ELECTRIC WEAPONS
ADDING POWER TO THE PUNCH

BY

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ABSTRACT

The application of the 'power station concept' in future warships means that very high levels of generating capacity are available, but a typical frigate can achieve upwards of 20 knots with less than half the installed power. This article discusses the opportunities for utilization of this electrical dividend to power electric weapons in future warships. It explores the various concepts and technologies, explaining their key features and identifying the current state of the art. Technical challenges are discussed, together with the implications for ship integration, which extend beyond the power system and must consider total system energy management.

FIG.1 – HMS *VICTORY*

Introduction

For centuries, power projection from the sea has demanded improvements in the range and accuracy of naval weapon systems. For 300 years since the 16th Century naval gun systems were based on cannon fire, initially muzzle loaded. Destructive effect was caused by the impact of the shot and largely dependent upon the mass of the cannon ball, with muzzle velocities constrained by powder technology and the metallurgy and manufacturing techniques used for the barrels. Battles were fought at close quarters with shot aimed to destroy sails and rigging and cause incapacitation from flying splinters and wreckage. At the 'Battle of Trafalgar' in October 1805, HMS *Victory* (FIG.1) would have fired a broadside of 32 pound cannon balls (i.e. an approximate mass of 15kg) each with the following Kinetic Energy (KE):

$$KE = \tfrac{1}{2}mv^2 \qquad [1]$$
$$KE = 0.5 \text{ x } 15 \text{ x } (50)^2 \text{ Joules } (kg.m^2/s^2)$$
$$KE = 18.750 \text{ kJ}$$

Operations also took place close to land, with blockade and shore bombardment being effected from naval guns. Now, 200 years after Trafalgar, modern navies face an increase in operations in the littoral.

For the first half of the 20th Century, Naval guns were the primary weapon systems used by warships. These guns were massive in construction and launched explosive projectiles that, in some circumstances, weighed in excess of one ton at calibres of 16 to 18 inches. Launch was achieved by the use stored chemical energy in the gun charge which, on release in the form of a high pressure expanding gas, propelled the projectile efficiently and effectively to a range considerably in excess of that achieved by the much smaller Land based gun systems of the era. However, the ‘useful’ range of these projectiles was limited to 30km by their accuracy, whilst their effectiveness at longer ranges was, at best, dubious.

The battleships of World War II had truly awesome firepower. However, the advent of aircraft carrying bombs and torpedoes saw the demise of these previously invulnerable armoured ships. Also, the inherent inaccuracy of gun launched projectiles required many ‘corrections’ to be applied to Naval ‘fire’ increasing the vulnerability of the firing platform.

Following World War II, UK warships tended to be smaller and their gun systems were designed as anti-air weapons with high firing rates. With the advent of the guided missile, their role was then limited to providing fire support to amphibious forces ashore. This Naval Gunfire Support (NGS) role was satisfied in the UK by the 4.5 inch Mk8 gun that delivered High Explosive and Starshell ammunition to ranges just in excess of 20km. This system has recently been upgraded both in platform (MOD1) and ammunition (4.5 inch Improved Ammunition) but these are the only significant upgrades that have occurred during the gun’s 40 year life. The Improved Ammunition provides a better response to external attack (Insensitive Munition) and with its base bleed unit, extends the range by about 25%. With the advent of new technology, driven by developments for Land gun systems, Naval guns offer a cost effective alternative to missile systems. However, these improvements to conventional Naval gun systems will be limited to Coastal Suppression and support to amphibious forces in the Littoral.

