REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
04/06/2015

2. REPORT TYPE
Future War Paper - School of Advanced Warfighting

3. DATES COVERED *(From - To)*
Oct 2014 - Apr 2015

4. TITLE AND SUBTITLE
THE FUTURE OF FIREPOWER: THE DISRUPTIVE POTENTIAL OF THE ELECTROMAGNETIC RAILGUN

5a. CONTRACT NUMBER
N/A

5b. GRANT NUMBER
N/A

5c. PROGRAM ELEMENT NUMBER
N/A

6. AUTHOR(S)
Major Christopher J. Carter, USA

5d. PROJECT NUMBER
N/A

5e. TASK NUMBER
N/A

5f. WORK UNIT NUMBER
N/A

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
USMC School of Advanced Warfighting
Marine Corps University
3070 Moreell Avenue
Quantico, VA 22134-5068

8. PERFORMING ORGANIZATION REPORT NUMBER
N/A

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
N/A

10. SPONSOR/MONITOR'S ACRONYM(S)
N/A

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
N/A

12. DISTRIBUTION/AVAILABILITY STATEMENT
Unlimited

13. SUPPLEMENTARY NOTES
N/A

14. ABSTRACT
Artillery delivered fires over the past fourteen years of war in Iraq and Afghanistan was frequently reserved for the delivery of expensive precision munitions from a single cannon or missile launch. The advancement of the Electromagnetic Railgun by the Office of Naval Research could transform the employment of artillery across the services. Specifically, a ground based Electromagnetic Railgun with increased capabilities in range, rates of fire, and precision coupled with reductions in logistics requirements, costs, and projectile weight could provide the warfighter with superior firepower capability in the close and deep fight in future wars.

15. SUBJECT TERMS
Electromagnetic Railgun, Field Artillery, Future War

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			MCU / School of Advanced Warfighting
					19b. TELEPHONE NUMBER *(Include area code)*
Unclassified	Unclassified	Unclassified	UU		703-784-6800

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

United States Marine Corps
School of Advanced Warfighting
Marine Corps University
3070 Moreell Avenue
Marine Corps Combat Development Command
Quantico VA 22134

FUTURE WAR PAPER

TITLE:

THE FUTURE OF FIREPOWER: THE DISRUPTIVE POTENTIAL OF THE ELECTROMAGNETIC RAILGUN

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF OPERATIONAL STUDIES

AUTHOR: MAJ Christopher Carter, USA

AY 2014-15

Mentor: Dr. Gordon Rudd, Professor of Military History

Approved: [signature]

Date: 28 MAY 2015

DISCLAIMER

THE OPINIONS AND CONCLUSIONS EXPRESSED HEREIN ARE THOSE OF THE INDIVIDUAL STUDENT AUTHOR AND DO NOT NECESSARILY REPRESENT THE VIEWS OF EITHER THE SCHOOL OF ADVANCED WARFIGHTING OR ANY OTHER GOVERNMENTAL AGENCY. REFERENCES TO THIS STUDY SHOULD INCLUDE THE FOREGOING STATEMENT

Table of Contents

Introduction

Artillery delivered fires ascended to the forefront of warfare during World War I and have inflicted more combat casualties than any other weapon system in the 20th century. Over the past fourteen years of war in Iraq and Afghanistan, however, the employment of indirect fire weapon systems by United States forces was frequently reserved for the delivery of expensive precision munitions from a single cannon or missile launch. Instead of massing fires to gain a desired effect on the battlefield, commanders relied on artillery units to destroy point targets that required the smallest possibility for collateral damage. Guided Multiple Launch Rockets (GMLRS) and Excalibur rounds became the munition of choice. Outside of the availability of precision munitions, standard artillery munitions were a last resort. The requirement for massed effective artillery fires still exists, and the development of future capabilities could change artillery employment and weapon systems in the next 15 years. The advancement of the Electromagnetic Railgun by the Office of Naval Research could transform the employment of artillery across the services. Specifically for the Navy and Marine Corps, rail gun technology could fill the gap of naval gunfire in the Anti-Access/Area Denial (A2AD) domain. However, the successful advancement of electromagnetic railgun technologically could also have significant implications on ground based indirect fire. A ground based Electromagnetic Railgun with increased capabilities in range, rates of fire, and precision coupled with reductions in logistics requirements, costs, and projectile weight could provide the warfighter with superior firepower capability in the close and deep fight in future wars.

