US ARMY RDECOM

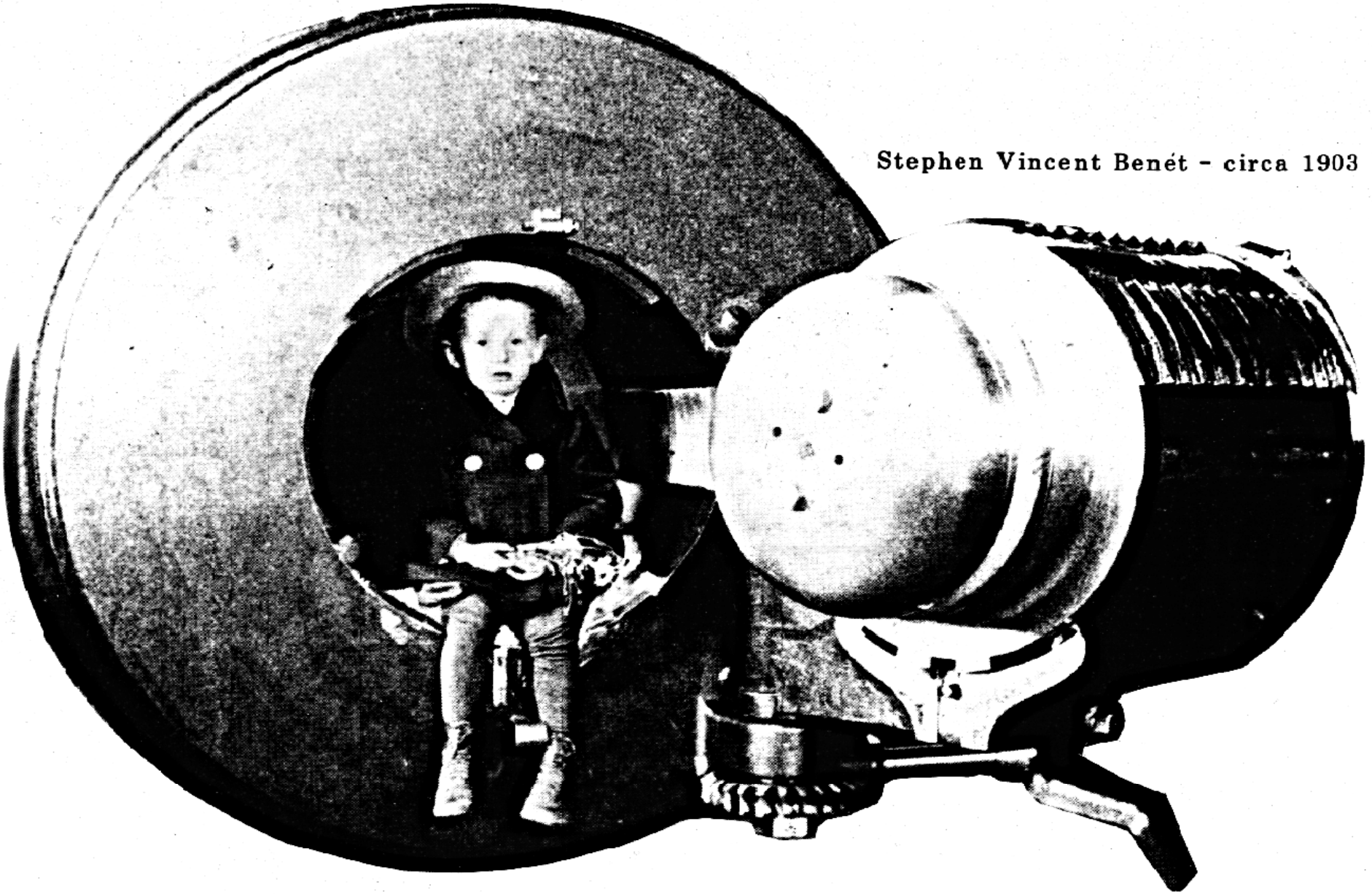
U.S. Army Research, Development and Engineering Command

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Cutting Down the Kick:
Understanding and Managing Large Caliber Recoil

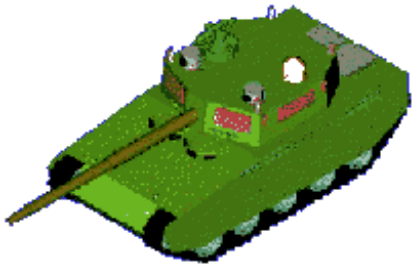
Dr. Eric Kathe, US Army RDECOM-ARDEC's Benet Labs
NDIA, April 2015

