CANADIAN FORCES COLLEGE / COLLÈGE DES FORCES CANADIENNES
JCSP 33 / CCEM 33

EXERCISE/EXERCICE NEW HORIZONS

New Naval Weapons Systems and Their Revolutionary Impact on Operations

By

LCdr Knorr

ABSTRACT

Increasing globalization of the world economy makes oceanic transport more important than ever to the nations of the world. To ensure unfettered access to this vital transportation resource, maritime forces comprised of capably armed and crewed warships will continue to be necessary. The environment that these forces will be operating in will be global in nature and the threats, both conventional and asymmetric, will become increasingly complex. This in turn will necessitate the development of revolutionary new naval weapons systems and attendant employment doctrine in order to counter these threats. This paper argues that two classes of weapons, directed energy weapons and electromagnetic rail guns, which are currently in development and on the cusp of being employed operationally, will revolutionize the conduct of naval warfare in the 21st century. It then analyzes these two naval weapons systems, both separately and jointly, against a diverse range of possible future threat scenarios for their expected impact on tactical, operational and strategic naval war fighting doctrine. Finally, this paper concludes with a projected timeline of when these two naval weapons systems are expected to enter service.

INTRODUCTION

What will be the importance of maritime power in the 21st century? Two facts are particularly relevant to the discussion. One is that about seventy percent of the world's population lives within one hundred and fifty kilometres of a coastline and with some seventy percent of the surface of the globe covered by saltwater, the world is still dominated by the oceans. While cyberspace has shrunk the world in terms of communications, physical participation anywhere remains subject to the tyranny of distance. Increasing globalization of the world economy makes oceanic transport more important than ever and hence more states and non-governmental entities than ever are concerned with secure and reliable paths at sea.[1] These paths extend far and wide, stretching from alongside berths to the sea lines of communications of the high seas and littorals of all coastal states. The ongoing security of these paths can only be assured by responsible and trustworthy nations' maritime forces employing capably armed and crewed warships ready, willing, and able to apply force as, when and where necessary. The environment that these forces will be operating in will be global in scope with increasingly complex threats to be countered from land, sea, air, and possibly space. These threats will be both traditional and asymmetric in nature, and moreover, will be overlaid with an ever-accelerating pace of change. All in all, a daunting prospect for the world's navies.

Ever since ships were first armed with weapons there has been an endless series of developments to improve and expand the capabilities of these weapons along with attendant

---

[1] W.J. Holland Jr., "THE FLEET low profile today, VITAL TOMORROW," *U.S. Naval Institute*

changes to the tactics used to employ them. In the main, these developments have followed an evolutionary, incremental path. However, on rare occasions, the developments have been radically innovative in nature. For example, the invention of submarines equipped to fire torpedoes while submerged and aircraft carriers able to launch and recover armed attack aircraft indisputably and unalterably fundamentally changed the nature of warfare at sea.[2] Another arguably comparable revolutionary[3] advance in naval weapons' development is fast approaching along two new main technological axes.

One class of these new weapons, directed energy weapons, is expected to largely displace guns and missiles from their kinetic interceptor[4] roles in ship and theatre area air defence as well as adding new offensive capabilities to warships. Whereas, it is anticipated that the other new weapons class, electromagnetic rail guns, will put naval gunfire support back into the Navy as a key capability area once again. A capability that was largely lost due to surface-to-surface missiles coming to the fore and the subsequent decommissioning of the last of the big-gunned ships; U.S. Iowa class battleships, in the early 1990's.[5]

Weapons systems such as directed energy weapons and electromagnetic rail guns have

---

Proceedings Vol. 132, Issue 5 (May 2006): 53; http://proquest.umi.com; Internet; accessed 5 February 2007.

[2] Terry C. Pierce, *Warfighting and Disruptive Technologies: Disguising Innovation* (New York: Frank Cass, 2004), 25.

[3] The Merriam Webster Dictionary defines revolutionary as: constituting or bringing about a major change. From: "Merriam-Webster OnLine," http://www.m-w.com/dictionary/revolutionary; accessed 19 April 2007.

[4] Kinetic interception is where projectiles are used to intercept and shoot down other incoming projectiles. Also known as a "hard kill".

[5] John McFarland and Ian R. McNab, "A Long-Range Naval Railgun," *IEEE Transactions on Magnetics*, Vol. 39, No. 1 (January 2003): 289.

recently moved from the realm of science fiction and are now close to being ready to move from the laboratory to experimental and thence operational platforms. These weapons systems have the potential to dramatically change the conduct of warfare at sea. Change it not only at the tactical level but, as well, at the operational and potentially even as far as the strategic level. In turn, these new capabilities will drive significant revisions to naval tactics and operational doctrine in particular and to a more limited extent that of strategic doctrine. This essay will analyze the implications contained therein.

This paper will discuss each of these new weapons systems in turn, first introducing the weapons system, then briefly describe its technical aspects, proceeding to elaborate on the new capabilities it brings to the Navy, and lastly, explore the tactical, operational and, if applicable, strategic implications for naval operations in the future. The summary and conclusion section will then draw all of these weapons systems' discussion threads together to provide a comprehensive view of envisioned Naval capabilities and attendant tactical, operational, and strategic naval warfare doctrine in the near to medium future. As the directed energy class of weapons is considered to be the most revolutionary of the two, it will be analyzed first.

