120mm Rarefaction Wave Gun For Large Area Defense

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16 May 2012
Bringing balance to the asymmetry of active defense

Advances in low latency target location and guided munitions technology are increasing the viability of large caliber high velocity guns for intercepting airborne and maneuvering targets.

“...too little is being done to prepare for the inevitable day when our enemies turn these (UAV) weapons, which are growing cheaper, more powerful and more ubiquitous, against us.” Armed Forces Journal, Dec’11

It is the purpose of this presentation to invigorate discussion. And make a case for a novel launcher within the context area defense.
Prior Anti-Aircraft Artillery

120mm M1 Gun


90mm M1 Gun

US Army Air Defense Artillery Museum  (as cited in Werrell, 2005.)

76mm M51 “Sky Sweeper” Gun

USAF Army Air Defense Museum  (as cited in Werrell, 2005.)
### Prior Anti-Aircraft Artillery Performance & Current Tank Gun

<table>
<thead>
<tr>
<th>Gun Designation</th>
<th>Towed Antiaircraft Gun*</th>
<th>Baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cartridge</td>
<td>M73 M71</td>
<td>M829A3†</td>
</tr>
<tr>
<td>Diameter (mm)</td>
<td>120 90 75 120</td>
<td></td>
</tr>
<tr>
<td>Projectile (Kg)</td>
<td>22.7 10.6 5.8 10.0</td>
<td></td>
</tr>
<tr>
<td>Velocity (mps)</td>
<td>945 823 904 1555</td>
<td></td>
</tr>
<tr>
<td>Kinetic Energy (MJ)</td>
<td>10.1 3.6 2.4 12.1</td>
<td></td>
</tr>
<tr>
<td>Impulse (kN*s)</td>
<td>36.0 13.0 8.3 25.6</td>
<td></td>
</tr>
<tr>
<td>Range (km)</td>
<td>24.7 17.8 13.5 20‡</td>
<td></td>
</tr>
<tr>
<td>Altitude (km)</td>
<td>17.5 10.4 6.1</td>
<td></td>
</tr>
<tr>
<td>System Mass (Tonne)</td>
<td>22.1 8.6 8.7</td>
<td></td>
</tr>
<tr>
<td>Rate of Fire (rpm)</td>
<td>12 25 45</td>
<td></td>
</tr>
</tbody>
</table>

* [http://en.wikipedia.org/wiki/120_mm_M1_gun](http://en.wikipedia.org/wiki/120_mm_M1_gun) … 90_mm_Gun_M1/M2/M3 … Skysweeper (estimated cartridge w/out data)


‡ M829A3 would fly very far. 20KM for an interceptor was estimated by Geswender and Hinsdale, "Trade Space on Appropriate Caliber Ammunition for Terminal Defense Guided Projectile," Presentation to 42nd Annual Gun and Missiles Conference, April 23, 2007, and is nominally consistent for a high explosive round.
Unguided Interceptors

- In analogy with extended-range unguided surface fires, probability of kill per round is low, especially against maneuvering targets.
- Large-caliber unguided antiaircraft artillery does not work unless all of the possible target trajectories are saturated with projectiles.
- Notional static surface fires accuracy is nominally 1m/Km azimuth and 5m/Km range*.

* E.g., http://www.army-technology.com/projects/g6/g65.html
The speed and altitude of jet aircraft, and extreme lethality of nuclear bombers rendered antiaircraft artillery wholly ineffective*

The switch to guided surface launched missiles was sudden. Nike AJAX was first deployed in 1954. The antiaircraft guns were out of domestic service by mid 1960*

Jet fighter cost was an order of magnitude greater than an AJAX.

First guided surface to air interceptor: Nike AJAX

Prior AAA guns could deliver effects into the outer tier—but, would be ineffective.

Modern fire control, guidance, and effects may render such weapons effective.

Modern sub-caliber launch of high ballistic coefficient projectiles may extend the battle space through the outer tier.

Taken to an extreme (not advocated in this presentation) railguns may launch exo-atmospheric interceptors*.

• Interceptor launchers are a small part of an area defense system that requires:
  1) Detection, 4) Interception, and
  2) Tracking, 5) Debrief.
  3) Defense Planning,

  With tracking playing a parallel role with planning and interception*.

• Advances in all of the supporting technologies will proceed with or without a gun solution and are not highlighted in this talk.
  – Gun specific challenges include slew, rates of fire, and interceptor constraints on setback acceleration, mass, bore diameter, etc.

• The potential advantage of a high velocity gun is rapid fire and depth of magazine. This may prove better suited for asymmetric or saturation attacks.
  – Especially within a combined architecture to reduce reliance upon (or protect) higher performance missiles.
  – Low valued threats such as some UAV’s may be engaged by inexpensive shoot-look-shoot to reach out beyond the outer tier.

Disadvantages of Big Guns.

Geswender and Hinsdale ‘07 considered guided interceptors from the two largest turreted guns in the Army inventory—120mm Abrams and 155mm Paladin*. They concur with increased range with caliber. Principle shortcomings were:

- **Low firing rate** 1 for manually loaded guns.
- **Delay time** 1 to engage.
- **Gross vehicle weight** 2 to support the guns.

Additional show stoppers and shortcomings:

- Abrams lacks sufficient elevation.
- Paladin lacks traverse and elevation rates to enable slew to cue.
- They require four man crews.