Railgun Background and Development

An electromagnetic railgun consists of two conductive rails with an inert conductive projectile placed between them. The conductive projectile, sometimes known as the "armature," completes the circuit between the rails. To launch the armature, a large pulse of electric current ("pulsed power") is delivered from energy stored in "super capacitors" and applied through the rails and armature, creating magnetic fields. These magnetic fields generate the force necessary to propel the armature forward along the rails.[1] Overall, the full electromagnetic railgun consists of five parts: a launcher, energy storage system, pulse-forming network, high velocity projectile, and gun mount.[2]

The concept of using electromagnetic energy to propel objects at extremely high velocities is not a new one. Westinghouse Electric conducted the first successful test of an electromagnetic rail gun in the United States in 1980 when they accelerated a 300 gram mass to over 4 km/s.[3] Since then, interest in the potential for electromagnetic energy use in direct and indirect fire weapon systems as well as ballistic missile and air defense has fluctuated. Uncertainty in the experimental application of the technology, cost, and incredibly large energy requirements has hampered electromagnetic railgun development. Nevertheless, the highly attractive theoretical capability of an electromagnetic railgun appealed to the United States government and Department of Defense.

During the early 1980's, researchers across the United States began studying and testing the possibilities of electromagnetic railgun technology. In 1985, The RAND Corporation published a Defense Advanced Research Projects Agency (DARPA) sponsored report highlighting the potential benefit of electromagnetic railgun use for the defense of American airbases in Europe against Soviet non-nuclear tactical ballistic missiles.[4] In 1986, the United States Army awarded multiple contracts to laboratories, universities, and defense companies to develop a railgun for employment on a tank.[5] In 1988, the United States Army officially patented the technology for a portable railgun.[6]

Despite military drawdowns and budget cuts, military funded research continued into the 1990's. The Institute of Applied Technology (IAT) at the University of Texas-Austin developed the first electromagnetic railgun proportional in size to a conventional weapon, and conducted research and testing for the United States Army. In the early 2000's the United States Army considered developing the electromagnetic railgun in its Future Combat System program of vehicles, and the United States Marine Corps showed interest in including the technology in its proposed Marine Expeditionary Family of Fighting Vehicles.[7] However, during this period many conventional weapons programs were cancelled or reduced in favor of programs that focused on the challenges of counter insurgency and terrorism. Additionally, energy requirements for an electromagnetic railgun still required warehouse sized power production facilities that were not suitable for ground based employment. Despite the daunting requirements for a power source, the United States Office of Naval Research (ONR) continued research and development on its own electromagnetic railgun program. The United States Navy electromagnetic railgun program has shown the most promise in the advancement of this technology and capability for military application.

The Naval Electromagnetic Railgun Innovative Naval Prototype (INP) program was established by the ONR in 2005 to improve existing railgun technologies for development of a railgun capability at sea. General Atomics and BAE Systems delivered functional railgun prototypes to the Navy at its Naval Surface Warfare Division in Dahlgren, Virginia. Both continue to make ground breaking progress in launcher, power, and projectile technology, overcoming critical limitations of the past. Before discussing the implications that this capability and technology has on the future of conventional weapons, a description of the Navy's advancement of railgun technology is in order.

As previously mentioned, an electromagnetic railgun consists of five parts: a launcher, energy storage system, pulse-forming network, high velocity projectile or "armature," and gun mount. The armature under current military testing and design is a solid inert metallic mass of tungsten weighing 10kg (22 pounds). This type of projectile relies on kinetic energy at the target impact, rather than explosive material, to create desired effects. The pulse of electric current sent through the railgun delivers 32 mega joules (MJ) of energy to the projectile. This force propels the armature at muzzle velocities over 2.5km/s, or Mach 7, with velocity on impact greater than Mach 5.[8] By comparison, a typical artillery cannon launches a projectile with a muzzle velocity of 0.4km/s with a velocity at impact around 0.2km/s. The velocity on impact of a railgun launched projectile would be greater than the velocity of a conventionally fired projectile at the time of launch. These are record breaking figures and represent firepower capabilities unmatched today.

