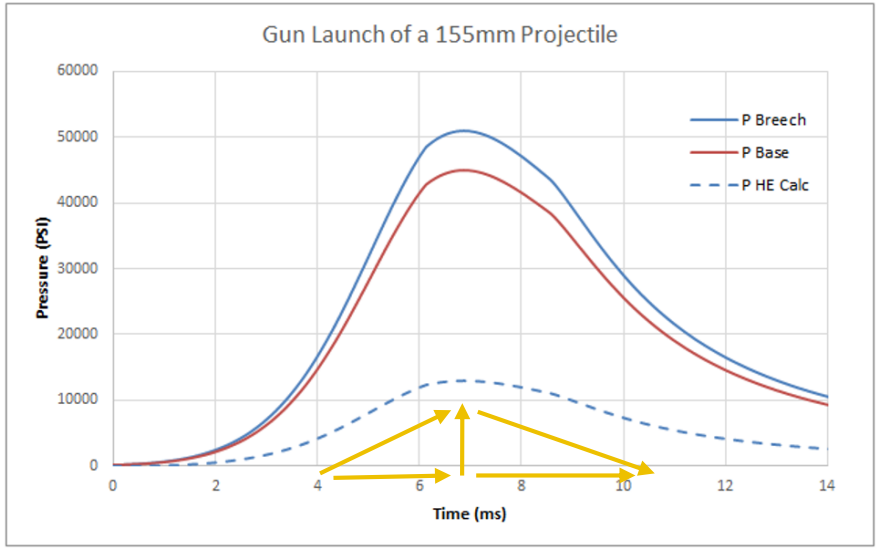
Pb = pressure in breech
Ps = pressure at projectile base
Phe = theoretical HE base pressure
c = propulsion charge weight
w = projectile mass
a = acceleration (G's)
ρ = density of fill
h = column height of HE fill

Eq. 1 $Ps = (1 + \frac{c}{w})Pb$

Eq. 2 $a = \frac{Ps * Area}{w}$

Eq. 3 $Phe = \rho * a * h$

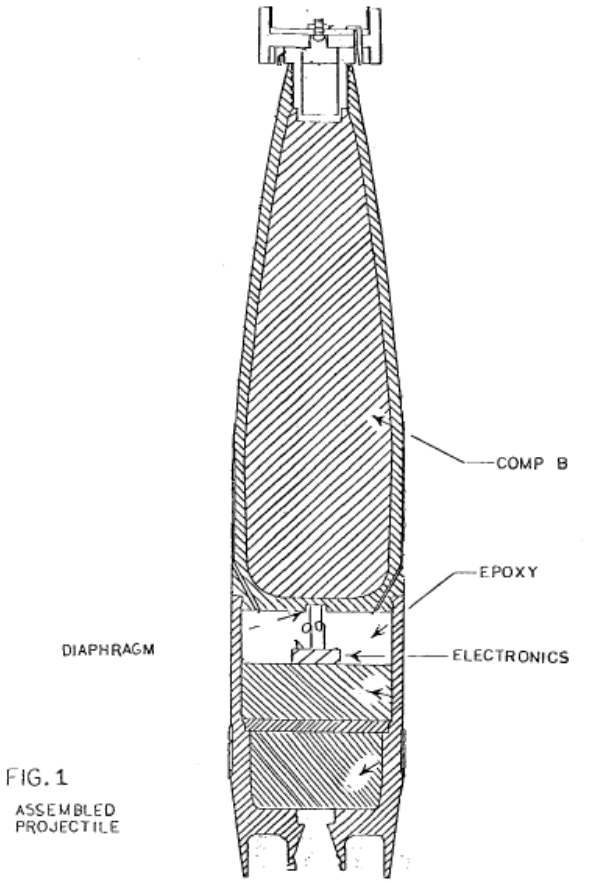




Loading profile on a 155mm projectile during launch

EXPLOSIVE LOADING ON WARHEAD

- **Testing on instrumented 155mm projectiles with comp B**
- **Higher quality explosive fill demonstrated lower pressures at base vs with defects**
- **Possible factors that may influence loading**
  - Presence of defects
  - Explosive material behavior
  - Support from warhead geometry
  - Bonding/adhesion HE to warhead



