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MARINE CORPS

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IN THIS ISSUE

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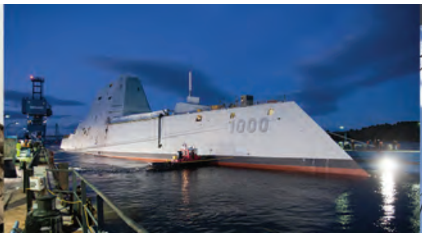

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SPEAKING OF S&T

By Brig. Gen. Benjamin T. Watson, USMC

Photo by Lance Cpl. Joshua Brittenham

Commandant of the Marine Corps General David H. Berger, in his *Commandant's Planning Guidance*, is clear: the Marine Corps is returning to its naval roots. Naval operational challenges are now, once again, the Marine Corps' concern. Questions of how the Marine Corps can support power projection, sea denial, and sea control are invigorating the Marine Corps. The answers require novel concepts such as expeditionary advanced base operations and distributed maritime operations, coupled with evolving doctrine, tactics, techniques, and procedures. Because the Marine Corps is the 21st-century naval force in readiness, fighting today and tomorrow, it requires commensurate revolutionary technologies that support the Fleet Marine Force.

The *Commandant's Planning Guidance* is deliberate and expressively committed to investment in key science and technology projects—what he refers to as "modernization catalysts"—over the next several years. These projects support the Marine Corps' ability to persist inside an adversary's weapon engagement zone. This important Marine Corps capability—to function as stand-in forces—creates mutually contested space, within the range of adversary fires, in support of the larger naval campaign and as a key joint force enabler. This pertains equally to competition (or, as the *National Defense Strategy* defines it, the contact layer) as well as to during conflict (which is the blunt layer).

As vice chief of naval research and commanding general of the Marine Corps Warfighting Laboratory (MCWL), I believe that strong investments in key science and technology projects within the Office of Naval Research (ONR) portfolio will provide the warfighting capabilities necessary for the Marine Corps' future competitions and conflicts. Key technologies that will allow the Marine Corps to dominate in contested maritime environments include: long-range precision fires, unmanned systems, command and control in degraded environments, air and missile defense, distributed logistics capabilities, and artificial intelligence.

Given the commandant's priorities and the importance of naval integration, ONR is holding itself accountable to provide greater focus on the following three technology areas:

- Next Generation Network: ONR will make it a priority to ensure interoperability between the MCWL Fused Integrated Naval Network and ONR's Next Generation Network to support a naval tactical grid that will enable high-speed data connectivity between the fleet and embarked or disembarked Marine forces.
- Artificial intelligence, machine learning, and data science: Meant to tackle the hard challenges of talent management, predictive maintenance, logistics, intelligence, and training, ONR's artificial intelligence projects such as Minerva will have direct warfighting effects with respect to operational tempo, while the Elektra project will focus on survivability. We will work as a naval team to determine opportunities for including these projects in naval experiments, wargames, and demonstrations in order to define applications and benchmarks.
- Swarming technologies that enable amphibious operations and affect capacity and lethality: We will work closely as a naval team and demonstrate how these technologies provide multi-domain effects that will enable manned operations and platform effectiveness. Manned and unmanned teaming is essential to leveraging the full potential of unmanned systems.

Each technology area necessitates critical effort from ONR, which will strengthen the preexisting ONR/MCWL connection. I expect the team to move out smartly on these three technology areas while remaining vigilant of the smaller, quick-win projects that need our attention as well.

Within this issue are examples of further achievements that are a direct result of our naval partnerships.

Brig. Gen. Watson is the Vice Chief of Naval Research and the commanding general of the Marine Corps Warfighting Laboratory.

MARINE CORPS SCIENCE AND TECHNOLOGY

The essential US Marine Corps warfighter always has been the Marine with a rifle. Twenty-first-century naval research is making that Marine more lethal, more interconnected, and more effective than ever before.

▶▶ By Colin E. Babb

THE MARINES GO VERTICAL

EVEN AFTER NEARLY FIVE DECADES IN MARINE CORPS SERVICE, THE HARRIER REMAINS ONE OF THE MOST DISTINCTIVE AND VERSATILE AIRCRAFT IN THE WORLD. THE STORY OF HOW IT CAME TO BE IS AS REMARKABLE AS THE TECHNOLOGY THAT MAKES IT FLY.

On the night of 21 March 2011, a US Air Force F-15E Strike Eagle was on a combat mission over eastern Libya during Operation Odyssey Dawn when it developed a fatal weight imbalance. Its right wing now too heavy after dropping a 500-pound bomb from one of its left wing pylons, the aircraft spun out of control and the two crewmen ejected. An almost entirely Marine Corps-centered rescue team sprung into action aboard USS Kearsarge (LHD 3) off the Libyan coast, as two MV-22 Ospreys, two CH-53E Super Stallions, and two AV-8B Harrier IIs from the 26th Marine Expeditionary Unit flew to rescue the Strike Eagle's pilot (the weapons officer, who landed some distance from the pilot, was rescued by Libyan rebel forces).

Marine Capt. John Grunke, the pilot of one of the AV-8Bs flying above the rescue mission, was one of the first to communicate with the downed pilot, who said he could hear dogs barking and unidentified vehicles headed in his direction. "Initially, when I made contact with him, I could see the vehicles he was talking about," Grunke said. "I looked out . . . and I could see their searchlights on as they were making their way through the desert trying to find him."

Grunke dropped several 500-pound bombs on the oncoming vehicles, trying to keep away any intruding forces—whose friendliness or aggressiveness was unknown—from the pilot on the ground. As the Harriers kept watch above, one of the MV-22s swooped in and landed within 50 yards of the pilot, who was quickly brought on board. Less than 90 seconds later, the aircraft was in the air again.[1]

One way of looking at the entire operation is as a showcase of the state of the art of US Marine Corps aviation technology, and the flexibility and combat effectiveness that technology has made possible. The aircraft from that night with the oldest lineage—the AV-8B Harrier II—exemplifies the Corps' commitment to getting Marines into and out of situations quickly.

The story of the Harrier is not just a tale about a distinctive aircraft that can take off and land vertically; it is a narrative about how the Marine Corps acquired an innovative technology through an international partnership that involved a French designer's idea, British engineering, and American financial support. Its unique acquisition pathway, beginning as a largely privately led project by the United Kingdom's most renowned aircraft manufacturer and ending up as the essential combat aircraft of the US Marine Corps and the primary carrier aircraft of five different navies, set the Harrier apart from its peers at least as much as its characteristic mechanics. It also symbolizes, perhaps more than any other single platform, the often forward-looking and yet always practical ways by which the Marine Corps has equipped its warfighters.

In the aftermath of World War II, the possibilities of vertical lift received considerable attention on both sides of the Atlantic. Helicopters, taking advantage of existing propeller and engine technology already in use with conventional aircraft, were the first vertical take-off-and-landing systems to see wide service. Their ability to carry heavy (and hence combat-worthy) loads, however, was limited. The potential for jet engines to provide vertical lift as well as power and higher take-off weights was intriguing—but the engineering problems that needed to be overcome to create a viable jet-powered vertical lift aircraft were daunting. The low thrust-to-weight jet engines of the time appeared to be unsuited to making vertical take off and landing possible—what was needed was an engine powerful enough to provide thrust, but small and light enough not to overburden the aircraft. "There are about fifteen

Photo by Cpl. Nathan Reyes

different known ways to achieve VTOL [vertical take-off and landing], and each of these received attention," writes historian Mike Rogers. "VTOL aircraft resulted not from gradual evolution, but rather from trying every possibility in the hope of finding one which would work."[2]

The efforts in the United States explored several widely different approaches to vertical lift. Among the more interesting types were the tailsitters—a type pioneered by the Germans during World War II. These included both jets and propeller-driven aircraft. US Navy interest in developing a fighter that could be deployed on multiple types of ships with limited space resulted in a design competition beginning in 1948 between the Lockheed XFV and the Convair XFY Pogo. Both of these were small single-seat, propeller-driven aircraft that sat on their tails and took off and landed vertically. They were so challenging to fly that by 1955 both projects were canceled. The US Air Force tested a jet-powered aircraft of similar size, the Ryan X-13 Vertijet, but ended the program in 1957 in the absence of a clear role for the aircraft.

Another area of interest was in developing lift craft that could provide personal transport or observation platforms on the battlefield. This resulted in a number of odd aircraft that resembled flying discs. Hiller Aircraft, under contract with the Office of Naval Research, developed a circular-shaped, direct-lift rotor craft that used contra-rotating ducted fans designated the 1031-A-1. The US Army also showed interest in the project, and this resulted in a slightly modified type called the VZ-1 Pawnee. The performance of these craft proved to be limited and the program was canceled after a few tests. Another Army vehicle was the HZ-1 Aerocycle, essentially a personal helicopter meant to provide mobility to individual infantrymen. Like many of these small experimental aircraft, the Aerocycle proved far more complex to fly than anticipated (especially when the intention was to have untrained GIs as pilots) and the program ended in 1956. Although all these American efforts largely proved to be dead ends, they nonetheless primed the military services for the future acceptance of jet lift—if and when the state of the art would finally be able to fulfill expectations.

On the other side of the Atlantic, Britain emerged as the leader in Europe among those looking into the possibilities of vertical-lift jets. By the late 1950s, estimated one British engineer, there were at least 37 separate active programs around the world looking at jet lift alone.[3] There were many on the continent particularly concerned about the vulnerability of postwar airfields—now much larger, longer, and fully paved to meet the needs of modern jet aircraft—that could be put out of action quickly with relatively minimal damage to runways (and were also potential targets for nuclear strikes as well).[4] Vertical lift offered the possibility of using unconventional basing sites—such as forest clearings or West German autobahns, for instance—to disperse combat aircraft. This was a problem seen as far more serious in Europe, and the engineering efforts dedicated there to solving it ended up being more substantial than those in the United States.

