NAVAL RAIL GUNS ARE REVOLUTIONARY

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With the all-electric ship on the horizon and recent advances in technology, the time is ripe for developing naval rail guns that can deliver the capabilities of hypersonic missiles at costs closer to those of guns.

The Navy recently set out its vision of how it will organize, integrate, and transform.[1] According to the Sea Strike concept of "Sea Power 21," naval forces will employ technologies including "electromagnetic rail guns" to "distribute offensive striking capability throughout the entire force."[2] The Chief of Naval Operations' Strategic Studies Group XVI was the first to conclude that "recent advances in rail gun technology offer the most promising option for delivering affordable, extended range naval fires."[3] Several recent studies sponsored by the Office of Naval Research and Dahlgren agree that rail gun technologies are now sufficiently mature to proceed with development of a full-scale demonstration of long-range ship-based rail gun capabilities.[4] Investing in naval rail gun development and Sea Trial experiments offers the potential to meet every naval surface fire support requirement with a system that can deliver the capabilities of extended hypersonic missiles at gun-like cost.[5]

Expanding Requirements

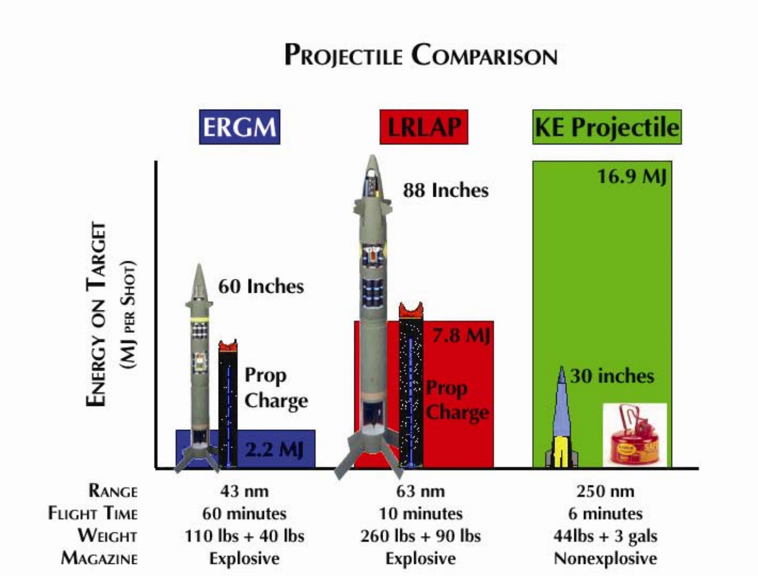
In future conflicts, U.S. naval forces envision conducting ship-to-objective maneuvers as an integral part of the joint campaign. Joint ground elements will consist of increasingly light, highly maneuverable forces that will employ indigenous light, lethal fires from advanced ground combat vehicles while directing heavy joint fires that will be delivered increasingly from the air and sea. The integration of special operations forces and joint fires during Operation Enduring Freedom was just a glimpse of how the relationship between ground forces, fires, and maneuver elements will transform future military operations. Naval forces must continue to extend their operational reach from the beach to 200 miles inland and beyond. Future operations will require the capability to engage thousands of targets a day, up from the current capability of sea-based missiles and carrier aviation to engage a few hundred targets in that time frame. To support the ground campaign, sea-based naval fires also must achieve performance equal to or greater than that currently available from shore-based artillery systems. The Marine Corps naval surface fire support (NSFS) requirements serve as good benchmarks for developing fire support systems needed to support the full range of joint forces.[6]

The Navy has three fire support options today: short-range guns, long-range missiles, and carrier aviation. Tactical aviation assets bear the lion's share of the power-projection burden. Recent fire support studies determined that "a combination of guns and missiles with guns applied to the majority of the target sets is the most cost-effective solution."[7] "Long range precision guns would provide a revolutionary capability," the studies concluded, "but none of the conventional gun concepts can cover the target set due to range."[8]

Employing unconventional technologies to extend the range of naval guns, then, could provide the precision and volume of fire needed to liberate tactical aviation assets to focus on conducting strikes against more challenging pop-up, mobile, and relocatable targets, particularly when information about the targets is less than perfect.