Instrumented 155mm projectile measuring pressure at HE base

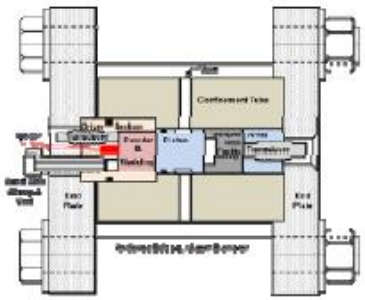
SUBSCALE TESTING

- **Test capabilities exist among different laboratories for subscale testing on explosives**

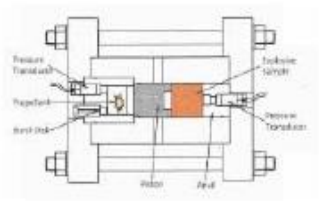
- **Loading is applied to deform or collapse defects in samples**

- **Device pistons driven by**
  - Compressed Gas
  - Drop Weight
  - Propellant Combustion

Examples of some lab scale setback simulators



NSWC-IHD



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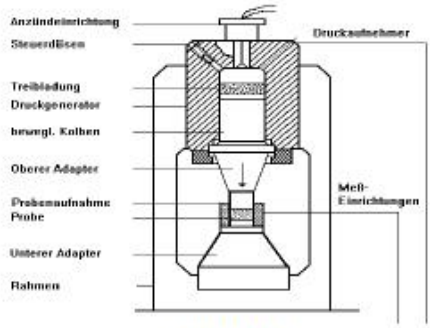

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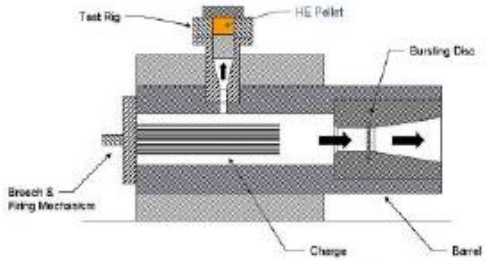
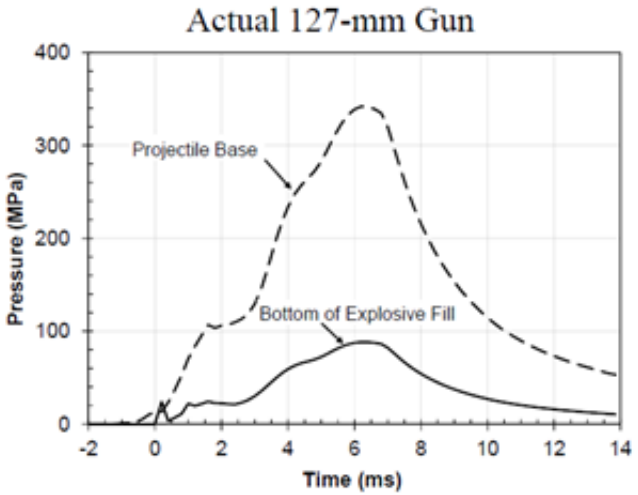


