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Tactical Agility: Operational Energy Enabling Concept for Expeditionary Advanced Base Operations

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OF THE REQUIREMENTS FOR THE DEGREE OF
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DISCLAIMER

EXECUTIVE SUMMARY

Title: Tactical Agility: Operational Energy Enabling Concept for Expeditionary Advanced Base Operations (EABO)

Author: Major Jacob A Clayton

Thesis: A Marine Expeditionary Unit (MEU) can gain tactical agility while conducting EABO through a distributed operational energy approach using a hydrogen based energy generation and delivery system. This military opportunity can result in three subsequent advantages in addition to gaining tactical agility: reduced maintenance requirements, improved operational endurance, and reduced battlefield signature.

Discussion: The academic year 2019 Gray Scholar war game set out to determine how a Marine Expeditionary Unit (MEU) could generate options for the wider operational force during Expeditionary Advanced Base Operations (EABO) resulting in the MEU Construct document for the Marine Corps Warfighting Lab (MCWL). In conducting research for this war game, one aspect in conducting EABO continued to emerge across the elements of the Marine Air Ground Task Force (MAGTF). This is the operational energy aspect. Units will need to operate in a distributed manner which creates a cascading logistics requirement to store and deliver fuel. Additionally, the risk from the Anti-Air / Access Denial (A2AD) strategy from the adversary compounded the risk to force which required logistics units to rely on strategic and operational level assets to assure fuel delivery. The war game showed that the most significant vulnerability is in assuring operational energy delivery in a contested environment. Operational energy is the "energy required for training, moving, and sustaining military forces and weapons platforms for military operations."[i] The vulnerabilities of delivering operational energy in a contested environment are based on the fiscal cost of transporting fuel on water and land as well as the tactical and operational cost of storing the fuel in the operational area while providing security for the delivery of the fuel at the last tactical mile.

Conclusion: The Operational Energy Enabling Concept for Expeditionary Advanced Base Operations explores the impacts of a new operational energy paradigm through the lens of four energy systems: surface, sub-surface, air, and wearable. This concept is nested in the Marine Operating Concept (MOC) and the Department of Defense (DoD) Operational Energy Strategy.

- Operational energy is the energy required for training, moving, and sustaining military forces and weapons platforms for military operations.

- A MEU can gain tactical agility while conducting EABO through a distributed operational energy approach using a hydrogen-based energy generation and delivery system[ii].

    - Advantages: reduced maintenance requirements, improved operational endurance, and reduced battlefield signature.

    - Disadvantages: new procurement and training requirements and additional investment in research and development of high TRL projects currently underway.

[i] 10 US Code § 2926 (b)
[ii] The MIT Lincoln Labs are conducting a systems analysis to demonstrate the reduction in fuel transportation 'costs' if a tactical unit operated in a distributed network of hydrogen generators using aluminum fuel.

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PREFACE

The academic year 2019 Gray Scholar war game set out to determine how a Marine Expeditionary Unit (MEU) could generate options for the wider operational force during Expeditionary Advanced Base Operations (EABO) resulting in the MEU Construct document for the Marine Corps Warfighting Lab (MCWL). In conducting research for this war game, one aspect in conducting EABO continued to emerge across the elements of the Marine Air Ground Task Force (MAGTF). Units will need to operate in a distributed manner which creates a cascading logistics requirement to store and deliver fuel. Additionally, the risk from the Anti-Air / Access Denial (A2AD) strategy from the adversary compounded the risk to force which required logistics units to rely on strategic and operational level assets to assure fuel delivery. The war game showed that the most significant vulnerability is in assuring operational energy delivery in a contested environment. Operational energy is the "energy required for training, moving, and sustaining military forces and weapons platforms for military operations."iii The vulnerabilities of delivering operational energy in a contested environment are based on the fiscal cost of transporting fuel on water and land as well as the tactical and operational cost of storing the fuel in the operational area while providing security for the delivery of the fuel at the last tactical mile.

INTRODUCTION

PURPOSE

The Operational Energy Enabling Concept for EABO explores the impacts of a new operational energy paradigm through the lens of four energy systems: surface, sub-surface, air, and wearable. This concept is nested in the Marine Operating Concept (MOC) and the Department of Defense (DoD) Operational Energy Strategy. The MOC specifically addressed the operational energy challenge 6.4.7 Operational Energy in that Marines must, “Continue to experiment with concepts and emerging technologies to enhance energy stowage, distribution, and throughput capabilities to support 21st century maneuver warfare.”[iv] The Operational Energy Concept addresses this challenge in addition to the Operational Energy Strategy’s objectives, “[i]ncrease future warfighting capability by including energy throughout future force development, [i]dentify and reduce logistics and operational risks from operational energy vulnerabilities, [e]nhance mission effectiveness of the current force through updated equipment and improvements in training, exercises, and operations.”[v]

THESIS STATEMENT

A MEU can gain tactical agility while conducting EABO through a distributed operational energy approach using a hydrogen-based energy generation and delivery system. This military opportunity can result in three subsequent advantages in addition to gaining tactical agility: reduced maintenance requirements, improved operational endurance, and reduced battlefield signature.

TIME HORIZONS / ASSUMPTIONS / RISKS

Current DoD hydrogen projects outlined in the Necessary Capabilities section are under development currently. The Operational Energy Enabling Concept for EABO reviewed air, sub-surface, surface, and wearables solutions that could reach Initial Operating Capability (IOC) in six to twelve months for the surface solution. The other projects can reach IOC with appropriate funding and research in a relatively short time frame.

The EABO concept identifies operational energy as a challenge since the contested environment will increase military costs to assure fuel delivery. The assumption is that an abundant supply of energy and delivery capability will be a challenge in a contested environment. Additionally, the endurance, maintenance, and signature of our mobile systems will further compound this challenge.