BENÉT LABORATORIES



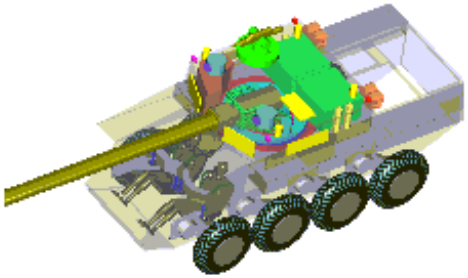
Stephen Vincent Benét - circa 1903

Some Examples of Light Vehicles



General Dynamics
Stryker
Light Armored Vehicle with 105mm
M68 gun

United Defense
M8 Armored Gun System
Light Tank
with 105mm M35 gun



German Wiesel
Airportable Armored Vehicle
with 7 TOW ATGM Missiles

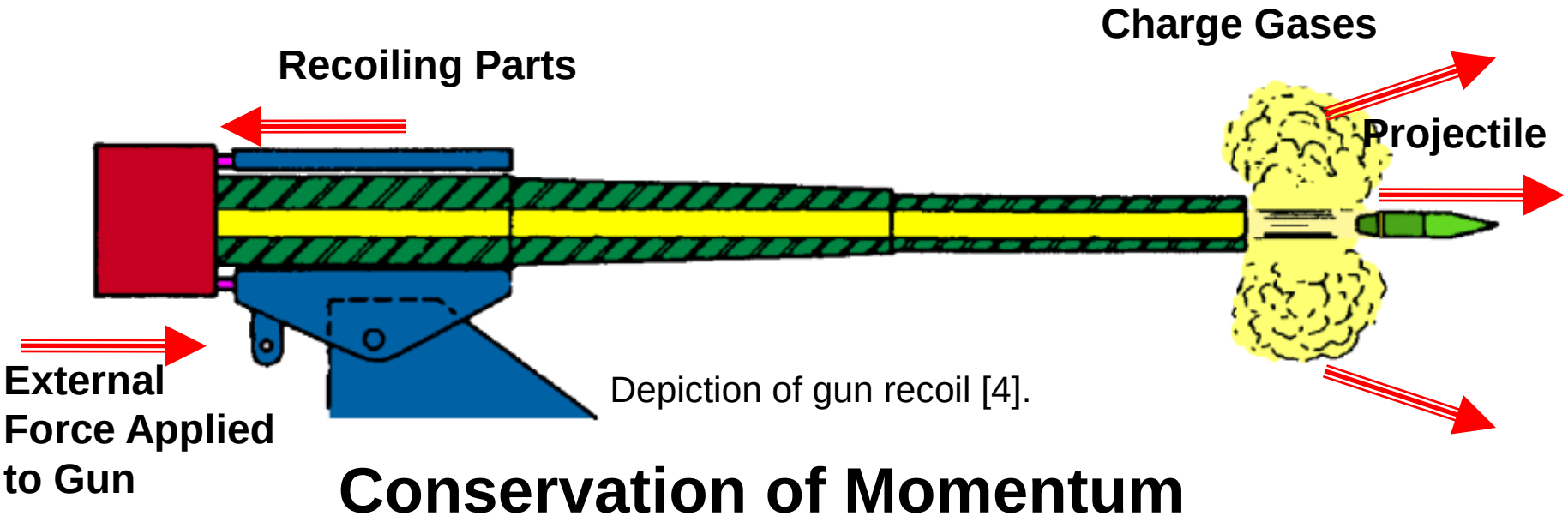
Why?


Gun Challenges
Gun Weight
Recoil Force
Vehicle Stability
Thermal Management

Catch 22

- Airborne Rule:
  - Must fit on C130
    - Weight limited to < 20ton
- Design of Fighting Vehicle Rule:
  - Recoil Should Not Exceed 900 Ns/Metric Ton
    - The impulse of a current 120mm tank cannon requires about 32 tons.
    - New suspension/ergonomic technology is enabling modest increases in impulse to weight rules of thumb.

Basics of Recoil Momentum



Depiction of gun recoil [4].

Conservation of Momentum

Momentum Imparted to Projectile and Propellant Gases must be Equal and Opposite to That Imparted to a Freely Recoiling Cannon.

$$m_{gun} \times v_{gun} + m_{charge} \times v_{charge} + m_{projo} \times v_{projo} = 0$$

