Report of the

Naval Research Advisory Committee

Marine Corps Capabilities for Countering Precision Weapon Threats

for the

Commanding General,

U.S. Marine Corps

Combat Development Command

July 2012

This report is a product of the Naval Research Advisory Committee (NRAC) Panel on *Marine Corps Capabilities for Countering Precision Weapon Threats.* The opinions, recommendations, and/or conclusions contained in this report are those of the NRAC panel and do not necessarily represent the official position of the Department of the Navy, or the Department of Defense.

Executive Summary

Background

The challenges and risks to Marine Expeditionary forces in the contemporary operational environment are well known. What is less well known is the emergent risk associated with the employment of precision weapons against U.S. forces – particularly during an amphibious assault. If amphibious operations are to remain a core capability of the Marine Corps, steps must be taken to understand and counter this evolving threat.

The study, sponsored by the Commanding General, Marine Corps Combat Development Command, provides an overview of the precision weapon challenge, insight into the technology for countering the weapon, and recommendations for the Marine Corps' response to the challenge.

The study terms of reference led the Panel to: characterize known and potential precision weapons and munitions types; review and assess the current and planned Marine Corps policies, strategies, approaches (including training), and capabilities for responding to potential precision weapons; identify promising science and technology areas; and to recommend initiatives that should be undertaken by the Marine Corps for responding to the exploitation of precision weapons by our adversaries.

Findings

<u>The Threat:</u> Precision weapons are generally considered to be categorized as guided rockets, artillery, mortars, and missiles (G-RAMM). The threat from precision weapons is current and real – although sophisticated CONOPS, integrating Intelligence, Surveillance and Reconnaissance (ISR) to support coordinated attacks is considered a far-term threat. During recent U.S. operations in Iraq, Afghanistan and elsewhere, military and intelligence units forcefully demonstrated the lethality of U.S. produced precision weaponry across a wide range of operations and terrain. Rough equivalents of these extremely precise weapons systems are now being produced by our peer competitors. Accordingly, these weapons will undoubtedly proliferate among unfriendly countries and terrorist groups operating in the littorals. In fact, it was reported that various types of

precision weapons were pilfered from unguarded Libyan ammunition bunkers after the demise of Col. Gaddafi's regime in late 2011.

Technology applications: To meet the challenge of countering precision weaponry, the U.S. Army is investing in a system to protect forward operating bases in the theater of operation. Despite significant weight, cube, and ammunition requirements, the Army is modifying a Navy-developed PHALANX variant that uses kinetic rounds to defeat incoming rockets, artillery, mortars, and missiles – whether they are guided or not. Its 26 ton weight (without ammunition) rules out its use for Marine expeditionary operations. Also, there is a joint service program called RELI – Robust Electric Laser Initiative – to develop a high energy laser (HEL) weapon to dazzle, damage or degrade precision weapons, or destroy sensors used for precision weapon targeting. UAVs are important both as potential precision weapons and as over-the-horizon targeting platforms. The Expeditionary Maneuver Warfare & Combating Terrorism Department (Code 30) of the Office of Naval Research will leverage RELI for their Future Naval Capability S&T effort GBAD-OTM – Ground-Based Air Defense on-the-Move. It will investigate the feasibility of using a high energy laser linked to ground radar to disrupt low and slow UAVs targeting deployed Marine units. It was also noted that unmanned systems offer new capabilities for Marines – especially when utilized to replace manned connectors during ship-to-shore transit.

Technology limitations: The DOD has spent years and millions of research dollars in developing high energy lasers. But, there continue to be barriers for a fully capable HEL system – including economic, policy, and technology-based issues. To generate the requisite power and beam quality for target disruption, large heavy-weight systems are required. Environmental factors and the threat to friendly systems (e.g., helos and low orbit satellites) will degrade effectiveness. There is a ready market for industrial lasers whose beam quality at high power will not meet the needs of a weapons system. This means that DOD must be the leader (and bill payer) for the development of a truly high energy laser market. Also, the low "duty cycle" – laser shooting time vs. recharge time – may require the use of multiple, integrated systems.

Process limitations: During the fact-finding phase of the study, the Panel was offered several overview "process" briefings to enhance the Panel's understanding of the policies, strategies, and approaches to amphibious warfare under the threat of precision weapons. Also, several Panel members observed the Amphibious Capabilities Working Group (ACWG) wargame. The Panel feels there is a lack of emphasis in the expeditionary force development process on the precision weapons threat, especially in the emphasis on identifying specific near and long-term threats associated with commercial technology applications that directly support precision weapons systems (e.g., Google Earth, etc.). This goes hand-in-hand with a lack of specific emphasis on experimental testing of precision weapons threats in realistic environments. Also, current efforts seem to lack a holistic approach to counter the threat – a process that leads to interrupting the precision weapon's C3ISR capability or through the use of obscurants, decoys, and deception.

Recommendations

The Panel makes a number of specific recommendations to enhance the expeditionary force development process: promote the acquisition of threat weapons systems; accelerate the analysis of precision weapon weaknesses and vulnerabilities; accelerate the transition of threat vulnerability analyses into countermeasures options via S&T initiatives, program planning, and CONOPS development; test the effectiveness of countermeasures and tactics in laboratory & operational environments (e.g., Black Dart); integrate threat analyses, countermeasures, and S&T planning into the expeditionary force development process; conduct experiments on the use of airborne platforms and/or electronic support measures to track small, slow, low-flying UAVs; design and conduct experiments on the use of current and planned unmanned platforms; design and conduct experiments on Cyber and Electronic Attack threats and countermeasures in amphibious environments; and, establish an *Integration Cell* to support, sponsor, and monitor the activities outlined above.

Table of Contents

Terms of Reference

- **<u>Characterize</u> known and potential <u>precision weapons and munitions types</u> that could be potentially exploited by hostile governments and non-state actors, to include relatively inexpensive, home-made-type weapons**
- **<u>Review and assess</u> the current and planned Marine Corps <u>policies, strategies, approaches (including training), and capabilities</u> for responding to these potential precision weapons and munitions**
- **<u>Identify promising science and technology areas</u> for Marine Corps capabilities to respond to these potential precision weapons and munitions threats, which can include detection, tracking, identification, engagement, and ways to counter damage caused by precision weapons, as well as others**
- **<u>Recommend any other initiatives that should be undertaken</u> by the Marine Corps in an effort towards improving their overall capabilities for responding to the potential exploitation of precision weapons and munitions by adversaries**

The original TOR, reflecting the interests of LtGen Flynn (then Commander, MCCDC) called for an examination of the threat to Marine Corps operations posed by known and potential precision weapons and munitions. Later, LtGen Mills (incoming Commander, MCCDC) requested that the panel consider the impact of known and potential precision weapons and munitions on Marine Corps amphibious operations. The panel examined both the weapons and their enabling technologies (Command, Control, Communications, Intelligence, Surveillance and Reconnaissance – C3ISR), in the context of Ship to Objective Maneuver (STOM). Importantly, all responses, from countermeasures to operational concepts, were examined from the perspective of a highly-mobile expeditionary force.