An early example of a vertical jet-lift that produced results was the Rolls-Royce Thrust Measuring Rig—more well known today as the "Flying Bedstead." Designed by engineer Alan Arnold Griffith, the Thrust Measuring Rig was a collaboration between Rolls-Royce and the Royal Aircraft Establishment, a Ministry of Defence research facility. First tested in August 1953, the rig was essentially an engine with four downward facing thrust nozzles, without any of the typical control surfaces of regular aircraft. Capable of only brief flights at extremely low altitude, the rig's successful demonstration of vertical jet lift nonetheless led directly to the development of the Rolls-Royce RB108 engine in 1955. Five of these engines (four for vertical lift and one for horizontal flight) were incorporated into the Short SC.1, a project of the Ministry of Supply and the first British vertical lift jet aircraft. Although the large number of engines would prove unwieldy for future vertical-lift jets, the SC.1 proved to be a useful test aircraft and provided valuable experience that eventually was used to develop and refine the Harrier.

Ultimately, the central technological creation that led to the development of the Harrier was the revolutionary engine that powered it, the Pegasus turbofan designed by Bristol Siddeley and later built by Rolls-Royce. The Pegasus itself began as an idea by a French aircraft designer, Michel Wilbault, who had spent decades working in the French, British, and American aircraft industries. His research in the early 1950s was privately funded by an American philanthropist, Winthrop Rockefeller, and resulted in a number of patents in several countries. His innovation was the concept of vectored thrust—directing thrust from a single jet engine into a series of (first two, and later four) nozzles that could be rotated rearward or downward. This was a significant innovation in weight savings and efficiency, since it avoided the problem of having to use multiple engines, which could easily overburden most aircraft of the time. In 1955-6, Wilbault brought his ideas and patents to the attention of NATO's Mutual Weapons Development program—an outgrowth of the Mutual Security Act of 1951, a kind of military Marshall Plan that began as a US effort to support European militaries—and US Air Force Col. John Driscoll. Driscoll saw merit in the French designer's ideas, and introduced Wilbault to Stanley Hooker at Bristol Engines (which later became Bristol Siddeley).[5]

Bristol began the development of what would become the Pegasus engine in 1956 on its own, with the majority of funding coming from the Mutual Weapons Development Program. It would be a year later that Hawker Aircraft—Britain's largest aircraft manufacturer—became involved and saw the potential of the engine for a new vertical take-off-and-landing aircraft. Development of what would become the P.1127 began largely as Hawker's private venture. Although there was no clear RAF or NATO requirement or official support for the aircraft yet, the progress of the P.1127 was watched closely by American and European observers. In 1958, models of the P.1127 were tested at NASA's Langley Research Center. The next year, Hawker began construction of two prototypes. The first flight would take place on 21 October 1960 at RAF Dunsfold. Successful test flights garnered increasing interest in the aircraft, resulting in a preproduction version that came to be known as the Kestrel, of which nine airframes were made. It would be this aircraft that would receive intense international interest in a series of flight tests in the mid-1960s by the United States, United Kingdom, and West Germany. Finally, a requirement for a subsonic ground attack aircraft was issued by the RAF, and the first production aircraft of what would be designated the Harrier began in 1967.

Perhaps ironically, the service that would end up using the Harrier the longest only became interested in the aircraft nearly a decade into its development. The US Marine Corps' experiences with close air support in Vietnam had made the service's leaders realize that a difference of only a few minutes of lag time between a call for support and getting weapons on target could be decisive. The Marines' participation in the Air Force's centralized air control system over South Vietnam had resulted in delays that sometimes could have tactical consequences. Experience suggested that getting aircraft over a target in under 30 minutes was good; in ten minutes or less was even better.[6] Short of moving airfields even closer to the battlefield, a new aircraft with a heavy punch was needed. Marine pilots, however, had not been a part of the initial three-country testing of the Kestrel during the mid-1960s.

In 1968, several officers in the office of the Deputy Chief of Staff, Aviation—Col. Thomas Miller and Lt. Col. John Metzko—brought a film of recent tests of the Harrier to the attention the Assistant Deputy Chief of Staff (Air), Brig. Gen. W.G. Johnson, as well as their boss, Maj. Gen. K.B. McCutcheon. This resulted in meetings at the British Embassy and a trip to the United Kingdom of Miller and a test pilot—Lt. Col. Bud Baker—who would be the first Marines to test the Kestrel/Harrier.[7] Impressed by the possibilities of the aircraft, McCutcheon spearheaded an effort on Capitol Hill to add money to the budget for 1970 for 12 Harriers, the first of an eventual 114 AV-8A that would be purchased for the Marine Corps.[8]

The Marine Corps' AV-8A, which entered service in 1971, was essentially the Harrier GR.1—and indeed all of the first American version of the aircraft were produced in Great Britain on the same assembly line as their Royal Air Force counterparts as a cost-saving measure. One issue with the early Marine Corps Harriers was that their ordnance capacity was less that that of the other contemporary ground attack jet aircraft, the A-4 Skyhawk. In the mid-1970s, Hawker Siddeley and McDonnell Douglas began development of what would eventually become the AV-8B Harrier II in an effort to allow the aircraft to carry a heavier weapons load. Initially a project to upgrade existing AV-8As, two aircraft were modified into what was designated the YAV-8B, which flew for the first time in 1978. Despite encountering some resistance within the Navy and Defense Department, an aircraft with longer range and heavier payload capacity that would be designed the AV-8B Harrier II finally entered service in 1985. AV-8Bs would go on to serve in every major US conflict since the 1980s, including the Gulf War, Kosovo, Iraq, Afghanistan, and Libya.

In addition to serving in the armed forces of the United Kingdom and the United State in a career spanning more than 50 years, various versions of the Harrier and Harrier II also have served in the Indian, Italian, Spanish, and Thai navies. The aircraft now is in its final years of useful service: the Thai and Indian navies retired their Harriers in 2006; the United Kingdom retired its Harriers in 2011. Those Harriers that remain in US, Italian, and Spanish forces are due to be replaced in the coming years by the F-35 Lightning II. To a degree even greater than the Harrier, the Lightning II has been a program characterized by international collaboration both in its development as well in its prospective customers. In fact, what was an innovative approach in the 1960s has become, if not mainstream, a major force especially in aviation development, from the Panavia Tornado to the Eurofigher Typhoon—both of which were developed by international consortia.

Through a mixture of opportunity, economy, and innovation, the US Marine Corps has found ways to develop a world-class fighting force in a financial environment that rarely, if ever, could be characterized as prodigal. The Harrier represents one of the more notable examples of how the Marine Corps was able to take advantage of the research and development complex that had grown up in the aftermath of World War II, and match an experimental aircraft developed with very different needs in mind with the requirements of Marine warfighters. The international interconnectedness of the various services, researchers, engineers, and companies involved had helped create opportunities for development and acquisition that otherwise might not have been possible.

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INFORMING NEXT-GENERATION RECONNAISSANCE

By Jeff Bradel and Justin Halls

ADVANCED RECONNAISSANCE VEHICLE TECHNOLOGY DEMONSTRATIONS—SUPPORTED BY THE OFFICE OF NAVAL RESEARCH—WILL HELP EVOLVE THE ART OF THE POSSIBLE FOR NEXT-GENERATION RECONNAISSANCE, SURVEILLANCE, AND TARGETING.

The Office of Naval Research (ONR) is sponsoring research to support the development of the Marine Corps' next-generation, armored ground reconnaissance platform—called the Advanced Reconnaissance Vehicle (ARV)—and related advanced supporting technologies. The ARV is the Marine Corps' initiative to transform its light armored reconnaissance battalions into next-generation reconnaissance, surveillance, and target acquisition formations. Projected ARV capabilities will enable these formations to function as security area battle managers and "quarterbacks" of manned/unmanned teams employing ground- and aerial-based sensors that will significantly improve the resiliency and span of a naval expeditionary force's sensor web.

ONR's ARV science and technology investment is part of the command's Future Naval Capabilities program, which aims to discover, assess, and fast-track new technologies into acquisition programs of record. ARV research activities also inform the requirements development process and assist in the refinement of platform system attributes and performance parameters, by using a structured knowledge point process to reduce risk and better position the planned acquisition program for success.

ARV research program technology demonstrations will employ transformational sensor, communications, and combat capabilities to collect and communicate information, while integrating robotics and artificial intelligence technologies into manned/unmanned teams. The ARV will enable a crew to sense the operating environment and convey that information using advanced on-board sensors and networked communications systems augmented by unmanned systems to detect, recognize, identify, and report threats at extended ranges. In addition, the ARV has the potential to provide Marines with a survivable, mobile, networked, and lethal platform optimized for naval transport and amphibious employment in the littorals.

Beginning in 2018, ONR awarded several contracts for full system concept/trade studies and for individual advanced technology research efforts. In 2019, ONR selected two vendors—General Dynamics and SAIC—to design, fabricate, and test full-scale technology demonstration platforms. The General Dynamics Land Systems demonstrator vehicle will incorporate advanced technologies designed around a notional unit price point. The other demonstrator, by SAIC, considers alternative advanced technologies and design approaches to further push the state of the art. Both technology demonstrator platforms are expected to be ready for government evaluation near the end of 2020.

In addition, ONR is investing in component technology development meant to enhance the armored reconnaissance mission of the future through investments in platform cybersecurity, logistics management, mobility, and autonomous aerial vehicles with Battelle, Cougaar Software, QinetiQ, and SRI International.

To accelerate and streamline processes and to facilitate the participation of small and large nontraditional industry members, ONR offered an Other Transaction Authority contracting approach to potential vendors. Contractors do not need a government-approved accounting system or deep knowledge of federal acquisition regulation requirements to compete for government funding. Other Transaction Authorities also benefit the government in that contractors can contribute to the project through cost sharing. This allows the Department of Defense to leverage the unique knowledge and creativity of businesses that might not normally bid on typical government contracts.

