



U.S. Army Research, Development and
Engineering Command



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Propulsion System Design in Low
Pressure Gun Systems

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Introduction



- ❑ A significant trend in large caliber ammunition today is demands for guided, non-line-of-sight munitions.
- ❑ These munitions typically rely on seekers, sensors, and aerodynamic control surfaces, i.e. delicate components.
- ❑ These qualities make the projectiles more fragile than the legacy ammunition that rely on overwhelming velocities or explosive mass to defeat targets.
- ❑ Such munitions require softer gun launches which pushes towards the low-end of the envelope of gun system performance.
- ❑ Since at least from the development of the MGM-51 *Shillelagh* in the 1960's, armaments engineers have struggled to find a good way to launch a missile-like projectile from a gun.

Two Totally Different Performance Regimes

HIGH PERFORMANCE/HIGH ENERGY

- Use all available gun tube strength to generate high pressures.
- Increase projectile weight or muzzle velocity as high as possible without damaging recoil system. Faster and heavier is better.



SOFT LAUNCH/LOW PERFORMANCE

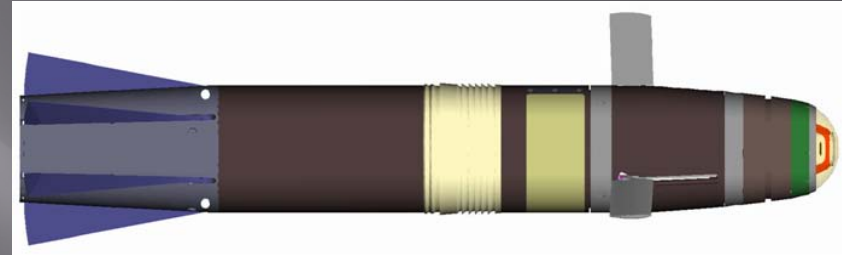
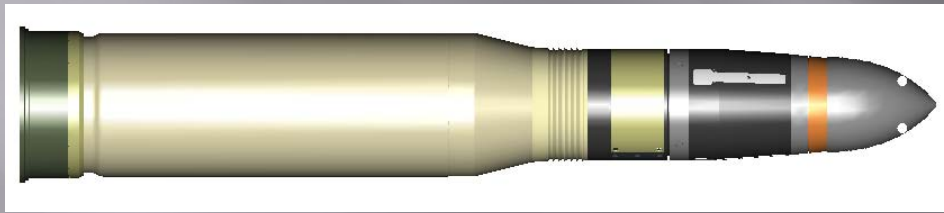
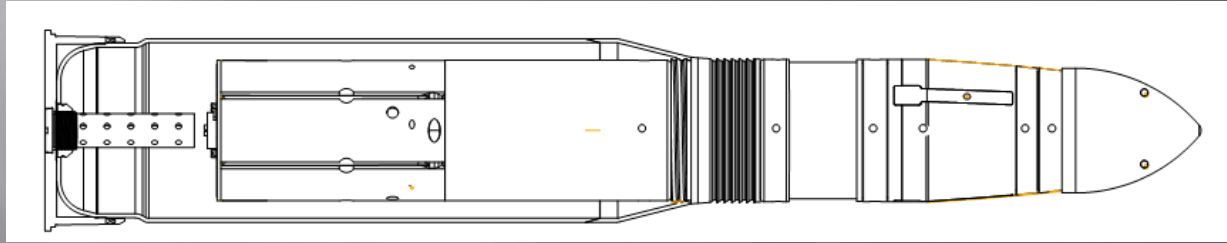
- Keep pressures and accelerations low to allow a wider variety of electronics and airframe options.
- Lift-generating and rocket powered projectiles need only a small initial velocity, however the gun typically needs a minimum velocity to cycle without jamming.



About the Presentation

- ▣ The purpose of this presentation is to communicate to the gun and propellant engineering community the lessons learned regarding munitions design in a low-pressure, low-velocity system.
- ▣ The Mid-Range Munition (MRM) program is referenced often because it is the best example of this theme, however this will not be a presentation of the MRM program per se.