Distance and span of EABO creates a cascading problem for the DoD to project power because of the topology of the energy distribution network and maintenance requirements will create a cascading problem for military planners. The hydrogen fuel cell proposal does assume risk in that many systems will need to be procured for this concept to work in addition to the training requirements to employ these systems.

MILITARY PROBLEM

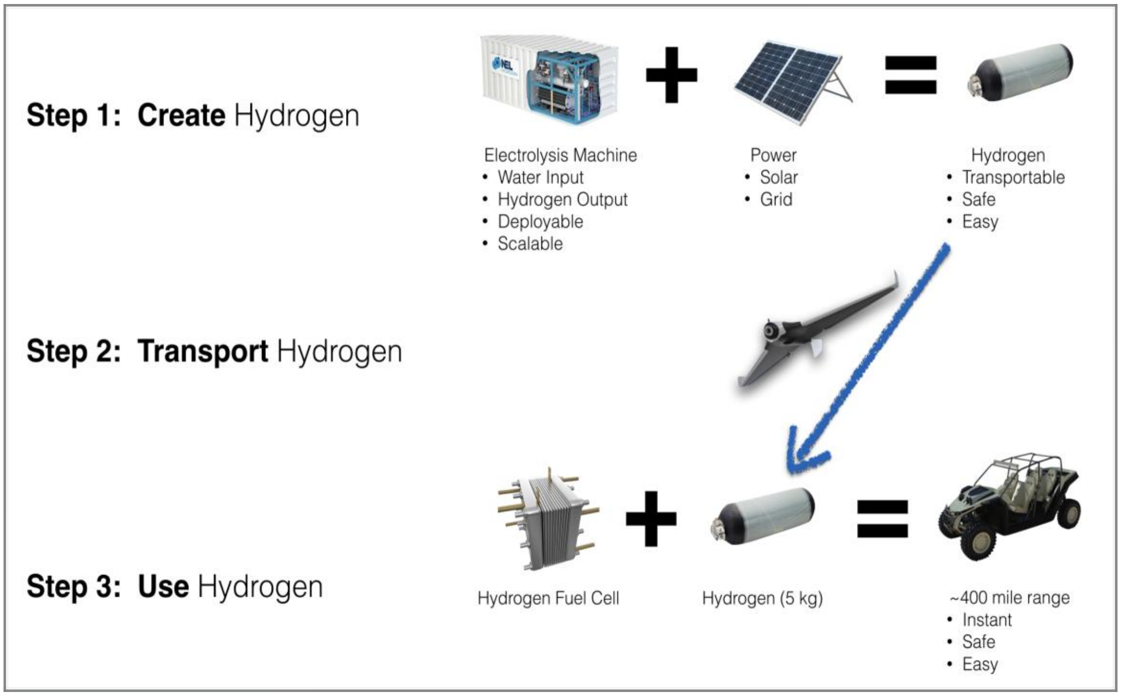
INTRODUCTION

History can be an amazing teacher, especially if you read it. The specific military problem that the Tactical Agility Concept attempts to address is not a new one. In fact it is very similar to the strategic naval concept that the French developed called Jeune École. The French concept advocates using small distributed boats with powerful weapons to at least disable a ship.[vi] While the French developed this concept in response to the British having the strongest Navy, this concept can be used by any force to create an unsustainable cost curve for an adversary. This concept is an application of Horizontal Escalation versus Vertical Escalation.[vii]

THE PROBLEM STATEMENT

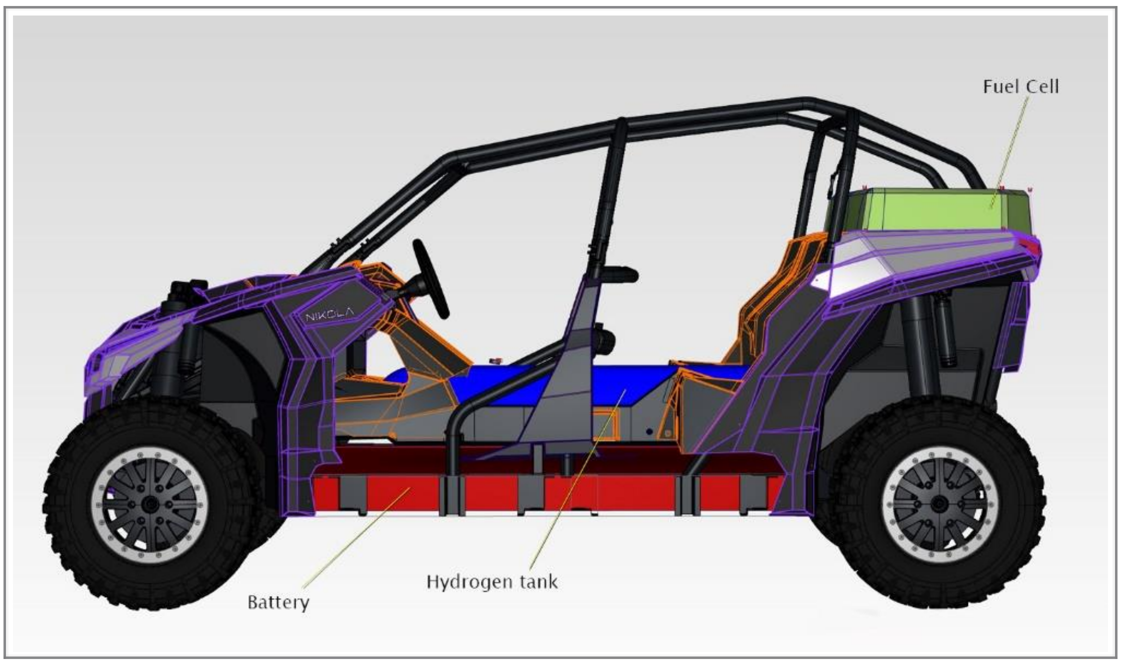
The Marine Corps published the Expeditionary Advanced Base Operations[viii] (EABO) concept that seeks to, “further distribute lethality by providing land-based options for increasing the number of sensors and shooters beyond the upper limit imposed by the quantity of seagoing platforms available.”[ix] In a ‘*War on the Rocks*’ article, a system of Warbots[x] accomplishes this EABO concept through distributed capabilities spread across a set of islands.   Every single technology described in these concepts will require energy, and some will require a lot of energy. This energy generation and distribution is an issue, but it is also an opportunity for the Marine Corps because it can gain a significant endurance improvement in its systems while reducing the logistical burden for distributing military-grade fuel and minimizing the thermal and audible signatures for its energy systems. The Marine Corps can realize this opportunity by endorsing and experimenting with hydrogen fuel cells that power military systems.