The complete study Terms of Reference (TOR) are in Appendix A.

Panel Membership

Dr. Michael Bruno
Study Panel Chair
Stevens Institute of Technology

Dr. Frank Fernandez
Study Panel Co-Chair
Independent Consultant

VADM Bill Bowes, USN (Ret)
Independent Consultant

Dr. Missy Cummings
MIT

Dr. Frank Shoup
Independent Consultant

<u>Executive Secretariat</u>

Maj Ryan Hansen
MCCDC

Mr. Greg Kesselring
MCWL

Mr. Timothy Lockhart
MCCDC

The Panel, although limited in size, combined a comprehensive skill set to fully investigate and deliberate the issues presented in the study. The chairman, Dr. Michael Bruno, Dean of the School of Engineering and Science of the Stevens Institute of Technology, has an extensive background in maritime systems and technology from a national security perspective. Dr. Frank Fernandez has strong S&T and entrepreneurial credentials as a former DARPA director and founder of several high-tech companies. Vice Admiral (retired) Bill Bowes has several decades of significant major systems development and acquisition experience in government and private industry including a stint as acting Assistant Secretary of the Navy for Research, Development and Acquisition. Dr. Missy Cummings, a former Navy fighter pilot, is the director of the MIT Humans and Automation Laboratory who has led efforts to understand and explore unmanned systems and human control. Dr. Frank Shoup, a former senior DOD civilian, has a comprehensive background in scientific and technical research, operational testing, and weapon systems analysis and was a former director of the CNO's Science and Technology Division (OP-987).

The Executive Secretary, Major Ryan Hansen, assisted by Mr. Greg Kesselring and Mr. Tim Lockhart, facilitated the panel's fact-finding, and contributed their own technical and operational expertise and experience during the deliberations. The findings and recommendations contained herein owe much to their efforts.

Panel member biographies are in Appendix B.

Context

(Lt Gen Mills, 28 September, 2011)

- Future of amphibious operations against emerging threats?
- What adjustments will be required to these operations?

Approximately four months into the Panel's fact-finding process, the focus of the study was further refined when LtGen Mills, in a meeting on 28 September, 2011 requested that the Panel consider the impact of known and potential precision weapons and munitions on amphibious operations. This request was significant to the study's conduct and outcome in many respects. It provided important context in which to examine not only the threat posed by these weapons systems, but also the range of responses to the threat.

Bottom Line Up Front

Precision weapon systems projected for the future threat environment present a realistic threat to the feasibility of future amphibious operations. Staying ahead of emerging threats will require:

1. **An integrated Sea-Air-Ground operational capability, including**
   - A **survivable networked sea-air-ground system** for communication, detection, cueing, tracking and engaging
   - Increased use of **unmanned systems** as connectors, ISR nodes, airborne comm. relays, GPS surrogate

It is the Panel's view that precision weapon systems (i.e., the weapons as well as their enabling technologies – including C3ISR) pose a realistic threat to the feasibility of future Marine Corps amphibious operations. Although the production of precision weapons currently requires capabilities found only in nation states, these weapons are being proliferated world-wide. As a result, it is the Panel's judgment that our adversaries – both nation states and non-state actors – could possess precision weapons in the very near future. Just as significant, the C3 and ISR capabilities needed to employ these weapons are readily available from commercial sources. These capabilities may themselves soon pose a threat to U.S. Marine Corps amphibious operations, e.g., by reducing the tactical advantage of over-the-horizon maneuvering.

An effective response to the threat posed to amphibious operations by precision weapon systems must be characterized by a holistic approach to the threat. Countermeasures and strategies must be aimed not only at the weapons themselves but also at their enabling technologies. There is very likely no single solution to address the precision weapon threat. The response should include a fully integrated sea-air-ground system approach. It must provide C3ISR to support a seamless command structure across the entire battlespace – as well as the ability to detect, cue, track and engage precision weapons. The goal of this networked system is to be effective in GPS-denied areas, and survivable against all threats including cyber and electronic attack.

It is the Panel's opinion that the Marine Corps should seriously consider an increased use of unmanned systems – aerial, surface (ground and sea), and underwater – to support amphibious operations in threat environments that include precision weapon systems. These unmanned systems can serve as ship-to-shore connectors, as well as nodes to support ISR, communication relays, and GPS surrogates.

Bottom Line Up Front (2)

2. Expansion of the current USMC expeditionary force development process

- Accelerate the analysis and exploitation of potential threat weapons systems' weaknesses and vulnerabilities
- Accelerate countermeasures development and testing
- Accelerate the integration of threat analyses, S&T programs, and the USMC expeditionary force development process

3. Consider the establishment of an Integration Cell to support this expansion

- Cell functions: Foreign Materiel Exploitation requirements, intelligence analysis, S&T programs, laboratory and range tests, USMC concept development and wargaming, acquisition program requirements

The Panel believes that the Marine Corps has the expertise and the processes necessary to address the threats posed to amphibious operations by precision weapons. However, the Panel believes that in view of the short timeline associated with the appearance of this threat, an *acceleration* of the process to understand and respond is necessary. The Panel believes that the Marine Corps should ensure that the expeditionary force development process include accelerated programs to:

- Acquire, analyze and exploit identified weaknesses and vulnerabilities of potential threat weapons systems,
- Develop and test countermeasures in realistic environments, and
- Integrate threat analyses and S&T programs into the expeditionary force development process.

It was noted that multi-agency approvals for selected, realistic experiments have been difficult to obtain. This is an issue that should be addressed.

The accelerated understanding of, and response to, threats arising from precision weapons systems can – in the Panel's opinion – benefit greatly from the establishment of an *Integration Cell* that can support, sponsor, and monitor the following activities:

- Foreign materiel exploitation,
- Intelligence analysis,
- S&T,
- Experimentation, including laboratory and range tests in realistic environments,
- Concept development and wargaming, and
- Acquisition program requirements.

The Integration Cell should be broad-based, and should explore technologies available from the commercial sector as well as the military sector, both within the US and overseas. The Panel believes that this Integration Cell does not necessarily require the creation of a new organization, but rather can draw individuals from existing groups, e.g., Amphibious Capabilities Working Group, NRL, Black Dart (sponsored by JIAMDO – Joint Integrated Air and Missile Defense Organization).

One positive aspect of the use of precision weapons against U.S. forces is that their complexity (from an operational perspective) requires sophisticated CONOPS and training and therefore may be exploitable by our Intelligence Community.