Today, the Navy's electromagnetic railgun has successfully demonstrated the capability to launch a projectile over 115 miles (185km) and seeks to expand that capability to 230 miles (370km) in the next 15-20 years.[9] Meanwhile, the Navy plans to test a 20 MJ electromagnetic railgun system at sea on board the Joint High Speed vessel USNS *Millinocket* (JHSV 3) in 2016.[10] The Navy realizes the potential advantages and implications that advancement of the electromagnetic railgun has on the future of naval gun fire capabilities. Not only is it an improvement in capability and range to existing weaponry, the railgun can also provide better defense of the ship and safety of the crew. The requirement for carrying hazardous gunpowder and explosive chemicals aboard the ship is eliminated by the use of electric energy and inert munitions, and the extra space created by eliminating the need for a propellant can be used for additional munitions or power generation.[11] If converted to a surface based capability, the electromagnetic railgun would have similar advantages and more. In order to understand the impact of the electromagnetic railgun as a surface based indirect fire weapon system, first a basic description of indirect artillery fire is in order.

Overview of United States Artillery

Artillery originally developed as a means to engage the enemy at greater ranges than the standard infantry weapon. The ballistic elements behind the launch of indirect fire weapon systems are similar to that of a gun only at much larger proportions, and have become more efficient over time. Essentially, a projectile is seated at the base of a metal tube and a chemical propellant is placed behind the projectile. The base of the tube is sealed, and the propellant is ignited. The ignited propellant produces gases that rapidly fill the space behind the projectile, creating a force that propels the projectile forward. Increases in weapons technology and tactics over the years have increased the effective range and required effect of indirectly fired munitions. This includes changes in caliber, length of tubes, mobility, and types of munitions in order to provide desired effects on the battlefield.[12] While advances were made in technology there remained a delicate balance between weight, timeliness, and logistical burdens that each artillery type entailed.

Today, United States military forces employ various types of indirect fire weapon systems. The United States Army fields 105mm and 155mm towed howitzers, and 155mm self-propelled howitzers (M109A6 Paladin). The United States Army also employs Multiple Launch Rocket Systems (MLRS) and High Mobility Artillery Rocket Systems (HIMARS). The United States Marine Corps fields a 155mm towed howitzer and HIMARS as well.

Artillery was effectively integrated into maneuver operations on the drive to Bagdad in 2003, however, once the conditions on the battlefield changed from a conventional fight into a counterinsurgency fight the requirement for overwhelming fire power was less urgent in both Iraq and Afghanistan. Additionally, the advancement of precision munition technology and decreased acceptance for collateral damage reduced the requirement for overwhelming artillery fires. Complete supremacy of the airspace coupled with increasing restrictions on collateral damage led to the preferred use of air delivered munitions over surface or sea based indirect fire. Artillery systems were dispersed on Forward Operating Bases (FOBs) or smaller outposts with a primary mission of counter-battery fire, or fire support of ground units that were within range. Maneuvering artillery weapons within range to support ground operations was no longer a consideration due to the overwhelming availability of air support. Ground troops became more dependent and more comfortable with close air support (CAS) from fixed wing aircraft or close combat attack (CCA) fires from attack helicopters. Dependence on air support became so great that if poor weather conditions prevented air operations, ground missions would be cancelled if air coverage was a requirement despite the availability of all-weather surface fires. As a result, many United States field artillery units left their howitzers in the United States and deployed to the battlefield to conduct a multitude of missions outside of their field artillery specialty such as civil affairs, military police, transportation, and infantry missions. The preferred use of precision fires dominated the use of field artillery assets in both campaigns. As the United States military looks to the future, increasing the precision and accuracy of existing artillery weapon systems remains a focal point for field artillery development.[13] Adding electromagnetic railgun into the equation would be a dramatic increase to existing capability.

Railgun Advantages

Typical challenges that an indirect fire weapon system must overcome are accuracy, range, rate of fire, effects on target, mobility, and logistical requirements. As mentioned, precision and accuracy have risen to the forefront of current and future artillery requirements. Increased range is also becoming more important as technology increases the operational reach of military forces, and increases the standoff distance of enemy weapons capabilities, thereby increasing the depth of potential battlefields. The capabilities of a ground based electromagnetic railgun could overcome these challenges in range.