DIRECTED ENERGY WEAPONS

What are directed energy weapons? The concept of such weapons has been around for decades, particularly in the realm of science fiction of the comic book variety where "death rays" have long been staple fare. However, it was not until the advent of the U.S.'s Star Wars program that the technology began to mature to the point of feasibility. This research spawned two kinds

of directed energy weapons: lasers and high power microwaves.[6] These high power microwave weapons in turn split into two broad classes – broadband and narrowband. In simple terms then, the class of weapons being discussed here includes the range from electronic jammers to laser cutting torches.[7]

Even though there are many different types, all lasers work in a similar fashion. Essentially, a laser is a light source which, when stimulated in a particular manner, produces a coherent, narrowly-focused beam of light at a single wavelength. The minute cross-section combined with the coherent nature of the light results in a beam with a very high energy density; energy which can then be conveyed a considerable distance across a suitable medium before being attenuated. Raise this beam's energy density to a sufficiently high level, marry it up with a cueing, tracking, and control system such that the beam can be directed and locked onto an object and one now has a directed energy weapon capable of affecting targets by heating them to the point where the target sustains material damage and eventually - destruction. The higher the energy density of the laser beam and the narrower the beam-width the greater the energy conveyed over a given distance and hence the longer the effective engagement distance obtainable.

Analagously, all high power microwave devices work in a similar fashion, but instead of using light energy, they employ electromagnetic energy. Once again, raise the density of the

---

[6] Note: in some parts of the literature the term radio-frequency weapons is used instead of high power microwaves. The two terms are interchangeable but for the sake of consistency this paper will use high power microwave weapons exclusively.

[7] Bob Preston, *et al*, *Space Weapons: Earth Wars* (Santa Monica, CA: Rand, 2002), 24-25.

microwave energy high enough and channel it in a suitable direction and one now has a directed energy weapon capable of affecting targets; this time through disruptive / destructive electromagnetic interference. This type of weapon comes in two forms. The first is wideband, which, like a flashlight, radiates electromagnetic energy over a wide spectrum but with a relatively low power density. The other is narrowband which, like a laser, emits energy over a small band of frequencies with a very high power density. In general, narrowband high power microwave devices are designed to be tuneable and reusable – firing "pure energy" pulses - which makes them relatively complex to construct, whereas wideband devices tend to be simpler to construct but usually at the cost of being only one-shot devices,[8] intended to be used as off-board weapons. Consequently, the most common variety of wideband high power microwave weapons are similar to conventional kinetic-based naval weapons in that they will require onboard magazine capacity along with attendant re-supply considerations.

The central historical problem with creating effective directed energy weapons has been the practical difficulties in generating the levels of power necessary to affect targets at an operationally useful stand-off distance. Why, then with all of these development problems has the concept of directed energy weapons persistently maintained their allure for military commanders throughout the years? The underlying rationale is found here:

> Directed energy weapons [DEWs] will provide revolutionary combat capabilities to U.S. Armed Forces in the early twenty-first century. Operational fires delivered by DEWs represent a dramatic departure from employment of current weapons. Laser and RF weapons offer the ability to

[8] Michael Abrams, "Dawn of The E-Bomb," *IEEE Spectrum* Vol. 40, no. 11 (November 2003): 26.

> precisely deliver lethal power to points across the globe at instantaneous speeds - deeply altering our conception of operational factors time, space and force.[9]

In a word, speed. Without a doubt, the current iterative spiral of one-upsmanship occurring with missile developments becomes completely altered when incredible speed differentials such directed energy weapons operating at Mach 1 million have over missiles operating at speed Mach 2-3 are introduced into the equation.[10] This multiple orders of magnitude increase in speed of effect is the key reason why it is contended that directed energy weapons will have a revolutionary effect on the conduct of naval warfare in the future.

In comparing and contrasting the two types of directed energy weapons one finds that they share many similarities but also possess some key differences. The two types are similar in that both provide a new form of weapon where destructive power travels at light-speed[11] and both are capable of providing a graduated range of effects, from degrade through to disrupt, damage and destroy.[12] This graduated range of weapons' effects is a singularly valuable characteristic to a commander in that it provides a multitude of escalatory

---

[9]Sean L. Jersey, Major, USAF, "Twenty First Century Warfare – Theater Operations as the Speed of Light." (Newport: Naval War College, 03 February 2003), 1- 2; http://www.stinet.dtic.mil/; Internet; accessed 05 March 2007.

[10]William J. McCarthy, Captain, USN, "Directed Energy and Fleet Defense: Implications for Naval Warfare," (Montgomery: Air War College, Air University, Center for Strategy and Technology, Occasional Paper No. 10, May 2000), 20; http://www.stinet.dtic.mil/; Internet; accessed 29 January 2007.

[11]Note: although the blast effect from the one-shot wideband subset of high power microwave weapons does travel at light speed, as previously discussed, these weapons are first deployed off-board via projectiles which travel at many orders of magnitude less than the speed of light. So clearly, this particular sub-type of directed energy weapon when viewed from the overall weapon systems' perspective does not operate at the speed of light.

[12] McCarthy, Directed Energy and Fleet Defense: 28, 30.

options. Consider the scenario whereby one is confronting a conventional threat armed with electro-optical and electromagnetic sensors used for surveillance, tracking and weapons cueing and guidance. At the non-lethal end of the escalatory scale, one could employ both types of directed energy weapons at low power to "jam" and degrade the performance of these sensors. Ratcheting up the power a few notches, one could override the sensors' input signals thereby disrupting their performance but not yet causing any materiel damage. Moving up the escalation scale towards the lethal end, additional power could then be added to overwhelm the sensors' protective circuitry to the level where irreparable damage occurs and, at a certain point, sensor destruction.

Looking at a more unconventional situation such as near-littoral[13] operations, where, for example, emerging and evolving urban conflict scenarios in which combatants are indistinguishably intermingled with civilians gives rise to new weapons requirements such as: greater precision, non-lethal anti-sensor / anti-electronic weapons to both minimise collateral damage and permit controlled escalation – particularly important for peace support ops-[14] one once again finds that this "graduated effects" capability of directed energy weapons is particularly relevant and useful to an on-scene commander. No other weapons system can provide this unique combination of precision, scalability, and speed of effect.