Since H.G. WELLS contrived the Martian heat ray in *War of the Worlds* in 1898, the ability to focus, control and adjust destructive power has long been an aspiration. Furthermore, with modern high speed sensors and communications, the ability to deliver energy to a target at or near the speed of light offers clear advantages. Electric weapons provide the capability to do this and can generally be considered to exist in 2 main groups. Firstly, Direct Energy Weapons (DEW), which include high energy lasers and Radio-Frequency (RF) weapons (also known as high power microwaves or ultra wideband weapons). Secondly there are those that use electrical energy as a means of accelerating, or controlling the acceleration of, a projectile. These systems include Electro-Thermal Chemical (ETC) guns, Coilguns and Railguns. Electric weapons may need very large electrical power supplies and the All Electric Ship (AES) concept is a key enabler for their realization.

DEW

In a naval setting, DEW use concentrated laser or microwave power, accurately targeted, to dazzle, disrupt or destroy incoming anti-ship missiles, aircraft or projectiles. Lasers excite atoms to release photons in powerful bursts of single-frequency, single-phase light that can be focused and aimed by mirrors. Laser Damage Weapons (LDW) are designed to counter threats from Munitions and Missiles carrying Electro-Optic (EO) sensors in the short term, soft-skin targets in the medium term and hard kill targets in the long term. RF weapons operate in the lower frequency, longer wavelength part of the spectrum to generate bursts or beams that are designed to disrupt or destroy electronic systems. DEW systems provide both Close-in and Point Defence at a high speed of response and with improved target identification, and they are planned to have a multi-target engagement capability. Power requirements are dependent on the target 'hardness' and the ability to generate the power required. Typical values for LDW are at Table 1.

TABLE 1 – *Typical LDW Power Requirements*

TIMEFRAME	**TARGET**	**POWER**
2007-2010	EO Sensors	2 – 10 kW
2015	Soft-skin	100 – 250 kW
2025	Hard target	> 1 MW

RF systems need to defeat the incoming munition or missile threat at sufficient range so that direct and secondary damage from the threat platform does not occur. An analysis of these factors indicates that an optimum power requirement of 100kW – 250kW is required to enable the threat platform to be engaged at sufficient range.

ETC Gun Systems

The ETC gun was first developed during the mid-1980s, the aim being to improve performance by introducing small amounts of electrical energy into the breech of the gun to control and augment the production of gas from a conventional propelling charge. Early research concentrated on the mechanism of gas generation and the influence of adding electrical power to the propelling charge. Results identified the potential of increasing the muzzle velocity, and hence range of the munition, by up to 40% with little change to the underlying gun design.

FIG.2 – QINETIQ 155MM ETC RESEARCH GUN (1999)

Following this research, a number of options were identified to extend the performance of land based Direct and Indirect Fire and Naval gun systems. Initially, developments of ETC guns in the UK concentrated on land based Indirect Fire gun systems and particularly for adaptation to Self-Propelled (SP) Guns (FIG.2). The combination of sufficient vehicle mass and volume coupled with the relatively small power requirements to enhance the propelling charge gas generation rate was considered to offer a feasible option for implementing extended range. However, the Land requirement for incremental modular charge systems to achieve the necessary range zoning required a power source that was not considered cost effective to be integrated within an existing SP gun. However, the benefits of single piece fixed charge system employed for both Direct Fire and Naval Gun systems were identified as ideal opportunities for an optimized ETC charge system. Also, the power requirements for naval ETC gun systems were sufficiently low to make ETC guns a potential option for enhancement of any conventional naval gun propelling charge system. Power requirements to control the combustion rate of the propelling charge gas generation and charge ignition is approximately 3MW and 30kW respectively.

Further advantages have been identified from ETC gun technology. These include:

- Improving the consistency and reliability of conventional gun propelling charge ignition.
- Facilitating the introduction of new generation ‘insensitive’ (i.e. safer to handle and store) propelling charge systems by providing a repeatable, consistent means of ignition.
- Facilitating the introduction of new generation ‘high loading density’ (i.e. higher performance) charge systems by providing a repeatable, consistent means of ignition.
- Providing a means to compensate for charge temperature coefficient effects (i.e. removing the variations in muzzle velocity as a function of operating temperature which are inherent in conventional propelling charges).
- Minimization or elimination of pressure waves within the propelling charge system.