Brief Overview of the MRM Round



Key Requirements:

- ▣ Launched from 120mm Abrams main gun
- ▣ Has same survivability as legacy tank ammo, e.g.
 - Resistance to inadvertent ignition of energetic components
 - Resistance to physical threats such as being dropped or crushed

Major Problem Areas

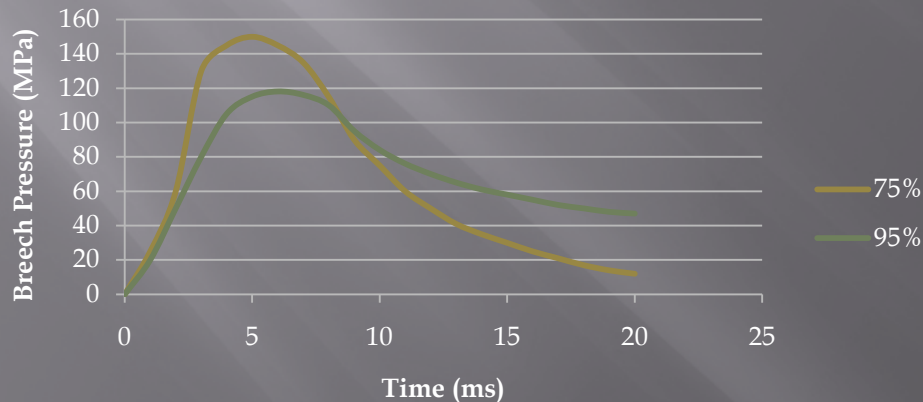
1. Incomplete propellant combustion (safety hazard)
2. Large amounts of paint residue from cartridge case (interferes with the chambering of subsequent rounds)
3. Low recoil resulting in unreliable operation of the breech mechanism (gun prone to jamming)

Propellant Design

- ▣ St. Marks Hybrid® was chosen for favorable pressure/velocity ratio
- ▣ Propellant combustion time was maximized to keep gas pressure and projectile acceleration at a minimum



Base Pressure vs. Time for
Propellant Burn-out as a Percent of
Firing Time



- Area under pressure vs. time graph is proportional to muzzle velocity
- Therefore, the two graphs result in the same velocity, although one exerts a lower peak force on the gun and projectile

Propellant Design

- ▣ Lengthening the time interval over which the propellant burns increases the risk of incomplete propellant combustion
- ▣ This is well-understood, however low pressure environments present a problem
 - Propellant burn rate usually not well-studied at low pressures
 - Closed bomb testing usually not optimized for pressures less than 70 MPa
 - Propellant burn rate is not linear, and large errors result from extrapolating burn rates from higher pressure regimes
- ▣ Without accurate burn rate data, propellant grain design becomes difficult and relies more on trial-and-error than solid engineering design.

Propellant Design Conclusions

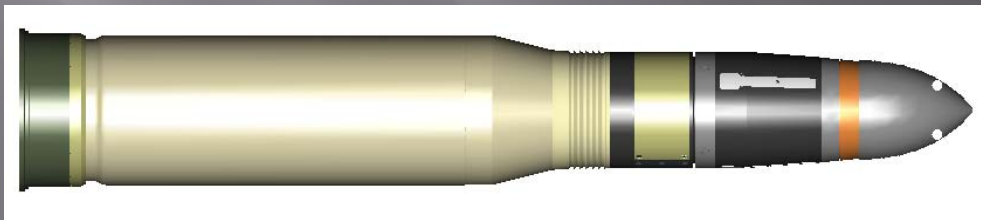
- Explore the low-pressure behavior of propellants more thoroughly:
 - Optimize closed bomb test setup for lower pressures.
 - Employ alternative test methods (strand burner) that are better suited for measuring burn rates at low pressures.



Strand burner and closed bomb images courtesy of Design Integrated Technology, Inc.

Paint Residue

- ❑ The primary purpose of the paint is to *resist combustion* when the ammunition is subjected to external ignition threats such as sparks, flame, and hot surfaces.
- ❑ This conflicts with the requirement that the paint be fully consumed or ejected from the gun after the shot.
- ❑ Legacy ammunition is painted with an aluminized epoxy paint that meets both these requirements.
 - This paint was used for the first-cut MRM round for lack of any alternative and to avoid the design and qualification costs of developing a new coating.



