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Electromagnetic Rail Gun: Providing Greater Flexibility for the 21st Century

ABSTRACT

The DON Office of Naval Research (ONR) is pursuing a Science and Technology (S&T) Innovative Naval Prototype (INP) program with a goal of increasing the electromagnetic rail gun (EMRG) muzzle energy from the 2004 "state-of-the-art" level of 8 mega Joules (MJ) to tactical energy levels of 64 MJ.

The overarching ONR INP focus is to mature the EMRG technologies into a sea-based, 222-nautical mile (NM) indirect fire weapon system that will provide time-critical strike and long-range Naval Surface Fire Support (NSFS) by the 2020 to 2025 timeframe. Tactically, the EMRG will provide fire support compatible with the operational radius of the V-22 Osprey. This article provides an overview of the four major elements of the tactical EMRG: the launcher, the *pulse* power system (PPS), the source of *prime* power, and the projectile. Each element presents significant challenges for both development and integration of this weapon system onto a shipboard platform.

Benefits of the EMRG include enabling maneuver forces to move quickly to their objectives ashore with a reduced logistical tail and improving end-to-end logistics made possible by the use of non-explosive projectiles. Recent history has shown that explosives significantly complicate sustained and stability operations. Additionally EMRG provides operational support for danger-close and terrain masked targeting.

INTRODUCTION

Electromagnetic rail gun (EMRG) concepts have been around for years with their promise of lower cost per shot, increased safety, and reduced logistic tail. The US Navy Office of Naval Research (ONR) is aggressively turning this concept into a reality for the US Navy. This article will provide an overview of the Navy's rail gun program and insights into its potential to radically increase the flexibility of Navy-Marine Corps operations. The capabilities of the Navy's rail gun will be described along with the secondary effects: smaller ashore footprints, simpler logistic tail, lower per shot cost, all weather capability, and increased ordnance safety.

PURPOSE

The ONR is currently pursuing a Science and Technology (S&T) Innovative Naval Prototype (INP) program with a goal of increasing the EMRG muzzle energy from the 2004 "state-of-the-art" level of 8 mega Joules (MJ) to tactical energy levels of 64 MJ. At these energy levels, an EMRG can provide a much needed, low-cost, high-volume, all-weather Naval Surface Fire Support (NSFS) indirect fire weapon system on a ship at sea to support US military forces ashore at a range of approximately 50 to 222 nautical miles (NM). At this range, a single EMRG system can cover a doughnut-shaped area of approximately 200,000 square miles (*INP* 2007).

BACKGROUND

The EMRG is the first ONR INP, an initiative to develop mission-critical technologies and aid in the critical transition from S&T to a program of record. An INP supports the development of technologies considered "disruptive." In other words, technologies that—for reasons of high risk, departure from an established requirement, or unique concept of operations (CONOPS)—are unlikely to survive without top leadership endorsement (Memorandum 2005). INP candidates are reviewed and approved by the US Navy S&T Corporate Board, which includes some of the most senior officers in Navy leadership. The focus is on Applied Research (6.2 level) and Advanced Technology Development (6.3 level). An INP should be planned to achieve a level of technical maturity suitable for insertion in acquisition programs. The primary goal of the INP is to reduce risk in acquisition, where a budget would normally be in the billions of dollars for an Acquisition Category 1 (ACAT 1) program, by working with the acquisition community to accelerate development and leverage S&T prototypes where costs are much lower.

As shown in Figure 1, the EMRG INP will be executed in two phases. INP Phase I is currently focused on technology risk mitigation of key EMRG projectile components and the development of a 32-MJ launcher and pulsed power system. INP Phase II will focus on the development of prototype system components, continued technology development for the projectile to achieve a 64-MJ tactical muzzle energy level, and a long-range 64-MJ component validation demonstration to achieve a Technology Readiness Level (TRL) of 5 by the completion of INP Phase II in 2016.

In addition, NAVSEA PMS-405 (Directed Energy and Electric Weapon Group) will be conducting a parallel Advanced Component Development and Prototype (ACD&P) Phase commencing in 2014. This ACD&P Phase will culminate with a transition to an ACAT 1 program of record at Milestone B in the 2016- 2018 timeframe. The main focus of the ACD&P is to develop and demonstrate a 64-MJ prototype weapon system at sea or at a land-based facility to achieve a TRL of 6. This will minimize system integration risk to the extent possible prior to program initiation.