therefore… $v_{gun} = (\Sigma \text{ Launch Momentum}) / m_{gun}$

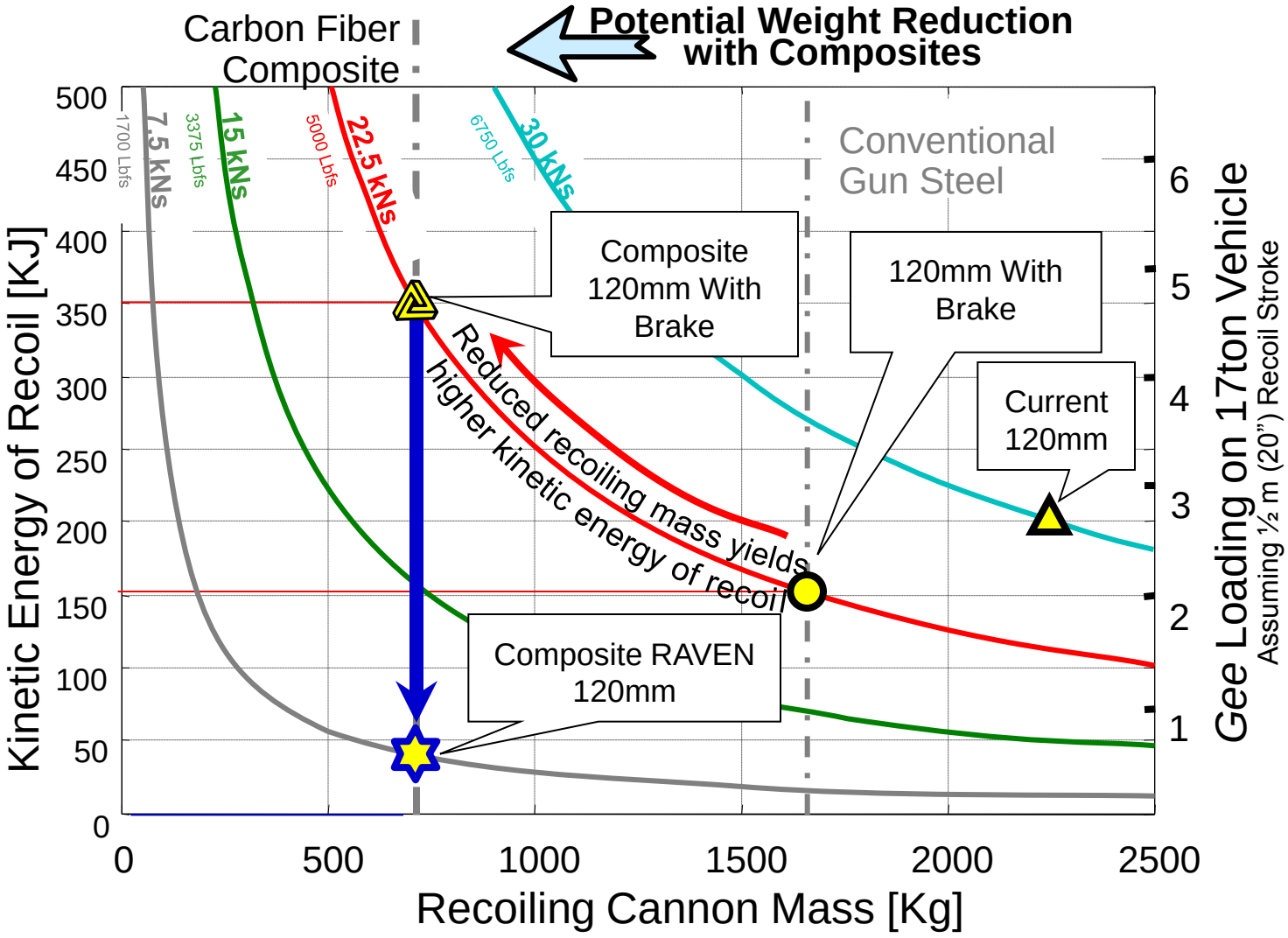
Recoil Momentum and Energy

- Momentum imparted to the cannon during firing is manifest as kinetic energy.

$$KE = 1/2\ m_{gun}\ v^2_{gun}$$

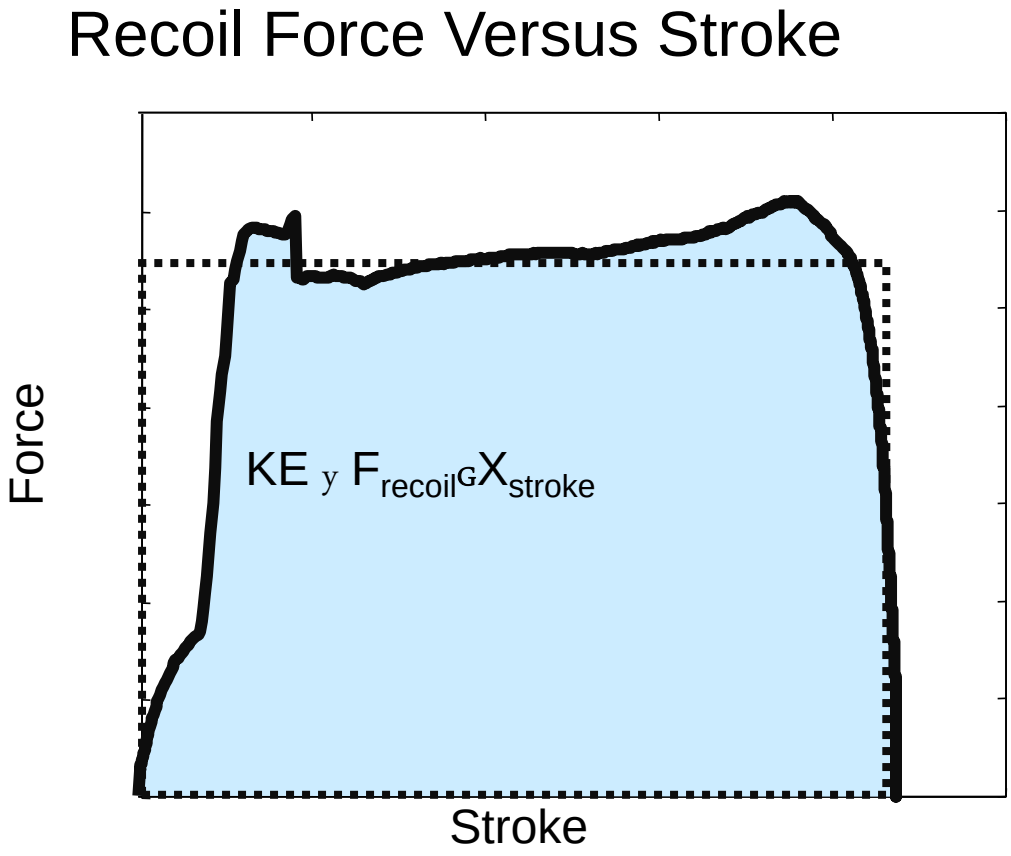
OBSERVATION: For a given momentum, the kinetic energy of a recoiling gun is inversely proportional to its mass.

Light Guns Kick Too Hard



- Recoil systems extract the kinetic energy over the available recoil stroke.

$$KE = \int_{0}^{Stroke} F_{recoil}\, dx$$



Flat recoil force profiles result in the lowest maximum load for a given recoil stroke.

Methods of Recoil Mitigation

Two Paths:

- Recoil Reduction:

  Reduce the launch momentum.

  – muzzle brakes.

  – RArefaction waVE GuN (RAVEN).

- Recoil Management:

  Deal with recoil more effectively.

  – Increase recoil stroke.

  – Increase recoil mass.