The Panel expended significant effort in identifying the relevant aspects of the problem and their potential effects on future Marine Corps expeditionary operations. In the initial fact-finding phase, the Panel sought briefings from multiple sources for insight into the near, mid and far-term precision weapon threat regime, relevant "countering" technology domains, and various commercial and military technology applications of the countering capabilities. As briefings were reviewed and analyzed, the Panel was able to move into new avenues of inquiry. They examined a number of S&T efforts that are currently in the planning stage, and heard briefings from independent technology evaluators. Also, several Panel members observed MCCDC's Amphibious Capabilities Working Group wargame in October 2011.

The complete set of briefers and their organizations are listed in Appendix C.

The Emerging Threat

Present Danger: Missing Missiles in Libya

"Experts told ABC News they are concerned that the weapons stockpiles including as many as 20,000 surface-to-air missiles are out in the open and could fall into the hands of terrorists"

An abandoned AA-8 Aphid air-to-air missile found at an unguarded weapons stockpile near Sirte, Libya.
© 2011 Peter Bouckaert/Human Rights Watch

"Human Rights Watch found at least 14 empty crates that had once contained a total of 28 SA-24 missiles. More than 20 SA-7 surface-to-air missiles remained in their original packaging. At a second site ... located a massive, unsecured ammunition storage facility with at least 70 bunkers containing explosive weapons. Inside the bunkers, ...found large quantities of munitions, as well as thousands of guided and unguided aerial weapons."

Even prior to the dissolution of the Soviet Union in the early 1990s, the U.S. defense establishment worried about sophisticated weapons winding up in the wrong hands after a "regime change". During the upheaval in the Mid-East known as the Arab Spring, we have seen photographic evidence of exposed, unsecured weapons' bunkers – some with stockpiles of precision weaponry. We can assume that the proliferation of precision weapons is now a fact of life.

It must therefore be assumed that some of these weapons are now in the hands of Al-Qaeda or other similar organizations that have the *will and the ability* to use them against U.S. forces. A particularly vulnerable portion of expeditionary warfare in the littorals is the slow, deliberate movement of Marines from amphibious ships to the shore in a non-permissive environment. This is where the precision weapon threat must be taken very seriously.

Guided Rockets, Artillery, Mortars and Missiles (G-RAMM) can be further categorized:

- Guided munitions are those that require an operator in-the-loop to function. This usually requires a direct line-of-sight (LOS) between the operator (or the sensor being used by the operator) and the target. The LOS requirement gives guided munitions an inherent ability to precisely engage specific targets.

- Smart munitions are those that have a self-contained capability to search, detect, acquire, and engage targets, but have minimal capability to discriminate among target classes or target types. They are designed for many-on-many engagements where multiple munitions are directed into an area known to contain many targets.

- Brilliant Munitions are those that have the ability to discriminate and to selectively identify and engage specific classes of targets.

Guided Munitions are the fastest growing threat because their capabilities and numbers are increasing, and the countries and non-state actors that possess them are also increasing. Although only 3% of the world's ammunition stockpile is now categorized as guided, smart or brilliant munitions, steadily decreasing costs and rising demand will lead to an increase in the number of these systems. Although the high cost and complexity had previously made precision munitions the province of only the U.S., its allies and peer competitors, today precision munitions are becoming readily available from arms merchants worldwide.

An example of precision guided artillery that is sold on the world market is the Russian laser-guided Krasnopol which has been sold to more than 12 countries, including China, India, Pakistan, and Belarus. And, it should be noted that India has become a producer of precision guided artillery.

The Swedish 120mm Strix guided mortar which uses an IR seeker, the Israeli-Raytheon Dagger GPS-aided 120mm mortar, and the Russian Gran 120mm laser guided mortar are examples of guided mortars now being sold on the world market.

Guided missiles have also proliferated across the spectrum of nations. These include Man-Portable Precision Air-Defense Systems (MANPADS) such as the third generation infrared shoulder-fired SAMs (including the French Mistral, the Russian SA-18, the U.S. Stinger B). These use single or multiple detectors to produce a quasi-image of the target and have the ability to recognize and reject flares dispensed from aircraft.

A threat that is of particular concern is the antitank guided missile class of weapon that can target amphibious combat vehicles.

Unmanned Aerial Systems (UASs) with PW Capabilities

- **Most countries are developing ISR UAVs**
  - Could be the source of precision weapon guidance
- **UAVs of any size with GPS can be used as a suicide precision weapon**
  - Current threats typically require close-in operations & line of sight
- **Both China and Iran have UCAVs in development that could carry PGMs**
  - Likely 5-10 years from operational capability
- **Multi-UAV coordinated operations 10-20 years in the future for adversaries**

Harpy
Israel/China
Range ~300mi
Loitering Munition
70lb payload

Ababil/Swallow
Iran
Range ~90mi
ISR/Attack
88lb payload

Due to the low cost of entry, many countries have the capability to develop unmanned aerial vehicle (UAV) capabilities – primarily for Intelligence, Surveillance, and Reconnaissance (ISR) applications. As threat platforms, they could be used for C3ISR as well as precision weapons (e.g., expendable, "suicide" systems). In addition to the United States, several other countries are developing weaponized UAVs (referred to as Unmanned Combat Aerial Vehicles – UCAVs). These large UAV systems serve as launching platforms for precision guided munitions, most notably in development by Iran and China.

The Harpy, as shown above, is a loitering weapon system with variants owned by both Israel and China. It is a one-way, precision-guided weapon with a range of approximately 300 miles and a 70lb payload that can loiter above the battlespace until a target of opportunity emerges. The Iranian Ababil/Swallow has both ISR and attack capabilities (somewhat similar to the USAF Predator series UCAVs), but has an estimated range of 90 miles with only an 88lb payload (as compared to the Predator's range of 1000 nautical miles and payload of approximately 3,800 pounds).

A primary concern when considering UAVs as a threat in any setting is their low-flying, slow-moving capabilities that make them very difficult to detect, track, and defeat. Moreover, they do not have to be armed with any traditional weapons to be lethal – such vehicles could carry biological and chemical warfare payloads which do not require sophisticated and heavy launch systems.

While the numbers of weaponized UAVs will likely remain small as compared to the number of ISR UAV platforms for most countries, it should be noted that ISR platforms could become targeting-assist platforms to aid manned and unmanned aircraft in the precision delivery of weapons. Also, a UAV with off-the-shelf GPS technologies could be used as a suicide precision weapon. Thus, it is critical that developments continue in networked sensor architectures to counter such threats. While the UAV threat to amphibious operations is a clear and present danger to Marines and is likely to increase as these technologies become more accessible, there are also known limitations. For example, the current UAV threat platforms typically require close-in operations with line-of-sight control – severely limiting enemy operations such that they must be in close physical proximity to the battlefield.