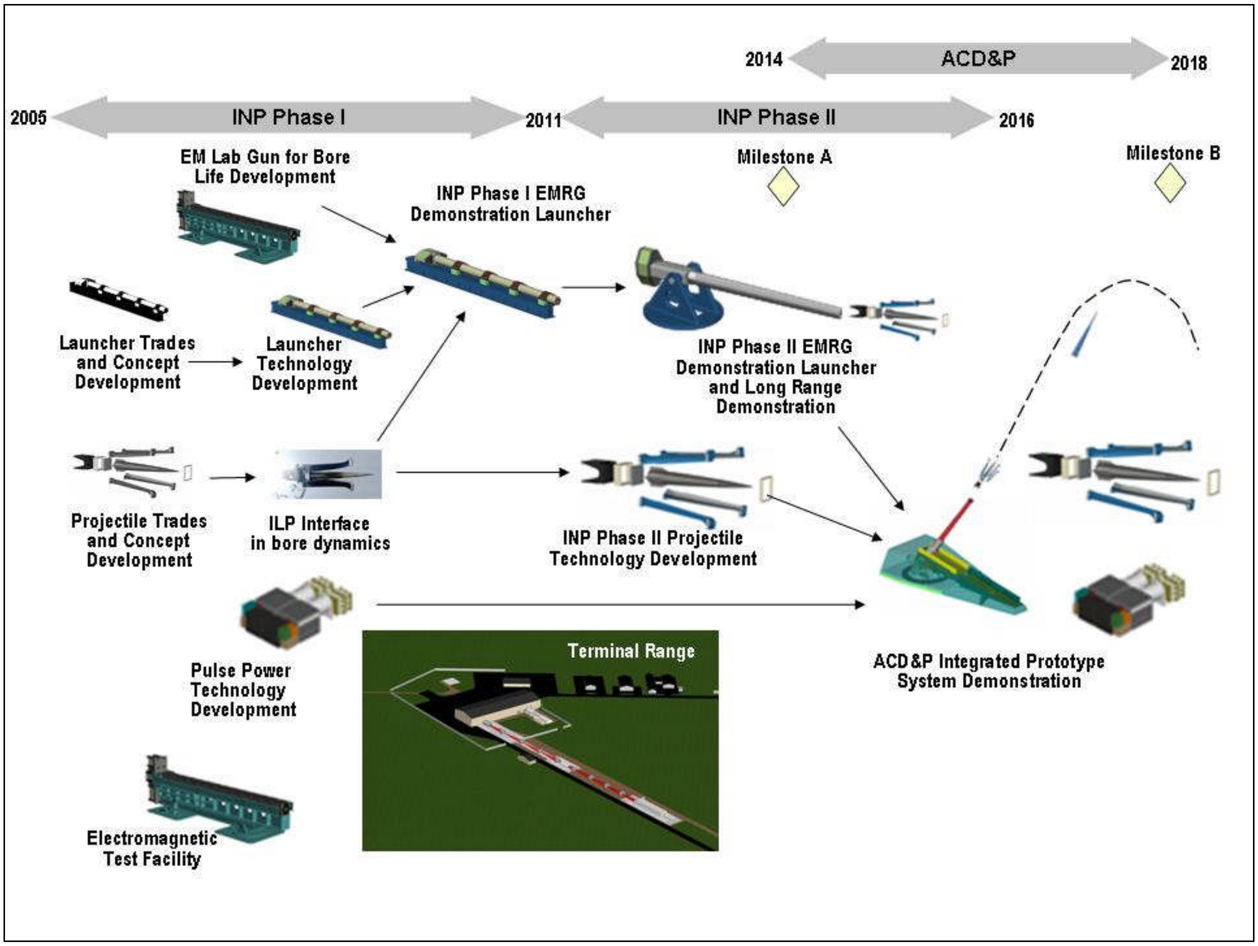

Figure 1: EMRG Technology Development Roadmap

Initial operational capability of the EMRG at the full 64-MJ tactical energy level (222 NM) is projected for the 2020 to 2025 timeframe.

EMRG OPERATIONAL PRINCIPLES AND PRIMARY ONR INP FOCUS AREAS

The basic mechanism by which the EMRG operates is diagrammed in Figure 2. Electric current (in the range of 3 to 5 million amps) from the pulsed power network from either capacitive or rotating machinery flows through one of a pair of parallel rails though an armature and back down the other parallel rail. This current flow produces a magnetic field that interacts with the armature generating a Lorentz Force that accelerates the sliding armature and projectile. This notional bore contains two rails separated by an insulator encased in a composite material wrap to contain the rail repulsive forces, which are typically on the order of 40,000 pounds per square inch (psi).