To ensure full collaboration and a smooth transition of research products to the Marine Corps, close alignment is maintained with the acquisition and requirements representatives from the program manager for light armored vehicles within the Marine Corps Systems Command, the Program Executive Officer for Land Systems, and Headquarters Marine Corps, Combat Development and Integration, Ground Combat Element Division. This core group of organizations makes up the ARV technology oversight committee, which meets biweekly to provide status updates on their respective areas of responsibility. With this approach, all parties are fully aware of any new developments, thereby enabling a more streamlined, efficient, and coordinated transition from research to acquisition.

Other regular participants in the integrated product teams consist of representatives from Headquarters Marine Corps, Deputy Commandant for Plans, Policies and Operations; the Office of the Deputy Assistant Secretary of the Navy for Air and Ground; various Army organizations (including the Combat Capabilities Development Command Ground Vehicle Systems Center); and supporting government and contracted test facilities. Several technical integrated product teams also were formed in areas such as lethality, cyber, and advanced battery chemistry. Government experts meet with industry counterparts on a regular basis to share progress and to discuss any technological hurdles.

In parallel with the ongoing research at ONR, Marine Corps combat developers are drafting requirements documentation and concepts of employment aligned with emerging force design, while the materiel developer is planning an acquisition program and associated documentation to support initiation of a competitive prototyping phase in fiscal year 2021. Products from the research program (which ends in fiscal year 2021) are aligned with key program decision points to ensure a smooth transition to an acquisition program of record.

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FIRST LINE OF DEFENSE:
NEW TOPCOATS FOR AIR AND GROUND VEHICLES

By Craig Matzdorf

PAINT ON MILITARY VEHICLES IS EVER-PRESENT—WITHOUT IT, GROUND AND AIR VEHICLES WOULD BE MORE SUSCEPTIBLE TO CORROSION, MAKE THEMSELVES MORE VISIBLE TO ENEMIES, AND SIMPLY NOT LOOK "MILITARY." SEVERAL EFFORTS ARE UNDER WAY TO MAKE MARINE CORPS VEHICLE PAINT MORE AFFORDABLE AND EFFECTIVE.

Photo by Lance Cpl. Dalton Swanbeck

When someone mentions paint, one usually thinks of heading down to your local hardware store and picking out various colors for your latest home project. Modern paint, whether house paint, automotive paint, or paint used on Marine Corps aircraft and vehicles, is a complicated chemical composition designed specifically for each application.

House paint has advanced considerably in the past 50 years from oil-based systems such as leaded pigments to water-based, low-volatile organic content latex systems with no toxic heavy metals and very low use of organic solvents. Today's high-quality products are easy to apply, clean up, and last a long time. Paint for Marine Corp assets also has advanced considerably since the 1960s, but innovation stagnated until about 10 years ago.

Paint is the first line of defense for the long term-performance of Marine Corps weapon systems. It may seem somewhat trivial, but it provides critical corrosion resistance for aluminum and steel structures as well as camouflage for the asset from the surrounding environment. Without it, metals would deteriorate rapidly and systems would lose their function.

Today, a basic coating protection scheme for any asset is made of an epoxy primer and polyurethane topcoat. These vary some depending on whether you are protecting an AH-1Z Super Cobra or an a High Mobility Multipurpose Wheeled Vehicle (or Humvee). For aircraft, the epoxy primer comes as two components, which are separately stored and then mixed before application. Some versions contain "chromate" or hexavalent chromium-based corrosion inhibitors, whereas some newer versions contain nonchromate corrosion inhibitors. The topcoat, usually applied to the exterior (but sometimes on the interior) to aid in cleaning, also is two components. Isocyanate- and hydroxyl-functional chemicals are the basic components.

Both the primer and topcoat layers form through a simultaneous two-step process of drying and chemical curing. In the drying step, solvents, including water, in the wet paint evaporate and allow the coating to thicken. The combination of solvents is optimized to enable easy mixing, spray application, and leveling, to prevent sagging or dripping, and to achieve the desired thickness. Chemical curing begins once the two parts of the paint are mixed and it accelerates once the coating forms. This curing, or chemical reaction, of the various components of the paint is fast enough so that the coating can be handled in a few hours, but it may not complete for up to two weeks.

Painting of Marine Corps assets carries a significant cost during original manufacture as well as maintenance. It costs in the range of $50,000 to $100,000 to remove old primer and topcoat from the exterior of a midsize aircraft to about $200,000 for a KC-130. This is a significant cost to the fleet for standard maintenance. The largest part of the cost is for the labor to remove old coatings and reapply new ones. The cost of the primer and topcoat is typically less than five percent of the total.

The primer and topcoat are usually fully removed at depot-level maintenance intervals, which are typically six to ten years depending on the asset. Removal occurs for two reasons: to enable inspection and repair of the underlying structure and to reapply new coatings that have full corrosion protection life, gloss, and color.

Aircraft primers and topcoats work well, but have some drawbacks. The topcoats are made from a chemical composition that contains isocyanates, which are sensitizers. As a result, areas where topcoats are sprayed have to be isolated while the coating cures. This is a significant burden for maintenance planning at the operational level, and especially on board a ship where entire hangar areas are roped off to comply with safety requirements.

The primers, based on epoxy chemistry, are not sensitizers, but have limited ability to resist corrosion in the Navy's tough operating environment of seawater and wide-ranging temperatures. This limitation forces products to be reapplied at shorter-than-desired intervals during an asset's life. Aviation primers also have historically contained chromate-based corrosion inhibitors that are toxic and carcinogenic. The key cost impact for handling chromated primers is at the depot level during coating removal, which can generate large amounts of contaminated dust. Current cost estimates for Fleet Readiness Center Southeast, East, and Southwest are over $1 million per year per site to comply with safety and health rules related to chromate dusts.

Based on the need for more durable, corrosion-resistant, and safer primers and topcoats, in 2011 the Office of Naval Research (ONR) began investing in research and development efforts at the Naval Air Warfare Center, Aircraft Division (NAWCAD) at Patuxent River and the US Naval Research Laboratory (NRL) through discovery and innovation and Swampworks projects.

NAWCAD research focused on new primers based on a novel aluminum-alloy inhibitor pigment, and NRL research focused on new topcoats based on novel one- and two-component polysiloxane resin systems. At NAWCAD, the initial idea for an aluminum-rich primer grew out of testing completed on magnesium-rich primers that were developed by the University of North Dakota, the Air Force, and Akzo Nobel. These primers were free from chromates and in laboratory tests performed well in comparison to chromated primers. Unfortunately, magnesium-based primers have one serious drawback: the magnesium powder in the primer easily reacts with moisture leading to "self-corrosion" within the coating, which greatly reduces the primer's life. This self-corrosion also can cause the primer to thicken and lead to adhesion problems.

This compelled researchers at NAWCAD to search for an alternative. Aluminum is known as a "sacrificial" metal, but its natural oxidation, which is a benefit for most uses, inhibits the ability of aluminum to act like zinc and magnesium, for which oxide layers form but are not bound to the metal. The key breakthrough was the discovery of aluminum anode alloys that already were being used in the US Navy and around the world to protect ships, submarines, piers, and other structures in the water. This alloy, Al-5%Zn-0.02%In, was designed to act just like zinc electrochemically and is interchangeable in bulk anode applications. NAWCAD's initial experiment in 2010 successfully showed that this alloy, atomized into 20 micron spherical powder, could perform well in a corrosion-inhibiting primer. Research continued from 2011 through 2015 maturating the primer into a sprayable product at a technology readiness level of five.

NAWCAD's research has led to seven issued US patents, five patents pending, and one new disclosure for primer and related intellectual property. Patent cooperation treaty forms were filed for all these, enabling patenting in foreign countries. NAWCAD began licensing the new intellectual property in 2014 and currently has licenses with eight companies covering the manufacture, use, and sale of products in the United States and selected foreign countries, including the European Union, Canada, and Mexico.

NRL's intellectual property focuses on the new topcoat technology, which has resulted in six US patents and several foreign patents. Originally developed for Navy surface ships, the polysiloxane family of resins was prototyped by NRL researchers for aircraft use in only two years. This rapid development was aided by a license and working relationship that NRL already had in place with NCP Coatings, Inc., a supplier of protective coatings for the

A Marine Corps AH-1Z Viper helicopter is painted with a camouflage gray polysiloxane topcoat, which was developed by chemists at the Naval Research Laboratory for aircraft to be safer for the environment and easier to apply. Photo by Erick Iezzi

Department of Defense as well as commercial customers. The key properties for an aviation topcoat are thickness, flexibility, and gloss and color retention over a long time.

By 2015, the new primer and topcoat performance had maturated to the point that ONR was ready to consider them for a Future Naval Capability project. Based on the potential value of these coatings a new, four-year project began in fiscal year 2017. It originally focused on both air vehicle and ground vehicle primers and topcoats, with partners including NRL, NAWCAD, and the Army Research Laboratory, as well as industry developers PPG, NCP, and Randolph Coatings. Changes in the Future Naval Capability program in fiscal year 2018 led to the split of the project. The topcoat project covered development and focused on the aviation products, and ONR's Mission Capable, Persistent and Survivable Naval Platforms science and technology department picked up support for the ground vehicle products, including the development of a new Chemical Agent Resisant Coating (CARC) topcoat based on polysiloxane technology.

Fast forward four years, and products are being field tested on Navy and Marine Corps aircraft, aviation support equipment, and Marine manned mobile facilities. Field testing on Marine ground vehicles is planned for this year, including new primers from the three industry partners and the new CARC topcoat from NCP.