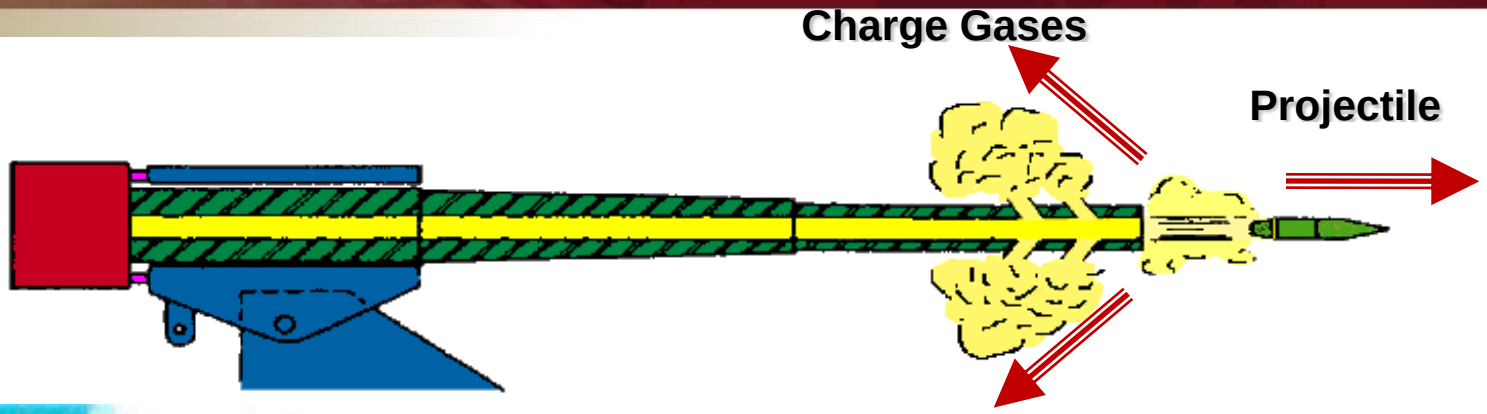
  – Improve vehicle/ground interface.

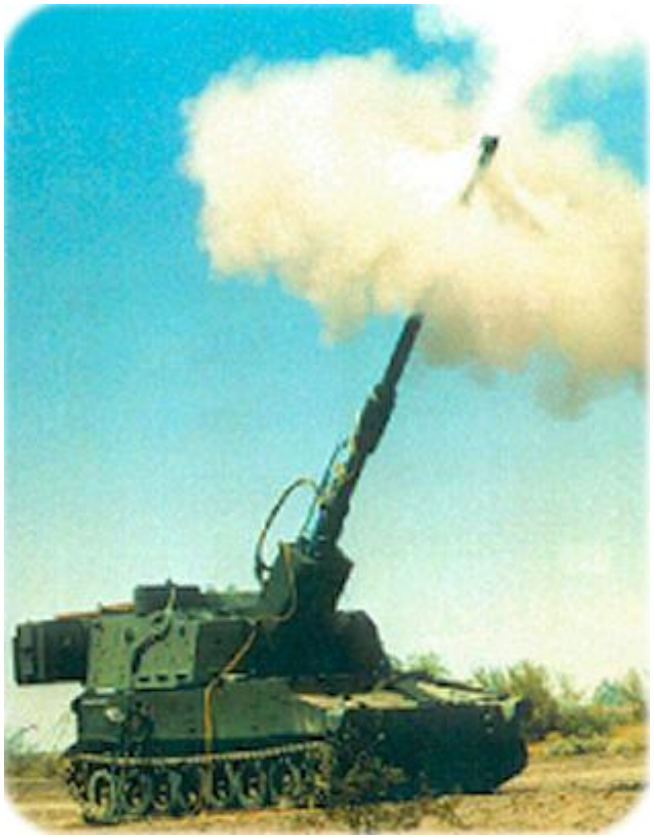
  – Improve man-machine interface.

Momentum Reduction Methods

MUZZLE BRAKES	Reduced or Reversed Forward Momentum of Charge Gas at/near end of Ballistic Cycle
RECOILLESS GUNS	Rearward Momentum of Charge Gas or Dummy Projectile During Ballistic Cycle
LIGHT WEIGHT PROJECTILES	Reduced Forward Momentum of Ordnance Projectile &/or Ancillary Structure (e.g. sabots)