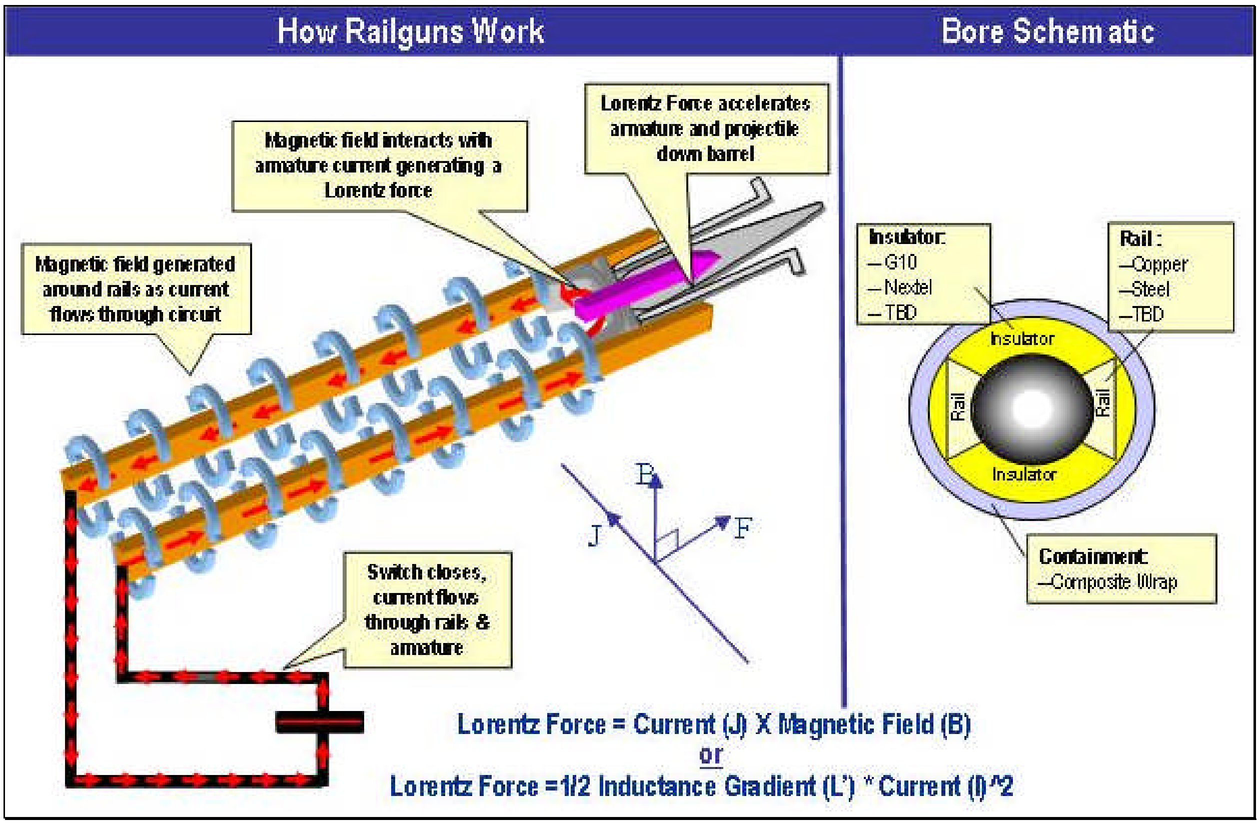

Figure 2: EMRG Basic Operating Principle

A tactical EMRG system is comprised of the following:

- Pulse Power System (PPS)
- Source of Prime Power Systems (i.e., generator, prime power, and associate power conditioning)
- Launcher Assembly
- Projectile

Each element presents challenges to both the development of the weapon system and the integration of this system onto a shipboard platform. Addressing these challenges with a range of solutions is the primary focus of the current phase of the ONR INP.

PPS

The PPS can either be a capacitor-based or rotating machine-based subsystem. The PPS charges up storing energy over several seconds and then releases this energy in a pulse to the launcher over several milliseconds. The pulse shape determines the acceleration profile of the projectile. A tactical 250-NM launcher will require a PPS with approximately 220 MJ of stored energy. This translates to an energy storage mass and volume that is a significant fraction of the overall weapon system footprint and will present a significant ship integration challenge. Improvement in capacitor energy storage density from the current state of the art of approximately 1 Joule per cubic centimeter (J/cc) to approximately 3 J/cc, thermal management, advanced switch technology development, and continuing development of the compact rotating machine PPS technology (through cooperative work with the US Army) are major focus areas of the ONR INP program.

LAUNCHER

While the majority of traditional Naval powder gun components (such as mount, train and elevate mechanisms, the loader, and fire control) may be modified for use in a shipboard EMRG application, the design of the barrel presents unique design challenges. Large currents at tactical firing rates (6 to 12 rounds per minute (rpm)) present challenges related to bore life and ship integration challenges related to thermal management. The ONR INP rail development efforts include a variety of geometries and material blends to optimize both the launcher core rails and insulators to provide optimized performance and shot life. Stiff, high-strength, composite fibers will be used to contain the rails and insulators under the large repulsive forces while maintaining the tolerances required for projectile launch.

Recent successes include a series of tests at the Electromagnetic Launch Facility at the Naval Surface Warfare Center, Dahlgren Division (NSWCDD). These tests, conducted using a series of notional core configurations in a laboratory containment system, yielded over 100 shots on the same set of rails and insulators at muzzle energy levels over 10 MJ. The ONR INP set a series of new world record muzzle energy levels since initially breaking the 10-MJ level in January 2008. Recently, they have begun a test series that will result in a 50-shot series at a muzzle energy of 16 MJ on the same set of rails.