The featured aircraft topcoat demonstration is on five H-1 aircraft: two UH-1Ys painted at Marine Corps Air Station New River and three AH-1Zs painted at Marine Corps Air Station Camp Pendleton in early 2019. For these, the entire exterior received the new polysiloxane topcoat. Aircraft will be tracked for two years observing coating performance, especially gloss and color. These successful demonstrations show that a nonisocyanate topcoat can be applied at production facilities during normal maintenance processes.

An additional benefit of the new flat gray topcoat is that it is only one component. This eliminates metering and mixing risks that are typical with two-component systems, and it reduces the number of products that must be ordered and stored in hazmat lockers. Both of these benefits help streamline the overall painting process, reducing time and handling of products. One-component topcoats have proven to be very successful for the Army; similar benefits are anticipated to be captured by the Navy and Marine Corps.

The featured demonstrations for the primer so far are on support equipment. This primer is different than the aviation vehicle primer, as it is designed to work on both steel and aluminum, compared to just aluminum for aircraft. It also is used on Marine Corps and Army ground vehicles. Current field tests are under way on a NET-4 trailer, spotting dolly, and fire truck. The spotting dolly and fire truck have been deployed on the aircraft carriers USS *John C. Stennis* (CVN 74) and USS *Dwight D. Eisenhower* (CVN 69).

Additional demonstrations of the aviation vehicle primer have been under way on two MV-22 Ospreys since November 2018, with more planned for 2020 and 2021 on a variety of aircraft. A gloss white topcoat also is being demonstrated on support equipment with an additional fire truck planned to round out the test set.

The final year of the Future Naval Capability project is focused on maturating the various primer and topcoat products as much as possible, with scale up and cost reduction featured thrusts. Currently, up to 15-gallon batches have been made, which are sufficient for qualification to material specifications and initial use in the fleet.

The Marine Corps should start benefitting from these new products in the next one to two years. They will enable more efficient painting processes and better resistance to corrosion while having state-of-the art safety and health properties.

About the author:

Craig Matzdorf is the senior engineer in the materials engineering division at Naval Surface Warfare Center Carderock Division.

SCIENCE ADVISORS CONNECT MARINES TO SCIENCE AND TECHNOLOGY

By John Phillips

OFFICE OF NAVAL RESEARCH GLOBAL SCIENCE ADVISORS HELP BRING NEW TECHNOLOGIES TO THE FLEET AND FORCE—SUCH AS THIS DEMONSTRATION OF AUTONOMOUS SYSTEMS AT A POST STEEL KNIGHT 2020 OPERATIONAL EXPERIMENTATION EVENT—AND ENSURE THE NEEDS OF WARFIGHTERS IN THE FIELD ARE MET.

What do Office of Naval Research Global (ONRG) science advisors do, and how can they help you? They are civilian scientists, engineers, and technologists selected through a competitive process to serve as special staff members to combatant, component, joint sub-unified, Navy, or Marine Corps commanders. Science advisors collaborate globally to connect Marines and Sailors with the Naval Research and Development Establishment--which includes ONR, the US Naval Research Laboratory (NRL), the Marine Corps Warfighting Laboratory, and naval warfare centers—to ensure research is focused on technologies that are most relevant to the Navy and Marine Corps. They are your connective tissue between all of these organizations and the Fleet and Fleet Marine Force. Science advisors stand ready to foster the technologist-warfighter partnership by enabling:

- Scientific observations of training, simulations, experiments, or exercises
- Warfighter workshops to discuss specific problems, technologies, or proposed designs
- Support for off sites, program reviews, or scientists-to-the-field opportunities
- Integration of technology into live, virtual, or constructive training
- Support to technology readiness level assessment demonstrations
- Integration of technology in major exercises or operational deployments
- Better understanding of the challenges of integrating ONR technologies with current programs of record
- Better understanding of naval, joint, and coalition integration issues
- Hands-on ONR technology experience for Marines and Sailors that can provide rapid feedback that is not achievable in the lab.

Science advisors serve as a command's senior liaison with science and technology organizations in government, academia, and industry. To communicate the needs of a command, science advisors engage with the fleet and force to maintain awareness on how science and technology can help fill gaps in support of current and future mission accomplishment. Science advisors help connect Navy, Marine Corps, and Defense strategic documents down to specific command needs that support emerging warfighting concepts and operations plans.

A science advisor's engagements range from a direct line of communication with their respective commanders to regular engagements with Marines and Sailors at every level, from privates and seamen to flag and general officers. Science advisors communicate requirements

Photo by Bobby Cummings

and needs back to the NRE and the NR&DE to help focus investments to shape future naval capabilities.

To shape future naval capabilities Marine Corps science advisors work with their respective staffs to develop Science, Technology, and Experimentation priority letters in support of Marine Expeditionary Force, Marine Forces Pacific, and Marine Corps Forces Command commanders. These priority letters align with the *Commandant's Planning Guidance*, which provides clear direction for investment areas for the Marine Corps. The letters provide amplifying information on the specific needs of that command and enhance understanding of the differing operational environments. The command priorities may be tailored to support specific operations plans and areas of operations, and incorporate changing needs related to distributed maritime operations, littoral operations in contested environments, and expeditionary advanced base operations. These signed letters represent a clear demand signal communicated across the NRE and NR&DE to ensure the future naval capability needs of each command are addressed.

There are currently 25 well-connected science advisors serving worldwide. These science advisors collaborate to inject technology to solve fleet and force operational challenges. Naval integration in support of the fleet and force efforts take place on a regular basis through the science advisor network. Commands often leverage these relationships to create the necessary connections needed to move naval integration capabilities forward. If science advisors do not have answers to questions, they will reach out to their networks to find them.

Science advisors access the naval science and technology community to provide technology insertions into limited or extended user evaluations, fleet exercises, or deployments, or they can surge capabilities in support of high-priority challenges. Examples of where ONRG has inserted technologies using the experimentation and analysis campaign plan include:

- Mine countermeasures technologies during exercise Steel Knight in December 2019
- TechSolutions programs that rapid prototype capabilities in support of the Fleet Marine Force
- Mine Clearing Line Charge Foreign Comparative Testing awarded by the Office of the Secretary of Defense Comparative Technology Office.

What does this linkage to the fleet accomplish? Here are two examples that bridged the full range from understanding a problem to attaining a path forward:

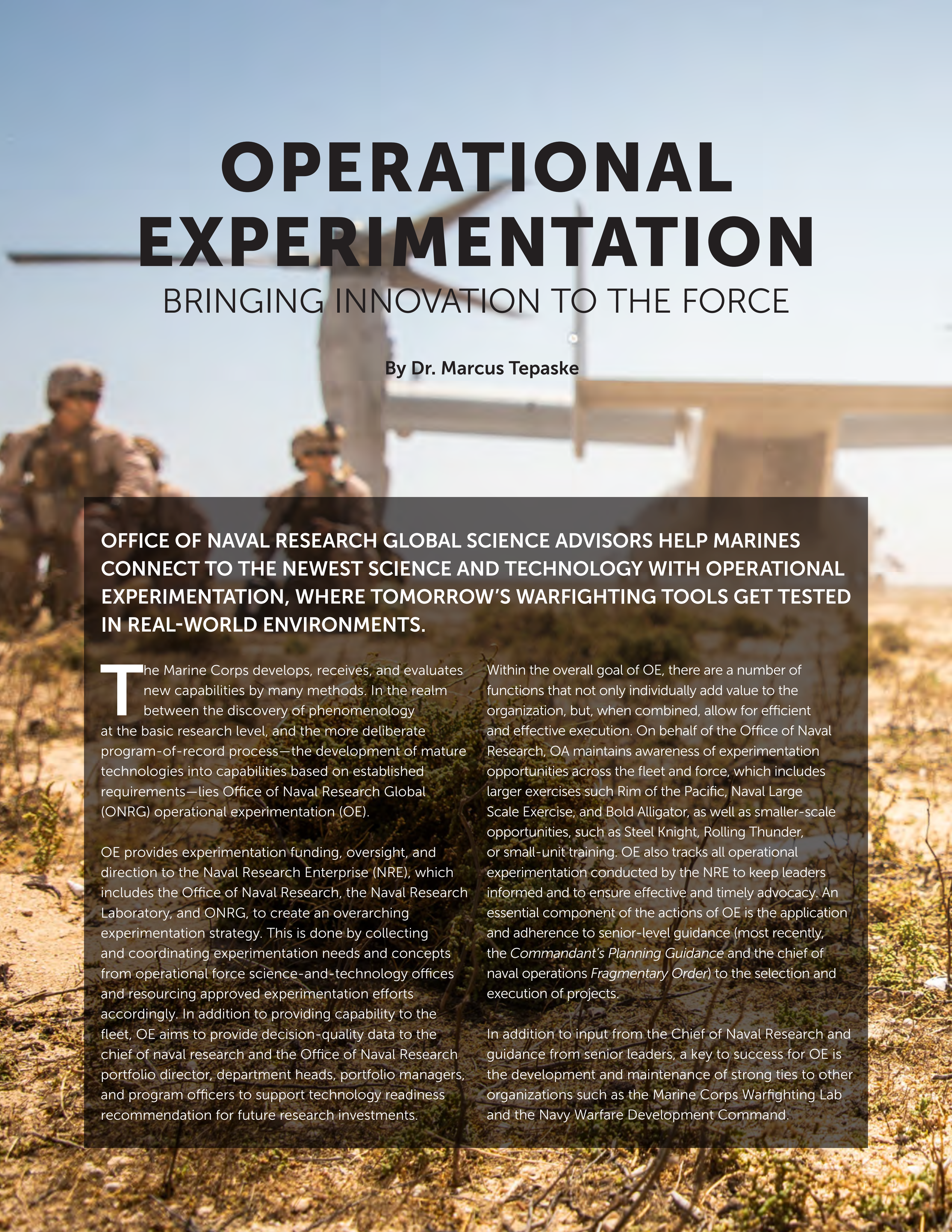
The III Marine Expeditionary Force science advisor learned of the force's limited spectrum access for legacy high-frequency and very-high-frequency communications. Following a free-space optics test in August 2018, the force's commanding general named the technology as his number-one, science-and-technology priority. The force's science advisor collaborated with NRL to pursue funding for prototypes, submitted a Rapid Prototyping Program proposal, and organized a demonstration at Marine Corps Base Quantico for the Deputy Commandant for Combat Development and Integration, Marine Corps Systems Command, Marine Corps Warfighting Laboratory, the Strategic Capabilities Office, and Naval Sea Systems Command. These efforts resulted in a fully funded, $10.8-million program and delivery of a new capability, years ahead of the target initial operational capability.