Moreover, the large majority of global UAV developments are focused on ISR missions with only a few major efforts towards UCAV development. In countries like China and Iran, who are actively engaged in UCAV development, such efforts are not likely to reach operational status for at least 5-10 years for single vehicles. The primary limiting factor for these developments is not the technology itself (e.g., the vehicle development), but rather the challenges in the development of robust ground control stations, the associated command and control infrastructure, and training and concepts of operations.

While UAV development is generally advancing quickly for our adversaries, the critical "system" portion of Unmanned Aerial System development has substantially lagged vehicle development. Because of these difficulties, it is likely that coordinated multi-UAV operations are at least 10-20 years in the future for our adversaries – and possibly for U.S. efforts for the same reasons.

Unmanned Systems: Both a Threat and a Capability Enabler

- As threats, UASs could be used as C3 and ISR platforms AND precision weapons
  - Low-flying, slow-moving small UASs are very difficult to detect, track, and defeat
  - A netted sensor architecture is a requirement for countering such a threat
- As future operational capability enablers, unmanned systems could include:
  - UASs for ISR and defense against PWs
  - USVs (Unmanned Surface Vehicles) for beach assaults
  - UUVs for ISR

While the discussion to this point has focused on UAVs as a threat to amphibious operations, it should be noted that in such settings, they also represent substantial future capabilities for Marine Corps operations. Indeed, the future possibilities of all unmanned systems including water surface, underwater, and ground unmanned vehicles, in addition to airborne assets, could be veritable game changers in these settings.

In terms of possible future UAS capabilities in amphibious operations, unmanned systems could be used for ISR and defense against precision weapons. Unmanned Surface Vehicles (USVs) could be used for beach assaults while Unmanned Underwater Vehicles (UUVs) could conduct stealthy clandestine operations, as well as other ISR-related missions. Hybrid USV-UGV (unmanned ground vehicle) platforms are also a future possibility. Indeed, it is not a far stretch of the imagination to envision a first wave of an amphibious assault completely populated by unmanned vehicles of various types.

PW Threat Summary

- Even small organizations can field more lethal and capable weapon systems, maintain awareness of the battlespace, and coordinate activities among dispersed forces.
- Precision weapons and supporting technologies are proliferating
  - **Weapons**: G-RAMM systems, specialized ammunition, advanced optics
  - **Comms**: high-level encryption, fiber-optic networks, cellular, satellite, VOIP, Twitter, web-presence
  - **ISR**: commercial satellite imagery, “Google Earth”, commercial UAVs w/cameras
  - **Robotics**: a multitude of unmanned systems flooding the market, providing affordable, effective remote platform capabilities for air, land, and maritime surface/sub-surface environments

Increasingly, sub-state/non-state forces will be able to execute attacks on security forces, critical infrastructure, and key resources from greater range, with increased precision,
and with little or no warning

As has been stated, precision weapons and supporting technologies are proliferating. Commercial technologies are being applied in very inexpensive ways to create precision munitions. The ubiquitous Apple iPhone with its camera and “FaceTime” application can be used to provide a targeting capability to a small unmanned vehicle carrying a munition – and turning it into an effective precision weapon.

Guided munitions depend on communication between the operator and the weapon. The acceleration of technological advances in high-level encryption, fiber-optic networks, cellular and satellite technologies, Voice Over Internet Protocol (VOIP), social networks such as Twitter, and web-presence are enablers to the capabilities of guided munitions. They significantly increase the degree of difficulty for defeating essential precision weapon communication links.

With commercial satellite imagery, “Google Earth”, and GPS, coupled with low cost unmanned aerial vehicles outfitted with a simple camera, any non-state actor can easily and inexpensively add an ISR capability to his UAV and intrude into the asymmetric advantage the U.S. has enjoyed in ISR over the years.

With these capabilities, sub-state/non-state forces will be able to execute attacks on our security forces, critical infrastructure, and key resources from greater range, with increased precision and with little or no warning.

Amphibious Operations

NRAC Observations
re: Amphibious Operations

Current:	Future:
• US has asymmetric advantage in weapons, C3, ISR	• Uncertain threat environment, esp. with precision weapons
• Battlefield preparation	• Condition setting ashore (must include electronic attack, counter C3, counter ISR)
• Counter-battery (adversary only gets one shot...)	• Single Naval Battle, including air-to-ground situational awareness, C3, integrated fires
• Come-as-you-are	• Come-as-you-are as the key enabler for fast response in an increasingly chaotic world

Today the U.S. has an asymmetric advantage in weapons, and C3ISR, but with an uncertain threat environment and proliferation of precision munitions, amphibious combat vehicles will become easy targets. If an adversary can generate the requisite targeting, even by visual observers, and if his weapons have a high probability of hitting their targets, the success of an amphibious assault can no longer be assured using the tactics that have been effective in the past.

The single, integrated Sea-Air-Ground naval battle (i.e., the "Single Naval Battle") with its seamless command structure across all modalities will be critical for adequate preparation of the battlefield. In the future, this preparation will become even more important – using the appropriate electronic attack methodology to counter the adversary's C3ISR capabilities.

The Marine Corps counter-battery protocol has been and will continue to be a critical capability for amphibious assaults. This capability should not be changed, but should be expanded to not only counter the shooter but to break the adversary's kill chain by interrupting the command links and targeting sensors that are used for his smart weapons.

Today – as well as in the future – the entire Amphibious Task Force (amphibious ships with embarked MAGTFs) will need to provide the cross-domain expertise to enable effective “come-as-you-are” engagements with flexibility and adaptability in an increasingly chaotic world.

Current and Planned USMC Capabilities, Developments, and S&T

USMC Capabilities for Responding to PW Threats

(current and planned)

- Single Naval Battle (Integrated Sea-Air-Ground)
- Battlefield preparation, including, e.g.,
  - ISR and counter fire
  - Electronic signatures, decoys, obscurants. Military deception may prove essential
- Interceptor: kinetic and/or functional kill of the PGM
- Electronic Attack and Cyber Attack
  - "Deny, degrade, disrupt"
  - GPS jamming and spoofing
  - C3 and video link jamming

Essential and particularly challenging in the littorals, near high-density population centers…

In order to respond to the evolving precision weapons threat to amphibious operations, the Marine Corps is pursuing a multi-pronged approach.

First and very importantly, the USMC and Navy are expanding their capability to wage a single, integrated Sea-Air-Ground naval battle in concert with the other services' ground and aviation units, the intelligence community and special operations forces. This emergent operational concept provides for, among other things, ship-based remote fires for initial protection of the amphibious force. This enables early "boots on the ground" for the detection, identification, and location of hidden enemy ground positions in an Anti-Access/Area Denial role.