---

[13] The Royal Australian Navy defines the littoral as: those areas on land which are subject to influence by units operating at or from the sea, and those areas at sea subject to influence by forces on or from the land. From: Australia, Department of Defence, *Australian Maritime Doctrine* (Canberra: Defence Publishing Service, October 05, 2001), 11. In practice, from a ship's perspective, the near-littoral is generally considered to be from the outer limit of contiguous waters to the shoreline – a distance of 24 nautical miles for most nations while the far-littoral is generally considered to be bounded by the outer limit of the exclusive economic zone – a distance of 200 nautical miles.

[14] Gerd Wollman, "Directed Energy Weapons: Fact or Fiction?," *Military Technology* Vol. 27, no.4 (April 2003): 80.

In both of the aforementioned examples, a key constraint on operations would be the length of time that a ship could remain on station without resupply. Here, as "pure energy" vice kinetic weapons, contingent upon power being available, directed energy weapons have the unparalleled advantage over conventional weapons of essentially having a bottomless magazine.[15] Hence both types of these weapons have the potential for use in a wide range of both defensive and offensive naval conflict scenarios. This flexibility of employment of directed energy weapons both across the spectrum of possible conflict scenarios and spanning the escalatory scale of said conflicts is another key reason why one contends that they will revolutionize future naval warfare.

One key difference amongst the two classes of directed energy weapons is that unlike lasers, microwave emissions are unaffected by weather. This is particularly advantageous in military operations as military arsenals contain few weapons that can retain full function regardless of the weather.[16] Implied in this contention is the fact that ship-based high power microwave weapons would need to be equipped with gyro-stabilised antennas and posses an alternate capability to be cued onto targets from other platforms either above or beyond inclement weather in order to truly have an "all weather" capability.

Another key difference is that of stealth. Unlike the majority of lasers which utilize

---

[15] Note: this does not apply to the one-shot wideband subset of high power microwave weapons because, as previously discussed, these weapons are deployed off-board via non-reusable projectiles.

[16] Ellen M. Walling, Colonel, USAF, "High Power Microwaves Strategic and Operational Implications for Warfare," (Montgomery: Air War College, Air University, Center for Strategy and Technology, Occasional Paper No. 11, May 2000), 7; http://www.stinet.dtic.mil/; Internet; accessed 29 January 2007.

visible light beams,[17] high power microwave weapons operate without visible emanations and this has led some commentators to refer to them as "perfect weapons" as follows:

> …the perfect weapon would literally stop an enemy in its tracks, yet harm neither hide nor hair. Such a weapon might shut down telecommunications networks, disrupt power supplies and fry an adversary's countless computers and electronic gadgets, yet still leave buildings, bridges, and highways intact. It would strike with precision, in an instant, and leave behind no trace of where it came from.[18]

The advantages of possessing such a covert weapons system are evident, as, when combined with the aforementioned "graduated effects" and rapid response capabilities, they become ideal for politically sensitive situations such as exercising the right of innocent passage or while anchored in another nation's territorial waters.[19] The more sophisticated the adversary's infrastructure and armaments, the greater the advantage. Nevertheless, even against relatively low-technology foes the ability to disrupt their surveillance activities and communications and defend against attacks from any motorised craft, still gives the possessor a considerable advantage.

What effect will directed energy weapons have on the tactical, operational and strategic doctrine underpinning naval warfare in the twenty-first century? United States Navy Captain

---

[17] Note: although in theory lasers can be created from light sources spanning the entire spectrum of visible and invisible light, in practice, for technical reasons, the majority of lasers suitable for weaponization have been developed using visible light sources.

[18] Abrams, Dawn of The E-Bomb, 24.

[19] McCarthy, Directed Energy and Fleet Defense: …, 43.

William McCarthy, who has written extensively on the topic, asserts that:

"The introduction of directed energy weapons has the potential to change naval warfare as fundamentally as the transition from sail to steam."[20] This is not an isolated opinion, other commentators have also posited similar sentiments such as:

> They [directed energy weapons] all share certain characteristics which mark them as potentially revolutionary….First, they deliver lethal blows at the speed of light….Second, the cost of firing such weapons is typically a small fraction of what it costs to fire a missile or large gun …method of destruction pure energy…Third…provide warfighters with surgically precise and discriminate firepower…. Finally, …potentially enable warfighters to very rapidly engage many different targets, because of their instantaneous effects.[21]

While there may be a considerable debate in the literature as to what extent directed energy weapons will revolutionize naval warfare in the years to come, there was no credible body of evidence found which disputed the belief that not only would their impact be momentous but ever increasingly so with the passage of time.

The potential uses of ship-based directed energy weapons in both tactical and operational scenarios are wide and varied. Defensively, these range from protection of ships in harbour via placement of high power microwave barriers around ships through to speedboat pursuit and disablement and up to and including creating a barrier of off-board high power microwaves as

---

[20] *Ibid.,* 1.

[21] Loren B. Thompson, "The Emerging Promise (And Danger) of Directed Energy Weapons," (Lexington Institute Capitol Hill Forum on Directed Energy, Washington D.C., 11 Jul 2002): 2; http://lexingtoninstitute.org/255.shtml; Internet accessed 06 March 2007.

anti-missile systems[22] as well as intercepting missiles via disabling or destructive laser and high power microwave energy pulses generated from reusable weapons systems. Certainly, as a minimum it is reasonable to expect that directed energy weapons will replace CIWS-like[23] projectile-based defence systems for last-ditch platform defence against missiles and aircraft. Similarly, concerning operational scenarios, suitably equipped warships' directed energy weapons with their orders of magnitude speed and consequent stand-off distance advantage over conventional guns and missiles will be able to provide a multi-layered area defence against all manner of surface and airborne threats up to and including theatre ballistic missiles.