PRIME POWER SYSTEMS

On the one hand, installation of dedicated prime power to charge the pulse power network will present significant shipboard integration challenges. On the other hand, though not required for a shipboard installation, an Integrated Power System (IPS), such as that used in the Zumwalt Class (DDG-1000) destroyer, is an excellent complement to an EMRG weapon system.

Traditional US Naval vessels have dedicated and separate prime movers to drive shipboard propulsion and electrical service loads. On a typical warship, nearly 50% of the installed shipboard propulsive power (on the order of 40 mega watts (MW)) is only used to power the ship through the final 5 knots to a ship's maximum flank bell and adds redundancy to lower speed operations. Based on a typical operational profile, a ship will only operate at flank bell less than 5% of its underway time. These propulsion prime movers are typically mechanically coupled to the propeller or water jet via a shaft and reduction gear box.

The significant levels of unused propulsive power capacity have been addressed in the DDG-1000 land attack destroyer. DDG-1000 is the first US warship to employ a sophisticated electrical distribution system to direct the total available installed power (approximately 80 MW) for use in both the electric propulsion motors and to support the full range of shipboard electrical loads.

In addition to prime power via the IPS, the ONR INP is also investigating the use of next-generation, compact, high-speed generators and methodologies for the dual use of prime power currently dedicated to direct drive propulsion. Developing technologies, such as hybrid electric drives and novel power takeoff systems, may enable the use of electrical weapon systems, such as the EMRG, on existing Naval platforms without significantly compromising their current mission sets.

PROJECTILE

A hypervelocity launch at an initial velocity of approximately 2,500 meters/second (m/sec) subjects the projectile to severe in-bore launch dynamics followed by thermal shock and aero thermal loading during flight. Sea-level-launched projectiles can reach maximum temperatures near 3,000 degrees Celsius. These extreme conditions, high temperatures, thermal shock, and aerodynamic shear exceed the capabilities of most readily available high-temperature materials. Acceleration forces, up to 50,000 G setback during launch and large balloting loads, present additional challenges to the internal guidance package.

The ONR INP projectile work is focused on the characterization of the projectile in-bore and flight dynamics, projectile lethality modeling, and the development of concepts for hypervelocity guidance. Other key areas include the development and integration of key components and technology capable of surviving the intense environmental loading conditions, projectile high temperature and ablative resistant projectile body materials, and insensitive dispense mechanisms.

EMRG OPERATIONAL CAPABILITIES

The primary focus of the ONR INP is the development of a sea-based, 222-NM range, indirect fire weapon system to provide time-critical strike and long-range NSFS in the 2020 to 2025 timeframe. Analyses are currently being conducted on several naval and various commercial shipboard platforms options, including the Littoral Combat Ship (LCS), DDG-51, DDG-1000, T-AKE, and various commercial platforms. The US Army is also considering a mobile weapon system for long-range (70-NM) precision fires. Both services are considering a containerized version that is air-transportable for use at fixed firebases. All of these systems will benefit from similar logistics and safety advantages that are discussed in the next section.

The employment of long-range systems, such as ship-based and shore-based EMRG variants are anticipated in future requirements and mission statements. In March 2002, Lt. Gen. Edward Hanlon, Commanding General of the Marine Corps Combat Development Center (MCCDC), stated:

> "Our operational concepts drive fire support requirements that can be met only by complementary, overlapping, and redundant fire support systems."

In a land-based employment, several containerized EMRGs at a forward operating base (FOB) could support a large area with on-call fire support that would otherwise be difficult or impractical to service because a large number of smaller conventional FOBs would be required. Although not intended as a replacement for current 105 and 155 millimeter (mm) artillery, a 70-NM EMRG firebase along with shipboard EMRG systems that can reach more than 200 NM inland, can be a powerful complement to existing artillery solutions. Based on a maximum range of 30 kilometers (km) (16.2 NM) for a 155-mm gun and 20 km (10.8 NM) for a 105-mm gun, a single 70-NM range EMRG can cover the same area as approximately forty 105-mm or twenty 155-mm guns.

The use of these containerized EMRGs at an FOB eliminates the tremendous resource logistics and protection force required for the many conventional FOBs with shorter range weapons. Movement of munitions to the FOB is simplified by reduced size, weight, and the non-explosive projectile. The vulnerability of munitions stockpiles is also reduced because sympathetic detonation is less of an issue.

The *Marine Corps Vision and Strategy 2025*, written in 2008, provided the following requirements:

> "Recent combat has confirmed the need to improve the essential fires and maneuver capabilities of Marine ground forces, especially within complex urban terrain. Schemes of maneuver in future operations will often necessitate coordinated, precise fires from ground, air, and naval surface fire support platforms. These fires must be available 24 hours a day, 7 days a week under all weather conditions, and they must be able to rapidly and precisely engage the fleeting opportunities often found in irregular warfare."