This integrated battle will include preparation of the battlefield including ISR, counter fires, decoys, and obscurants to confuse the enemy, and the capability to intercept or functionally kill precision guided munitions.

Of particular importance in the future will be the capability to perform electronic attack (e.g., GPS jamming and disruption, C3 and video link jamming) and cyber attacks on enemy forces in the littorals and near high-density population centers without causing significant collateral damage or fratricide. This will be a very challenging problem.

S&T Contributions to USMC Capabilities

- Marine Corps-led
  - GBAD-OTM (Ground-Based Air Defense On-The-Move), G/ATOR (Ground-Air Task-Oriented Radar)
- Marine Corps-leveraged
  - Army IFPC (Indirect Fire Protection Capability)
  - Industry-led and other nations' Kinetic Energy concepts
  - High Energy Lasers (HEL)
  - Obscurants, decoys
  - Leverage and influence Foreign Military Exploitation activities of the Intel Community
  - Unmanned systems
  - Electronic Attack and Cyber Attack – aim to disrupt the C2 and ISR, rather than killing the PW

But, effectiveness of ground-based hard kill systems (esp HEL) against indirect fire may be degraded by terrain, atmospheric effects, air de-confliction and predictive avoidance

The ongoing S&T efforts that will help the USMC in countering future precision weapons threats includes work that is being led by the USMC, and ongoing programs in other government and commercial sectors which the Marine Corps may choose to leverage.

The USMC is developing a versatile, digital, multi-function radar system named the Ground-Air-Task Oriented Radar (G/ATOR) to replace several fielded ground radars. This new radar system will be delivered as part of the amphibious early strike package – slated to reach Initial Operational Capability (Increment I) in 2016.

In addition, the Office of Naval Research Code 30 has begun a new USMC Future Naval Capabilities program for Ground-Based-Air Defense On-The-Move (GBAD-OTM). This FNC effort will focus on coupling the G/ATOR radar with a High Energy Laser (HEL) system to defeat enemy unmanned aircraft systems with

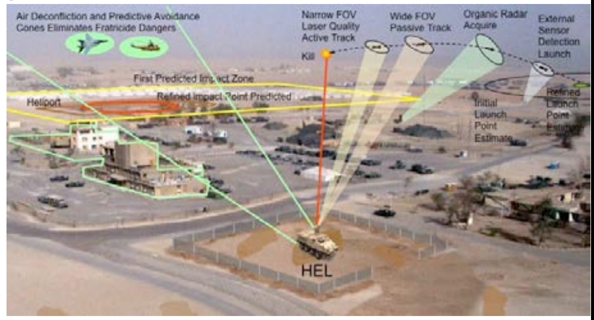
ISR and PW capability. This program begins in 2012 and is expected to provide a proof-of-concept prototype by FY 17.

However, the effectiveness of ground-based radar and HEL systems against precision enemy indirect fires may be degraded by amphibious terrain, atmospheric effects (i.e., visible moisture), air de-confliction (e.g., friendly fixed-wing and helo operations) and satellite predictive avoidance policies. Airborne versions of these radar and HEL capabilities (with look-down capability) might ameliorate these problems.

In addition to the USMC-led efforts described above, the Marine Corps is carefully monitoring the Army's Indirect Fire Protection Capability (IFPC) developments, other joint-service HEL work at various agencies, unmanned systems advancements, intelligence community-based Foreign Military Exploitation (FME) activities, and obscurants, decoys, and electronic and cyber attack developments.

High Energy Laser Systems: Issues

- Need for cueing (esp. against slow, low, small UAVs)
- Maritime environment affects performance
- Lack of commercial market for power increase
- All GBAD-OTM laser contenders at low level of technical maturity



- Predictive avoidance/de-confliction for ground-based lasers (technology/policy)
- Airborne lasers: size, weight, and power challenge
- 5% duty cycle: e.g., 40 sec magazine, 15 min recharge
- Ultra short pulse (10^{-15} sec) lasers. Lower level tech maturity than GBAD. Potentially unique propagation and kill mechanism

This chart summarizes some relevant technical issues that should be considered when evaluating Marine-led Counter Precision Weapons (CPW) programs that utilize HEL devices to defeat unmanned aircraft systems. HEL systems must use narrow beams to obtain the requisite high power densities for a target kill – and therefore are not volume search-kill systems. They need accurate cueing from some other system – usually radar – that has time and space synchronization. The radar or HEL system must classify as well as detect and track targets to avoid collateral damage or expending their weapon magazine on false targets. The clutter caused by moving objects on the ground is a very difficult problem against small, slow, low altitude UAVs – especially in crowded urban environments.

In addition, as the range to the threat increases, the energy density arriving on a target is very strongly affected by the maritime environment, especially the moisture and the turbulence in the atmosphere. For ground-based lasers, low altitude targets at long-range require the laser pulse to travel long distances through the atmosphere, increasing the significance of environmental effects. This laser pulse will require longer dwell time (in the order of 4-5 seconds) on the same spot on the target – requiring very precise beam tracking – which will diminish the ability of the laser to engage multiple near-simultaneous targets.

Ten kilowatts (10 kW) of laser output power is about the maximum required for commercial applications and which has sufficient beam quality for a long-range laser weapon. For some commercial applications (e.g., materials processing) higher powered lasers are employed, with reduced beam quality, because their usefulness at the very short "commercial" ranges is maintained. But the reduced beam quality of these systems makes them unsuitable for laser weapon use. At this time, there is no commercial need to develop a long-range materials processing capability.

HEL weapons systems will require more than ten kWs of laser power. To achieve higher total power, most of the current laser weapon development programs involve combining multiple laser beams to increase the power density on the target. This adds complexity and cost to the system: all of the current GBAD-OTM laser contenders are currently at a low level of technical maturity – even though the laser itself is commercially available off-the-shelf.

The fact that the some of the laser energy continues to propagate past the target, through the atmosphere and into space requires serious efforts to de-conflict friendly air targets that are nearby and to perform predictive avoidance to safeguard sensitive components of friendly low orbit satellites. This may seriously limit use of a laser weapon.

Current laser systems with the requisite weight (i.e., light) and power (i.e., sufficient) for either airborne or expeditionary operations are limited to about a 5% duty cycle. In this case, duty cycle refers to the time that the laser can "shoot" compared to the time required to re-charge the batteries). State-of-the-art batteries for these systems only allow for about 40 seconds of lasing (i.e., the "munitions magazine") with about 15 minutes of recharging. Operationally, the duty cycle and magazine issues will probably require multiple lasers to be networked in order to provide the flexibility to counter actual threats – adding another level of cost and complexity.