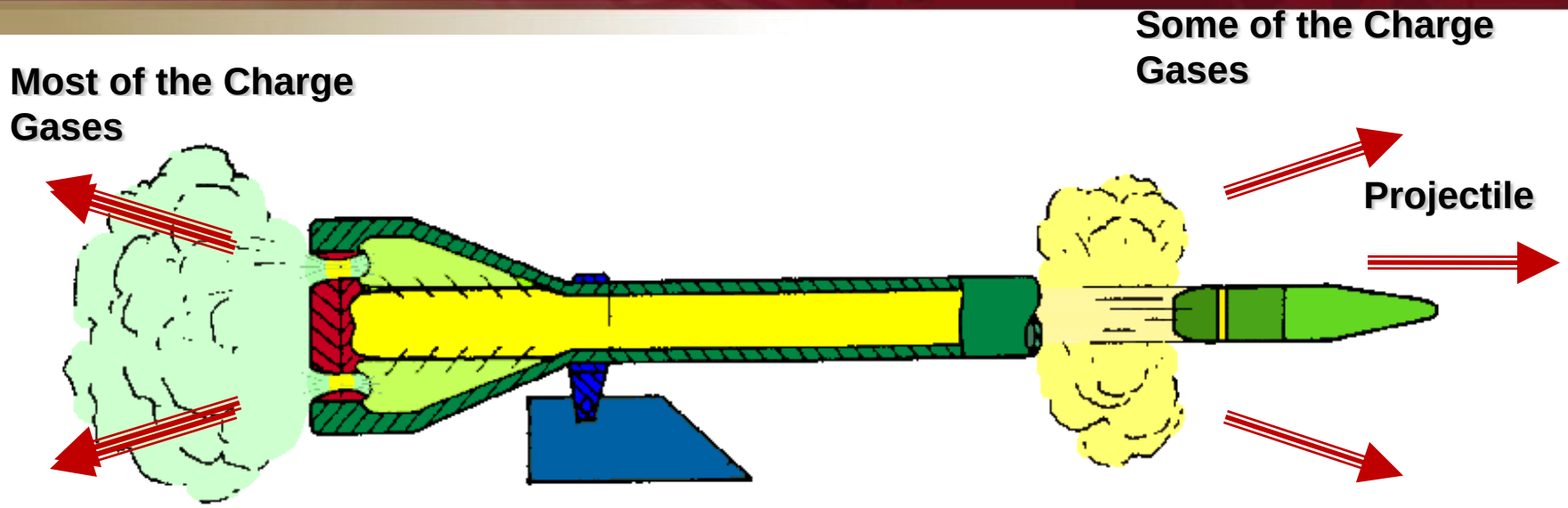
Muzzle Brakes

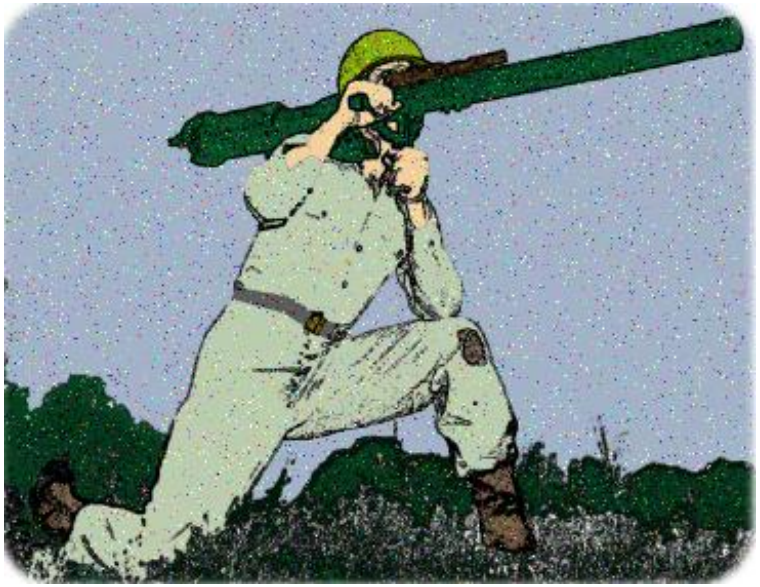




- Typical muzzle brake reduces launch momentum by 20%
- Blast overpressure and obscuration principle disadvantages.

Recoilless Guns



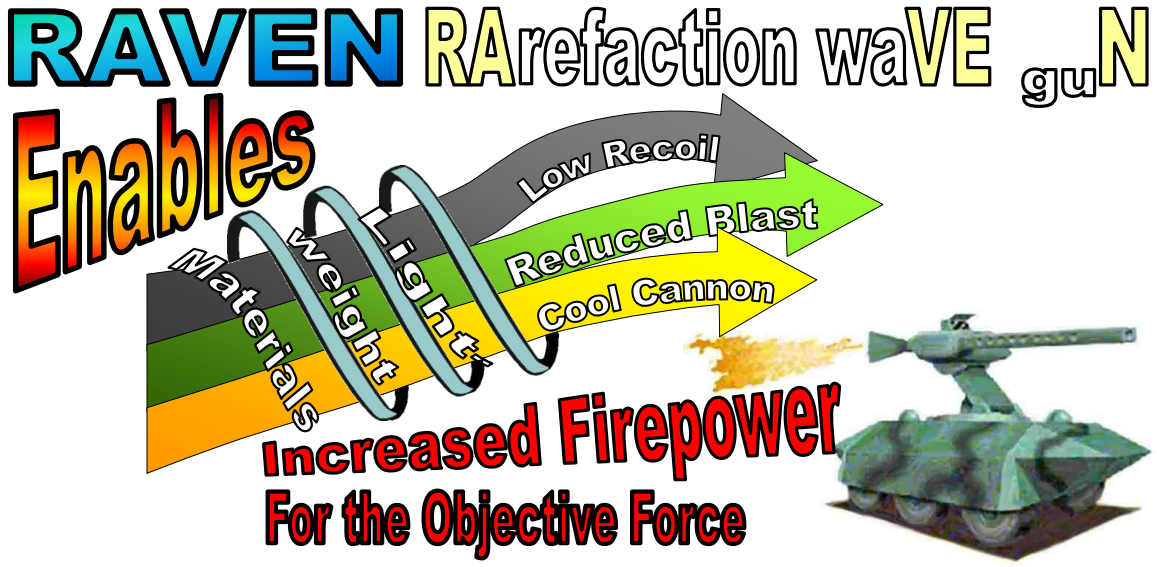


- Inefficient ballistics results in charge masses four times closed breech gun requirements.
- High signature and dangerous back blast.

RArefaction waVE guN

RAVEN is a hybrid propulsion that achieves:

- The thermodynamic efficiency of orthodox guns.
- The recoil advantage of prior recoilless rifles.
- Unprecedented reductions in barrel heating.
- Blast reduction.