The strategy also called for maximizing speed and freedom of action through seabasing, while minimizing the footprint ashore, as well as noting the critical importance of minimizing collateral damage.

Figure 3 shows the anticipated capabilities of a shipboard EMRG at the 64-MJ tactical energy level with an indirect fires range of 50 to 222 NM. Range is adjusted mainly by varying the firing angle, with a peak altitude of approximately 800,000 feet (ft) at 50 NM and approximately 500,000 ft at 222 NM. Muzzle velocity will be approximately 2.5 km/sec, about Mach 7.5, with an impact velocity of about Mach 5.0. During its flight trajectory, the projectile spends approximately 5 minutes of its 6-minute flight above the sensible atmosphere (greater than 100,000 ft), thus simplifying airspace deconfliction and susceptibility of the projectiles to jamming. Circular error probability (CEP) is predicted to be approximately 5 m, based on anticipated projectile technology advances.

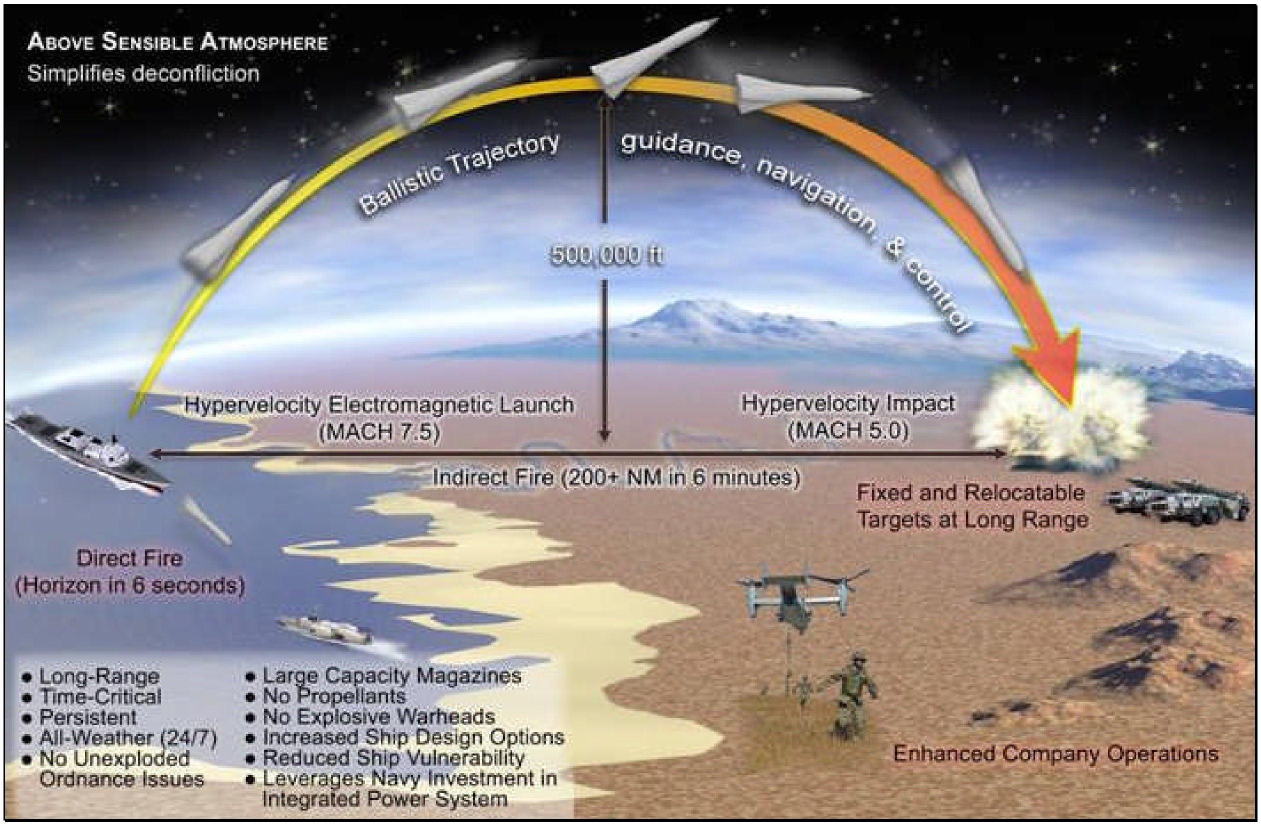

Figure 3: EMRG 64-MJ Capabilities

The anticipated range of the EMRG at 64 MJ (222 NM) exceeds the anticipated range of all current or near-term projectiles including the Long Range Land Attack Projectile (LRLAP) and supports the future assault range of the US Marine Corps (USMC) MV-22. (See Figure 4.) This capability will allow the EMRG to complement USMC MV-22 tactical air assets in high operational tempo engagements and may be used to provide support to forces ashore when operational or environmental conditions do not permit the flow of air power to the target location. Even at 32 MJ (half the full tactical energy level), the EMRG will have an anticipated range of approximately 110 NM, which is equal to the current USMC "ship-to-objective maneuver" (STOM) distance of 200 km (about 110 NM).