Coil Guns

Coil guns, as the name implies, consist of a number of coils in axial alignment, which form the barrel of the gun. A ferromagnetic projectile is placed inside the coil array at one of its ends (FIG.3). When a large electrical current is pulsed into the first coil, eddy currents are induced by the changing field. This produces a force, which accelerates the projectile towards the next coil, which is excited in turn to produce a further force, and so on progressively accelerating the projectile down successive stages.

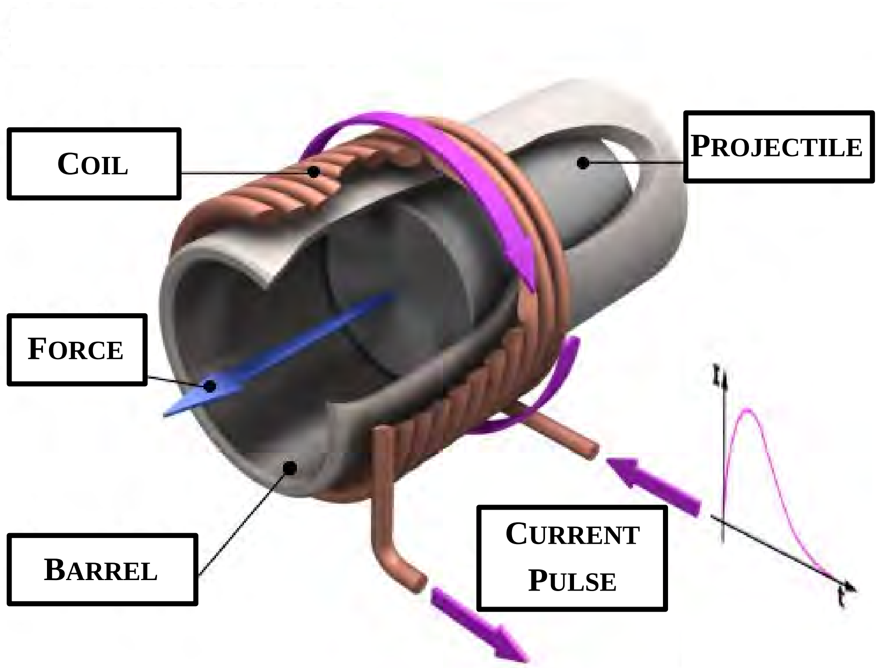

FIG.3 – COILGUN PRINCIPLE

Considerable efforts were put into coil gun technology during the 1980's and systems were built that could launch projectiles at velocities up to 1000 m/s. However, higher velocities became problematic due to the complexities of synchronizing the coil pulses with the in-bore positioning of the projectile. Thus, coil gun technology remains an attractive technology for relatively low velocity launch applications (such as a mortar) but not for the higher velocity regimes.

Electro Magnetic (EM) Railguns

The origins of EM railgun technology can be traced to the pioneering work of Marshall et al in Australia in the early 1950's.[1] The operation of the railgun is simple in principle and can be easily understood by application of Flemming's Left Hand Rule as depicted in (FIG.4). A large current flows along the launcher rails via the projectile and the resulting force produced by two parallel currents accelerates the projectile along the rails. In principle, there is no theoretical limit to the velocity that can be obtained from such a system. However, a practical velocity limit in the region of 2.5km/s exists at the moment because of the inability of present day launch rail and projectile materials to handle the huge electrical currents involved without incurring damage.