A New Performance Curve

Constrained by physics and cost, conventional guns have reached their inherent limitations. The limits of gas expansion prohibit launching an unassisted projectile to velocities of greater than about 1.5 kilometers per second (km/sec) and ranges of more than 50 miles from a practical conventional gun system. Alternatively, the extended range guided munition (ERGM) and advanced gun system (AGS) would launch rocket-assisted shells to extend the range of conventional guns, but tradeoffs between size, rocket fuel, and lethal payload requirements make these options prohibitively expensive beyond their expected ranges (right). These cost constraints have led fire support experts to conclude that "missiles are a better solution than rocket propelled shells for ranges of greater than about 100 miles."[9] Historically, however, missiles cost on the order of $1,000 per mile. While technical solutions may reduce costs by as much as 50%, it is unlikely that any missile program, especially one with a hypersonic capability, will be cost-effective when compared with advanced guns. The problem, then, is that an affordable extension of naval gun ranges beyond that of AGS mandates an unconventional approach.



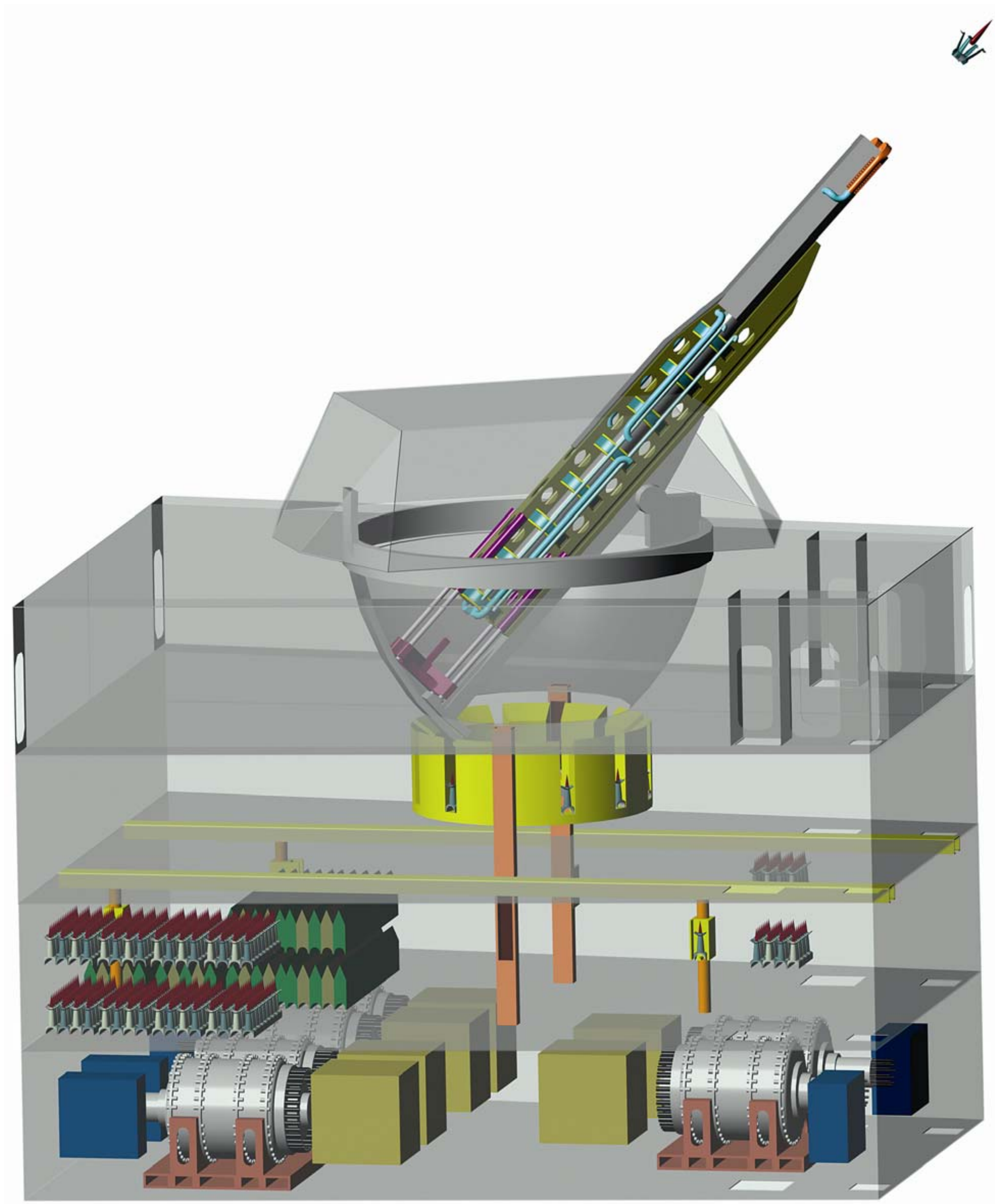
Electromagnetic rail gun technologies offer the most mature, unconventional, extended-range fire support solution. Increased muzzle velocity is the key to cost-effective increases in range, lethality, and responsiveness because it provides these benefits without onboard propellants or explosives. Rail guns are the only systems that have demonstrated a capability to launch projectiles to 4.4 km/sec, and recent technical developments have significantly reduced the technical barriers to fielding naval systems.[10]