The Marine Corps Forces Command science advisor sought solutions for safety issues and the ineffectiveness of the legacy, mobile, Mine Clearing Line Charge (MICLIC) system. Safety issues with the current system included concerns about electrostatic discharges, its tendency sometimes not to deploy and detonate as designed, and overall reliability. There also are concerns about the effectiveness of the MICLIC against modern mines and obstacles. The science advisor collaborated with the Logistics Combat Element Systems, Advanced Technology Integrator at Marine Corps Systems Command and the ONRG Foreign Comparative Test Office to submit a foreign comparative testing proposal to the Office of Secretary of Defense Comparative Technology Office. Commander, Marine Corps Forces Command, provided a letter of endorsement for the endeavor. Following an eight-month effort with key stakeholders, the test was funded for $2.05 million from the Comparative Technology Office, $600,000 from ONR, $400,000 from Marine Corps Systems Command, and $100,000 from the US Army Engineer School. Based on the results, Marine Corps Systems Command is prepared to procure a suitable replacement or supplemental capability for the MICLIC system.

Science advisors serve as the Chief of Naval Research's ambassadors at their commands and support senior flag and general officers' decision-making processes. Most important, science advisors build and maintain effective relationships among the NRE, NR&DE, fleet, and force.

About the authors:

John Phillips has served as the science advisor to Marine Corps Forces Command since April 2018. He is currently detailed from the Naval Surface Warfare Center Carderock Combatant Craft Division. For his efforts with the Marine Corps, he was selected as the ONR Science Advisor of the Year in September 2019.



OPERATIONAL EXPERIMENTATION

BRINGING INNOVATION TO THE FORCE

By Dr. Marcus Tepaske

OFFICE OF NAVAL RESEARCH GLOBAL SCIENCE ADVISORS HELP MARINES CONNECT TO THE NEWEST SCIENCE AND TECHNOLOGY WITH OPERATIONAL EXPERIMENTATION, WHERE TOMORROW'S WARFIGHTING TOOLS GET TESTED IN REAL-WORLD ENVIRONMENTS.

The Marine Corps develops, receives, and evaluates new capabilities by many methods. In the realm between the discovery of phenomenology at the basic research level, and the more deliberate program-of-record process—the development of mature technologies into capabilities based on established requirements—lies Office of Naval Research Global (ONRG) operational experimentation (OE).

OE provides experimentation funding, oversight, and direction to the Naval Research Enterprise (NRE), which includes the Office of Naval Research, the Naval Research Laboratory, and ONRG, to create an overarching experimentation strategy. This is done by collecting and coordinating experimentation needs and concepts from operational force science-and-technology offices and resourcing approved experimentation efforts accordingly. In addition to providing capability to the fleet, OE aims to provide decision-quality data to the chief of naval research and the Office of Naval Research portfolio director, department heads, portfolio managers, and program officers to support technology readiness recommendation for future research investments.

Within the overall goal of OE, there are a number of functions that not only individually add value to the organization, but, when combined, allow for efficient and effective execution. On behalf of the Office of Naval Research, OA maintains awareness of experimentation opportunities across the fleet and force, which includes larger exercises such Rim of the Pacific, Naval Large Scale Exercise, and Bold Alligator, as well as smaller-scale opportunities, such as Steel Knight, Rolling Thunder, or small-unit training. OE also tracks all operational experimentation conducted by the NRE to keep leaders informed and to ensure effective and timely advocacy. An essential component of the actions of OE is the application and adherence to senior-level guidance (most recently, the *Commandant's Planning Guidance* and the chief of naval operations *Fragmentary Order*) to the selection and execution of projects.

In addition to input from the Chief of Naval Research and guidance from senior leaders, a key to success for OE is the development and maintenance of strong ties to other organizations such as the Marine Corps Warfighting Lab and the Navy Warfare Development Command.

Photo by Sgt. Kyle Talbot

According to the *Commandant's Planning Guidance*, the Marine Corps Warfighting Lab "will serve as the focal point and integrating ground for new concepts, capabilities and technologies that we develop, as well as a key enabler for accelerating the Service's future force development efforts. The Lab will continue to prioritize the development of naval concepts, and Fleet Marine Force support to naval campaigns."

As such, OE has built a strong relationship with the lab's experiment division that plans, executes, and analyzes the results of a program of concept-based, live-force experiments. These experiments inform the combat development and integration requirements process and the efforts of other organizations to advance Marine Corps capabilities. In support of their guidance, the lab's experiment division has developed the Service Level Experimentation Campaign Plan, which will inform and shape the Marine Corps' future force structure, technology investments, and doctrine. OE is working closely to imbed technology experimentation into those events.

Beyond the Marine Corps Warfighting Lab, OE engages with the operational forces at all three Marine expeditionary forces as well as Fleet Marine Forces Atlantic and Pacific. This is done primarily through ONRG science advisors, who serve as the command's senior liaisons with science and technology organizations in government, academia, and industry. Science advisors communicate needs and requirements back to the ONR and NRE to help shape science and technology investments. They leverage the naval science and technology community to provide rapid technology insertions, long-term investment, and surge capability in support of high-priority fleet issues.

Similarly, on the Navy side, ONRG Experimentation and Analysis works closely with the Naval Warfare Development Command, which manages and executes the fleet experimentation program on behalf of Fleet Forces Command and the Pacific Fleet. Naval Warfare Development Command plans, designs, conducts, and assesses experiments in response to the fleet's highest priorities to deliver products to warfighters. ONRG Experimentation and Analysis also engages many Navy commands through the science advisor network.

OE executes approximately 20 experimentation efforts a year within the Navy and Marine Corps. A few recent efforts include:

>Automated Critical Care System field experiments in Australia with the US Marine Corps and Australian Defense Force. The experiment consisted of the integration of a heads-up display to the system, which allowed for external monitoring of a person's vital signs and in the delivery of the casualty between two nodes. It is informing the development of robotic autonomous capabilities with the potential of providing robot extraction of wounded personnel from combat. This successful US-Australia collaboration has generated commitments of future funding support. These capabilities are of high interest to the Army, Navy, Air Force, and Marine Corps.

>Installation of an autonomy package on an operational Naval Expeditionary Combat Command 34-foot patrol boat to conduct high-value escort mission experimentation. This proof of concept incorporated unmanned surface vessels into a manned/unmanned team to reduce risk and manning requirements in the coastal riverine community. It showed that two heterogeneous unmanned surface vessels (one Navy, one Coast Guard) can assist in an escort mission of high-value units, with a further adaptation of already proven autonomous behaviors, allowing for risk reduction to personnel and assets for the two sea services.

>Close-in Covert Autonomous Disposable Aircraft super swarm experimentation. This record-setting effort simultaneously launched 1,000 unmanned aerial vehicles out of a C-130 and demonstrated behaviors critical to future super swarm employment. Data from the experiment will drive performance and effectiveness models and design trade-studies. Manufacturing data will inform efforts for on-shore unmanned aerial system manufacturing.

>Mine countermeasures technology capability experimentation used the information systems to operations model to federate mine/obstacle data from autonomous systems to plan a route and conduct an amphibious landing of an autonomous amphibious assault vehicle from very shallow water onto the beach and beyond. This was an initial experiment with follow-on experiments looking to bring in Navy data from shallow and deep water to enable an autonomous first wave that can sense and maneuver from deep water to objective.

This mine countermeasures experiment represents the first step in an overarching OE campaign plan for ONRG. The office will develop, coordinate, and execute a multiyear (three-to-five year) Naval Research Enterprise experimentation plan, informed by naval concepts (distributed maritime operations, littoral operations in the contested environment, expeditionary advanced basing operations) and aligned with enterprise efforts to support the discovery, investigation, and exploration of potential solutions sets. This will satisfy existing and future naval domain capability gaps and requirements, which will result in a significant advantage over our adversaries. The purpose of the campaign plan is to become more proactive in experimentation and to help focus investments from across the enterprise based on senior-level guidance and alignment with the Marine Corps Warfighting Lab's service level experimentation campaign plan and Naval Warfare Development Command's fleet experimentation program. The campaign plan will be understandable, coordinated, and executable, informing Naval Research Enterprise leaders on future investment decisions and guiding the science and technology community for future experimentation operations.

Operational experimentation plays a critical role in providing useful capability and informing science and technology investments. It leverages its network throughout the enterprise and the fleet and force. The alignment of OE within ONRG has dramatically improved its connections to operational forces and experimentation efforts have proven new capabilities for numerous Marine Corps and Navy commands.

About the author:

Dr. Tepaske is currently the Office of Naval Research Global Experimentation and Analysis director where he manages the operational experimentation and operational analysis portfolio in support of fleet and force capability needs.

For more information or to propose or request an experiment, visit the website https://wiki.nre.navy.mil/display/EandA, or contact ONRG OE at: onr_experimentat.fct@navy.mil.