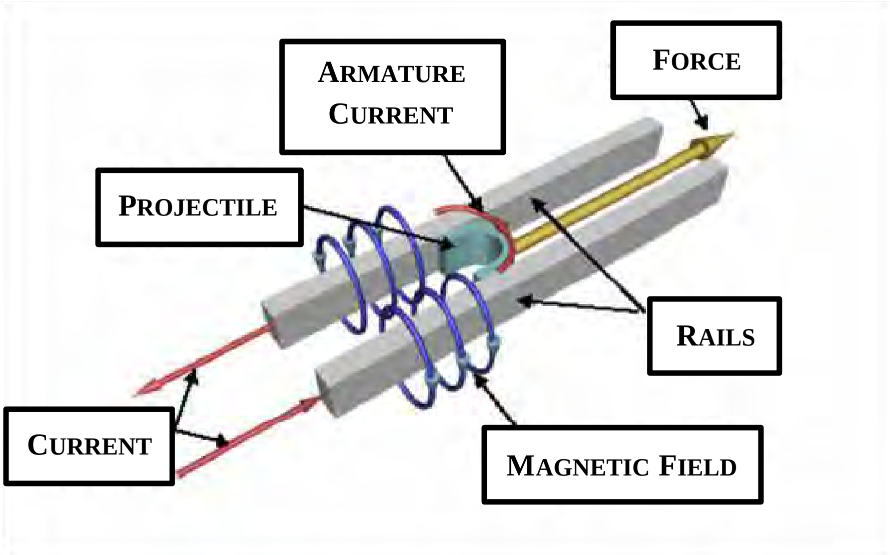

FIG.4 – RAILGUN PRINCIPLE

The efficiency of conventional guns falls exponentially as a function of velocity – as the velocity is increased most of the energy released during chemical propulsion is used up by accelerating the gas itself and not the projectile. Thus for all practical purposes, conventional artillery guns operate typically between 900m/s – 1100m/s. Thus, even within the present materials limitations, EM launch offers a significant advantage over conventional chemical propulsion. The current power requirement to achieve the projected range for Land Attack and enable the gun to achieve a rate of fire of 6 rounds a minute is approximately 20MW. It is expected that the power requirement would double if a firing rate of 12 rounds a minute was required. Additional benefits of EM technology applied to weapon systems are:

- The technology makes feasible the possibility of using hyper-velocity projectiles to engage targets at extreme range (FIG.5).

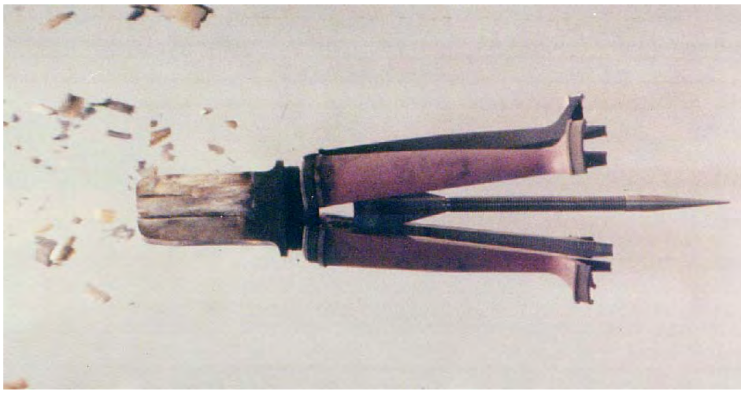

FIG.5 – QINETIQ ELECTRO-MAGNETIC GUN PROJECTILE FIRED AT THE UK ELECTRO-MAGNETIC LAUNCH FACILITY

- There are no energetic components in the propulsion or munitions (utilizing a KE warhead), thereby opening up the possibility of massive savings on whole life costs and greatly improved survivability of the ship.
- The reduced size, mass and volume of the munition offers considerable logistic support advantages.
- The technology has application to both Air-Defence and Anti-Fast Inshore Attack Craft requirements in addition to the Naval Fire Support and Anti-Surface Warfare capabilities.
- It offers the possibility of a single, multi-effects, weapon system.