State-of-the-art rail gun technology uses a combination of power conversion devices and a linear electric motor to accelerate projectiles to hypersonic velocities. Rail guns require a pulse power system to convert prime electrical power to the instantaneous current pulse necessary for electromagnetic launch. The most advanced pulsed power systems use rotating alternating current machines, called pulsed alternators, to supply electromagnetic current pulses to the rails. The current flowing in the rails produces a magnetic field between the rails, and this field interacts with the current flowing in the armature to produce Lorentz forces that propel the projectile to the desired muzzle velocity. Fielded rail guns systems are expected to achieve muzzle velocity of from 2.5 to 6 km/sec.

Developing rail gun technology would shift the possibilities for naval fire support to a new performance curve, allowing tremendous future growth potential in gun technology. To put things in perspective, our current 5-inch gun has a muzzle energy of 10 megajoules (MJ). ERGM will increase this to 18 MJ, and AGS will press the limits of conventional gun physics by attempting to achieve a muzzle energy in excess of 33 MJ. In contrast, naval rail guns will achieve muzzle energies from 60 to 300 MJ. Research indicates that a notional first-generation naval rail gun with a 2.5-km/sec muzzle velocity could deliver a guided projectile with an impact velocity of Mach 5 to targets at ranges of 250 miles at a rate of greater than six rounds per minute. Mature rail gun technology (illustration on next page) is predicted to produce a much greater capability.

Speed Kills

In the 21st century, the Navy's strike responsibilities are only going to increase, including deep strike, interdiction, close-air support, and NSFS. A naval rail gun is uniquely suited for the NSFS mission. A first-order analysis comparing the 200-mile volume of fires capability of a single hypersonic naval rail gun to the ordnance delivery capacity of a carrier air wing of F/A-18s is instructive. In the first eight hours of conflict, a single naval rail gun could deliver twice the payload, three times the energy, to ten times as many fixed aim points as carrier aviation.[11]



An important advantage of rail guns is the ability to exploit the high kinetic energy (KE) stored in the projectile for extremely lethal effects. One test demonstrated that the release of the rail gun projectile's kinetic energy alone would create a 10-foot diameter crater, 10 feet deep in solid ground, and achieve projectile penetration to 40 feet. Hypervelocity projectiles provide deep penetration to destroy hardened targets that are extremely hard to kill by other methods. Nothing prohibits the use of explosives, but lethality studies suggest that rail gun KE projectile concepts will be sufficiently lethal—three to five times more deadly than current gun systems.

In addition to range and lethality, rail guns offer time-of-flight advantages that are becoming increasingly important to supporting the highly maneuverable ground forces of the future. A Mach 7 rail gun could deliver a lethal payload 100 nautical miles in about two minutes. High power requirements, however, probably will limit rail guns to somewhat lower firing rates than conventional gun systems. Scientist estimate that six rounds per minute is a conservative firing rate for a naval rail gun system, but analysis shows that a rail gun projectile's rapid time of flight can more than make up for its lower firing rate. Given a range of 100 nautical miles, a 6 rounds/minute rail gun and the 12 rounds/minute 5-inch ERGM will provide the same number of rounds on target during a 15-minute engagement.