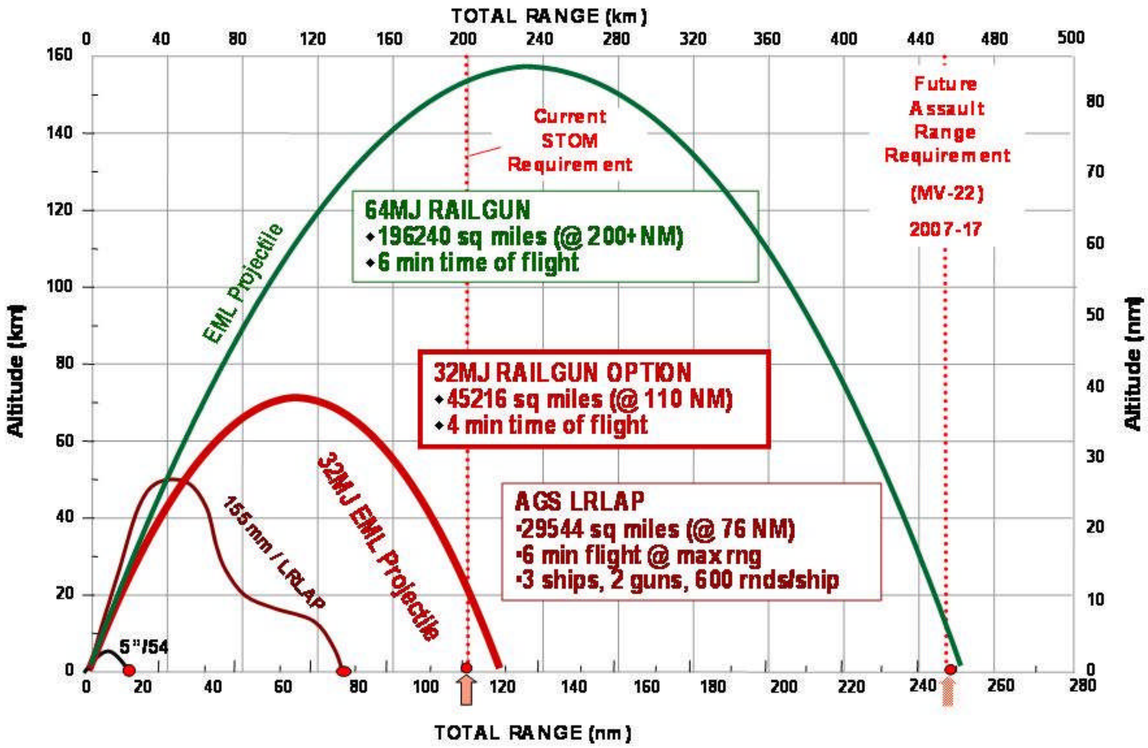

Figure 4: Family of Gun Weapons

The EMRG will provide Joint Forces a unique capability for volume fire at long range, enabling rapid engagement of a wide variety of targets including stationary structures, such as buildings and bridges, and relocatable targets, such as surface-to-air missiles for Suppression of Enemy Air Defense (SEAD) (Pifer et al. 2007). Current weapon systems, such as tactical aircraft (TACAIR) or cruise missiles, have comparable or greater ranges than a 64-MJ EMRG projectile at significantly greater costs, but cannot provide an equivalent volume of fires. Other Naval guns can provide volume of fires, but at significantly shorter ranges. The EMRG provides a truly unique capability for volume fire at long range and an ability to engage targets in a high-threat environment. The use of the EMRG enables rapid engagement of a wide range of target sets, while freeing up TACAIR and cruise missiles to concentrate on high-value targets that are not likely to be engaged effectively with first-generation EMRG weapon systems.

Finally, the high-altitude flight profile and steep attack angle of EMRG projectiles provide greater flexibility to attack targets effectively in mountainous terrain by using projectiles that are practically invulnerable to enemy counterattack. It is impractical for the enemy to engage EMRG projectiles as they descend into the target area. The projectile’s small size and extremely high velocity present a very difficult target and an unfavorable geometry to enemy defensive systems. In addition, the large number of EMRG projectiles will likely overcome any enemy defensive system. Future EMRG system development could enable an unprecedented capability to place rounds in a pre-determined pattern to dramatically increase target lethality over a wide range of potential threats.

EMRG LOGISTICS ADVANTAGES

The EMRG enables lean maneuver forces to move quickly to their objectives unburdened by the logistical tail associated with organic artillery. It will also dramatically reduce the quantity and associated cost of fuel required for aircraft and support vehicles ashore. Additionally, transport aircraft may be allowed to focus more on moving maneuver forces around the battlefield and less on transporting and resupplying their field artillery, particularly early in a conflict.