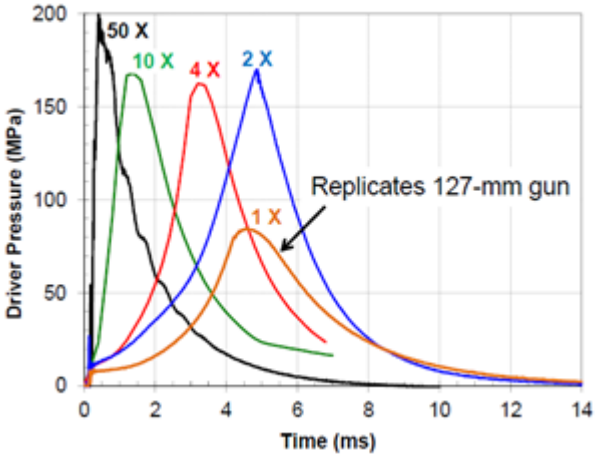
BAE-GCS
Gun Launch Simulator

TESTING DEVICES

- **In cases the devices can match the expected loading environment well**
- **Actuator Control Function**
  - Peak pressure
  - Loading rate
  - Duration
- **Known Adverse Issues**
  - Ignition due to device interfaces such as pinch points
  - Interpretation of response and reaction violence
  - Comparison with known legacy materials or munitions



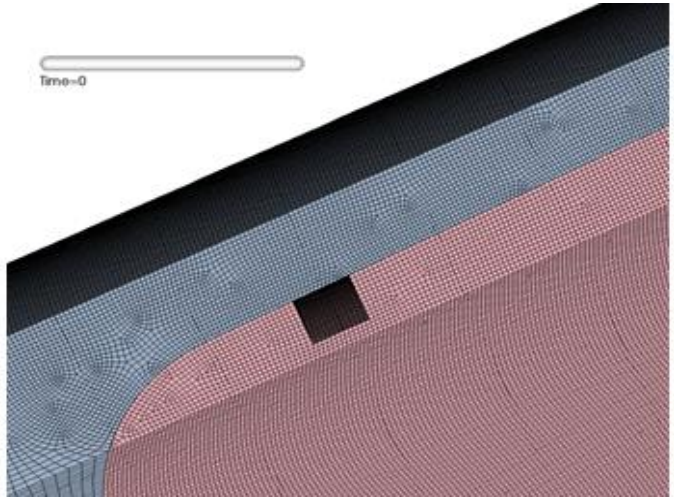
P-t plot for a 127mm projectile



Loading in NSWC IH Setback Device

MODELLING AND SIMULATION

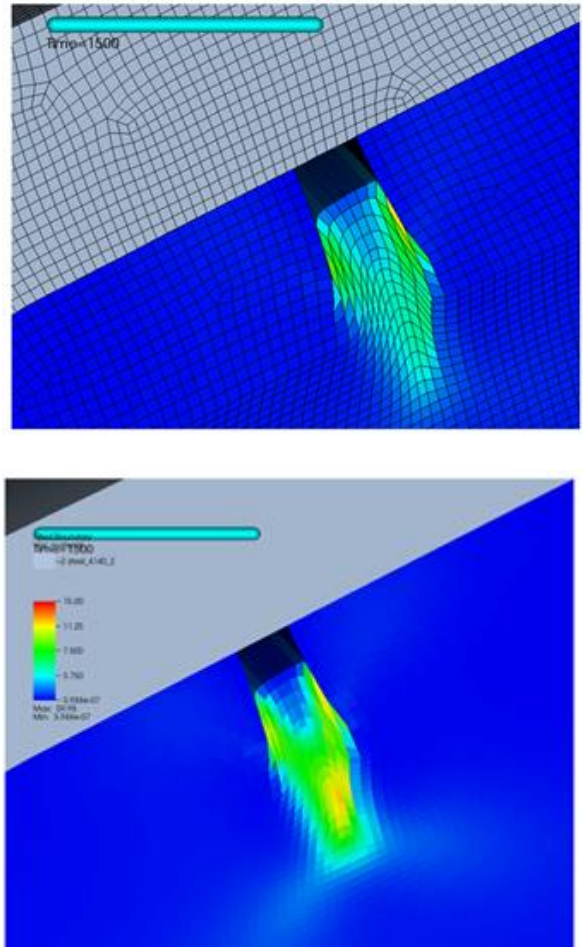
- **Use of M&S can supplement analysis**
- **Development of ignition and growth models**
  - IM event model
  - Accident response
- **Scenarios**
  - SDT – shock to detonation
  - DFT – deflagration to detonation
  - Shear damage/burning
- **Variety of models exists, HERMES (High Explosive Response to MEchanical Stimulus)**