The volume of ordnance on target is only half of the equation. There must be sufficient rounds stored aboard ship to support multiple engagements throughout the duration of the conflict. Rail guns will use kinetic energy projectiles that allow for the elimination of propellants and explosive warheads, yielding safe, sustainable rounds for a full range of applications. All-metal rail gun rounds allow for a smaller, safer magazine or a much greater storage capacity for a given magazine size. The AGS magazine is expected to hold up to 1,500 rounds; more than 10,000 rail gun all-metal rounds could be stored in the same volume.

Rail Gun Technology Risks

Driven by the necessity to penetrate explosive reactive armor, the Army has made a substantial investment in rail gun technology for direct fire application associated with ground combat vehicles. Obviously, that application places a huge demand and constraint on the technology, particularly in comparison to a rail gun for a ship. Over the past decade, Army research (right) has markedly improved our understanding of pulsed power, rail design, and electromagnetic launch. The Navy can leverage the Army research on power systems and barrel materials for a much lower risk incorporation into ships, especially if they have electric propulsion and an integrated power system. Fielding the technology for naval applications, however, requires a unique investment in larger scale rail gun systems and hypersonic guided projectile technologies.

Projectile and Barrel Design

Scientists know how to solve the challenges of shell ablation, flight control, hardened electronics, and stability for long-range hypervelocity projectiles. But solving these problems in a single, integrated package capable of withstanding electromagnetic launch poses a significant technical risk. By limiting the first-generation naval rail gun muzzle velocity to 2.5 km/sec (Mach 7.5), it is anticipated that engineers can meet projectile requirements at a manageable cost much less than that of current guided rocket-assisted projectiles. The recent success of the Barrage Round ATD, a 40-mile conventional KE projectile initially designed for launch from extended range rail guns, has retired some of the projectile development risk.

The long flight trajectory of a rail gun projectile will require an inexpensive guidance system. The competent munition program is developing and testing a miniature Global Positioning System/Inertial Navigation

System (GPS/INS) guidance package. This 8-cubic-inch volume system includes full GPS/INS guidance, electrical power supply, and a miniaturized electromechanical reaction torque flight control actuation system that would be perfectly suited for rail gun as well as other projectile systems. The Barrage Round developers assembled these components at a projected cost of less than $3,000 per projectile, limiting overall projectile cost to an estimated $10,000. Even if these estimates are off by a factor of three, rail gun projectiles will be more cost-effective than any comparable missile.

Some of the most difficult challenges to rail gun development are the gouging and wear that occur during the acceleration of projectiles to hypervelocities. In the last year, rail materials research has yielded impressive results. Using advanced conductive materials, researchers have conducted dozens of launches at greater than 2.5 km/sec without any evidence of rail gouging and with manageable rail and armature wear.

Pulse Power System

Pulse power generators take prime power (ship's service in our case) and convert it to the instantaneous pulse needed for projectile launch. In the past decade, advances in alternating current pulse power systems have reduced the size from that of a warehouse to a compact generator more suitable for mobile battlefield applications. Naval engineers can exploit favorable scaling issues to develop larger power supplies easily supported by naval combatants. Navy pulse power machines would incorporate proven technology less risky than that already demonstrated by the Army's rotating, subscale machine. Based on existing technology, studies have shown that the pulse power system needed to support a 250-nautical-mile rail gun would be comprised of four 1-meter diameter machines and could fit in existing 5-inch gun mounts, leaving 70% of the mount's volume for projectile storage.

Power Requirements

Meeting projectile and system design challenges still would leave one potentially show-stopping issue: a naval rail gun with a high-firing rate (six rounds/minute) would require power on the same order of magnitude as needed for ship propulsion. Taking full advantage of rail gun technology will require a dedicated energy management strategy for future surface combatants. Rail gun power requirements can best be met by developing the proposed all-electric warship with an integrated power system (IPS) that could simultaneously support the demanding energy requirements of electric propulsion and high-energy weapon systems. IPS brings with it many additional advantages, including a more than 25% life-cycle fuel savings and a highly efficient, survivable electric power generation and distribution system. Rail guns could be backfitted, however, into non-IPS ships at a much lower firing rate of one to two rounds per minute.