Hypersonic Projectiles

Very long ranges are possible from EM Guns by using a ballistic trajectory. Clearly this requires very careful and complex projectile design, not least because the launch package must sustain hypersonic flight. This demands high strength materials for survivable launch, a high ballistic co-efficient for efficient flight whilst maximizing the useful projectile mass (i.e. minimizing the parasitic mass of the launch package that is discarded at muzzle exit). Typical trajectories are shown at (FIG.6). With a muzzle velocity of 2.5 km/s an effective line of sight range might be 13 km (taking 6 seconds). With ballistic flight, however, ranges in excess of 200 nm have been postulated.[2] In this case the projectile takes 20 seconds to exit the atmosphere and must sustain a peak ascent temperature of around 1,450K as it reaches a height of 137 km in 168 seconds. The projectile will remain in exo-atmospheric flight for a total of 5 minutes or so after which re-entry dynamics must be controlled before being steered for the final 40 seconds to the target.[3]

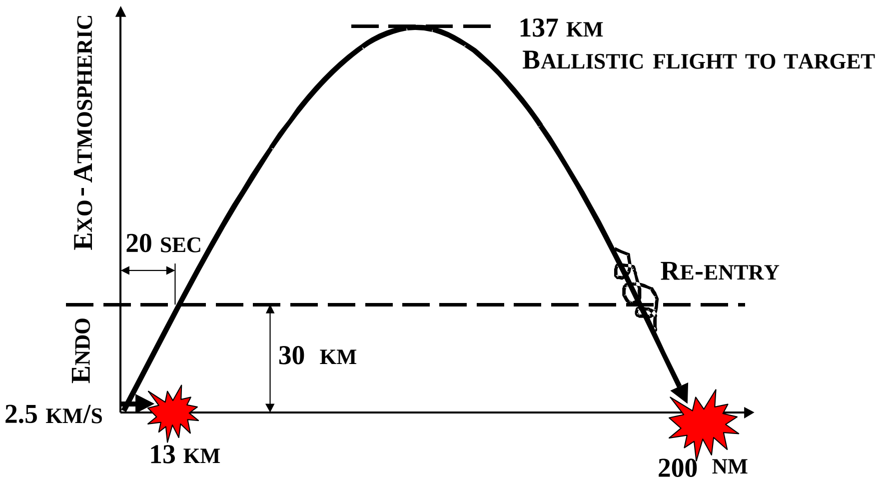

FIG.6 – TYPICAL TRAJECTORIES FOR 2.5 KM/S LAUNCH.

A typical Integrated Launch Package (ILP) might comprise a carbon tipped, tungsten penetrator, and specialist composite materials with space for a fragmentation charge and guidance. Flares may provide stability at high speed and fins, grooves, flutes or spin may improve performance. Above 2 km/s nose tip ablation may be necessary. Miniature, low cost, robust guidance and control is necessary for guided flight.

The energy of impact of a 15kg hypersonic projectile reaching its target at 1.5 km/s is 16.875 MJ. This approximates to a TOYOTA CAMRY hitting a brick wall at 80 miles per hour and is 3 orders of magnitude greater than the 32 pound cannon ball of 1805. There are a number of significant challenges to overcome in the maturation of EM guns for naval and land application. These include:

- The development of a compact and reliable power source to meet the projected firepower requirements. The rate of progress being made in this area is close to that required to meet likely in service dates in the 2014-2020 timeframe.
- The ability of mass efficient projectiles to survive the transmission of the current across the launcher rails. Novel projectile designs and the implementation of new materials have enabled projectiles to survive the environment and be launched at velocities well in excess of 2000m/s.
- Devising suitable launcher rail and insulators with the durability to last the 10,000 + rounds demanded by naval guns. To date, durability of the order 100 rounds has been demonstrated at large calibre.
- The development of smart, manoeuvring projectiles that can survive the high acceleration and high magnetic fields imposed during launch. Whilst some progress has been made in some of the key elements (e.g. successful EM launch and operation of electronics packages) the rate of progress in this area is slow at present and it requires investment.
- Weaponisation of the technology into a fieldable form. At the present time, much of the EM launch technology is at a relatively low technology readiness (TRL 3-4). Clearly much effort is still required to mature the technology and system readiness levels. Advanced technology demonstrators in the 2006-2010 timeframe are called for, and are being considered.