As regards potential changes to offensive naval doctrine, given that warships and aircraft are bristling with communication and sensor antennae, they become prime targets for an attack with high power microwave weapons.[24] So, it is not difficult to imagine a scenario whereby an attack is carried out by first using high power microwave weapons to covertly "blind" the enemy followed by a combination of laser "energy" fires and kinetic missile and gun fires to overwhelm the opponent – with a significant portion of the striking power being delivered at nearly instantaneous speeds.

Given the fact that:

---

[22] Wollman, Directed Energy Weapons: Fact or Fiction?, 83.

[23]Close-in Weapon System (CIWS) is a shipboard weapon system used for detecting and destroying incoming anti-ship missiles and enemy aircraft at short range. Thus it is the anti-air defensive capability of "last resort". A typical CIWS consists of a combination of radars, computers, and multiple rapid-fire medium-caliber guns on a rotating gun mount. It is considered to be standard fitted equipment for warships corvette-sized and up.

[24]McCarthy, Directed Energy and Fleet Defense: …,12.

> In the case of lasers…intense beams of monochromatic light can be precisely aimed across hundreds or thousands of kilometers to disable a wide range of targets, from missiles to satellites to aircraft to ground vehicles and even people…. They can also be reflected off of mirrors in space to hit targets not visible from their source while retaining much of their initial influence.[25]

it is evident that the laser-based class of directed energy weapons has the potential to have a significant effect on naval warfighting doctrine beyond the tactical and operational levels all the way up to the strategic level. It is important to note that if this strategic level of laser weapons usage is in fact developed and exploited, this would move naval warfare actively into a new frontier - space – which would have a myriad of implications for existing space usage and arms control treaties. Unquestionably, such a move into the geostrategic realm would have a profound effect on future naval strategic doctrine.

In summary, directed energy weapons will revolutionize both defensive and offensive naval operations while, at the same time, offer significant future growth potential for range, lethality, and accuracy which in turn will expand both the type and scope of missions that can be undertaken by warships. However, they will not carry out this revolution alone. Rather, they will be aided and abetted by another emerging class of naval weapons – electromagnetic rail guns – to which this essay will now turn its attention.

---

[25] Thompson, The Emerging Promise …, 1.

ELECTROMAGNETIC RAIL GUNS

What is an electromagnetic rail gun? It is a gun in the conventional sense in that it fires a projectile from a gun barrel but it is unconventional in that it does not use a combustible chemical propellant to do so and its barrel is two electrically- conducting rails vice a sealed chamber. The scientific theory underpinning the operation of electromagnetic rail guns (hereafter referred to as rail guns) is relatively simple and straightforward. Essentially, rail guns operate by exploiting the basic physical property of magnets that opposite magnetic poles attract each other and like magnetic poles repulse each other. A rail gun then is nothing more than a series of electromagnets oriented in such a way that they all have the same polarity and hence create repulsive forces which are then used to impart propulsive energy to a metal projectile.[26]

As the amount of energy imparted to the projectile is proportional to the square of the current and length of the rails[27] by using either a large current or long rails or a combination of both, one can achieve a very high muzzle velocity and hence a long range[28] coupled with both a

---

[26] Note: A more detailed technical explanation of the EM rail gun's construct follows. Reviewing basic electromagnetic principles: electromagnets are created by flowing an electric current through a conductor which in turn creates a corresponding magnetic field around the conductor with a field strength proportional to the square of the current and with a polarity dependent upon the direction of the current flow. Therefore, the basic design of an EM rail gun consists of: two rails situated in parallel – both of which are capable of conducting electricity, a metal projectile sized to fit snugly enough between the rails to form a circuit capable of conducting electricity from one rail to the other, and lastly an electrical power supply connected across one end of the two rails. Upon energization, current flows out of the power supply, along one rail, across the base of the projectile, down the other rail and back into the power supply thereby completing the electrical circuit. Now since the polarity of the magnetic fields created around the conductors is the same, the resultant electromagnetic forces act in opposition and hence all of the conducting elements attempt to repel one another. Because the rails are fixed in place but the projectile is free to move, the energy imparted by these repelling forces accelerates the projectile along the rails; continuing until such time as the projectile leaves the rails and the electrical circuit is broken.

[27] Note: the longer the period of contact the greater the energy transferred from the rails to the projectile.

[28] Note: for a fixed rail length a rail guns' muzzle velocity can be altered simply by changing the input current. Thus providing the option of varying the projectile's range and kinetic energy delivered to target without altering either the size or mass of the projectile or the elevation of the rail gun.

short flight time and a large amount of kinetic energy delivered to the target.

The rail gun has many advantages over a conventional gun and they all stem from one source – very high muzzle velocities. This makes it possible to use the rail gun projectile's kinetic energy directly as the lethality mechanism vice using exploding projectiles.[29] This then allows the use of high density materials for the flight body which in turn reduces projectile size and consequent aerodynamic drag and hence further increases both the range and kinetic energy delivered to the target.[30] The amount of kinetic energy that can be delivered by one of these relatively small projectiles is impressive. For example, one study has found that: "A 60 kg EM gun round impacting at 2km/s delivers 80% of the energy in an Iowa-class 16" gun round, and fifteen times the energy of the current 5" gun high explosive projectile."[31] In essence then, each round from a typical naval EM rail gun would provide the same amount of firepower as a sizeable missile.

In addition, the inert kinetic energy rounds also require no propellant, therefore ship survivability is significantly enhanced with the elimination of the 9000 MegaJoules (MJ) of chemical energy typically found in a double 600-round magazine of conventional five inch

---

[29] Note: As there is no factor prohibiting their use in rail guns, high explosive or fragmenting rounds could be carried for those missions requiring such munitions. But at the cost of magazine space due to their decreased density and hence increased size along with reduced survivability of the ship as a result of replacing inert material with explosives.