The potential maximum effective range of an electromagnetic railgun exceeds that of conventional weapons and could provide a solution in the deep fight. As mentioned, current tests of the railgun demonstrate the ability to launch a projectile 115 miles (185km) with the potential to reach a final capability of 230 miles (370km). At this range, projectiles would reach exo-atmoshperic altitudes, allowing them to travel nearly drag free, and they would impact the target at over mach 5.[14] Currently, long range artillery fires in the United States military are provided by rockets launched from an MLRS or HIMARS. The max effective range of a standard rocket is 30km. This range is increased by the GMLRS precision rocket out to 70km. Both fall far shorter than the effective range of a railgun. The only munition capable of similar effective ranges as the railgun is the Army Tactical Missile System (ATACMS) missile. However, the United States Military will phase out the ATACMS missile as it eliminates Dual Purpose Improved Conventional Munitions (DPICM) from its inventory in accordance with the 2008 Cluster Munition and Unintended Harm to Civilians policy.[15] The United States Army is currently conducting tests for a replacement rocket with extended range capability. The electromagnetic railgun not only fills the void of losing this capability but surpasses all rocket launched range capabilities.

The electromagnetic railgun's range capability over cannon artillery is drastically greater. The max effective range of standard munitions delivered by both the 105mm and 155mm howitzers in the United States military inventory are generally under 30km. The physical limitation of chemical propellant gas expansion produces muzzle velocities far inferior to that of the railgun. The electromagnetic railgun launches projectiles with such a high muzzle velocity it could hit targets at a 30km range with a straight trajectory.[16] Despite its high energy launches, the railgun could be configured to fire munitions within this shorter range as well. Projectiles would still be inert, weigh less than 23 pounds, and travel at a high velocity, reducing the time of flight to the target. By reducing the time of flight, warning time for a potential enemy is reduced as well as the time loop required to assess effects on target and re-engage other potential targets.

The electromagnetic railgun dramatically improves current indirect artillery range capabilities in the United States military. The ability to project fire power deep on the battlefield will continue to increase with advancing technology. Five strategically placed railguns could provide complete coverage of the entire surface area of Iraq. In addition to far surpassing the capability of current weapon systems, the railgun also provides a significant reduction in cost compared to today's long range capabilities.

The proposed hypervelocity round for the railgun under development by BAE is significantly cheaper than rockets and missiles used by the United States military for long range surface to surface strikes. The projectile is estimated to cost $25,000 per round. As previously discussed, the comparable surface to surface munition to the railgun capability is GMLRS and ATACMS. The average cost of a GMLRS rocket is $110,000, and the ATACMS missile cost roughly a million dollars a piece.[17] Over 500 ATACMS missiles and 2,600 GMLRS rockets have been launched in support of combat operations.[18] By cutting per unit costs between four to twenty fold, the reduction in munition costs for long range land attack capability could significantly relieve budget pressure during fiscally restrained times. These cost reductions could also be seen when compared to Naval land attack munitions.

The most common land attack munition from United States naval surface ships is the Tactical Land Attack Missile (TLAM) commonly known as the Tomahawk cruise missile. Since 1989, the TLAM has been fired from sea over 2,100 times in support of combat operations.[19] Two operations paint a vivid picture of how quickly sea based missiles can become excessively expensive. In 1998, the United States launched 75 TLAMs against land based Al Qaeda targets at the cost of $75 million.[20] Similarly, in

2008 the United States launched 184 TLAMs in support of Operation Odyssey Dawn at a cost of $260 million.[21] The Tomahawk cruise missile has proven to be an exceptionally capable munition for United States military forces, but comes with a high cost. With a price tag of over $1 million per missile, engaging hundreds of targets ashore proves costly, especially during individual operations. The ability to reach the same targets and generate similar effects with a significantly cheaper munition fired from an electromagnetic railgun, ashore or on land, would dramatically decrease these costs and provide commanders the flexibility to engage targets as frequently as necessary without concerns for excessive costs.