To understand how the Marine Corps can benefit from a tactical hydrogen fuel system, it needs to connect with industry, academia, and national laboratories to first understand how the components of a hydrogen energy system works. As a quick overview, hydrogen gas is different from hydrocarbons, such as diesel fuel, in that the byproduct is water. In comparison, the byproduct of diesel exhaust is a carcinogen that is harmful to humans and leaves a visible signature.[xi] A hydrogen fuel cell is a series of plates in a structure that converts hydrogen gas to electricity and water by mixing the hydrogen with oxygen. This fuel cell is attached to a tank that contains the energy source: hydrogen gas. Historically, fuel cells have been expensive, difficult to manufacture, and inefficient which did not make them a good alternative to existing battery or combustion engine sources of energy. Today fuel cells are ready for mass production and are used in commercial vehicles such as semi-trucks[xii], cars[xiii], and even drones[xiv]. Looking specifically at the drones, the fuel cell in these drones are able to increase their endurance by 400%.[xv]



The key issues the military will need to address is how to generate the hydrogen while forward deployed in a safe manner. First, the distributed generation can take place through many methods, but this concept will focus on the most common method: electrolysis. A Hydrogen Electrolysis System[xvi] takes the inputs of electricity and water to make hydrogen gas. The gas is then compressed and transferred to a tank for storage. These electrolysis systems are powered by an array of solar or grid power. The key advantage is that an electrolysis system can remain in a small container while converting solar power to hydrogen fuel. Units will then be able to move to a forward deployed refueling point and completely refuel their tank in under a couple minutes. This is a huge advantage compared to the multiple hours required to recharge a battery system. Additionally, the hydrogen tanks are rated to survive a direct shot from a high-caliber round. In fact, hydrogen is a relatively safe alternative to current diesel energy solutions. A visit to the U.S. Department of Energy's website on the military's use of hydrogen will show that a diesel leak tends to pool at the low point under a vehicle and burns for a long duration. Hydrogen is much lighter than air and will dissipate or burn quickly. This reduces the threat of secondary ignitions. Lastly, there is an emerging opportunity in the hydrogen space to generate hydrogen while forward deployed by scavenging aluminum and then converting that into hydrogen through a process developed at the Massachusetts Institute of Technology (MIT) Lincoln Labs by their operational energy team. So there is a clear opportunity to begin to transition to hydrogen based fuel systems.

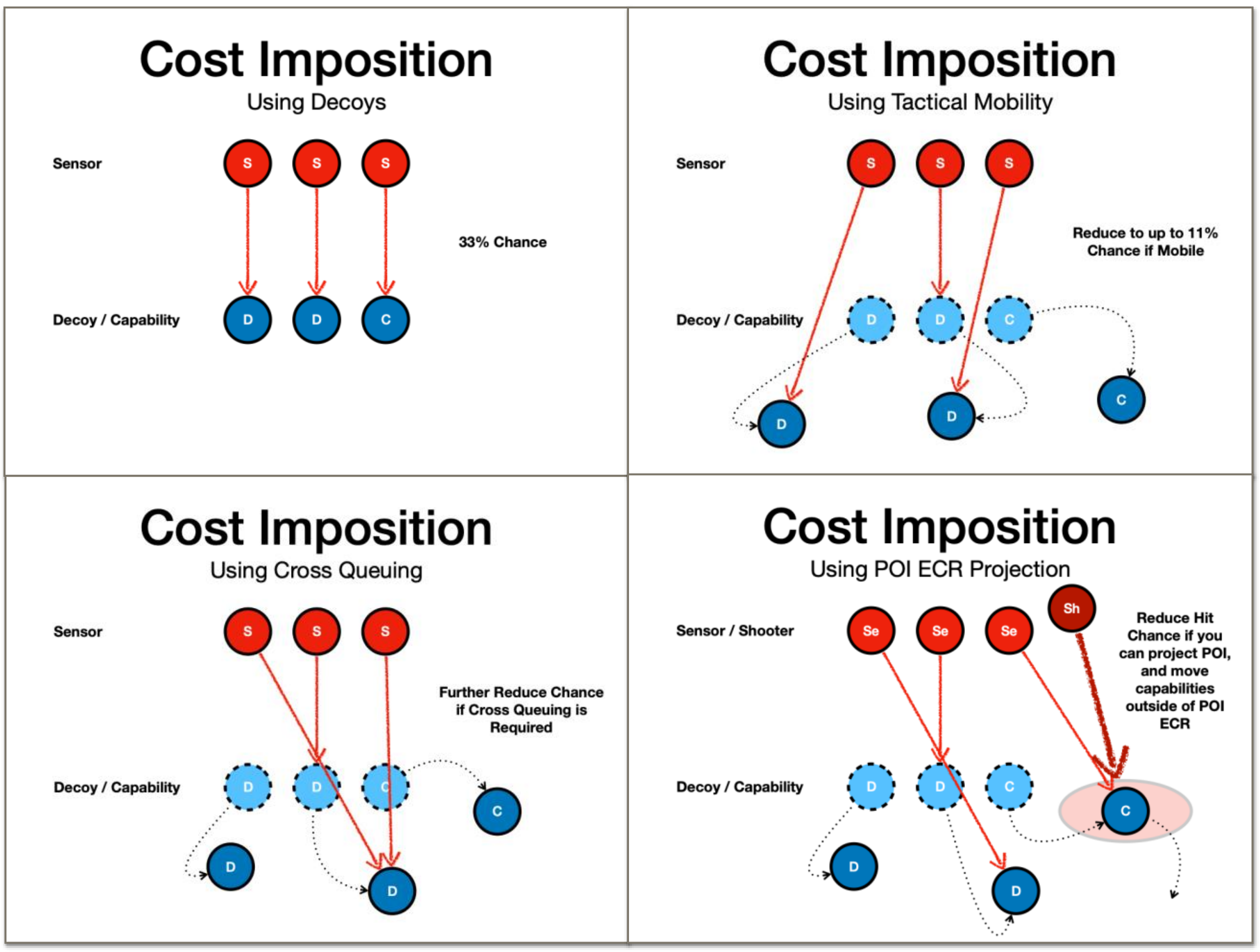
If the military combined the benefits of a tactical hydrogen fuel system with an electric drive UTV[xvii] that is internally transportable in an MV-22, then they would be able to provide a