Paint Residue

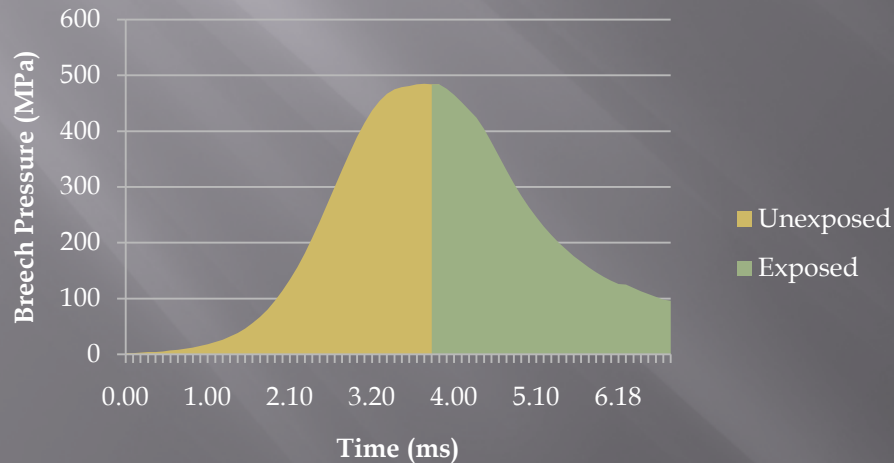


- ❑ Initial ballistic testing showed large amounts of unconsumed paint after almost all cold and ambient shots
- ❑ An investigation into this phenomena revealed several interesting things about the paint:
 - This paint does not burn per se, since its ignition temperature is above the propellant flame temperature.
 - The paint degrades slowly under high heat.
 - In legacy systems, a large amount of the paint is not consumed, but is instead fractured into small pieces and blown out of the gun (evidenced by confetti-like pieces of paint found in front of the gun)
 - This fracturing is believed to be caused by turbulence during the ballistic cycle.

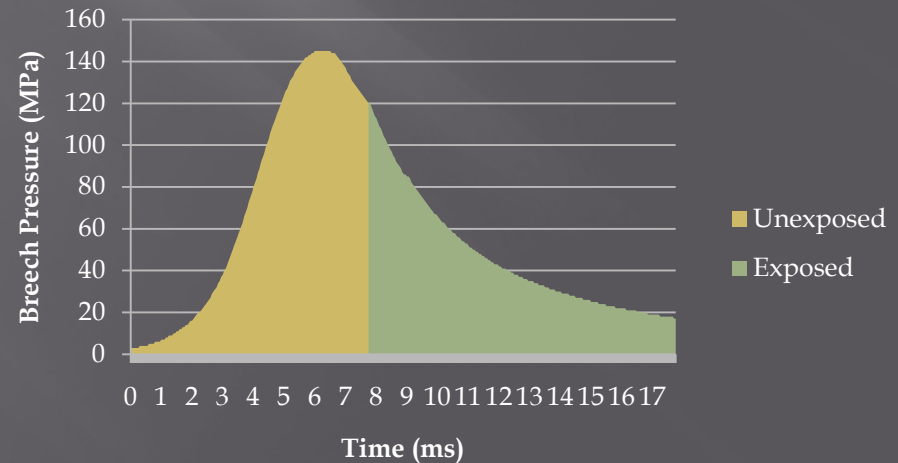
Paint Residue

- Three major factors were postulated that contribute to paint residue:
 - Low pressure results in less mechanical action working on the paint, leaving behind larger chunks.
 - Low projectile/gas velocity results in less paint being expelled from the gun.
 - The combustible case protects the paint for a large portion of the ballistic cycle, specifically the portion where gas turbulence is highest.

Paint Exposure to Propellant Gasses, M865



Paint Exposure to Propellant Gasses, MRM



Paint Residue Conclusions

- ▣ Try to understand paint behavior during ballistic cycle better.
 - Tailor the paint formulation and thickness to balance between low residue and good combustible case protection.
- ▣ Investigate alternative combustible case formulations with increased burn rate.

Impulse, Recoil, and the M256 Cannon

Recoil: Distance traveled by the moving parts of the gun in reaction to the motion of the projectile.

Impulse: Momentum (force \times time) felt by the gun due to the motion of the projectile.