However, because of a laser weapon's "zero flight time", its inherent capability to deal with multiple moving targets at various speeds, the ability to obtain a hard kill or negate weapon system functionality (referred to as a soft kill), laser weapons should continue to be studied for countering the precision weapons threat.

Finally, there is current research in ultra short pulse lasers – whose time duration is in the order of a femtosecond ($10^{-15 \text{ second}}$). This technology is at a lower level of maturity than the current GBAD laser contenders – but offers a potentially unique propagation capability in the atmosphere and a unique kill mechanism, and therefore should be closely monitored by the S&T community.

Findings - What's Missing

- A mechanism to provide the expeditionary force development process with required information, including threats and countermeasures
- An ability to predict the near and long-term threats associated with commercial technology advances (e.g., Google Earth)
- This drives the requirement for **adaptability**
  - Requires frequent experimentation
    - Known and predicted threats and countermeasures in a realistic environment (geopolitical understanding, influence of other factors, e.g., commercial shipping and fishing)
    - Experiments must connect the technology developers with the operators

The first point to be made by this analysis is that forces conducting amphibious operations in the anticipated threat environment will need to be able to *adapt* to the threat environment as it evolves. This suggests a systems approach such as that of tactical aircraft, which are upgraded throughout their lifecycle to accommodate emerging threats by incorporating improved countermeasures. To do this, it will be necessary to *accelerate the process* for acquiring and exploiting threat precision weapon systems, assessing their weaknesses and vulnerabilities, and developing effective countermeasures and counter-tactics. Fortunately, options for achieving this goal are becoming available as threat weapons are becoming available in the worldwide arms markets.

To achieve the desired acceleration of the process for analyzing threats and developing countermeasures for amphibious systems to address emerging threats, the Panel is including recommendations for *expanding the expeditionary force development process.*

What’s Missing (cont.)

- Ship-to-Shore connectors with adequate capacity, speed, armor, and defensive capabilities remain a challenge
  - Consider unmanned systems, e.g. “Unmanned Breacher Vehicle”*
- A holistic view of counter PWs – defeat the critical systems, not only the weapon. Countering philosophy must include shaping the battlefield and must address the entire kill chain, e.g., C3 and ISR capability, obscurants, decoys, deception
  - Panel was unable to examine some countermeasures (Cyber and Electronic Attack)

***“The Next Wave: Assault Operations for a New Era”**
Naval Institute Proceedings, November, 2011
LtCol J. Noel Williams, U.S. Marine Corps (Retired)

As a complement to the traditional amphibious platforms and systems, *unmanned systems* may offer capabilities which merit examination, such as the unmanned breacher vehicle proposed in the Naval Institute Proceedings article referenced above. Other unmanned systems offering interesting future capabilities include *airborne communications nodes and ISR platforms***.**

And finally, the full range of countermeasures to advanced weapons systems needs to be addressed – some of which could not be reviewed during this study. Specifically, consideration of the systems most threatening to amphibious operations suggest a high payoff from incorporation of *Electronic Attack and Cyber countermeasures technologies* for enhancing the survivability of advanced amphibious platforms. To achieve the synergies between electronic and hard kill defensive systems, an expansion of the current expeditionary force development process would be useful.

Recommended Initiatives

NRAC Recommended Initiatives

- Enhance the expeditionary force development process by:
  - Promoting the acquisition of threat weapons systems
  - Accelerating the analysis of weaknesses & vulnerabilities
  - Accelerating the transition of threat vulnerability analyses into countermeasures options via S&T initiatives program planning, and CONOPS development
  - Testing the effectiveness of countermeasures & tactics in laboratory & operational environments (e.g., Black Dart)
  - Integrating threat analyses, countermeasures, and S&T planning into expeditionary force development process

Establish an Integration Cell to support, sponsor, and monitor the activities outlined above

The Panel believes that the Marine Corps presently has the expertise and the processes necessary to address the threats posed to amphibious operations by precision weapons. However, in view of the short timeline associated with the appearance of this threat, an *acceleration* of the process to understand and respond is necessary. In summary, the panel believes that the Marine Corps should ensure that the expeditionary force development process includes accelerated programs to:

- Acquire, analyze and exploit identified weaknesses and vulnerabilities of potential threat weapons systems,
- Develop and test countermeasures in realistic environments, and
- Integrate threat analyses, countermeasures, and S&T programs into the expeditionary force development process.

We noted that multi-agency approvals for selected, realistic experiments have been difficult if not impossible to obtain. This is an issue that should be addressed.

The accelerated understanding of, and response to, threats arising from precision weapons systems can – in the panel's opinion – benefit greatly from the establishment of an Integration Cell that can support, sponsor, and monitor the following activities:

- Foreign materiel exploitation,
- Intelligence analysis,
- S&T,
- Experimentation, including laboratory and range tests in realistic environments,
- Concept development and wargaming, and
- Acquisition program requirements.

The Integration Cell should be broad-based, and should explore technologies available from the commercial sector as well as the military sector, both within the US and overseas. The Panel believes that this Integration Cell does not necessarily require the creation of a new organization, but rather can draw individuals from existing groups, e.g., the Amphibious Capabilities Working Group, NRL, Black Dart (sponsored by JIAMDO – Joint Integrated Air and Missile Defense Organization).

NRAC Recommended Initiatives

- Conduct experiments on the use of airborne platforms and/or electronic support measures to track small, slow, low-flying UASs
- Design and conduct experiments on the use of current and planned unmanned platforms as
  - Ship-to-Shore connectors
  - Counter-battery airborne ISR nodes
  - Airborne communication relays
  - Airborne GPS surrogate

Exploit all available range and laboratory facilities for the conduct of these experiments, with MCWL as executor.

- Design and conduct experiments on Cyber and Electronic Attack threats and countermeasures in amphibious operations environments

The panel believes that Unmanned Aerial Systems (UASs) represent a realistic, near-term threat to the conduct of Marine Corps amphibious operations. In particular, the panel heard from several experts that small, low-flying, slow-moving UASs are especially difficult to detect, classify, and track because of the background noise or clutter associated with, e.g., land vehicles. The panel believes that airborne systems and/or networked land-based systems will be necessary to detect, cue, and defeat these threats.

The panel believes that we are approaching a time when even a small number of possibly inexpensive, precision weapons could pose a serious threat to Marine Corps personnel and platforms. The panel advises that the Marine Corps accelerate the consideration of unmanned platforms as

- Ship-to-Shore connectors,
- Counter-battery airborne ISR nodes,
- Airborne communication relays, and

- Airborne GPS surrogate.

This will require experimentation, in realistic environments, using current and planned unmanned systems, with the Marine Corps Warfighting Laboratory as the executor.