The Electromagnetic Railgun provides multiple other advantages in addition to the significant increase in range and decrease in cost. The railgun does not require the removal of a shell casing and therefore could be equipped with a rapid loading mechanism to increase rates of fire. There are also logistics advantages to railgun operations. The weight of standard conventional artillery munition is about 100lbs on average. By comparison, the railgun armature is significantly lighter with a weight of 22 lbs. Also, because the railgun uses electromagnetic forces to propel its munitions, there is not a need for the storage and care of hazardous chemical propellants. The use of a projectile that is inert, lighter than conventional artillery shells, and lacks a companion propellant charge significantly reduces the logistics requirements to employ artillery. Additonally, by removing explosive materials, the safety procedures required for transporting and handling hazardous explosive materials are no longer required.

Challenges

Similar to the development of Artillery systems throughout history, there are a number of challenges the Electromagnetic Railgun must overcome before accomplishing its full potential. These challenges are all associated with the massive amounts of energy a railgun can produce. The ability to store large quantities of energy in a small space, the lifespan of the railgun, and the durability of the munition and associated fuses are all potential challenges the railgun program seeks to overcome.

The stored energy requirements for an electromagnetic railgun are still considerably large. The electromagnetic railguns currently undergoing testing in Dahlgren, VA require "super capacitors" that fill a small warehouse. Research in power management is still essential to create smaller power generation systems required to develop a feasible mobile land based launcher system.[22]

Exposure to the large quantities of energy generated by a railgun have a significant impact on the life of the gun. Typical artillery tubes can handle over one thousand shots or more before requiring replacement or maintenance, however, current tests of the railgun can require dismantling after two or three shots. The gun gets hot and wears rapidly with such high energy exposure. The internal components need to be checked for durability during testing as well, which requires more dismantling. However, research is in progress to develop multi-shot railguns that can withstand possibly over 1,000 launches before requiring replacement or maintenance.[23]

The hypervelocity projectile also needs to be developed further to withstand the forces against it during very high acceleration. Conventional munitions are designed to withstand a force of approximately 6,000 g during launch. A 32MJ shot from a railgun exposes the projectile to g forces upward of 20,000-30,000 g.[24] A railgun capable of launching munitions over 370km could expose a munition to over 100,000 g.[25] In conjunction with the durability of the munition, any electronic guidance packages or fuses onboard the munition would need to withstand the same forces.

Despite these challenges, accomplishments over the past ten years and current testing are promising. Research and development computer models project that all of these potential roadblocks are surmountable within the next 15 years. Successfully overcoming these challenges and introducing an electromagnetic railgun on land should significantly impact the capabilities of artillery employment on the future battlefield.

Into the Future

The ability to propel a projectile at extremely high velocity and incredible distances has great potential for future technology. In addition to use as a surface to surface weapon for use by the United States military, the railgun could be converted for other military and commercial uses. Launching objects to exo-atmospheric altitudes is a capability that could be further developed by the National Aeronautics and Space Administration (NASA), the Air Force, or the Missile Defense Agency to name of few.

The United States Government is already approaching the potential cost saving alternative of electromagnetic railgun technology for ballistic missile defense. The strategic forces subcommittee of the House Armed Services Committee has requested both the US Missile Defense Agency (MDA) and the Strategic Capabilities Office determine the suitability of the railgun for technology transfer to the MDA for further development activity, perhaps realizing the fortuitous assessment by Rand in 1985.[26] In addition to ballistic missile and air defense, an electromagnetic railgun could be developed to shoot down satellites or other objects in low earth orbit.

NASA and commercial space launch companies have also expressed interest in the technology. Potential space applications could be designed to launch satellites into low earth orbit, or propel objects into outer space with the assistance of traditional rockets. Researchers are currently examining the potential of using unmanned pods, and if successful, envision launching manned vessels in the future.[27] Elon Musk, the founder of Tesla Motors and SpaceX has proposed using electromagnetic railguns for mass transit to propel passengers between American cities.[28]

In conclusion, a ground based Electromagnetic Railgun would provide a critical asset to the commander and warfighter in future conflicts. The potential improvement over existing capabilities should not be overlooked. The Electromagnetic Railgun provides a potential less expensive alternative to the multimillion dollar Tomahawk cruise missiles, GMLRS, and ATACMS missiles that have dominated the majority of recent long range surface to surface employment. Increase in range and rate of fire, alongside significantly reduced costs and logistics requirements can undoubtedly provide the warfighter with superior firepower in the close and deep fight. The electromagnetic railguns ability to propel lethal munitions at hypersonic speeds hundreds of miles away using magnetic fields, and generate devastating kinetic energy impacts will give United States forces a decisive advantage over any future adversary.