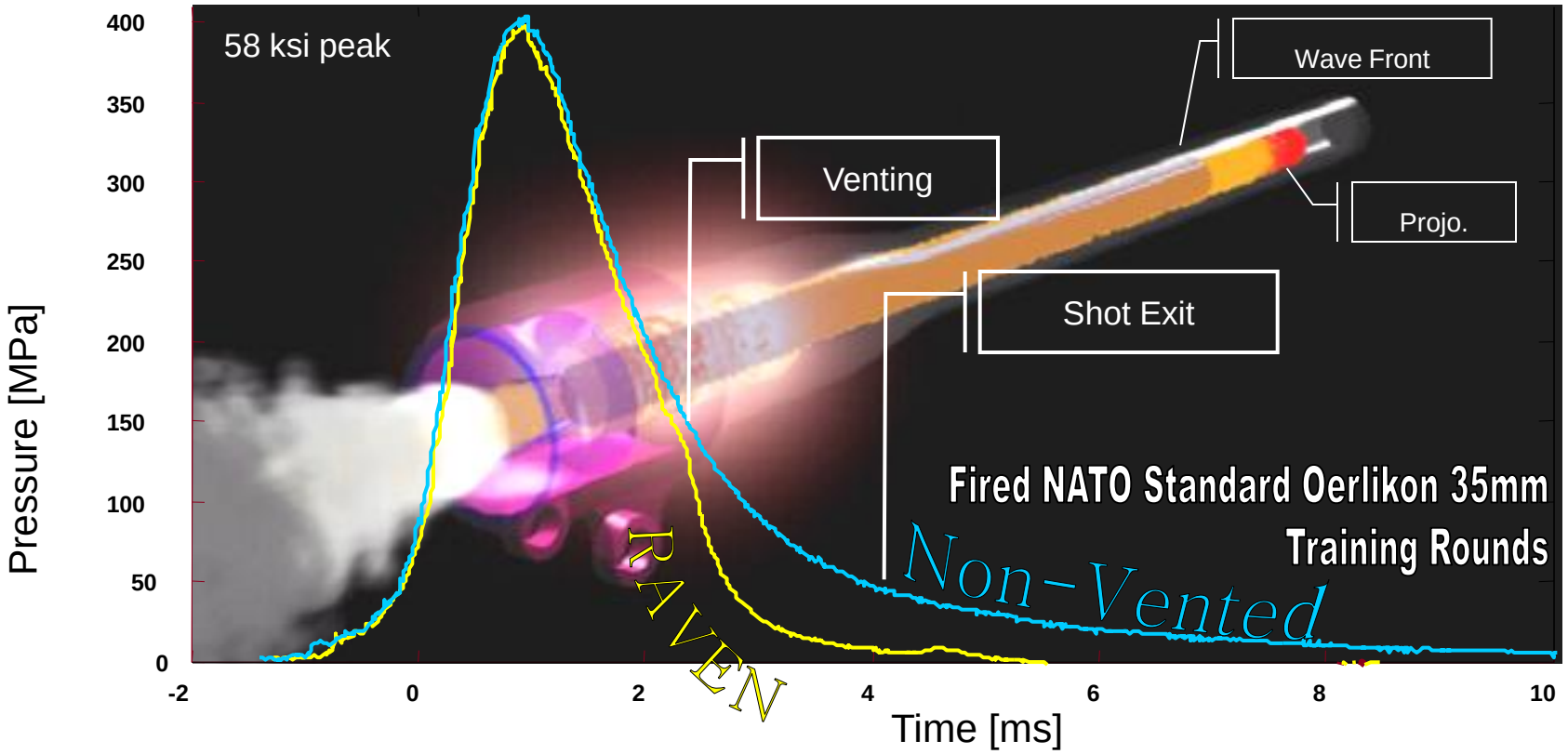
"Rarefaction Wave Gun Propulsion," Kathe, Dillon, Sopok, Witherell, and Dunn,. http://handle.dtic.mil/100.2/ADA389156

"Sonic Rarefaction Wave Low Recoil Gun," Kathe and Dillon, http://handle.dtic.mil/100.2/ADA398942

Late Venting Doesn't Slow the Bullet

Actual Chamber Pressure Data

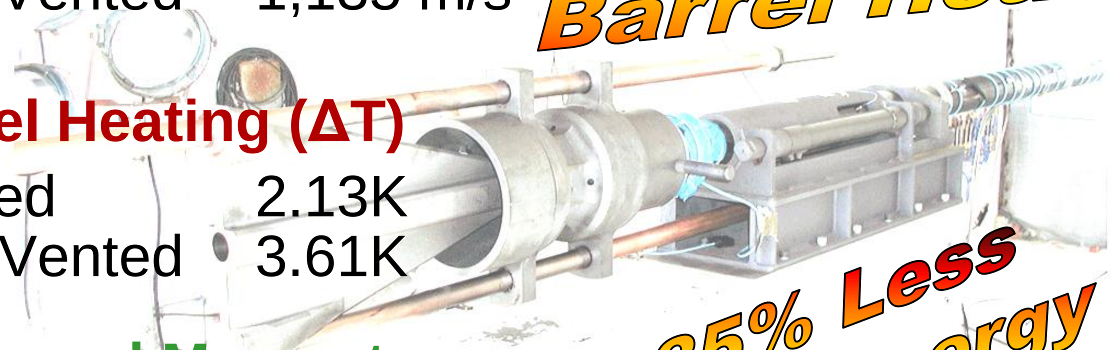
Vented and Non-vented Rounds With Same Muzzle Velocity



If the breech of the chamber of a gun is suddenly opened while the projectile is being propelled down the bore, a delay time will occur before the pressure loss at the chamber can be communicated forward to the base of the projectile.

Experimental Results

NATO Standard 35mm Training Round



Muzzle Velocity

Vented	1,131 m/s
Non-Vented	1,135 m/s

40% Less Barrel Heat

Barrel Heating (ΔT)