The panel was not able to review programs and technologies in the areas of cyber and electronic attack threats and countermeasures. However, given the Panel's recommendation that the most effective response to the precision weapon threat is a holistic approach that includes countering the enabling technologies (C3ISR), it is our opinion that cyber and electronic attack must be important components of the strategy for countermeasure development. Furthermore, with an understanding that our adversaries have or soon will have access to cyber attack and electronic attack capabilities, the Panel believes that future amphibious experiments and wargames should include such threats.

Appendix A

Terms of Reference

Objective

US Marine Corps Expeditionary Forces face constant threats that continue to evolve. This study will examine the Marine Corps capabilities for responding to the emerging potential for US adversaries to adopt and employ precision weapons and munitions to improve their lethality. The objective of this study is to identify the challenges for countering precision munitions and recommend opportunities to address this potential challenge.

Background

We saw the emergence of Forward Operating Bases (FOBs) during operations in Afghanistan, from which the Marine Corps sustains, deploys from, and accomplishes missions against the enemy with small units (squads to companies). Should these FOBs become subject to precision enemy fire, the Afghanistan mission risk will increase. The Intel community is seeing greater proliferation of relatively inexpensive Guided Rockets, Artillery, Mortars, and Missiles (G-RAMM), which can pose a great threat to future Marine operations. This threat is yet another example of cheap technologies with the potential to have a huge impact on future missions, much like the IEDs have had on recent ones.

Specific Tasking

This study will specifically:

- Characterize known and potential precision weapons and munitions types that could be potentially exploited by hostile governments and non-state actors, to include relatively inexpensive, home-made-type weapons;

- Review and assess the current and planned Marine Corps policies, strategies, approaches (including training), and capabilities for responding to these potential precision weapons and munitions;
- Identify promising science and technology areas for Marine Corps capabilities to respond to these potential precision weapons and munitions threats, which can include detection, tracking, identification, engagement, and ways to counter damage caused by precision weapons, as well as others;
- Recommend any other initiatives that should be undertaken by the Marine Corps in an effort towards improving their overall capabilities for responding to the potential exploitation of precision weapons and munitions by adversaries.

Appendix B

Panel Biographies

Panel Chairman-Dr. Michael S. Bruno. Dr. Bruno is Dean of the School of Engineering and Science, and Professor of Ocean Engineering at Stevens Institute of Technology, Hoboken, New Jersey. He is the Director of the Center for Secure and Resilient Maritime Commerce and Coastal Environments (CSR), a Department of Homeland Security National Center of Excellence. His research and teaching interests include ocean observation systems, maritime security, and coastal ocean dynamics. He is the author of more than 100 technical publications in various aspects of the field. Prior to assuming the duties of Dean, Dr. Bruno was the Director of the Center for Maritime Systems and Davidson Laboratory at Stevens from 1989 to 2007. During this period, he initiated the development of several ocean and weather observation and forecasting systems. Dr. Bruno is Chairman of the National Academy's Marine Board; Member of the Ocean Research Advisory Panel; and serves as the Editor-in-Chief of the Journal of Marine Environmental Engineering; Secretary-General of the Pan American Federation of Coastal and Ocean Engineers; and Visiting Professor at University College, London. A Fulbright Scholar (1996 appointment at the Aristotle University of Thessaloniki, Greece), Dr. Bruno is also a Fellow of the American Society of Civil Engineers. He received the Office of Naval Research Young Investigator Award in 1991, and the Outstanding Service Award from the American Society of Civil Engineers in 1988. Dr. Bruno holds a B.S. degree in Civil Engineering from the New Jersey Institute of Technology, a M.S. degree in Civil Engineering from the University of California at Berkeley, and a PhD degree in Civil and Ocean Engineering from the Massachusetts Institute of Technology and the Woods Hole Oceanographic Institution.

Vice Chair-Dr. Fernando Fernandez. Dr. Fernandez is a private consultant and a Director for various companies. From 2001-2006 Dr. Fernandez was a Distinguished Research Professor in Systems Engineering and Technology

Management at Stevens of Technology. In addition, he served as the Chief Technical Advisor to the President for Institute research initiatives, management of intellectual property and commercialization of technology. From 1998-2001, Dr. Fernandez was the Director of the Defense Advanced Research Projects Agency. Under his leadership, DARPA served as the Department of Defense's premier R&D institution, trailblazing paths in biological warfare defense, information security, precision strike and robotics. Before that he started and managed several successful R & D companies specializing in remote detection and identification of hidden objects. In 2001, he was awarded the Distinguished Public Service Award by the Secretary of Defense and an Honorary Doctor of Engineering degree by Stevens Institute of Technology. Dr. Fernandez received his Bachelor of Science in mechanical engineering and Master of Science in applied mechanics from Stevens Institute of Technology in 1960-1961. He received his Ph.D. in aeronautics from the California Institute of Technology in 1969.

Vice Admiral William Bowes. VADM Bowes, U. S. Navy (Retired) is an aerospace consultant, serves on a number of boards and is vice chairman of the NRAC. He served 33 years in the Navy in numerous operational and acquisition assignments. As a Vice Admiral he served as the Commander of the Naval Air Systems Command, the Principal Deputy Assistant Secretary of the Navy for Research, Development and Acquisition (RDA), and for six months was the Acting ASN (RDA). He is an accomplished test pilot, program manager and PEO. He served as the program manager for the F-14 and Phoenix missile program, the Joint Cruise Missiles Project, which developed and deployed the Tomahawk cruise missile, and was the first director of DOD’s Joint Unmanned Aerial Vehicles Project. After retiring from the Navy, Bowes joined Hughes Aircraft as a Senior Vice President and Deputy General Manager of the newly forming Sensors and Communications Sector. After Hughes was acquired by Raytheon, Bowes joined Litton Industries as the Vice President, Corporate Strategic Planning, and subsequently led the creation of the Military Aircraft Electronics Systems business unit after Litton was acquired by Northrop Grumman.