[1] Julianne V. Dickerson, "Toward Super Capacitor Based Pulse Power for Rail Guns on Naval Ships" (M.S.E.C.E., Purdue University), 2.
[2] "Setting Pulses Racing: High-Energy Weapon Systems Get Ready for Sea," *Jane's International Defense Review* 47, no. 6 (Jun 1, 2014, 2014),4-5.
[3] "HyperVelocity Guns," *Jane's Strategic Weapon Systems* (25 Jul 2014), 1.
[4] TB Garber, "Defending Airbases with Electromagnetic Guns," (1986), 1.
[5] Peter Waldman, "Firms to Develop Electromagnetic Guns for United States Tanks --- Pentagon's Work has Goal of Projectiles at Twice the Conventional Speed," *Wall Street Journal* (Sep 17, 1986), 1.
[6] Edmund L. Andrews, "Patents; Electromagnetic Gun," *New York Times,* Jul 2, 1988, 1.
[7] Nick Jonson, "Marines Seek Electromagnetic Gun for the MEFFV Family of Vehicles," *Aerospace Daily* 206, no. 21 (Apr 29, 2003, 2003) 1.
[8] Geoff Fein, *Navy Sets New World Record with Electromagnetic Railgun Demonstration* (Lanham, United States, Lanham: Federal Information & News Dispatch, Inc.,[2010]).
[9] *Setting Pulses Racing: High-Energy Weapon Systems Get Ready for Sea*, 4-5.
[10] Ibid, 4-5.
[11] Dickerson, *Toward Super Capacitor Based Pulse Power for Rail Guns on Naval Ships*, 1-2.
[12] Jonathan BA Bailey, *Field Artillery and Firepower (*Naval Institute Press, 2004) xv-xxvi.
[13] Christopher F. Bentley, "The Future of Field Artillery." *Fires* (Mar/Apr 2014): 8-11
[14] Richard Scott, "BAE Systems Takes EM Railgun Development Forward," *Jane's Defence Weekly* 50, no. 42 (Sep 18, 2013) 1-3.
[15] Gary Stephens, "Precision Fires, Rocket and Missile Systems Project Manager's Update," *Fires* (Jul/Aug 2013), 42-45.
[16] "Catapulting Ahead," *The Economist,* Mar 8, 2014, 23.
[17] http://www.bga-aeroweb.com/DoD-Missile-Programs.html
[18] Stephens, *Precision Fires, Rocket and Missile Systems Project Manager's Update*, 42-45
[19] http://www.bga-aeroweb.com/Defense/Tomahawk.html
[20] Kristofer Womack, "Railgun: A Revolutionary Surface Advancement," *United States Naval Institute.Proceedings* 137, no. 1 (Jan 2011, 2011), 73-75.
[21] Jeremiah Gutlier, "Operations Odyssey Dawn (Libya): Background and Issues for Congress," *United States Congressional Research Service* R41725 (30 March 2011), 25.
[22] Anonymous, *HyperVelocity Guns*
[23] *Catapulting Ahead*, 2
[24] "Bae Systems to Develop Next-Gen Guided Projectile for Us Navy," *SP's Naval Forces,* Nov 2013.
[25] Anonymous, *HyperVelocity Guns*
[26] *Bae Systems to Develop Next-Gen Guided Projectile for Us Navy, 1.*
[27] http://www.universetoday.com/73536/nasa-considering-rail-gun-launch-system-to-the-stars/
[28] *Catapulting Ahead.*

Bibliography

"Bae Systems to Develop Next-Gen Guided Projectile for Us Navy." *SP's Naval Forces* (Nov 2013, 2013): n/a.

"Catapulting Ahead." *The Economist* 410, no. 8877 (Mar 8, 2014, 2014): 23-SS26.

"Electromagnetic Gun." *Popular Science* 245, no. 5 (Nov 1994, 1994): 32.

"Marine Corps Proposes Electromagnetic Rail Gun Vehicle Weapon." *Defense Daily* 216, no. 8 (Oct 10, 2002, 2002): 1.

"Setting Pulses Racing: High-Energy Weapon Systems Get Ready for Sea." *Jane's International Defense Review* 47, no. 6 (Jun 1, 2014, 2014): n/a.