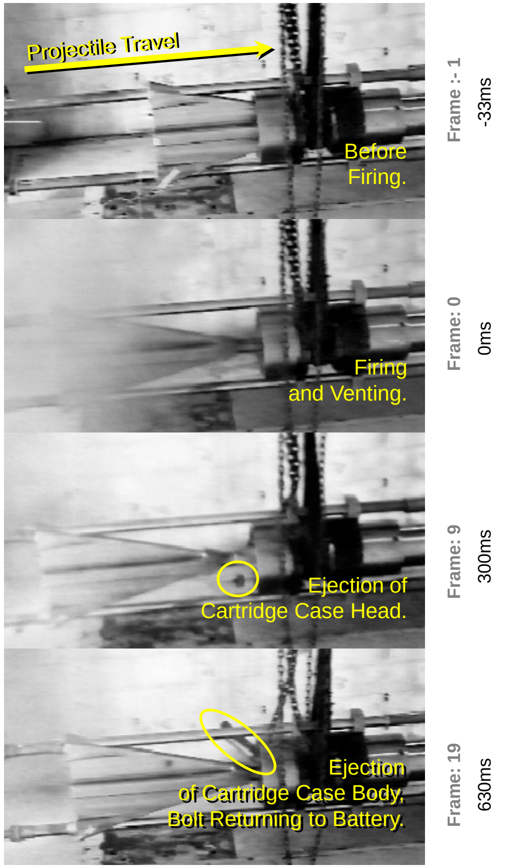
Vented	2.13K
Non-Vented	3.61K

85% Less Recoil Energy

Measured Momentum

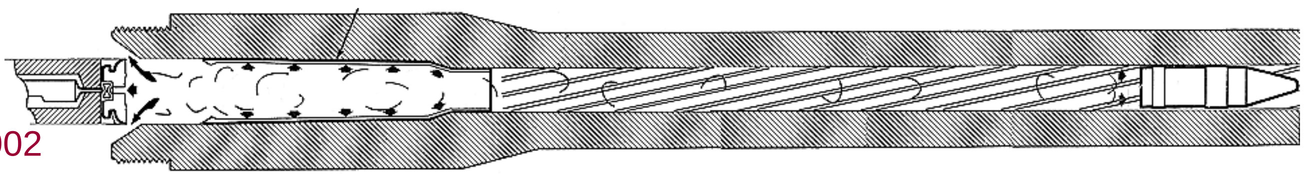
Vented	402 Ns
Non-Vented	1,031 Ns

Firing Video Sequence



Bolt-Action Blow-Back Bolt for Proof of Principle

Ph.D.
Rensselaer 2002



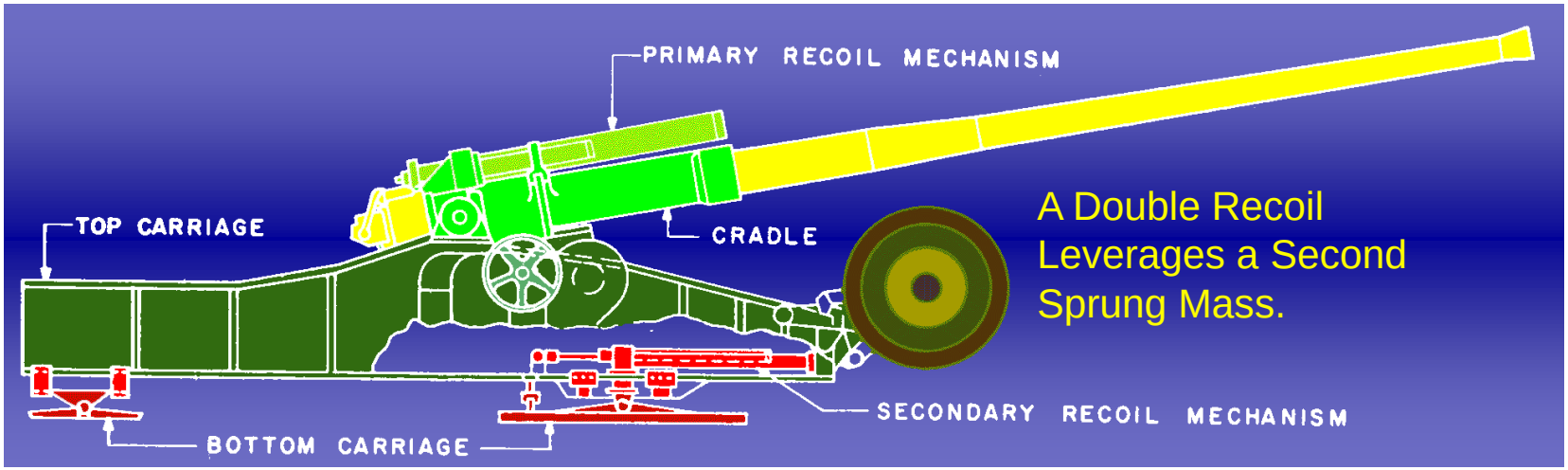
"Experimental Validation Of Raven Using Standard 35mm Nato TP Ammunition," Kathe, Glennon, Tortorici, Kertis, and Stamm, JANNAF 38th Combustion Meeting, Destin, FL, 08 April 2002.

Recoil Management Methods

INCREASED RECOIL MASS	Recoil energy inversely proportional to recoiling mass
INCREASED STROKE	Recoil loads inversely proportional to recoil stroke.
FIRE OUT OF BATTERY	Pre-acceleration of recoiling mass may reduce recoil velocity by as much as 50% with 75% reduction in kinetic energy
ACTIVE SUSPENSION	Active recoil mitigation suspension may enable vehicle to tolerate greater recoil momentum