EM Aircraft Lanch

Similar to the design philosophy of an EM Gun, EM aircraft launchers are based on linear motors (FIG.7). Their construction is relatively simple and there is the potential of an additional 30% increase in performance of EM launch against conventional steam powered catapults whilst allowing greater flexibility in the layout of the ship. The predicted power requirement is expected to be approximately 120MJ in a 2-3 second pulse.

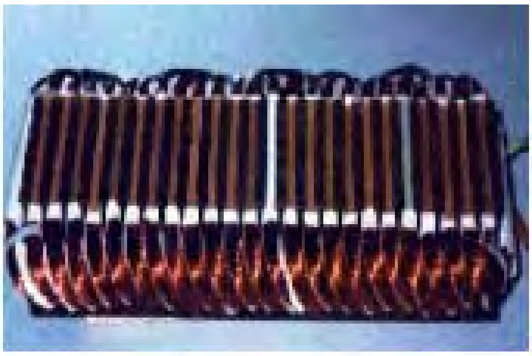

FIG.7 – ALSTOM'S LINEAR INDUCTION MOTOR STATOR AND REACTION PLATE

Previous work conducted by the UK MoD and ALSTOM developed the technology required to launch aircraft using an electro-magnetic catapult known as EMCAT based on linear induction motors.[4] This was achieved through design, system optimization, complete system modelling and model verification by testing, thus offering a de-risked and cost effective alternative to steam catapults.

Further work is now being conducted in the UK to design, produce and demonstrate the ability to launch Unmanned Air Vehicles (UAVs) from sea based platforms efficiently and with minimum impact on platform design. The results of this technology demonstrator programme will provide a greater understanding of the design constraints involved with EM launch technology. Whilst aimed primarily towards assisted launch for UAVs, the work will support any potential future requirements for manned aircraft as the launch system technical solution will be scaleable.

New Technology

With the advent of new technology, many of the previous disadvantages of gun systems have since been reversed:

- The use of the gun-hardened Global Positioning System (GPS), with an Inertia Measurement Unit (IMU) for backup, enables gun systems to match the accuracy of guided missile systems at extended ranges.
- New materials enable gun munitions to carry increased (over current in-service gun systems) payload masses and types, and thereby offering greater versatility in effect than can be realized from missiles.
- The use of both new materials, GPS/IMU and fin-stabilization has led to the ability of conventional gun system to double or treble the range while maintaining accuracy.
- The new generation of gun munitions offers considerable cost savings over missiles for equivalent capability.
- Novel munition launch systems have the potential to project payloads at hypersonic velocities thereby reducing engagement times considerably whilst offering an order of magnitude increase in range.
- Novel launch techniques could lead to a reduction or removal of energetic materials (gun propellants) from the ship, thereby having a massive impact on reducing the logistic burden, reducing through life costs and increasing the survivability of the platform.
- The introduction of the AES concept to future warships will enable a holistic approach to be taken to the power management and architecture required for ship propulsion, sensor surveillance and munition launch.

System Integration Issues

The use of electrical power to support weapon and other requirements is summarized in Table 2. These requirements illustrate the need for an integrated power system strategy for future electric ship design to manage the weapon based power requirements and their interaction between competing weapon systems and other loads. In addition, there is an issue with the impact of power loss that needs to be addressed.