[30] W.A. Walls, *et al*, "Application of Electromagnetic Guns to Future Naval Platforms," *IEEE Transactions on Magnetics*, Vol. 35, No. 1 (January 1999): 263.

[31] Ivan T. Luke, Jr. and Michael F. Stumborg, "The Operational Value of Long Range Land Attack EM Guns to Future Naval Forces," IEEE Transactions on Magnetics Vol. 37, no. 1 (January 2001): 60.

ammunition.[32] Further, the smaller-sized projectiles greatly increase the amounts that can be carried onboard. For example, the U.S. Navy's new 155 mm Advanced Gun System's magazine is expected to hold up to 1500 rounds. About 10000 EM rail-gun all-metal projectiles could be carried in the same-sized magazine.[33]

Why is it asserted that rail guns will revolutionize warfare at and from the sea? The following observation provides some insights:

> A navy that can directly oppose enemy land forces without access to foreign ports and airfields will be an extremely valuable instrument of national security in the current (and predicted) world order. A naval force that is a full and continuing participant in the land campaign is a radically new warfare concept, previously not considered due primarily to the expense and limited range of ship-based weapons systems.[34]

One could perhaps argue that this "radically new warfare concept" is merely the long-standing tactical / operational level naval mission of providing Naval Gunfire Support (NGS) to troops ashore and point to the recent U.S doctrinal changes to amphibious operations – Ship to Object Manoeuvre (STOM) – which mostly replaced landed artillery with continuous naval fire support and renewed the requirement for both larger calibre and longer-range naval guns[35] as evidence of the fact. One argues that that doctrinal change merely incrementally enlarged the battle space

---

[32] McFarland and McNab, A Long-Range Naval Railgun, 289.

[33] LCdr David A. Adams, "Naval Rail Guns Are Revolutionary," *U.S. Naval Institute Proceedings* Vol. 129, Issue 2 (February 2003): 37; http://proquest.umi.com; Internet; accessed 20 March 2007.

[34] Luke and Stumborg, The Operational Value of Long Range, …, 58.

[35] Massimo Annati, Captain ITN, "Naval Guns – Latest Developments in Mounts and Ammunition," *Naval Forces* Vol. 24, Issue 6 (2003): 111; http://www.ebscohost.com; Internet; accessed 28 February 2007.

that NGS could operate in; the reality is that conventional naval gun ranges, even with advanced projectiles, have essentially reached their theoretical physical limits.[36] In contrast, the unconventional rail guns with their range, speed, lethality and accuracy provided by guidable munitions will provide not only the capability to revitalise NGS but indeed totally revolutionize the concept.

A first generation rail gun firing a 16 kilogram projectile with a 2000 meters per second muzzle velocity would be capable of placing 13 MJ of kinetic energy on a target at about 140 nautical miles - at a continuous rate of 12 rounds per minute.[37] The second and third generations of these guns are forecasted to have ranges of about 250 – 300 nautical miles[38] and as far as 400 nautical miles[39] respectively. So, the primary naval supporting fires[40] roles will initially be NGS

---

[36] Note: which for conventional munitions is about 30 nautical miles. Of note, the future US Navy's DD(X)[next-generation destroyer] will be equipped with two 155mm Advanced Gun Systems (AGS). These will be the heaviest naval gun mounts built since WWII. They will deliver up to 12 rocket-assisted and Global Positioning System (GPS) / Inertial Navigation unit (INU) – controlled rounds [Extended Range Guided Munitions (ERGMs)] per minute at a maximum range of 100 nautical miles [here again this is considered to be at or near the theoretical limit for these types of munitions] or conventional rounds to 22 nautical miles. From: Massimo Annati, Captain ITN, "Naval Guns – Latest Developments in Mounts and Ammunition," *Naval Forces* Vol. 24, Issue 6 (2003): 111; http://www.ebscohost.com; Internet; accessed 28 February 2007.

[37] McFarland and McNab, A Long-Range Naval Railgun, 289.

[38] *Ibid*., 289.

[39] Michael F. Stumborg, "The Impact of Gun Dimensions on the Operational Effectiveness of a Naval Surface Fleet Equipped With Long Range Electromagnetic Guns," *IEEE Transactions on Magnetics*, Vol. 37 No. 1 (January 2001): 499.

[40] Note: there are two kinds of supporting fires, planned and on-call. Naval EM rail guns could replace a significant proportion of fire missions currently provided by land-based artillery. In concept, the rounds targetabilty could be exploited by firing a succession of rounds into a basket over the enemy's general location with each round being handed off to the ground elements "FOO's" for target assignment as the round re-enters the atmosphere. From Ivan T. Luke, Jr. and Michael F. Stumborg, "The Operational Value of Long Range Land Attack EM Guns to Future Naval Forces," IEEE Transactions on Magnetics Vol. 37, no. 1 (January 2001): 60.

to landed amphibious forces from the far-littorals. The second and third generations of rail guns will provide NGS to land forces up to about two hundred nautical miles inland for the former, and to three hundred nautical miles inland for the latter – again from the far-littorals ranging to blue water, thus reducing the ever-increasing risk to men and material that being close inshore brings to ships with all of the attendant land and shallow-water, sea-based hazards located therein. Further, ships providing NGS will have enhanced protection from submarines as well because these extended ranges will place them far enough at sea to cause deployment speed and sustainment issues for diesel-electric submarines in particular. Considering survivability from the counter-battery threat from ashore, two factors will be important: detectability and manoeuvrability. As there is no secondary combustion of unburned propellant at muzzle exit, the firing signature of a rail gun is expected to be substantially less than a conventional gun.[41] This, combined with increased distance from land and the ship's freedom to manoeuvre will considerably complicate efforts to detect and target the ship. As regards operational and tactical doctrine developments, significant changes to joint communications and targeting procedures with both amphibious and Army forces,[42] as well as upgrades to long-range communications capabilities will be required in order to fully exploit these new extended-range naval gunfire capabilities.