Rate of fire and response time is a trade with weight, requirements, and complexity. **Big guns can fire much faster than Paladin or Abrams**  

- Naval and Aviation (SAAB T18B) benchmarks are provided below.  
- Using specific power as a metric, the six fold increase for the aircraft armament provides optimism for significant lightening of larger calibers.

### Benchmarks

<table>
<thead>
<tr>
<th>Weapon System</th>
<th>Caliber</th>
<th>Time Period</th>
<th>MJ</th>
<th>RPM</th>
<th>Tonne</th>
<th>MW/Tonne</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swedish Bofor’s</td>
<td>120mm single*</td>
<td>circa 1960’s</td>
<td>8.5</td>
<td>80</td>
<td>28.5</td>
<td>0.40</td>
</tr>
<tr>
<td>French Creusot-Loire</td>
<td>100mm Compact*</td>
<td>modern</td>
<td>5.2</td>
<td>90</td>
<td>14.0</td>
<td>0.56</td>
</tr>
<tr>
<td>Italian OTO Melara</td>
<td>76mm &quot;super-rapid”*</td>
<td>modern</td>
<td>2.7</td>
<td>120</td>
<td>7.5</td>
<td>0.72</td>
</tr>
<tr>
<td>BAE/Swedish Bofor’s</td>
<td>57mm MK110‡</td>
<td>modern</td>
<td>1.1</td>
<td>240</td>
<td>7.5</td>
<td>0.59</td>
</tr>
<tr>
<td>Swedish Bofor’s</td>
<td>57mm M47 (Aircraft)‡</td>
<td>Circa 1940's</td>
<td>0.6</td>
<td>100</td>
<td>0.3</td>
<td>3.55</td>
</tr>
</tbody>
</table>

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Vehicle stability constraints drive platform mass for large caliber guns.

- Neglecting employment of spades, combat vehicles tolerate nominally one N*s of momentum per Kg*. (That would recoil the hull at about 1 m/s.)
- If Paladin’s armor were made significantly lighter, it would likely be constrained to employ its spade.
- Firing the M829A3 120mm tank gun cartridge will require about 25 tonne.
- Muzzle brakes may aid in vehicle stability at the expense of worsened blast pressures.

Armor provides essential inertia to enable big gun integration.

- Spades or similar ground coupling structures must otherwise be employed.
- Firing fan (azimuth) is limited off the spade axis.

“Since erosion is a thermally instigated phenomenon, it is not surprising that...” hotter propellants accelerate erosion*. Unfortunately, high energy propellants are essential to achieve high velocity. For solid propellants, high energy equals hot.

High burst rates of fire tax bore life by increasing the duration that gun steel temperatures exceed their phase transformation.

- The normal way to mitigate this is thermal mass—a heavy cannon, to radially conduct heat away from the bore between shots.
- Active cooling rates are very challenging (MWatt class).

Traditional solid propellant guns must be heavy ☢️ to endure rapid high velocity fire or they will burn out ⚠️.

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Recoiling Mass and Energy

Recoil energy is inversely proportional to recoil mass*.

\[ KE_r = \frac{1}{2} m_r v_r^2 = \frac{1}{2} m_r \left( \frac{I}{m_r} \right)^2 = \frac{1}{2} \left( \frac{1}{m_r} \right) I^2 \]

- We have matured composites for lightweight guns; but, recoil limits our ability to use them.

- Traditional guns must be heavy to manage recoil energy.

The rarefaction wave gun abruptly releases propelling gases through the breech when the projectile has traversed about a third or forth of its travel. Venting of the chamber generates recoil compensating thrust while hastening the expulsion of hot gas from the bore. The affect becomes more pronounced at higher muzzle velocities. E.g., higher muzzle velocities require more propellant, leaving greater residual gas impulse to generate thrust.
Rarefaction Wave Gun
Graphically Explained

Maturation of a rapid fire large caliber technology demonstration system is costly. Use of existing training munitions for weapon technology development is critical. The only large fixed case ammunition options are 76mm, 105mm, and 120mm tank gun.

- The smooth bore combustible case 120mm is preferred over the rifled bore metallic case 105mm.
- The 120mm provides growth potential to 140mm within the technology validation hardware envelope*.
- Precedent: A120mm smooth-bore tank-gun is mountable within existing M109 series (and towed)155mm systems†. The weight, outer diameter, and recoil are within the 155mm cannon envelope. This may facilitate early technology validation of exterior ballistics.

* "140 mm Advanced Tank Cannon (ATAC) System," Jane's Armour and Artillery Upgrades, August 2005.
† "Swiss propose 120mm multipurpose gun," Jane's International Defence Digest, August 2002.
The principle disadvantage of rarefaction wave gun propulsion is back blast; which is shared by rocket propelled missiles.

Historical jeep mounted M40 series recoilless rifles ejected over 3Kg of back blast generating propellant. They could be elevated to 65 degrees*.

The jeep mounted M29 155mm Davy Crockett discharged over 6Kg of propellant and is comparable to the amount to be discharged from a 120mm RAVEN.

Objective is 120mm remote weapon station technology validation*. Five ton envelope on an existing vehicle. Ambitious… Comment, Suggestions, Concerns are Welcome!

* Objective is to conduct applied research to mature and validated technology readiness. The objective is not to prematurely embark on a developmental demonstrator.