Exploiting the growth in naval rail gun capabilities, however, will depend on the development of an electric warship. Power requirements increase significantly from approximately 15 megawatts to more than 60 megawatts as each new generation of naval rail gun system is fielded. Adequate marine electric power systems already exist to support electric warship concepts. DD(X) is envisioned to have approximately 80 megawatts of installed power. To deploy a naval rail gun, though, support systems capable of meeting demanding switching, insulation, and thermal management requirements also must be engineered.

Future Experiments

Sea Trial 21 is the Navy's new process for accelerating transformation. Sea Trial recognizes that the key to delivering innovative capabilities is a solidly managed and led program with clear exit points should any phase of program development become prohibitive. Thus, a research-and-development strategy that mitigates the technical risks, controls costs, and moves selected technologies from the lab to the fleet in a timely manner is essential. As the executive agent for Sea Trial, Commander, Fleet Forces Command, will oversee development, tests, operational demonstrations, and fleet experiments designed to evaluate and select innovative concepts for continued funding and eventual deployment.

Characterized by solid physics and manageable risk, naval rail guns are the ideal candidate for incorporation into the Sea Trial process. A focused technology development program that leads to a series of experiments that culminate in a full-scale extended-range (250 nautical miles) naval rail gun proof-of-concept demonstration in fiscal year 2008 is a sensible approach. Admiral Robert Natter, Commander, Fleet Forces Command, has approved a 1/8th-scale demonstration using existing rail gun facilities this spring as a first step toward larger experiments and demonstrations.

Successful naval innovation requires that sound operational principles be fused with revolutionary technical developments.[12] A Navy serious about transformation cannot continue to rely exclusively on expensive missiles or conventional guns that have reached their inherent physical limitations. It is time to make a serious investment in naval rail gun research, development, and experimentation aimed at bringing a revolution in naval fire power to the fleet.

Notes

[1]Adm. Vern Clark, U.S. Navy, "Sea Power 21," *U.S. Naval Institute Proceedings*, October 2002, pp. 32-41.
[2]Clark, "Sea Power 21," pp. 32-41.
[3]Chief of Naval Operations' Strategic Studies Group XVI, Naval Warfare Concept Team Reports, June 1997, VI-9; Capt. James Carman, USN, et al., "Innovation for the Interwar Years," *U.S. Naval Institute Proceedings*, February 1998, pp. 27-31.
[4]I. R. McNab, et al., "Assessment of Feasibility of EM Railgun for Naval Applications," Final Technical Report on Office of Naval Research Research Grant 14-01-1-0900, September 2002; John L. Bean et al., "A Review of Electromagnetic Naval Gun and Hypersonic Projectile Technology Readiness," Naval Surface Warfare Center Dahlgren Division TR-02/5 June 2002; F. M. Bomse et al., "Electromagnetic Launcher and Projectile Assessment," CNA CRM D0006080.A5, April 2002.
[5]Cdr. Fred Beach, USN, "Hypersonic Naval Rail Gun," unpublished brief to Adm. Robert J. Natter, USN, 31 October 2002.
[6]Letter from MGen. Edward Hanlon Jr., USMC, to the Chief of Naval Operations, "Naval Surface Fire Support Requirements for Expeditionary Maneuver Warfare," 19 March 2002.
[7]NSFS COEA and IDA Study Results, unpublished briefing, The Pentagon, N-76B, 5 February 2000.
[8]NSFS COEA and IDA Study Results.
[9]Miles Palmer, "Fire Support Alternatives," unpublished study, SAIC Corporation, Arlington, Va., 5 August 1997.
[10]W. A. Walls, M. Plamer, Lt. D. Adams, USN, et al., "Applications of Electromagnetic Guns to Future Naval Platforms," *IEEE Transactions on Magnetics*, January 1999, pp. 262-67.
[11]Naval Warfare Concept Team Reports, VI-9.
[12]Stephen Peter Rosen, *Winning the Next War* (Ithaca, NY: Cornell University Press, 1991).

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