INCREASING SPEED TO CAPABILITY FOR EXPEDITIONARY WARFARE

By Brian Visser

PUTTING COMBAT-READY HARDWARE AND SOFTWARE IN THE HANDS OF MARINES SHOULD NOT INVOLVE A LENGTHY WAIT FOR THE USUAL ACQUISITION PIPELINE. THE RAPID RESPONSE INTEGRATION TEAM AT NAVAL INFORMATION WARFARE CENTER PACIFIC IS HELPING TO MAKE THAT WAIT SHORTER THAN EVER.

Agile software development, coupled with automation in test and processes, will allow defense science and technology communities to adapt and produce the technological tools and capabilities needed to support modern expeditionary warfare.

Expectations for warfighters have perhaps never been more complex—threats to national security have moved into continually contested environments across all domains (sea, land, air, space, and cyberspace) without being constrained to the traditional continuum of military operation. Most important of all for current and future warfighters are the concepts of employment, maneuver, and strategy that must be implemented to manage and dominate these domains effectively.

These new warfighting ideas will allow expeditionary forces to maintain consistent command and control even while disrupted and disconnected with a low probability of intercept and detection. Planning for these advanced expeditionary operations will soon be too complex and rapid for a group to conduct with traditional tools and methodologies.

For example, where can one place a communication relay to enable efficient mesh networking while maintaining a low probability of detection? How will a swarm of unmanned surface vehicles patrol a coastline to surveille the most likely path for hostile movements? Where should units maneuver within a weapon engagement zone to reduce the possibility of targeting but still have the ability to conduct a sea-denial mission? Can cyber effects disrupt hostile intelligence, surveillance, target acquisition, and reconnaissance capabilities while forward units maneuver?

Fleet forces at the tactical edge will have to integrate these capabilities; they also will have to re-plan continuously when a unit needs to relocate.

For the science, technology, research, development, and acquisition communities, the expectations are even higher. Not only do laboratories need to understand emerging threats and new warfighting concepts, they need to understand how technology can enable and support deployed fleet forces. Our technologies will be the underlying fabric that allows for rapid, integrated, and joint planning and execution.

To meet these challenges, the defense and science and technology communities have adopted agile development using continuous integration and continuous deployment as well as development, security, and operations (DevSecOps) processes, practices, and culture.

Speed to Capability

The Project Management Triangle model argues for the interdependency of cost, quality, and delivery speed in creating a product. If one of the elements must be changed or prioritized, it comes at the expense of the other two—i.e., if faster delivery is required, cost will increase and/or quality will go down. Recent research into elite and high-performing software organizations, however, shows that these tradeoffs are not accurate (DevOps Research and Assessment, "Accelerate: State of DevOps 2019," https://cloud.google.com/devops/state-of-devops). This research suggests that the best factor to focus on for a software development team is quality.

The key elements for enabling and increasing quality start with the automation of basic development tasks such as issue creation, revision control branching, and merging of changes processes. These processes should be "automatic" for the developer with very few, if any, decision points about what to do next. This essentially eliminates wasted time and avoids inconsistencies among the development team practices.

Another significant factor that plays into continuous deployment is test automation. To optimize for faster software deployment, one needs faster testing methods. With subsequent updates and feature additions to an application, software may become more complex and require extensive manual regression testing. This evolves into a time-consuming process. With the use of automation testing, test cases can run quickly and, more important, continuously. This allows the code to be developed and merged quickly with confidence—main functionality and corner cases are included in the test suite.

As the test set grows, it directly and positively affects continuous integration, which then positively affects continuous development. The progression of automated tests feeding integration and deployment will then feed into speed. The risk of any code that has been merged and automatically tested presents a very small risk to the overall system.

Rapid Response and Integration

The Naval Information Warfare Center Pacific Rapid Response and Integration (R2I) team foresaw these needs and began adopting rapid and agile methodologies over the past several years to deliver warfighter capabilities. R2I has always focused on early automation, security, and user participation while developing software, but it now has advanced to achieving a fully accredited DevSecOps implementation supporting multiple customers with three times as many deployments and up to a 97-percent reduction in accreditation controls. This mature implementation is extendable to software applications across the naval domain.

The R2I team began by transitioning the Software Interoperability Environment from the Office of Naval Research to Marine Corps Systems Command and the Tactical Service Oriented Architecture program of record. Since the transition, R2I has been a core member of the program's, developing both tactical and enterprise applications for warfighters. The fleet forces that supported this development included the information management offices of: I Marine Expeditionary Force, III Marine Expeditionary Force, 1st Marine Air Wing, and 3d Marine Division.

With the success of the R2I implementation to tactical applications, the team expanded to develop software for Headquarters Marine Corps Programs and Resources supporting business process automation and modernization. By using rapid, agile, and DevSecOps practices, R2I has become responsible for the development and sustainment of production services that support customers such as the inspector general and the financial management portfolio with their associated case management and enterprise risk management audit applications.

The R2I team has overcome many challenges being one of the first programs to implement agile software development practices within the Marine Corps. The process of nonstatic requirements, rapid deployments to test environments, and requiring the Marine user community to participate were contrary to the traditional systems engineering technical review and acquisitions processes. R2I mapped the various agile process and products to the technical review processes, artifacts, and milestones to prove to leadership that software maintained development rigor.

Once R2I was able to develop software and support business processes with rapid and agile methodologies, the next challenge was the speed of the accreditation process. R2I reconfigured the system and system-of-systems accreditation packages to allow smaller, more dynamic, and agile applications to be separate from the server. This methodology significantly reduced the authority-to-operate responsibilities of the application, allowing for much faster accreditation approval. For example, this model has allowed the Management Internal Control Remediation and Reporting audit application to have only 13 controls instead of the original 403, a reduction of approximately 97 percent. In addition, R2I worked with Deputy Commandant for Information Cybersecurity Division to formalize the DevSecOps policy, accredit a software workflow, and receive the first Marine continuous authority to operate.

The R2I DevSecOps implementation is now proven. Through the implementation of well-documented software practices, automated builds and security scans, direct user feedback, and changing policy to increase efficiency, the R2I team has been able to develop, accredit, and field 11 Marine Corps software products from squad to enterprise level. In addition, R2I was able to release 21 product deployments to the fleet—an increase of three times, on average, over the past four years. R2I plans to extend its capability to more customers and to continue to increase the number of releases by leveraging DevSecOps practices and deploying to tactical and enterprise cloud instances.

Conclusion

To achieve rapid deployment of software, programs need to focus on quality by investing in automation early in the development process. This groundwork will enable developers to commit code and have end users see the results of their requests, resulting in more deployments with greater user buy-in. In addition, once the system is established, incremental changes to the automation (unit and user acceptance tests for example) are far easier to include, reducing the opportunities to increase technical debt. At the end of the day, our success will hinge on our ability to iterate faster than our adversaries can in warfighting, business, and software development.

About the author:
Brian Visser is the project manager and former software developer of the Rapid Response and Integration program at Naval Information Warfare Center Pacific in San Diego.

Photo by Cpl. Bernadette Wildes

THE CORPS IS COMMITTED TO ADDITIVE MANUFACTURING

By Benjamin McKnight III, Ryan Fisher, Brennen Cheung, Jacob Aljundi, Akeel Channer, Ryan Forrest, and Dr. Caroline Vail

FABRICATION THROUGH 3D PRINTING HAS BECOME AN IMPORTANT PART OF GLOBAL MANUFACTURING—BUT IT REMAINS SOMETHING THAT USUALLY TAKES PLACE IN A LABORATORY OR AN INDUSTRIAL BUILDING. INITIATIVES ARE UNDER WAY TO HELP BRING ADDITIVE MANUFACTURING TO MARINES IN THE FIELD.

Additive manufacturing (AM), also known as 3D printing, comprises a family of technologies where material is added in layers continuously to create a part from a digital design. The Department of the Navy sees AM as a viable option to solve problems within the Navy and Marine Corps, and additive manufacturing implementation plans, released in 2016 and 2017, emphasize using this technology to enhance warfighter capabilities and increase readiness and sustainment. While these plans have accelerated the use of AM, the Marine Corps in particular has truly embraced this tool to address real world warfighting challenges.

The Marine Corps aims to increase the lethality of warfighters by incorporating AM into the toolset of the troops to improve equipment readiness. Waiting on materiel availability and long lead times can degrade readiness. One of the major benefits AM brings is the ability to reduce the complexity of the supply chain and its vulnerabilities by enabling point-of-need, scalable manufacture of components.

AM's disruptive nature allows warfighters to develop digital designs and realize them outside of a traditional industrial environment. The Marine Corps operates in environments where rapid solutions to immediate problems are critical. By providing this technology to the lower echelon, innovative solutions to problems seen throughout the Marine Corps are iterated and developed by the community that will use them.

The Marine Corps is driving AM: equipping, training, and performing targeted research to benefit Marines and enable their mission, and Naval Surface Warfare Center (NSWC) Carderock Division has been there throughout to assist.

Expeditionary fabrication (xFab) and tactical fabrication (TacFab) are two programs of record for AM within the Marine Corps. The former is a battalion-level asset that will travel with large maintenance groups as an expandable shipping container with a variety of advanced-manufacturing capabilities, consisting of large-format rapid printing, industrial-grade composite printing, prototype printing, 3D scanning, and laser cutting. The latter is a smaller advanced manufacturing capability that is meant to bring AM closer to the point of need and includes a composite printer, prototype printer, and small laser cutter. All of the items will be stored in hard cases and the size will allow rapid tear down and setup. Johns Hopkins University Applied Physics Laboratory prototyped the first TacFab unit. NSWC Carderock Division and Crane Division were instrumental in further development of both xFab and TacFab.