silent, autonomous, and zero-maintenance vehicle that is also a distributed energy delivery system. Initial estimates show that this electric drive UTV could reach a 400+ mile range on a single tank of hydrogen or provide enough energy to power a combat operations center for 30 days. This distributed energy generation and distribution system will address the current growing demand for energy to power our emerging capabilities, but it will also reduce the global network required to collect, process, and distribute military-grade fuel. By reducing the reliance on a global energy network, military units will gain more freedom of action and a reduction in our risk profile when logisticians take the fuel from a naval ship or pre-positioned diesel tanks and deliver it to units spread across multiple islands. This movement unnecessarily increases a unit's risk profile. A distributed energy generation and production system can eliminate this network and significantly reduce the signature of military units moving around the battle space. Outside of the energy purview, electric drive motors are rated to operate for over a million miles before the parts begin to wear down.

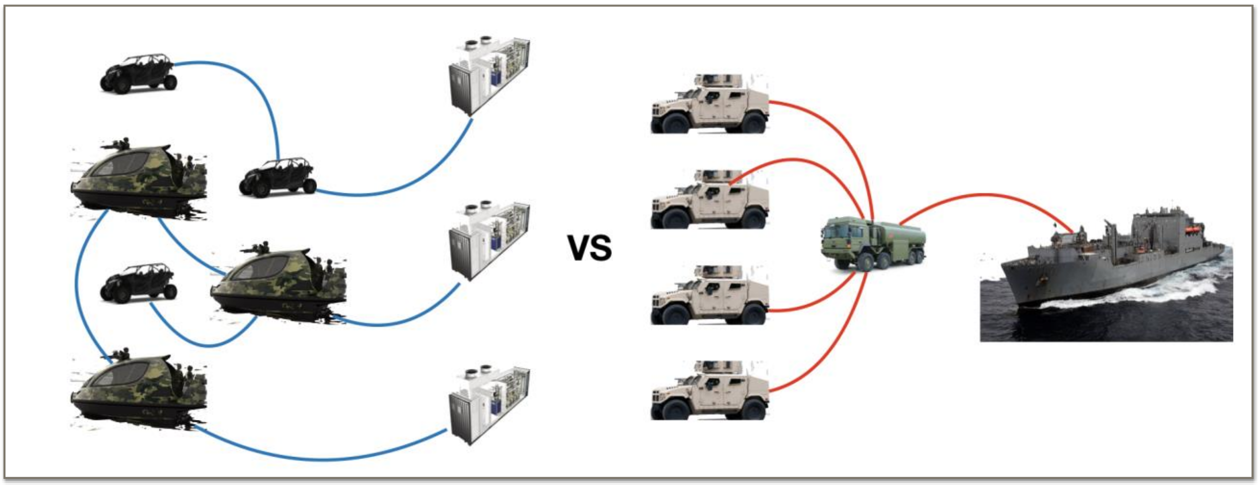
Central Idea

Lingchi (凌遲) is a method to prolong pain before death and is commonly referred to as, "death by a thousand cuts." A modern and mature version of this concept is the work on Cost Imposition Strategies. Can these strategies be applied at the tactical level by small units? This unit needs to operate in a distributed manner with a robust energy plan to ensure endurance and agility. A unit is tactically agile by generating options through small, safe-to-fail experiments;



the unit then amplifies successful maneuvers while dampening unsuccessful maneuvers. This self-organization occurs in a distributed network of units. A centralized or even decentralized network of units does not gain the advantages of agility because the central decision authority cannot sense and respond at the scale of a distributed network of units. To exploit emerging opportunities, these distributed units require the capability to respond with lethal and non-lethal means. So small, modular, and distributed systems create a swarming effect that imposes costs on the adversary to continue to engage.

The critical requirement to deliver these means is operational energy. A MEU can gain tactical agility while conducting EABO through a distributed operational energy approach using



Distributed Expeditionary Energy System vs. Centralized Expeditionary Energy System

a hydrogen based energy generation and delivery system.