TABLE 2 – *Typical Power Requirements*

SYSTEM	POWER	EFFICIENCY (%)	ELECTRICAL LOSS (HEAT)
Lasers	1-2MW	10	0.9-1.8MW
High Power Microwaves	500kW	10	450KW
ETC Guns	3MW	50	1.5MW
EM Guns	20-40MW	30	6-12MW
EM Aircraft Launchers	6.5MW	40	3.8MW

High power electric weapon systems demand high levels of platform integration, and the demarcation between those systems that are classically considered within the marine and weapon engineering domains will inevitably become less clear. There is no doubt that electric propulsion schemes have the potential to make high levels of power available for combat system use, without which the electric weapon could not be possible. The AES concept, with its improved through life cost benefits, also provides the generating capacity to enable powerful sensors, DEW and EM guns. However, the integration issues extend far beyond the generation and transmission of electrical power.

An integrated approach to energy management is necessary, where the first consideration might be obtaining the appropriate balance between ship speed and firing rate. For example, an All Electric Surface Combatant with a total generating capacity of 80 MW would be sufficient to operate 2 railguns, with a 63 MJ muzzle energy, at 12 rounds per minute and propel the ship at around 10 kts.[5]

The energy flow for an integrated electric weapon system is shown at (FIG.8). Given the projected losses identified at Table 2, heat rejection is a significant issue, which may demand new and novel approaches to overall platform thermal management. Indeed, a holistic systems engineering approach to platform design and integration is essential.

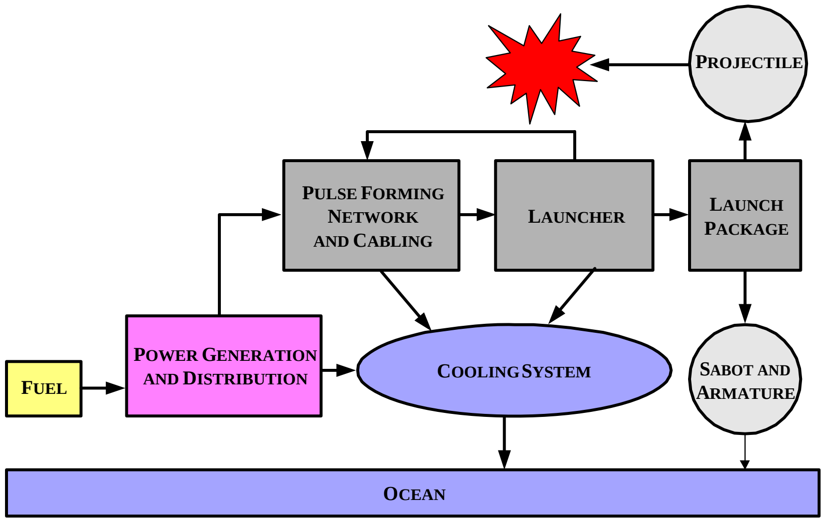

FIG.8 – ENERGY FLOW FOR INTEGRATED ELECTRIC WEAPON SYSTEM

Conclusions

The introduction of the AES concept is a major opportunity to marry new advances in electric weapons, sensors and launchers into the next generation of warship. It is over 300 years since the introduction of conventional guns into naval platforms and, after the last 50 years of stagnation, there is a renewed interest in naval gun technology. With recent emphasis on operations in the Littoral, together with the increased asymmetric threat, high speed of response and increased ranges are of particular importance.

The advent of direct energy weapons and novel guns that utilize electricity as the propulsion medium, coupled to low cost, gun launched, smart projectiles, opens the door to greatly increased capability, new concepts of operation, significant reductions in whole life cost of ownership, improved safety and a more robust logistic chain. The use of these high electrical power based systems will require careful design, especially in the marine environment and in close proximity to sensitive ship base sensor systems. Most importantly a holistic design approach is essential in order to balance the weapon and propulsion system loads and manage the overall platform energy, which may lead to new and novel approaches to thermal management. The success of the overall platform design therefore demands ever closer co-operation between marine and weapon engineer.

There are many technical and industrial challenges to be overcome, but perhaps the most dominant issue is to find the means of co-ordinating governments, industry and the technical base to realise this vision.

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