Andrews, Edmund L. "Patents; Electromagnetic Gun." *New York Times,* Jul 2, 1988, 1988.

Anonymous. "HyperVelocity Guns." *Jane's Strategic Weapon Systems* (25 Jul 2014, .

Bailey, Jonathan BA. *Field Artillery and Firepower* Naval Institute Press, 2004.

Bentley, Christopher F. "The Future of Field Artillery." *Fires* (Mar/Apr 2014, 2014): 8-11.

———. "State of the Field Artillery." *Fires* (Jan/Feb 2014, 2014): 9-12.

By Geoff Fein. *Navy Sets New World Record with Electromagnetic Railgun Demonstration.* Lanham, United States, Lanham: Federal Information & News Dispatch, Inc., 2010.

By Peter Waldman. "Firms to Develop Electromagnetic Guns for United States Tanks --- Pentagon's Work has Goal of Projectiles at Twice the Conventional Speed." *Wall Street Journal,* Sep 17, 1986, 1986.

Dickerson, Julianne V. "Toward Super Capacitor Based Pulse Power for Rail Guns on Naval Ships." M.S.E.C.E., Purdue University, 2013.

Eckstein, Megan. "Onr Advances Em Railgun, Researching Platforms for Future Capability." *Inside the Pentagon's Inside the Navy* 25, no. 9 (Mar 5, 2012, 2012): n/a.

Fein, Geoff. "BAE Systems to Develop High-Velocity Projectile for USN's Railgun." *Jane's International Defense Review* 46, no. 12 (Dec 1, 2013, 2013): n/a.

Garber, TB. "Defending Airbases with Electromagnetic Guns." (1986).

Gleckler, James M. "Neglected, Hard-Learned Lessons: Looking Back at Field Artillery Tactics, Techniques and Procedures in Major Combat Operations." *Fires* (Sep/Oct 2012, 2012): 53-62.

Gourley, Scott R. "Precision Brings Artillery Back into the Fight." *Army* 56, no. 12 (Dec 2006, 2006): 58-60,62.

Gutlier, Jeremiah. "Operations Odyssey Dawn (Libya): Background and Issues for Congress." *United States Congressional Research Service* R41725, (30 March 2011).

Jackson, Joseph A. "Moving Artillery Forward: A Concept for the Fight in Afghanistan." *Fires* (Mar/Apr 2011, 2011): 19-24.

Jonson, Nick. "Marines Seek Electromagnetic Gun for the MEFFV Family of Vehicles." *Aerospace Daily* 206, no. 21 (Apr 29, 2003, 2003): 1.

Li, Jun, Shizhong Li, Peizhu Liu, Yingchun Gui, Ning Su, Jiannian Dong, Jun Zhang, Yinghui Gao, Weiqun Yuan, and Ping Yan. "Design and Testing of a 10-MJ Electromagnetic Launch Facility." *IEEE Transactions on Plasma Science* 39, no. 4 (Apr 2011, 2011): 1187.

Paschal, Steve. "Return of the Gun Line." *United States Naval Institute.Proceedings* 140, no. 8 (Aug 2014, 2014): 50-54..

Ralston, David C. "US Field Artillery Azimuth 2005-2015." *Military Technology* 30, no. 2 (2006): 91-93.

Schmidt, Ed and Harry Fair. "The Institute for Advanced Technology - Advancing the State-of-the-Art in Electromagnetic and Hypervelocity Research." *Army AL & T* (Oct-Dec 2007, 2007): 20-23.

Scott, Richard. "BAE Systems Takes EM Railgun Development Forward." *Jane's Defence Weekly* 50, no. 42 (Sep 18, 2013, 2013): n/a.

Seligman, Lara. "Navy Working with Army on Ground Combat Applications for Electric Gun." *Inside the Pentagon's Inside the Navy* 27, no. 15 (Apr 14, 2014, 2014): n/a.

Stephens, Gary. "Precision Fires, Rocket and Missile Systems Project Manager's Update." *Fires* (Jul/Aug 2013, 2013): 42-45.

Womack, Kristofer. "Railgun: A Revolutionary Surface Advancement." *United States Naval Institute.Proceedings* 137, no. 1 (Jan 2011, 2011): 73-75.