VIGNETTE

The Marine Expeditionary Unit commander, Colonel Holt, gripped the fuel nozzle as his eyes followed the short rubber hose connected to the deployable hydrogen station. He looked across the vast ocean from the small island in the Indo-Pacific not able to see a single vessel in sight. He realized the importance of generating fuel at an advanced base because there was no way the Navy was going to risk regular small refueling missions to fifty locations while in range of the adversary's integrated missile defense system. Colonel Holt chuckled, because this base was really like a mobile strike team that could load up on small riverine boats that were conducting a screen about two miles off the coast. He actually looked forward to getting a notification on his watch when the phased array radar detected an incoming missile - and projected the point of impact on the advanced base. This information would be sent to all of the systems in the advanced base. The Marines would execute a well-rehearsed battle drill where the synchronized autonomous vehicles would move outside of the point of impact effective casualty radius. Since the advanced base was completely mobile and autonomous, the missiles reminded Colonel Holt of a story about three hundred Spartans holding off the Persian army. The Persian emperor-god threatened the Spartans with assured death simply from the millions of incoming arrows that would blockout the rays from the sun. The Spartan king responded that it would be nice to fight in the shade. The Marines felt the same way with their human performance training and recent revolutionary equipment set. This calm and ready attitude came from the confidence in the low audible, thermal, and visual signatures from the electric-drive platforms powered by hydrogen fuel. More important than that, the Marines did not experience a 'range' or 'endurance' anxiety because they could generate hydrogen through multiple sources, even by smashing up a local aluminum boat to be converted into hydrogen by adding gallium and water to their deployable hydrogen generation system. Because the Marines could generate all of the hydrogen fuel they would need, it was easier to purify water locally. The Marines were able to operate in a distributed manner for an extended period of time without the need of a global logistics footprint. Colonel Holt walked back to his electric drive UTV to continue checking on the rest of the Marines to ensure their anti-ship battle drills could destroy an adversary's ship many miles off the coast.

INSIGHTS FROM WARGAMES

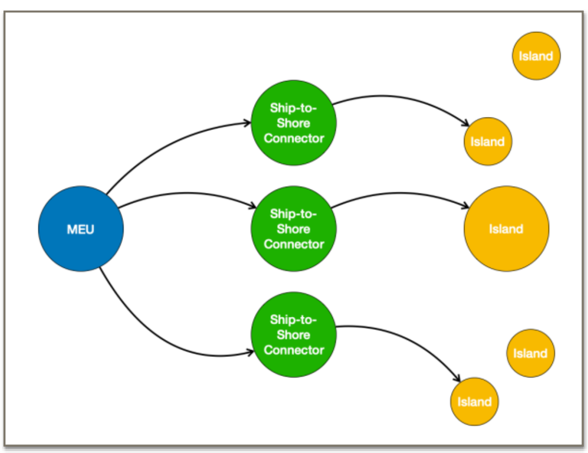
EABO Impact on MEU Logistical Support. EABO presents a monumental challenge for the LCE, even when the force is increased. The distributed manner of EAB has a cascading impact on logistical support requirements. The force design in this wargame attempted to address this by creating distributed systems (energy and water) to reduce the demand on the LCE. Further experimentation and concept development should focus on a systems-level analysis on identifying and addressing high-demand logistical requirements with alternative solutions.

Medical Capability. The new MEU construct added distributed medical treatment capabilities to the GCE which included a MWC outfitted with specialized medical equipment (life support systems), to collect vital information and treat wounded Marines. The key to implementing this capability is to connect these forward deployed medical MWCs to a market place of medical personnel that can advise corpsmen on treatment procedures. Additionally, the implementation of the new MEU construct would require additional trained medical personnel such as corpsmen, nurses, and corpsman to provide the necessary advanced resuscitative care of wounded marines closer to the point of injury.

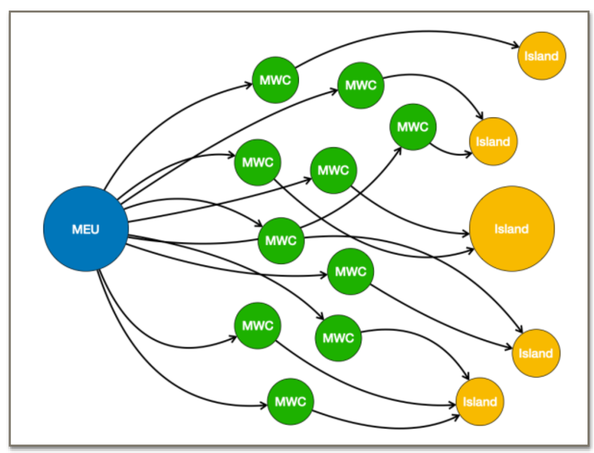
Projecting Power vs. Presenting Targets. The wargame discussion between presenting deterrent capabilities while reducing the footprint of Marines ashore during the contact layer needs further analysis. The outcome of simulated and service-level experimentation of this concept will define that balance. A key concern is the back-loading of significant capabilities of the MEU onto particularly vulnerable amphibious naval assets during the escalation from contact to blunt. Further, the nature of the complex operations being conducted ashore in a contested environment necessitated much more robust and resilient capabilities in command and control, logistics, medevac, fire support de-confliction, ground and airspace movement control.