Dr. Mary L. (Missy) Cummings. Dr. Cummings is the Boeing Associate Professor of Aeronautics and Astronautics at the Massachusetts Institute of Technology (MIT). She is the director of the MIT Humans and Automation Laboratory, and holds additional appointments in the MIT Engineering Systems Division and the MIT Computer Science and Artificial Intelligence Laboratory. She is currently serving as a program manager in the Naval Air Warfare and Weapons Department of the Office of Naval Research in an Intergovernmental Personnel Act (IPA) position. Her previous teaching experience includes instructing for the U.S. Navy at Pennsylvania State University and as an assistant professor for the Virginia Tech Engineering Fundamentals Division. Professor Cummings received her Bachelor of Science degree in Mathematics from the United States Naval Academy in 1988, her Master of Science in Space Systems Engineering from the Naval Postgraduate School in 1994, and her doctorate in Systems Engineering from the University of Virginia in 2004. A U.S. naval officer and military pilot from 1988-1999, she was one of the Navy's first female fighter pilots. Her research interests include human supervisory control, human-unmanned vehicle interaction, bounded collaborative human-computer decision making, simulation and evaluation of human interaction in automated systems, and the ethical and social impact of technology. Funding for her $10,000,000 laboratory comes from several Department of Defense agencies such as the Office of Naval Research, the Air Force Office of Scientific Research, and the Air Force Research Laboratory as well as other government agencies such as the National Science Foundation, the Federal Aviation Administration, and the Nuclear Regulatory Commission. She routinely partners with industry collaborators such as AAI, ABB, Alstom, Boeing, United Technologies, and several small companies across the United States. Professor Cummings has published over 100 peer-reviewed journal articles, conference papers, and book chapters and has served on several U.S. national committees such as the National Academy of Science Opportunities in Neuroscience for Future Army Applications Committee, the National Research Council Transportation Research Board En route Air traffic Control Complexity & Workload Model Review Committee, and as an advisor to the

U.S. Air Force Scientific Advisory Board for UAVs in Irregular Warfare. She currently serves on the National Research Council Board on Human Systems Integration and NASA's Space Human Factors Engineering Standing Review Panel.

Dr. Frank Shoup. Dr. Shoup's career has included experience in both scientific and technical research and management, and in operational testing and analysis. His Naval technical management responsibilities in the Office of the Chief of Naval Operations have included Director, Science and Technology Division (OP-987); Associate Director, Expeditionary Warfare Division (N-75); Chief Scientist, Systems Analysis Division (OP-96); and Scientific Analyst, Electronic Warfare Division (OP-944). Other Naval assignments have included the Chair of Physical Sciences and Chair of Electronic Warfare at the Naval War College; Science Advisor to the Commander, U.S. Naval Forces, Europe; Science Advisor to the Commander, U.S. Sixth Fleet; CNA representative to Commander, U.S. Pacific Fleet and CNA representative to Commander, Task Force 77. His most recent position was as Director of the Wayne E. Meyer Institute of Systems Engineering at the Naval Postgraduate School. While on active duty with the Air Force, he served as project officer for nuclear weapons effects testing programs in five major nuclear weapons test operations in the Nevada Test Site and the Pacific Proving Grounds. Dr. Shoup did his graduate work in physics and his undergraduate work in chemical engineering.

Appendix C

Fact-Finding Contributors

Contributor	Organization
Dr. Bill Powers	USMC Center for Emerging Threats the Opportunities (CETO)
Mr. Lou Kelley, Mr. Charles Brown, et al	Marine Corps Intelligence Agency
Mr. Paul Loura	National Ground Intelligence Center
Mr. Mike Strycharz	MCCDC, Operational Analysis Division (OAD)
Mr. Wes Hammond	WBB Consulting, Capabilities Based Analysis
Mr. Dakota Wood	Center for Strategic and Budgetary Assessments (CSBA)
Mr. Dennis Adomatis	Deputy Program Manager, C-RAM
Mr. Chris Zaffram and Col Peter Reddy	Marine Corps Systems Command
Dr. Bob Evans	Naval Research Lab
Dr. John Kim	Office of Naval Research
Dr. Jason Marshall	Staff Specialist, Directed Energy, Office of the Secretary of Defense
Mr. Lee Mastroianni and Major Bill Short	Office of Naval Research
Mr. Malcolm Airst and Mr. Tom Kennedy	MITRE Corporation

LtGen Richard Mills	Marine Corps Combat Development Command
Mr. Scott Boyd et al	Directed Energy Warfare Office (DEWO), NAVSEA Dahlgren
Mr. Art Corbett	Marine Corps Concepts, MCCDC
Mr. Chris Murphy	Lockheed Martin
Dr. Karl Scheibner	Lockheed Martin
Mr. Mike Friend	Lockheed Martin
Mr. Kenton Ho et al	Northrop Grumman
LtCol John Boehm and Maj Ethan McKenna (USAF)	Black Dart Office
Mr. Dave Hidinger	Lockheed Martin
Dr. Kurtis Kelly et al	Lockheed Martin
Dr. Dan Murphy et al	MIT Lincoln Lab
Mr. Michael Black	Boeing
Col Chris Naler (USMC)	Amphibious Capabilities Working Group (ACWG)
Col Groen (USMC)	Amphibious Capabilities Working Group (ACWG)
Mr. Richard Busse et al	Joint Electronics Advanced Technology (JEAT)

Appendix D

Acronyms

A2-AD	Anti-Access/Area Denial
ACV	Amphibious Combat Vehicle
ASN RDA	Assistant Secretary of the Navy for Research, Development and Acquisition
ATGM	Anti-Tank Guided Missile
C3	Command, Control, Communications
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance, Reconnaissance
CNO	Chief of Naval Operations
CNR	Chief of Naval Research
CONOPS	Concept of Operations
DON	Department of the Navy
EA	Electronic Attack
EW	Electronic Warfare
FME	Foreign Military Exploitation
FYDP	Future Years Defense Program
G/ATOR	Ground-Air Task-Oriented Radar
GPS	Global Positioning System
GBAD-OTM	Ground-Based Air Defense On-the-Move
G-RAMM	Guided Rockets, Artillery, Mortars, and Missiles
HEL	High Energy Laser
IFPC	Indirect Fire Protection Capability
IMU	Inertial Measurement Unit
IOC	Initial Operating Capability
ISR	Intelligence, Surveillance, Reconnaissance
MANPAD	Man-Portable Air-Defense System
MCCDC	Marine Corps Combat Development Command
MCWL	Marine Corps Warfighting Lab
NAVAIR	Naval Air Systems Command
NAVSEA	Naval Sea Systems Command
NGIC	National Ground Intelligence Center
NRAC	Naval Research Advisory Committee
NRL	Naval Research Laboratory
ONI	Office of Naval Intelligence
ONR	Office of Naval Research

OPNAV	Office of the Chief of Naval Operations
OSD	Office of the Secretary of Defense
OTH	Over the Horizon
PGM	Precision Guided Munition(s)
PM	Program Manager
PNT	Precision Navigation and Timing
POR	Program of Record
PW	Precision Weapon(s)
RDT&E	Research, Development, Test & Evaluation
SAM	Surface to Air Missile
SAP	Special Access Program
S&T	Science and Technology
SECDEF	Secretary of Defense
SECNAV	Secretary of the Navy
STOM	Ship to Objective Maneuver
SYSCOM	Systems Command
TOR	Terms of Reference
TRL	Technology Readiness Level
UAS	Unmanned Aircraft Systems
UAV	Unmanned Aerial Vehicle
UCAV	Unmanned Combat Aerial Vehicle
USV	Unmanned Surface Vehicle
UUV	Unmanned Undersea Vehicle