---

[41] McFarland and McNab, A long range naval rail gun, 289.

[42] Note: the distinction is made here between amphibious forces and Army forces because the former's doctrine has included naval gunfire as a key tenet since the force's inception whereas the inclusion of naval gunfire into the latter's doctrine has never been as important due to its inability to influence events more than a few miles inland from the shoreline. However, the rail gun will have a significant tactical /operational impact doctrine, training, etc. for the Army well inshore not just amphibious forces operating in the near - littoral as in the past.

It is envisioned that many future naval operations will require the capability to engage thousands vice hundreds of targets per day as is currently possible with sea-based missiles and carrier aviation. Further, to support ground and amphibious operations ashore solely from a sea-base, naval fires must meet or exceed current shore-based artillery capabilities.[43] A surprisingly small quantity of rail-guns could provide the requisite amount of firepower. For example, one analysis which compared the two hundred-mile volume of fires capability of a single rail gun to a carrier air wing of F/A 18s showed that over an eight hour period the gun could deliver two times the payload, three times the energy to ten times as many fixed aim points as the carrier air wing.[44]

Certainly no one is proposing that rail guns could replace carrier-borne aviation for the full land attack mission, however, a significant operational impact could be gained by employing unconventional technologies to extend the range of naval guns. Guns which could then 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.[45]

Another key feature of rail guns is that in addition to range and lethality, the flight time to target will also be greatly reduced – a Mach 7 rail gun projectile would travel one hundred nautical miles in two minutes – this is operationally significant for prosecuting highly

---

[43] Adams, Naval Rail Guns Are Revolutionary, 34.

[44] *Ibid.,* 35.

[45] *Ibid.,* 34.

manoeuvrable ground targets.[46] This short flight time coupled with guided munitions opens up a plethora of growth potential in providing NGS missions. For example, when coupled with a future system of fully networked targeting sensors organic to the naval force – Network Centric Warfare will be a key enabler – the rail gun will provide the accuracy needed to kill targets moving at up to sixty miles per hour; revolutionary leap as that is currently the domain of manned aircraft or expensive seeker-equipped missiles. This is foreseen to be achievable in the 2030 timeframe.[47]

A key logistical consideration for NGS planning is the degree to which a ship can sustain the fire support mission. Here again the rail gun provides a significant operational advantage over current NGS methods as denoted here:

> A large increase in projectile storage density is possible due to the smaller size of the EM [rail] gun rounds and lack of propellant …leading to … less need for rearming at sea by replacing tens of missiles with thousands of gun rounds. Recent advances in miniaturized and ruggedized components are likely to ensure that gun-launched rounds will be smaller and less expensive than missiles – a cost of $5000 - $10000 per round is possible.[48]

As well, given that re-arming ships' missile magazines at sea is an inherently risky and time-consuming evolution for warships, any reduction in frequency has a positive operational effect on the fleet.

---

[46] *Ibid.* 37.

[47] Luke and Stumborg, The Operational Value of Long Range …, 59.

[48] McFarland and McNab, A Long-Range Naval Railgun, 289.

In order to generate their extremely high muzzle velocities, rail guns, like directed energy weapons, must be supplied with enormous quantities of peak electrical power. This is a significant issue because at present, such quantities of power on mobile platforms - even ones such as large ships and aircraft - are not readily available, and even when it is, rarely is it in the form of switchable electrical power. Putting this in perspective, electrical power on the order of fifteen to sixty MegaWatts (MW) will be required. Therefore a new electric warship like the U.S. Navy's DD(X)[49] which will have about eighty MW total of power available will be required.[50] Thus this high power requirement currently limits envisioned rail gun deployment on a mobile platform to only a ship, not aircraft or land vehicles.

In summary, rail guns will revitalise the NGS mission with significant future growth potential for range, lethality, accuracy and rate of fire. Further, it will do so in a much more efficient fashion cost-wise than the current land-attack missiles can as well as doing it with much less risk to men and material than can carrier-born strike aircraft. The fact that both the volume of naval fires and the distance from which they can be delivered will be at least one and potentially two orders of magnitude greater than any current or planned capabilities from a comparable group of warships indisputably constitutes a major change to the NGS paradigm. It is for this reason, that one contends that rail guns will revolutionize future naval warfare doctrine.

---

[49] Note: the DD(X) ship program has been renamed to DDG 1000 – Zumwalt Class.

[50] Adams, Naval Rail Guns Are Revolutionary, 38.

TECHNOLOGY CONVERGENCE

Directed energy weapons and rail guns share the common characteristic of requiring large amounts of electrical energy to operate. In particular, the high power requirements of a rail gun means that ships will have to possess an electric drive and be equipped with an integrated power system in order to be practical. This availability of large amounts of easily redirected power then enables many possibilities because other high energy systems such as self-defence lasers now become feasible for sea-basing as well.[51] Further, as single-pulse, explosively-driven miniaturised high power microwave sources are currently under development as warheads for artillery and mortar shells and rockets and missiles,[52] one can envision these two revolutionary technologies converging together in the form of a naval rail gun delivering "electronic bombs" hundreds of kilometres inland to disrupt land-based electronic targets or as long range anti-missile interceptors at sea.

There is currently a ship in development that meets the requirements necessary to enable the deployment of these new technologies. After years of study about its relative merits, the U.S. Navy has designed and commissioned the build of the first all-electric warship with its new-generation DD(X) destroyer program. The DD(X)'s all - electric integrated power system will change the way power is generated at sea and will be a cornerstone technology for future weapon

---

[51] Luke and Stumborg, The Operational Value of Long Range …, 60.