Application and Integration of Military Functions

The MEU traditionally conducts ship-to-shore movement and/or ship-to-objective maneuver, but there is a gap in operating in an archipelago for Marines to accomplish rapid movement between islands when conducting small-unit composition and decomposition. Additionally, once a small water craft transported Marines to an island, the Marines needed a means of transportation in highly vegetated undeveloped terrain. When Marines operate in a distributed manner they needed to self-sustain for 10+ days. The core problem is the cascading impact on logistical movement required to conduct ship-to-shore movement, ship-to-objective



Large single purpose ship to objective connectors

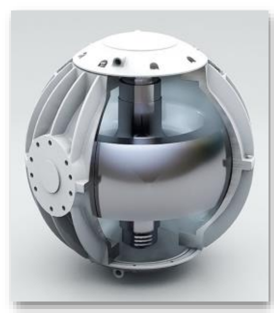


Small multi-purpose ship to objective connectors

maneuver, or intra-island movement and maneuver.[xviii]

To meet these challenges, a MEU could add small water craft that could internally transport a light tactical vehicle or a squad of Marines while generating sufficient energy and carry internal fire support and surveillance capabilities. To address this, the newly constructed MEU could add a Maritime Platoon and Mounted Platoon that can be task-organized in fire-team, squad, platoon, and company formations.

The newly constructed Maritime Platoons could employ an asymmetric strategy based on avoiding direct or sustained confrontations in littoral areas. At the squad and platoon level, a Maritime Platoon could employ surprise attacks, ambushes, and hit-and-run operations due to the relatively high-speed (40 knots) and low-signature of the electric-drive watercraft (audible and thermal). Maritime platoons are not equipped to inflict a decisive defeat to regular Navy forces, however it can effectively impose costs to an adversary at sea in the Contact Layer.



The Maritime platoons had tactical agility because they could refuel their hydrogen tanks at any of the Advanced Bases that were generating hydrogen while forward deployed. So not only where these Marines more flexible, they were able to generate options for senior decision makers due to the small footprint, survivability, and operational energy endurance. Additionally, the autonomous watercraft set conditions for Marines to employ novel tactics based on Manned / Unmanned Teaming (MUMT) and the Mosaic Warfare Kill-Websxix which offer suggested formations and tactics to squad and platoon maritime units. Each Maritime Water Craft (MWC) carried a compliment of capabilities that can be employed remotely or on-board. The key capabilities include: the Reconfigurable Integrated Weapon Platform (RiWP) turret, a Long Range Precision Fires (LRPF) missile, Marine Air Defense Integrated System (MADIS), Electronic Warfare (EW) kit, Coyote launchers capable of housing multiple effectors, 30mm Bushmaster Canon, electrical optical/infrared sensor all fused and integrated through a robust C2 system capable of clearing air, surface, and electronic fires. The crew stayed on-board this vessel for days at a time primarily because of the gyroscope stabilization system which prevented sea sickness.xx These MWCs could be used across the MEU elements to support Flash-FARP establishment, Forward Medical Units, C2 nodes, and transport Engineering equipment.

Once Marines solve the energy problem, they can go small and lethal while creating a larger aggregate effect via the Mosaic warfare kill-web. The Mounted Platoons employed an Electric-drive Light Tactical Vehicle (ELTV) that can be internally transported by an MV-22 and the MWC. The ELTV would allow the Mounted Platoons to rapidly move around the island while providing a distributed energy capability that could carry the Coyote launcher system. The vehicle had autonomous capabilities to augment the Marines by conducting security, deception, and logistics operations. Additionally, the ELTV and the MWC are tied into a C2 system that can project a point of impact (POI) from an incoming missile. Once a vehicle receives an incoming missile alert, the vehicle will move to an alternate position outside of the POI effective casualty radius (ECR) while manned or unmanned. The ELTV also carried a Coyote launcher tied into a wider C2 architecture to distributed fires and surveillance.

This approach does carry with it some risks. The risks are with the individual teams that could be overrun by adversary's naval militia. The Marines are sacrificing mass for speed and modularity but they are doing so by removing concentrated forces. This distributed layout will complicate resupply of ammunition and MEDEVAC however this can be addressed by a new class of transportation: one-way single purpose craft. Disposable drones can deliver ammunition and food or the autonomous jet speeders outlined below could transport heavier loads without the needs of risking twelve to thirty million dollar assault support aircraft with their crew to make a delivery. Lastly, this construct only works with robust communications. This can be achieved using exquisite strategic systems or simpler disposable systems which can be explored in a separate concept.

NECESSARY CAPABILITIES

This tactical agility through operational energy[xxi] is a military opportunity that can result in three subsequent advantages: reduced maintenance requirements, improved operational endurance, and reduced battlefield signature.

Reduced Maintenance

Current Internal Combustion Engine (ICE) solutions tend to be maintenance intensive due to their many moving parts, including regularly checking the numerous Petroleum, Oils, and Lubricants (POL) to include: engine oil, transmission fluid, coolant, fuel. Electric motors powered by a hydrogen fuel system significantly reduces the maintenance requirements due to only one part moving in the system.

Improved Operational Endurance

The DoD is experimenting with numerous hydrogen fuel systems in air, sub-surface, ground, and wearable configurations. Hydrogen increases the endurance of these systems as outlined below:

Examples of Current DoD Hydrogen Projects[xxii]

Unmanned Aerial Vehicles (UAV)

Ion Tiger with gaseous hydrogen (26 hr endurance) compared to a battery system (4 hr endurance).

Unmanned Undersea Vehicle (UUV)

US Naval Research Laboratory experimenting with UUVs to increase endurance and payload capacity.

Manned / Unmanned Ground Vehicle (MUGV)

MCWL and TARDEC experimenting with an electric drive UTV. Hydrogen fuel cell upgrade begin in April 2019.

Wearable Power Storage

CERDEC developing a wearable system to increase power storage with fuel cells.

Proposed Future DoD Hydrogen Projects

Riverine Craft

A hydrogen-electric watercraft for EABO operations at the squad level.

Manned / Unmanned Air Vehicle (MUAV)

A hydrogen-jet speeder that can reach speeds of 150 mph and 30 min duration for casualty evacuation and reconnaissance.