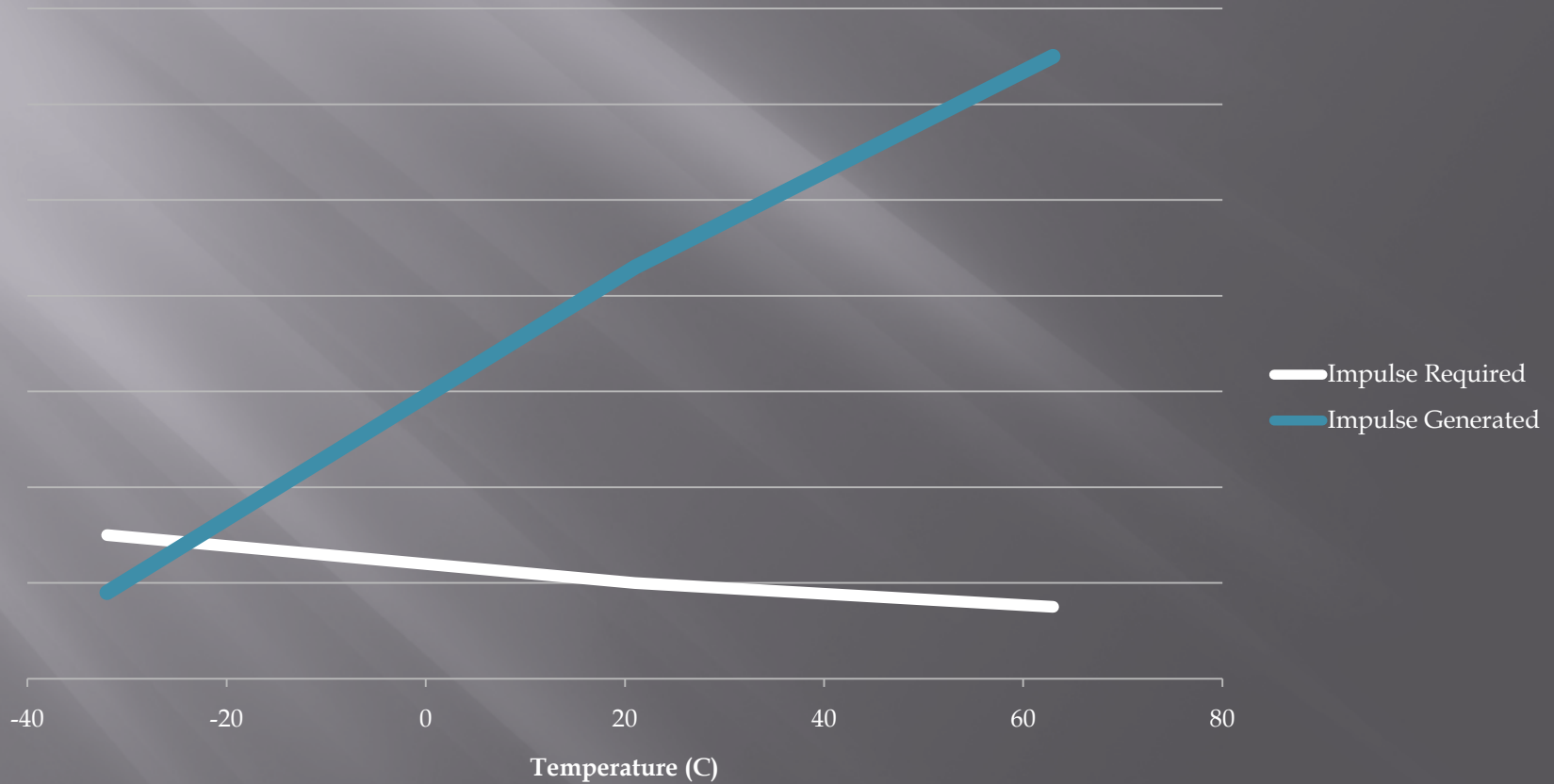
- ▣ Breech on M256 cannon opens automatically at the end of the shot cycle
 - This is accomplished by compressing a spring using the recoil of the gun, then using the spring to drive a cam that opens the breech.
 - This operation is expected to be reliable by the tank crew; a breech that fails to open is considered a malfunction.
- ▣ Recoil is controlled by the spring and a hydraulic damper.

Low Impulse/Low Recoil

- ▣ Since impulse is mostly generated by the momentum of the projectile ($\text{mass} \times \text{velocity}$), low velocity results in low impulse and shorter recoil.
 - Critically short recoil will prevent the breech from engaging the cam and the breech will not open.
- ▣ Although the M256 breech assembly functioned reliably during MRM ballistic testing, the gun was always at “Yuma Ambient” temperature (70+ °F)
 - In a cold gun, the hydraulic fluid is more viscous and exerts more damping force on the gun.
- ▣ MRM recoil was at the lower limit of that required for reliable breech operation, according to recoil models.

Limiting Temperature

MRM Impulse Generated and M256 Impulse Required as Functions of Temperature



Recoil and Impulse Conclusions

- ▣ Increase fidelity of recoil models
 - Include effects of dimensional tolerances and worn parts
- ▣ Supplement modeling efforts with recoil/impulse data from cold and hot-conditioned guns
- ▣ Include minimum recoil as a design requirement (duh).
- ▣ Begin designing guns that tolerate larger ranges of impulse across larger temperature ranges.

Conclusions

- ▣ Low pressure gun systems create obstacles that are just as challenging as their high-pressure counterparts.
- ▣ These challenges require different strategies and different ways of thinking about the gun system.
- ▣ New tools and test methods may be required to overcome these obstacles.

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