IMPACT OF FUEL SAVINGS

The cost of fuel and energy efficiency is taking on an increasing level of importance in the current fiscally burdened and resource-constrained environment. The importance will continue to grow during the "post-peak" oil production period that coincides with the projected 64-MJ EMRG initial operational capability (IOC) in the 2020 to 2025 timeframe. Post-peak is the era after global production of petroleum products has peaked and begins an irreversible decline. It is vital that the Department of Defense (DoD) begins to develop systems and build platforms that can put steel on target efficiently in the post-peak period. A brief discussion of the fully burdened cost of fuel (FBCF) and some impact on war fighters is provided in the Appendix.

An EMRG launch is extremely fuel efficient. Even at a full tactical energy level of 64 MJ, an EMRG projectile requires the equivalent of only three gallons of fuel per launch. This represents a dramatic reduction as compared to the fuel requirements of TACAIR. In light of the FBCF, the use of an EMRG, where mission conditions allow, can result in a dramatic reduction in the total cost required to neutralize a significant number of mission critical target sets.

BENEFITS OF NON-EXPLOSIVE MUNITIONS

The EMRG will utilize a pure kinetic energy round without the use of any propellants or explosives. By eliminating explosive elements from the logistics tail, the EMRG will provide the following to the future warship:

- Ability to carry nearly 10 times the current number of on-board rounds within the same space as current magazines (i.e., from thousands to tens of thousands of rounds, depending on the platform being considered)
- Ability to store projectiles in a greater number of shipboard spaces, thus extending time on station and enabling at-sea replenishment of projectiles via vertical replenishment (VERTREP) or connected replenishment (CONREP)
- Reduction of the EMRG platform vulnerability by eliminating sympathetic detonations in the event of attack
- Improvement of the total volume of fires that can be provided from the sea
- Precision strike with minimal collateral damage
- Reduction in weight (typically required for magazine armor), fire fighting systems, thermal insulation, and life-cycle cost

- Significant flexibility provided to the US Navy warship designer, not possible with conventional explosive munitions

The use of non-explosive projectiles also provides significant benefits by eliminating the risks associated with unexploded ordnance (UXO). Hostile forces cannot extract explosives from EMRG projectiles for use in improvised explosive devices (IEDs), and non-combatants are not endangered by UXO. Thus, collateral beneficial effects are reduced danger to both civilians and US forces. These are significant in counterinsurgency (COIN) and stability, security, transition and reconstruction (SSTR) operations.

CONCLUSION

The EMRG as envisioned in the current ONR INP is a “game changing” technology that has the potential to provide much needed, sea-based NSFS and novel, long-range firebases ashore. A key benefit of this technology is the potential to provide long-range fires that are less costly and more fuel efficient than anything in the current inventory. Vast improvements in the end-to-end logistics made possible by the use of non-explosive projectiles cannot be ignored. Simplified handling, safe and flexible storage, the ability to easily load projectiles at sea or alongside the pier, the potential for significant savings in fuel costs in the post-peak period, reduced risk of UXO, and the dramatic reduction of risk to shipboard personnel are just some of the numerous logistical advantages that stem from this new technology. As the system continues to mature, new and innovative applications for EMRG technology will inevitably emerge.

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John M. Johnson *is an electrical engineer with Lockheed Martin Information Systems and Global Services. Mr. Johnson has a BSEE from West Virginia Tech and an MPA from Virginia Tech. He has a combined 42 years of military, civil service, and industry experience. His career has included enlisted service in the US Air Force; circuit design, electronic warfare systems design, and project management at the Naval Surface Warfare Center (NSWC); various line management positions at the Joint Warfare Analysis Center (JWAC); and various staff assignments at Lockheed Martin. He is a member of the Institute of Electrical and Electronics Engineers (IEEE).*

APPENDIX—THE TRUE COST OF FUEL

A recent Defense Science Board (DSB) report addressed the true cost of fuel use in the battlefield. This report concluded that a primary challenge is “unnecessarily high and growing battlespace fuel use demand[s] that:

- Compromises operational capability and mission success;
- Requires an excessive support force structure at the expense of operational forces;
- Creates a high-cost, high-risk operation to move fuel to deployed forces; and
- Increases life-cycle operations and support cost” (Defense Science Board Task Force (DSBTF) 2008).”

“Were the true costs of fuel delivery and supporting infrastructure (including equipment, people, facilities, and other overhead costs) known, understood and factored into the cost of fuel, there would be proper visibility to focus the requirements and acquisition processes on the true benefits of improving efficiency” (DSBTF 2001).

The DoD currently prices fuel based on the wholesale refinery price and does not include the cost of delivery to its customers. This prevents an end-to-end view of fuel utilization in decision-making and does not reflect the DoD’s true fuel costs; energy efficiency benefits are masked; and platform choices are distorted. The logistical cost of delivering fuel to platforms is considered free, even though logistics accounts for about a third of the DoD’s budget and half its personnel; most of the tonnage delivered by the logistics effort is fuel. The services maintain huge infrastructures to ensure fuel delivery. As a result, increases in fuel efficiency would correspondingly reduce this overhead burden, enabling savings through reductions in logistics requirements far in excess of the investment.