Reduced Battlefield Signature

The MOC outlines the importance of the 'Battle of Signatures'[xxiii] While signatures in the electromagnetic spectrum provide an adversary an indication of DoD patterns of activity, other signatures such as audible and thermal indicate a granular pattern of activity even if all electromagnetic equipment is turned off. ICE provide a thermal and audible signature at night and add a visual signature with the black exhaust emitting from a military vehicle. Electric drive hydrogen fuel powered systems do not provide this signature thus giving tactical units an advantage.

CONCLUSION

The Operational Energy Enabling Concept for Expeditionary Advanced Base Operations explores the impacts of a new operational energy paradigm through the lens of four energy systems: surface, sub-surface, air, and wearable. This concept is nested in the Marine Operating Concept (MOC) and the Department of Defense (DoD) Operational Energy Strategy.

Operational energy is the energy required for training, moving, and sustaining military forces and weapons platforms for military operations.

A MEU can gain tactical agility while conducting EABO through a distributed operational energy approach using a hydrogen-based energy generation and delivery system.

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> Disadvantages: new procurement and training requirements and additional investment in research and development of high TRL projects currently underway.

[iii] 10 US Code § 2926 (b)
[iv] Marine Operating Concept, pg 23.
[v] Department of Defense Operational Energy Strategy, pp. 2-7.
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[vii] Mearsheimer, John J. (1986-01-01). "A Strategic Misstep: The Maritime Strategy and Deterrence in Europe". *International Security*. 11 (2): 3–57.
[viii] Expeditionary Advanced Base Operations, www.candp.marines.mil/Concepts/Subordinate-Operating-Concepts/Expeditionary-Advanced-Base-Operations/, accessed 15 Mar 2019.
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[xxii] https://www.energy.gov/eere/articles/4-ways-fuel-cells-power-us-military
[xxiii] Marine Operating Concept, pg 6.

APPENDIX A: HISTORICAL CASE STUDY

Historical Case

Introduction

Lingchi (凌遲) is a method to prolong pain before death and is commonly referred to as, "death by a thousand cuts." This Chinese phrase perfectly describes the systems design problem that the Department of Defense (DoD) faces today. These design issues range from manned to unmanned platforms that operate in the air, land, sea, and space domains. The core issue is that these vehicle systems have to operate in specific domains requiring specialized engineering efforts. However, even vehicles that operate in the same domain, such as sea, are further complicated by design parameters to accomplish a specific function. One example is the design changes required of a surface ship and a subsurface ship. The ship propulsion systems vary greatly even though they are conducting the same function, to turn the ship's propeller. Although there are many contextual issues that these vehicles must address, there is a general question as to how they are designed. One side of the problem is the manufacturing at scale to keep costs at a manageable rate, and the other side of the problem is maintaining these systems through heavy use and modernization efforts. Submarines are an interesting case study because they are highly specialized, operating in the sea sub-surface with stealth and lethality as their primary function. The DoD did address systems design issues with specific large systems, like the Virginia Class Nuclear Submarine, but has yet to address it with the many small to medium systems on land.

The issue is relatively simple to describe and difficult to address. It is one thing to build a system, but another to maintain and modernize it over time. The interesting thing here is that the Navy was on the forefront of addressing this issue relative to the other services when they researched the Virginia Class submarine manufacturing and maintenance methods. The Navy implemented low maintenance propulsion, long-term energy storage, and system-wide modularity in a submarine with the goal of continual improvement over time without having to rebuild the entire system from scratch. The Virginia Class submarine case study shows that the DoD can implement systems level integration in ground vehicles to realize a cumulative increase in performance and energy capacity while reducing maintenance costs.

Background

The Virginia Class Nuclear submarine is a case study that demonstrates the value of systems and human design principles to realize the benefit of complementary systems functions. In contrast, there are over 30,000 medium and heavy wheeled vehicles in the DoD's inventory with many variants that are not modular and have a host of different engines for propulsion. These numbers do not include the combat vehicles such as tanks and light armored vehicles. Typically the 'wrecker' variants of these vehicles have different power-trains to produce more torque. Further additions to power-train and transmission systems are due to modernization efforts or specialized variants. To include the engines used in generators as well as vehicles systems, there are approximately 50 types of engines in the entire USMC inventory. Each of these engines and transmissions require a separate parts inventory and maintenance requirements. This is the definition of a 'thousand cuts' where the design of the system does not scale well and requires exponential increases in personnel to maintain these systems all resulting in prolonged pain in terms of time and money.

The US Navy saw this cascading issue developing and they created a new generation of attack submarines to address it with the Virginia Class submarine. The submarine was designed in modular sections to address human interaction design as well as taking advantage of commercial off the shelf (COTS) parts in a relatively simple and upgradable system. This approach is called the Modular Open Systems Approach (MOSA) which provides multiple benefits to the designers, engineers, users, and maintainers. The core benefit is making the submarine future proof through modularity to facilitate technological updates. This design approach enables engineers to add new capabilities or replace technology in an efficient manner while not changing the entire system. This leads directly to the flexibility to change the configuration based on operational requirements. Additionally, the modularity and COTS solutions allows operators and maintainers to reuse parts, systems, or systems-of-systems from a supplier even when the original supplier stopped manufacturing the parts or systems. Together, these benefits create conditions for the opposite of cascading complexity and costs; it creates a system that is responsive to the operators needs while not inordinately increasing the work for the engineers and maintainers to unsustainable levels.

Case

The DoD can implement MOSA in ground vehicles to realize a cumulative increase in performance and energy capacity while reducing maintenance costs. There are three core functional areas that the US Navy developed to realize the full value of integrated systems: propulsion systems with as few parts as possible and low-maintenance requirements; flexible and safe energy storage; and modular design approach to upgrade and reuse systems as needed.