Mesh of a 155mm projectile with nodes removed to simulated a large defect in HE

IGNITION SIMULATION

- **Attempt to simulate defects causing ignition at CCD-AC**
- **HERMES (High Explosive Response to MEchanical Stimulus)**
  - Developed at LLNL (Lawrence Livermore National Labs)
  - Based off prior SDT, mechanical damage, and reaction growth to detonation models
- **Reaction onset is determined by an ignition criteria**
- **Model defines how explosive will behave as a structural model**
  - Example simulation of defect defines a ignition parameter level of ~15
  - HERMES model was applied to the Stevens test and a an ignition parameter of ~200 is required for



Simulation using the HERMES model to assess ignition during loading event

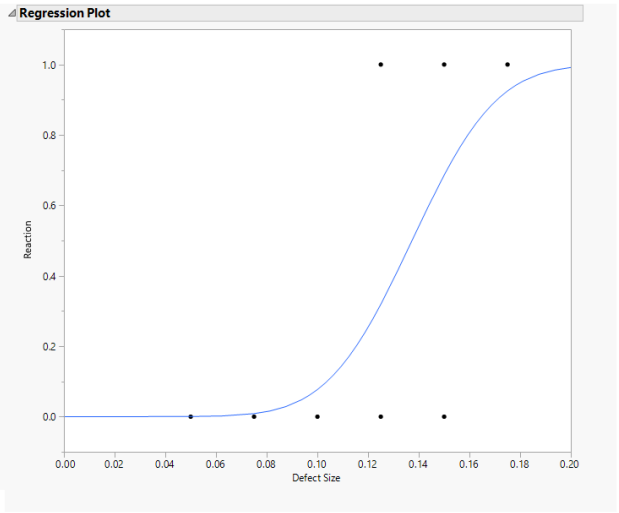
SUMMARY

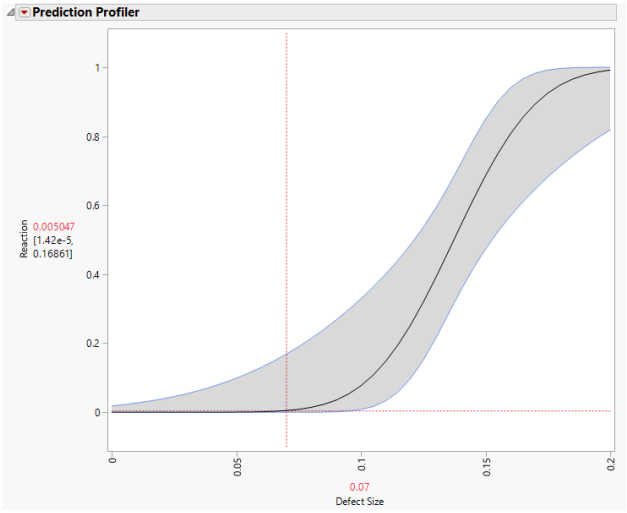
- Identify & provide background on subject areas related to explosive during launch
- Inspect & measure defects in explosives
- Characterize loading environment expected during launch
- Perform subscale testing on explosive formulation
- Use M&S capabilities to support information on defect failure
- Incorporate statistical analysis to define or measure likelihood of initiation
- Agreement on methodology for steps that may be used to assess safety and suitability during dynamic loading

END

Questions?

STATISTICAL ANALYSIS





- **Need for extrapolating limited data for new explosive fills to be used in munitions**
- **Example depiction of assumed response in subscale or full tests**
  - 30 test shots total
  - 5 repeats over 6 defect sizes
- **Use of data to determine probability for analysis**
- **Concerns – method of analysis can skew results, larger range in confidence intervals**