The fully burdened cost of fuel (FBCF) should guide acquisition investments for deployed systems. It should be used in all analyses of alternatives (AoA) and acquisition trades. The DSBTF 2001 reports that the DoD was systematically underestimating the true cost of supplying fuel to its battlespace forces. The report concluded with the recommendation to use a burdened cost for such fuel with the burden capturing the assets (i.e., the force structure) required for delivery and protection of fuel from the point of commercial supply to the point of use. Fuel delivery costs include the part of Military Sealift Command that delivers fuel, the US Air Force airborne tanker fleet, the amount of F-18 flying time spent serving as airborne tankers delivering fuel to other aircraft and the refueling vehicles owned by the US Army and US Marine Corps. Fuel delivery costs also include assets used to protect the fuel as it transits from the point of commercial supply to the battlespace. Improving the efficiency of a deployed system would reduce the amount of fuel needed for battle and, hence, the number of fuel logistics assets the DoD would have to buy, maintain, train on, buy fuel for, and protect. Those asset costs should be included in calculating the true cost of fuel to the DoD and should be compared with the cost to make deployed systems more efficient (DSBTF 2008).

In addition to direct savings in fuel costs, combat effectiveness will also be increased and resources, otherwise needed for resupply and protection, will be redirected. Truck drivers and convoy protectors can become combat soldiers, thus increasing combat capability while reducing vulnerabilities caused by extensive convoys (DSBTF 2008).

As a result of these factors, the FBCF far exceeds the commodity price. The delivered cost for fuel has the following price tags:

- $4 per gallon for ships on the open ocean
- $42 per gallon for in-flight refueling
- Several hundred dollars per gallon for combat forces and FOBs deep within a battlespace (DSBTF 2008).

By way of example, 10 years after the Cold War, over 70% of the tonnage required to position the US Army into battle was fuel. US Naval forces used millions of gallons of fuel each day to operate around the globe. The US Air Force is the largest DoD consumer and spends approximately 85% of its fuel budget to deliver by airborne tankers just 6% of its annual jet fuel usage. In 1997, DoD energy use was 1.2% of the US total (DSBTF 2001).

ABBREVIATIONS AND ACRONYMS

ACAT 1	Acquisition Category 1
ACD&P	Advanced Component Development and Prototype
AGS	Advanced Gun Systems (only in Figure 4)
AoA	analyses of alternatives
ASN	Assistant Secretary of the Navy
ASNE	American Society of Naval Engineers
ATL	Acquisition, Technology & Logistics
BSEE	Bachelor of Science, Electrical Engineering
CDR	Commander
CEP	circular error probability
CNO	Chief of Naval Operations
COIN	counterinsurgency
CONOPS	concept of operations
CONREP	connected replenishment
DDG	guided missile destroyer
DoD	Department of Defense
DSB	Defense Science Board
DSBTF	Defense Science Board Task Force
EML	Electromagnetic Launcher (only in Figure 4)
EMRG	electromagnetic rail gun
FBCF	fully burdened cost of fuel
FOB	forward operating base
G	gravitational force
GPS	Global Positioning System
IEEE	Institute of Electrical & Electronics Engineers, Inc.
IED	improvised explosive device
ILP	Integrated Launch Package (only in Figure 1)
INP	Innovative Naval Prototype
INSURV	Inspection and Survey
IOC	initial operational capability
IPS	Integrated Power System
J/cc	Joules/cubic centimeter
JWAC	Joint Warfare Analysis Center
Km	kilometer
LCS	Littoral Combat Ship
LRLAP	Long Range Land Attack Projectile
m/sec	meter/second
MCCDC	Marine Corps Combat Development Center
MIT	Massachusetts Institute of Technology
MJ	mega Joules
MNF-I	Multi-National Forces, Iraq
MPA	Master of Public Adminstration
MS	Master of Science
MW	mega Watt

NAVSEA	Naval Sea Systems Command
NM	nautical mile
NSFS	Naval Surface Fire Support
NSWC	Naval Surface Warfare Center
ONR	Office of Naval Research
PCN	Publication Control Number
psi	pounds per square inch
RD&A	Research Development & Acquisition
rpm	rounds per minute
S&T	Science & Technology
S&T	Science and Technology
SEAD	Suppression of Enemy Air Defense
SNAME	Society of Naval Architects & Marine Engineers
SSTR	stability, security, transition, and reconstruction
SUPSHIP	Supervisor of Ship Building, Conversion, and Repair
TACAIR	tactical aircraft
T-AKE	Dry Cargo/Ammunition Ship Class
TRL	Technology Readiness Level
USD	Under Secretary of Defense
USMC	US Marine Corps
USN	US Navy
UXO	unexploded ordnance
VERTREP	vertical replenishment

OUTLINE

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