[52] Wollman, Directed Energy Weapons: Fact or Fiction?, 82.

systems such as rail guns and free electron lasers.[53]

When will these revolutionary new capabilities likely begin to enter the U.S. fleets? In 2003, USN Rear Admiral Cohen, then director of the U.S. Navy's Office of Naval Research (ONR), stated that: "We think electromagnetic rail guns could be available for DD(X) by 2010; we believe in ONR that the free electron [laser] could be available … for DD(X) by 2010; and that all of these could be available for CVN-21."[54]

Unfortunately Rear Admiral Cohen appears to have been somewhat over-optimistic in his prognostication for both of these programs. The DD(X) ships are scheduled to be delivered to the U.S fleet starting in 2012[55] but on the current (unclassified)[56] plan, none of the class is slated to be fitted with either rail guns or directed energy weapons.[57] However, as the ships' integrated power system will provide the heretofore missing critical enabler of sufficient available electrical power then retrofitting of these new weapons systems will now be feasible.

---

[53] Merrick Carey, "A Zero Sum Navy," *U.S. Naval Institute Proceedings* Vol. 132, Issue 9 (September 2005): 2; http://proquest.umi.com; Internet; accessed 06 February 2007.

[54] Address to the Navy League's 2003 Sea-Air-Space Exposition, Washington, D.C., 15 April 2003, quoted in Hunter Keeter, "Lasers, Rail Guns Could Be Ready For DD(X) By 2010," Defense Daily Vol. 218, Iss. 12 (16 April 2003): 1; http://proquest.umi.com; Internet; accessed 06 February 2007.

[55] Program Executive Office Ships, "DDG 1000 Program Status / Phase IV Schedule," http://peoships.crane.navy.mil/DDG1000/schedule.htm; Internet accessed 20 March 2007.

[56] Note: most of the information on the current development status and attendant capabilities of Directed energy weapons is classified. Accordingly, it is certainly possible that the two U.S. Navy shipbuilding programs under discussion have plans to include at least some Directed energy weapons as initial fits.

[57] Program Executive Office Ships, "DDG 1000 Capabilities and Technologies," http://peoships.crane.navy.mil/DDG1000/Capabilities_and_Tech.htm; Internet accessed 20 March 2007.

The CVN-21 is the U.S. Navy's next-generation aircraft carrier which is anticipated to be built starting in 2008 with delivery of the first of class in 2015. Here as well, the current (unclassified) plan does not include fitting of either rail guns or directed energy weapons.[58] However, once again the critical requirement of sufficient available electrical power will be met to make retro-fitting feasible. Further, with the longer lead times to delivery, it is foreseeable that some of the latter ships in this class will be fitted directly with these new capabilities.

Given the steady progress made in maturing the technology of rail guns and directed energy weapons over the past decade with attendant doctrinal developments in the tactical, operational and strategic spheres as to how best to employ these capabilities; extrapolating outwards, one is led to conclude that it is entirely conceivable that both of these technologies could be fielded and operational within the U.S. Navy within the next decade.

SUMMARY AND CONCLUSIONS

In 2002 Admiral Vern Clark, then the U.S. Navy's Chief of Naval Operations, stated his vision that:

> The 21st century sets the stage for tremendous increases in naval precision, reach and connectivity ushering in a new era of joint operational

[58] United States Navy Fact File, "Aircraft Carriers – CVN 21 Program," http://www.navy.mil/navydata/fact_display.asp?cid=4200&tid=250&ct=4; Internet; accessed 20 March 2007.

> effectiveness. Innovative concepts and technologies will integrate sea, land, air, space, and cyberspace to a greater extent than ever before. In this unified battlespace, the sea will provide a vast maneuver area from which to project direct and decisive power around the globe.[59]

One contends that one of the key enablers of his vision will be the operationalising of directed energy weapons and rail guns on warships because long-duration deployments around the world at strategic speed will require ships of the next fleet to have the self-sustaining endurance for extended tours without strong logistics support. Further they must have the magazine capacities and high-quality sensors to defend themselves and others in company.[60] Only the combination of rail guns with their large magazines and directed energy weapons with their "bottomless magazines" of pure energy fires can hope to meet this stringent requirement. Traditionally, naval defence has protected the unit, the fleet, and the sea lines of communication. Tomorrow's Navy will do much more as it moves beyond just unit and task force defence to provide the nation with sea-based theatre and strategic defence.[61] Again, amongst the set of potential weapons systems on the horizon, directed energy weapons are the only ones with the projected combination of: speed, range, and flexibility needed to accomplish the mission.

Summarising, directed energy technology is beginning to deliver on its promised potential. Existing and planned laser and high power microwave weapons offer the ability to

---

[59]Admiral Vern Clark, U.S. Navy, "Sea Power 21: Projecting decisive joint capabilities," *U.S. Naval Institute Proceedings* Vol. 128, Issue 10 (October 2002): 34; http://proquest.umi.com; Internet; accessed 05 February 2007.

[60] Holland THE FLEET low profile today, …, 55.

[61] Clark, Sea Power 21: Projecting decisive joint capabilities, 32.

deliver precise doses of lethal power to distant targets at nearly instantaneous speeds, thereby raising the possibility for revolutionary advances in combat capabilities. However, operational fires delivered by directed energy weapons represent a notable departure from that of current weapons. Therefore, their use will require significant out-of-theater planning and coordination for effective command and control – issues that have only begun to be addressed.[62]

In conclusion, the long-awaited promise of these two new technologies and the enormous potential step-change in naval weapons capabilities that they bring are on the cusp of being realised. When they make their appearance in the very near future, they will revolutionize the manner in which twenty-first century naval power will be able to be projected and the way in which naval battles will be able to be fought both at sea and from the sea to both near and far distant locations ashore

---

[62] Jersey, Twenty First Century Warfare – Theater Operations as the Speed of Light, 18.