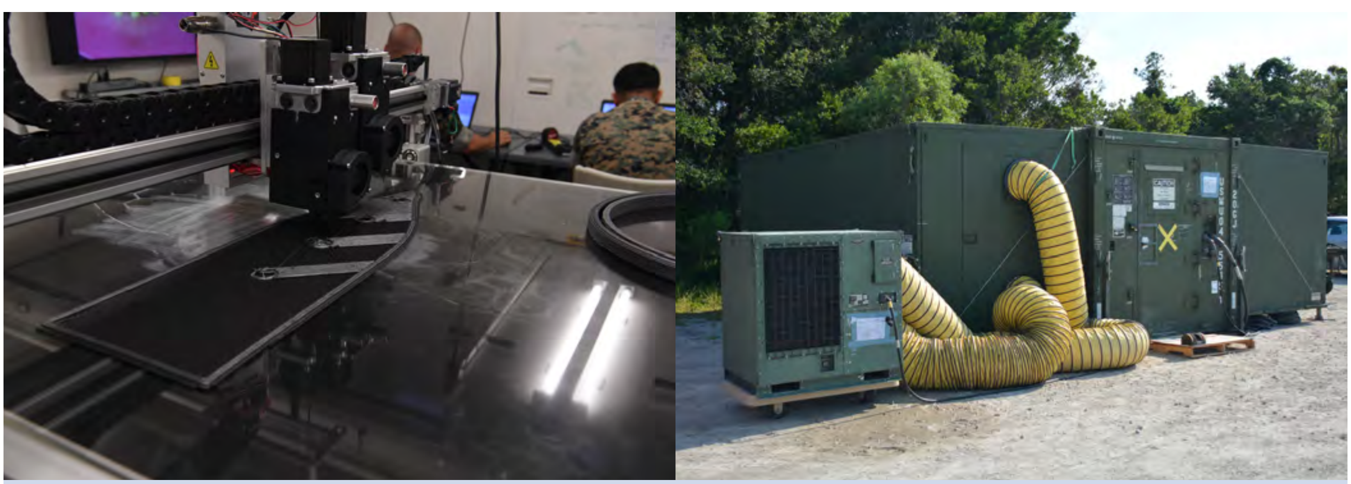
While there are many polymer materials available for AM, not all are suited to every situation. Akeel Channer at NSWC Carderock Division is hoping to help fill that gap. Channer is researching how varying environmental factors affect materials that are commonly used to 3D print to provide Marines with the best options to use based on their application.

"There are all types of materials you could use with whatever printers you have, but you have to keep in mind the kind of environmental conditions it could experience and what mechanical characteristics it needs to uphold," Channer said. "For example, polymer materials will react differently to different temperatures and fluids. We need to be able to provide that basic information to the warfighter so they can quickly assess what material they should use for non-critical applications".

While inexpensive polymer systems are in the field, Marines want the ability to generate metal parts using AM. All of these systems come with varying capabilities, build envelopes, costs, material selections, and necessary training. NSWC Carderock Division is conducting testing with multiple metal AM systems to provide the Marine Corps with a better picture of how to apply this technology to the force. Standard operating procedures and design guides are needed to push metal AM further.

Additive manufacturing does not replace the traditional manufacturing cycle and supply chain, but it is another avenue for Marines to reach a solution in an often more convenient manner. Operational readiness is the goal, and Marines are achieving readiness using AM to solve problems in operational environments quickly and inexpensively.

Using AM, a Marine unit at sea took matters into their own hands when they needed to replace a piece to fly their F-35B Lightning II aircraft. Without the part, the aircraft was grounded for safety reasons. Marine Fighter Attack Squadron (VMFA) 121 used a CLB-31 printer to produce a plastic bumper for a landing gear door to replace one worn out from a previous training event. The squadron worked with NSWC Carderock Division and Naval Air Systems Command



A 3D platform Work Series 300 (left) prints a shell for a boat mold as part of the Advanced Naval Technology Exercise East at Camp Lejeune, North Carolina. Naval Surface Warfare Center Carderock Division's Advanced Manufacturing Project Office demonstrated the use of the expeditionary fabrication facility, which used a 20-foot expandable shipping container (right) as a printing lab in the field. Photos by Kelley Stirling and Edward Adamos to obtain approval for the modification. Once approval was received, not only was the flight with the printed piece successful, but the mission was not put on hold to wait for a new piece to be delivered. If personnel followed conventional methods of repair, the entire door assembly would have needed to be ordered and replaced. AM enabled VMFA-121 to pick up exercises within a day, thereby salvaging time-sensitive testing hours. This win saved not only $70,000, but also the most important commodity for any military force: time.

“It helps put a stop-gap in the logistical chain,” said Brennen Cheung, who began his additive manufacturing work at Naval Air Station Patuxent River before he joined NSWC Carderock Division. “If they need a part now, what is the best way to get it at the point of need rather than doing the traditional manufacturing and waiting for it to get there?”

Thousands of parts sit on shelves to support readiness, but AM enables the reduction in footprint of the Navy’s depots. Numerous parts have a shelf life and maintenance requirements, so increasing the number of AM-capable parts by any margin means less waste and labor spent on keeping those parts to specification. Parts for legacy vehicles become increasingly difficult to obtain and can make logistics a problem that AM technologies can help solve. In most cases, parts are replaced one for one dimensionally; AM also lends itself to creating more unique and organic parts as long as they meet fit, form, and function. This method can help minimize large assemblies created with traditional manufacturing methods as well as lighten parts with AM design and new materials.

These types of efforts are what the Marine Corps hopes to standardize among its forces. Traditional manufacturing remains the preferred means of fabricating and repairing equipment, but not every situation makes this option the most feasible. This is where the flexibility of AM can enhance warfighters’ ability to support themselves outside of the logistics chain. In the instance of distributed operations where the ability to resupply may be limited and incur risk to a unit, the ability to 3D print a part may be the only option.

The Marine Corps is not just using AM to produce parts, but also to give Marines the ability to solve problems with novel solutions. Because AM reduces the barriers to producing a prototype, the role of the Marine in solving a problem has shifted from describing it to being an active designer of

A Marine with Combat Logistics Battalion 24 prepares to duplicate an original equipment manufacturer vehicle part for use within the battalion’s maintenance section in Kuwait. Photo by Sgt. David Bickel the solution. Some of the biggest effects on readiness are new designs by Marines, such as an environmental control unit duct cover that prevents the air intake from sucking up loose objects, or a clip that covers exposed metal screws on a radio handset that would have otherwise caused the handset to be discarded.

As Marine Corps units everywhere increase their AM capability, challenges that come with all new and innovative technologies continue to require a solution. One of these challenges in AM is proper management of the digital part files. The files need to be easily traced from a secure repository, while being readily available and functional for Marines to pull these files offline. Safeguarding the print files also poses an issue of susceptibility to cyber threats, much like any other digital file. If these files are altered in any way prior to a job, that change ultimately could endanger warfighters.

Arming Marines with the capability of AM still poses the challenge of accounting for the operational environment with this technology. AM technology is still being perfected, but it is still found primarily in labs because of the relatively new nature of the technology. The only deployable solutions are what is currently available: commercial 3D printers. Another challenge in AM is that commercial products are commonly neither ruggedized nor built to sustain weathered usage. Straying away from these conditions may not be sustainable with the technology or pass quality control and assurance measures.

Challenges remain in implementing quality control and assurance measures for all additively manufactured products. The material properties of these parts are different than traditionally manufactured parts, making it difficult to correctly assess the given part with the current test methods and standards. Technological maturation will help increase awareness. The current process for quality control and assurance are dependent on the material that is being used during the process, so every new material used in AM must go through strenuous characterization and testing to be qualified. Marines' safety and mission readiness depends on a sound strategy for quality control and assurance, particularly as approved applications are expanded.

There remains a relatively limited knowledge base within the Marine Corps in AM since the initial adoption of this technology. NSWC Carderock Division has been working to train deployed Marines and has teams sent out regularly to train and provide reach-back support. A broad, effective, and an integrated education system and formalized training curriculum are still very much needed. As AM in the Marine Corps world matures, acquisition policy will need to be updated to sustain it, and policies and optimal business practices to qualify and certify purchasing of novel AM technologies will need to be established.

Jacob Aljundi, left, an engineering instructor from Naval Surface Warfare Center Carderock Division provides a Marine with Combat Logistics Battalion 24 with guidance during 3D print training in Kuwait. Photo by Sgt. David Bickel

Incorporation of AM for readiness and sustainment in expeditionary environments is also occurring outside the Marine Corps. Naval Sea Systems Command is working to install AM systems on ships, to train Sailors, and to expand AM capabilities in the fleet.

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ADVANCED MANUFACTURING

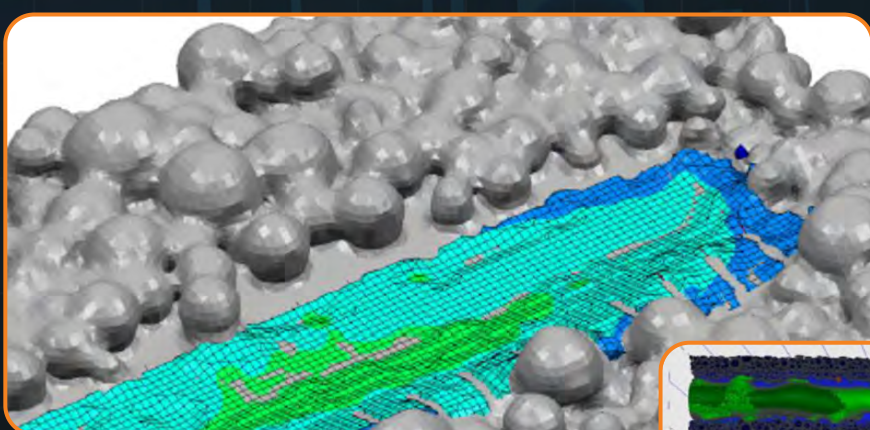
INNOVATIONS FOR THE FUTURE FORCE

By Jennifer Wolk and Maj. Matthew Munroe, USMCR

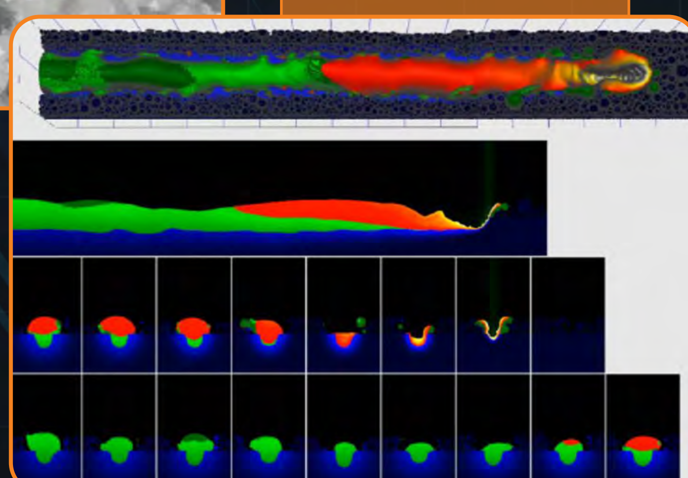
Since World War II, innovations in manufacturing have played a critical role in US defense. To support the future fleet, this article explores advancements in additive manufacturing (AM) and repair and the incorporation of new #manufacturing technology for demonstrations.