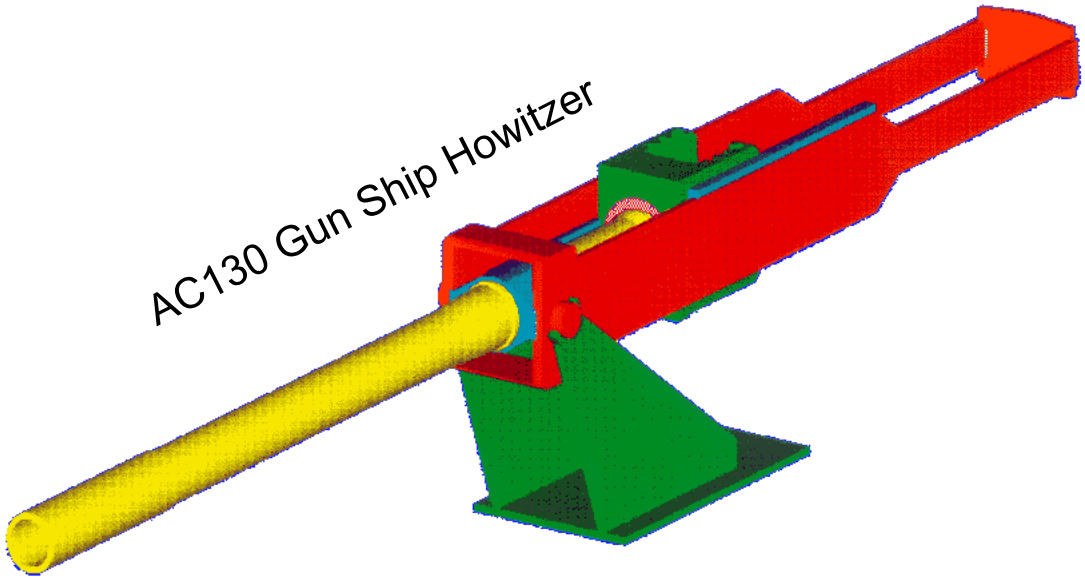
Increased Recoil Mass

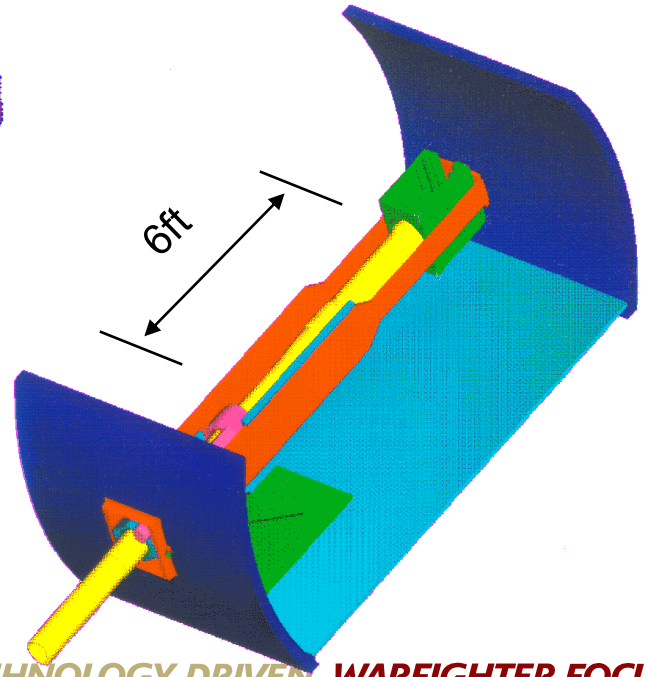
- Increased recoiling mass is counter productive for lightweight weapon platforms.
- The potential to leverage “some other” inertia (such as armor) using a double recoil is *intriguing*, yet challenging to implement.



Increased Stroke

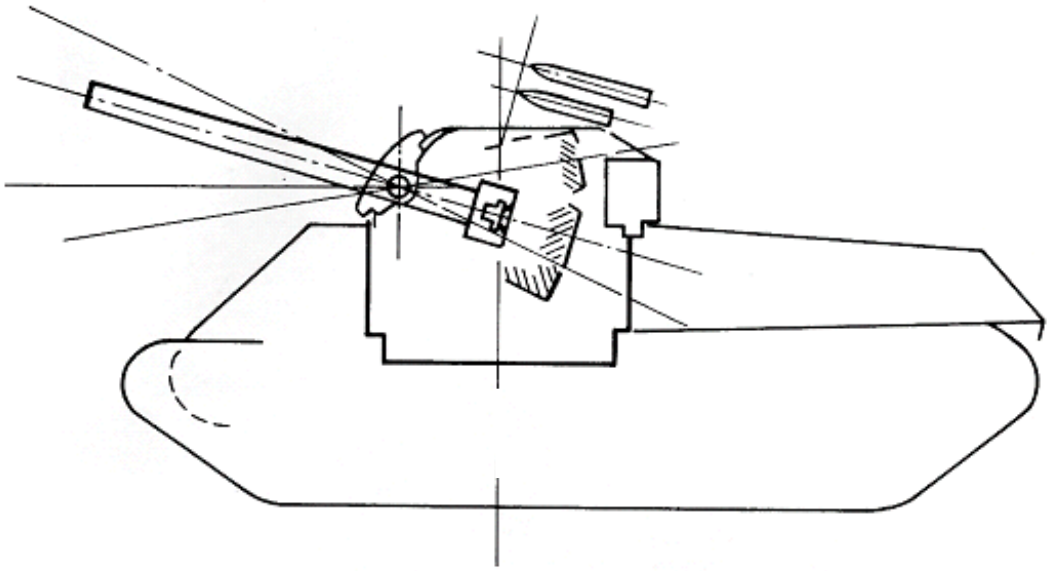
- Increased recoil stroke increases under armor volume, but is viable for external guns and special applications.





Turret Integration

- A gun must fit within a turret such that room exists behind the gun sufficient:
  - To prevent impact at max recoil extent at all elevations.
  - To enable munitions to be loaded.



Fire out of Battery M35

"A Fire Out-of-Battery Tank Gun: Theory and Simulation," Kathe, and Gast, http://handle.dtic.mil/100.2/ADA402105

The M35 105mm Tank Gun

A novel recoil method was applied where the cannon was pre-accelerated forward prior to firing. Upon firing, the forward motion of the cannon was reversed, sending it back to a catch latch.

This approach may theoretically reduce recoil by a factor of four. By splitting the momentum in half, the max recoil velocity is cut by two, and the kinetic energy is cut by four.

Practical consideration reduce performance to a factor of two. Over a 40% reduction was achieved in test.

WEIGHT: ……..~ 2920 LBS
BARREL LENGTH……220.5"
RECOIL LENGTH: ……22"
OPERATING PRESSURE: …~90 KSI

Questions

- Thank you for the opportunity to present a tutorial on recoil today.
- Questions are welcome.