Bibliography – New Horizons

Abrams, Michael. "Dawn of The E-Bomb." *IEEE Spectrum*, Vol 40, no. 11 (November 2003): 24 -30.

Adams, USN LCdr David A. "Naval Rail Guns Are Revolutionary." *U.S. Naval Institute Proceedings* Vol. 129, Issue 2 (February 2003): 34-38; http://proquest.umi.com; Internet; accessed 20 March 2007.

Annati, Massimo, Captain ITN. "Naval Guns – Latest Developments in Mounts and Ammunition." *Naval Forces* Vol. 24, Issue 6 (2003): 110 - 119; http://www.ebscohost.com; Internet; accessed 28 February 2007.

Australia. Department of Defence, *Australian Maritime Doctrine*. Canberra: Defence Publishing Service, October 05, 2000.

Carey, Merrick. "A Zero Sum Navy." *U.S. Naval Institute Proceedings* Vol. 132, Issue 9 (September 2005): 2; http://proquest.umi.com; Internet; accessed 06 February 2007.

Clark, USN Admiral Vern. "Sea Power 21: Projecting decisive joint capabilities." *U.S. Naval Institute Proceedings* Vol. 128, Issue 10 (October 2002): 32 - 42; http://proquest.umi.com; Internet; accessed 05 February 2007.

Fair, Harry D. "Electromagnetic Launch Science and Technology in the United States Enters a New Era." *IEEE Transactions on Magnetics* Vol. 41, no. 1 (January 2005): 158 -164.

Holland W.J., Jr. "THE FLEET low profile today, VITAL TOMORROW." *U.S. Naval Institute Proceedings* Vol. 132, Issue 5 (May 2006): 52 – 57; http://proquest.umi.com; Internet; accessed 05 February 2007.

Jersey, USAF Major Sean L. "Twenty First Century Warfare – Theater Operations as the Speed of Light." Newport: Naval War College, 03 February 2003; http://www.stinet.dtic.mil/; Internet; accessed 05 March 2007.

Keeter, Hunter. "Lasers, Rail Guns Could Be Ready For DD(X) By 2010," *Defense Daily* Vol. 218, Iss.12 (16 April 2003): 1 - 2; http://proquest.umi.com; Internet; accessed 06 February 2007.

Luke, Ivan T., Jr. and Michael F. Stumborg. "The Operational Value of Long Range Land Attack EM Guns to Future Naval Forces." *IEEE Transactions on Magnetics* Vol. 37, no. 1 (January 2001): 58 – 61.

McCarthy, USN Captain William J. "Directed Energy and Fleet Defense: Implications for Naval Warfare." Montgomery: Air War College, Air University, Center for Strategy and Technology, Occasional Paper No. 10, May 2000; http://www.stinet.dtic.mil/; Internet; accessed 29 January 2007.

McFarland, John and Ian R. McNab. "A Long-Range Naval Railgun." *IEEE Transactions on Magnetics*, Vol. 39, No. 1 (January 2003): 289-294.

Merriam-Webster OnLine, http://www.m-w.com/dictionary; Internet accessed 19 April 2007.

Pierce, Terry C. *Warfighting and Disruptive Technologies: Disguising Innovation*. New York: Frank Cass, 2004.

Preston, Bob, Dana J. Johnson, Sean J.A. Edwards, Michael Miller, and Calvin Shipbaugh. *Space Weapons: Earth Wars*. Santa Monica, CA: Rand, 2002.

Program Executive Office Ships. "DDG 1000 Capabilities and Technologies." http://peoships.crane.navy.mil/DDG1000/Capabilities_and_Tech.htm; Internet accessed 20 March 2007.

Program Executive Office Ships. "DDG 1000 Program Status / Phase IV Schedule." http://peoships.crane.navy.mil/DDG1000/schedule.htm; Internet accessed 20 March 2007.

Rogers, Paul. "Towards an Ideal Weapon? Military and Political Implications of the Airborne and Space-based Lasers." *Defense Analysis* Vol. 17, no. 1 (April 2001): 73 - 87.

Stumborg, Michael F. "The Impact of Gun Dimensions on the Operational Effectiveness of a Naval Surface Fleet Equipped With Long Range Electromagnetic Guns." *IEEE Transactions on Magnetics*, Vol. 37 No. 1 (January 2001): 498 - 501.

Thompson, Loren B. "The Emerging Promise (And Danger) of Directed Energy Weapons." Lexington Institute Capitol Hill Forum on Directed Energy, Washington D.C., 11 Jul 2002; http://lexingtoninstitute.org/255.shtml; Internet accessed 06 March 2007.

United States Navy Fact File. "Aircraft Carriers – CVN 21 Program." http://www.navy.mil/navydata/fact_display.asp?cid=4200&tid=250&ct=4; Internet; accessed 20 March 2007.

Walling, USAF Colonel Ellen M. "High Power Microwaves Strategic and Operational Implications for Warfare." Montgomery: Air War College, Air University, Center for Strategy and Technology, Occasional Paper No. 11, May 2000; http://www.stinet.dtic.mil/; Internet; accessed 29 January 2007.

Walls, W.A., W.F. Weldon, S.B. Pratap, M. Palmer and USN Lt. David Adams. "Application of Electromagnetic Guns to Future Naval Platforms." *IEEE Transactions on Magnetics*, Vol. 35, No. 1 (January 1999): 262 - 267.

Wollman, Gerd. "Directed Energy Weapons: Fact or Fiction?." Military Technology Vol. 27, no.4 (April 2003), 80-85.