Stealthy Propulsion. The Virginia Class submarine is the nuclear-powered fast attack submarine also known as the SSN-774. Its nuclear reactor outputs around 30 Mega-Watts (mW) to power propulsion, weapons, communications, and life-support systems. Even as the nuclear reactor powers these hosts of systems, it still has a virtually unlimited range. The only limiting factor in how long it can sustain undersea operations is its food and maintenance requirements.

The nuclear-powered system generates steam that turns a turbine to generate electricity. But even this relatively quiet propulsion system has a sound signature, which makes it a target. As opposed to a nuclear-powered option, the German Type 212 class submarine uses an Air-Independent Propulsion (AIP) system relying on electric drive motors powered by compressed hydrogen and fuel cells. Since there are no moving parts, the Type 212 class is vibration free making it virtually undetectable - unless the crew is rocking out to Van Halen's Atomic Punk. The key to stealthy propulsion is the electric motor with few parts as possible to prevent vibrations, reduce maintenance, and increase the energy efficiency of the motor.

Energy Storage. The nuclear-powered Virginia Class submarine uses the S9G High Energy Density Core which is specifically designed for and by the US Navy. The name stands for: S for submarine, 9 for the ninth generation reactor core, and G for the contractor General Electric. The S9G outputs 40,000 shaft horse power (shp) resulting in the 30 mW output. To put that into context, the S9G could power 3,000 homes in the United States for an entire year. However this energy dense systems requires numerous specialized engineers to maintain it and an entire industry to safeguard the spent fuel issue.

Modular Open Systems Architecture. The true value of the Virginia Class submarine is its ability to take advantage of current and emerging technologies because it has been designed from the ground up as a modular system. For instance, the Virginia Class's technological updates reduced the manpower requirements of it predecessor by 15 of the 149 Seawolf crew members (~10% reduction). This is significant because not only are you eliminating the space requirements, you are eliminating the support requirements for those people. But the brilliant part is that once advanced technological solutions are ready for fielding, the Virginia Class submarine can be reconfigured to receive them. So at manufacturing, the Virginia Class submarine reduces manpower by 15, in the future it can reduce it even further realizing cascading savings by not having to engineer and manufacture entirely new submarine systems. This benefit is due to the 'Construction Teaming' approach that divides up the submarine sections called, Modular Isolated Deck Sections (MIDS). These sections can be built at separate locations and shipped to a central assembly station for the final build. As the Virginia Class submarine is underway, these manufacturing facilities can assemble new sections to be added to the submarine upon its return and maintenance cycle.

Inference

The propulsion, energy storage, and MOSA elements combined create a system that is highly responsive to the emerging needs of the operators while not overburdening the engineers and maintainers. This same approach can bring about a significant increase in lethality and readiness for land and amphibious forces. Electric-Drive Military Vehicles enable warfighters to silently accomplish a range of missions in a high-torque vehicle with low-maintenance and high-redundancy that provides distributed energy storage. Although there should be a detailed study to confirm this, there are three requirements for land vehicles: light, medium, and heavy. The heavy option would be equivalent to a LVSR or semi-truck and the medium option would be equivalent to the JLTV or full size pickup truck. Lastly the light option would be equivalent to a utility terrain vehicle (UTV). A Modular Open System Approach would consider three sizes of a 'skateboard platform' encasing the propulsion, energy storage, and control systems that can carry an assortment of pre-constructed modular capabilities. Interestingly, the Rand Corporation concluded that the US military executes a range of mission sets that require a light tactical vehicle (LTV). Since this would be the highest constrained system, the DoD should focus its efforts to develop a small and powerful electric drive LTV. Then once the electric-drive, hydrogen fuel cell platform is ready for production, the same system can fit in the larger skateboard platforms. The same motor and power system could provide the propulsion system for every single military vehicle dramatically reducing the duplicative maintenance and spare parts requirements for the DoD.

A modular skateboard LTV design would need to meet the transportability and mobility requirements of a UTV in addition to providing a distributed energy storage system to power current and emerging electronic systems. This LTV can augment land based forces by conducting security, deception, and logistics operations in a Manned / Unmanned Teaming concept. Additional key capabilities could include: a Reconfigurable Integrated Weapon Platform (RiWP) turret, a Long Range Precision Fires (LRPF) missile, Marine Air Defense Integrated System (MADIS), Electronic Warfare (EW) kit, Coyote launchers capable of housing multiple effectors, electrical optical/infrared sensor all fused and integrated through a robust C2 system capable of clearing air, surface, and electronic fires.

Conclusion

The DoD can implement MOSA in a light, medium, and heavy ground vehicle skateboard platform to realize a cumulative increase in performance and energy capacity while reducing maintenance costs. This approach would give operators that ability to reconfigure vehicles based on mission requirements and maintainers could focus on only maintaining a single type of propulsion system. Submarines and locomotives have relied on electric-drive propulsion for decades because the motors are rated to operate for over a million miles. This reliability combined with the simple system design, the high torque output, and the ease of configuring a automated control interface with an electric motor all create a compelling argument to begin the transition to an all electric drive fleet of military vehicles. The Virginia Class submarine design team employed the MOSA philosophy making the exquisite system future proof and the DoD successfully implemented an innovative approach to manufacturing technological systems worth billions of dollars. There remains an opportunity to begin the transition to an all electric-drive fleet of military vehicles that can outperform the current fleet while dramatically reducing the maintenance requirements and increasing the options for energy collection and distribution. This real opportunity has the best chance for success if national and service research laboratories focus on developing a small and reliable electric drive hydrogen fuel cell vehicle to meet current and emerging mission requirements.