AM opens up a new design space, but how do we qualify and certify the complex designs made possible with this technology? Through the ONR (@USNavyResearch) Quality Metal Additive Manufacturing Program (QUALITY MADE), modeling and simulation of the AM process and materials are coupled with controls and sensors to enable rapid, cost-effective qualification.

ADDITIVE MANUFACTURING LASER-POWDER INTERACTION MODELS

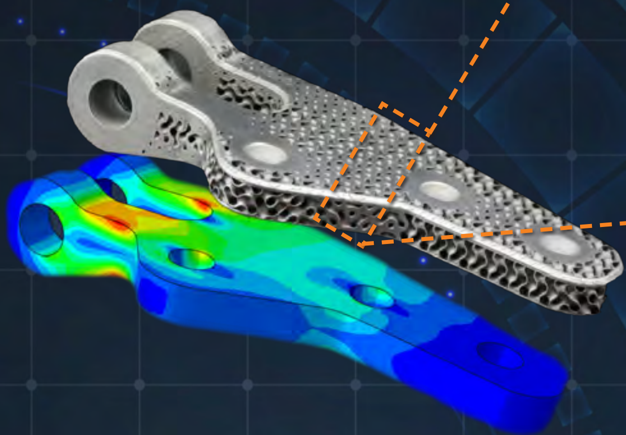


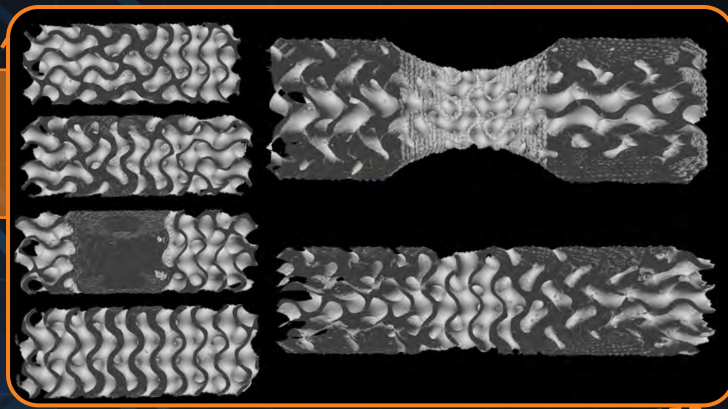
Predicted AM meltpool cross-sections from high-fidelity models show cooling rate differences in a single AM pass



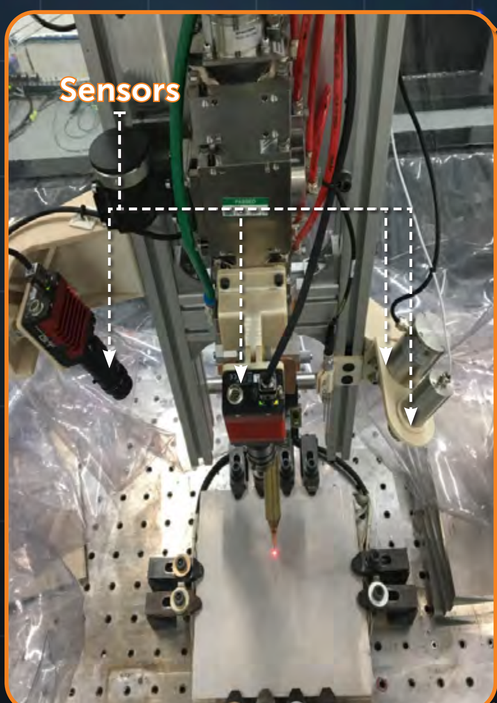
For an integrated computational materials engineering (ICME) approach to #additivemanufacturing, understanding material behavior from the part level to the microstructural level of the material allows us to predict the material performance. Modeling and monitoring the process behavior from a single laser strike to a melt pool cross-section to the AM raster pattern allows the QUALITY MADE GE team make sure (@GEResearch) is all on one line to understand, predict and monitor key process shifts for #rapidqualification.

Finite element analysis of part performance for a #topologyoptimized part. The optimized part shows significant material removal achieved through AM for weight savings





Modeling of the process and part performance allows better understanding of the material behavior before printing a part. The QUALITY MADE Current Tech team (@ConcurrentTech) is exploring the material behavior of topology optimized designs within their modeling tools. Designs can be optimized for material performance and characteristics such as lightweighting—where material is removed from the structure, making it lighter without compromising structural integrity.



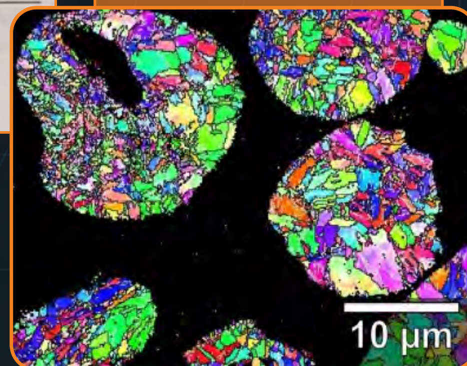
This system is an 8-axis industrial robot with a 6-kilowatt coherent laser and a build volume of 42 x 66 x 24 inches. The Lockheed Martin team has outfitted the system with pyrometers, vision, acoustic, displacement, and spectroscopy sensors for real-time #data

Additive manufacturing continues to push the bounds for changing the manufacturing paradigm. Using #machinelearning based approaches coupled with a range of sensors for large scale AM, the QUALITY MADE Lockheed Martin (@LockheedMartin) team is exploring high deposition AM with laser directed energy for titanium alloys. This focuses on fabrication of large, cost-effective structures.

@USNavyResearch / @USMC / @USNavy / @GEResearch / @ConcurrentTech / @LockheedMartin

Moving new technology rapidly to the fleet and force allows increased platform readiness. To expand implementation of the technology, ONR is developing process understanding and procedures @ARLPennState for Sailors and Marines.

@bamaengineering S3R is building material understanding from a single metal particle for deposition to understand the structural implications.



New solid-state manufacturing technologies are aimed at increasing platform readiness and #sustainment through structural repairs. While aerospace grade aluminum materials are not typically repairable, the ONR Solid State Structural Repair (S3R) Future Naval Capabilities program is developing in-depth understanding for structural repairs using technologies such as #coldspray for Aluminum 7050 at depots and maintenance facilities.

ONR, Navatek, and the University of Maine have worked closely for years to create this scale technology demonstrator of an amphibious vehicle to support the Navy and Marine Corps. In order to realize significant cost savings and shorten build time, ONR partners use complex modeling, novel materials, and "first-of-their-kind" #manufacturing processes. This innovative way of integrating #newtechnology for low cost manufacturability into the early design process helps to reduce initial investments and prevent cost overruns.

Photos are courtesy of the University of Maine.

The University of Maine's Advanced Structures and Composites Center, with ONR, unveiled a massive leap forward in #additivemanufacturing with this world record-setting printer for #3Dprinting. Not content to settle for one world record and anxious to show its capabilities, ASCC printed a 25-foot, 3,000-pound boat in just a matter of hours! This represents a #rapidprototyping capability the naval force has never had before. ONR and the University of Maine have plans to integrate advanced #composites into future hull forms and conduct multilayer, multimaterial testing to find the next generation of land, air, and sea materials.

CONCLUSION

As a result of the ONR team and their continuous, cross-cutting efforts in advanced manufacturing, the Navy and Marine Corps continue to lead the way in materials, manufacturing, qualification, and repair efforts for highly complex alloys and other novel materials. From the molecular level to the largest system of systems employed by the Department of Defense, programs such as QUALITY MADE, S3R, and the Ultra-Heavy Amphibious Connector remain at the cutting edge of what is possible. Our scientists and engineers are advancing materials and manufacturing processes to ensure that the warfighters they support never operate with less than the best. #NewTechnology #Innovation #Defense

@USNavyResearch / @USMC / @USNavy / @ARLPennState / @bamaengineering / @NavatekLLC / @UMaine / @UMComposites / @GWR

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Photo by Lance Cpl. Margaret Gale

UNMANNED LOGISTICS CAN SUPPLY THE BEACH AND BEYOND

By Lt. Cmdr. U.H. Rowley, USN (Ret.)

GETTING MARINES ON THE BEACH IS ONLY THE FIRST PART OF AN AMPHIBIOUS OPERATION. MAKING SURE FORCES ASHORE GET THE SUPPLIES THEY NEED AFTERWARD IS WHAT MAKES BUILD UP AND EXPLOITATION POSSIBLE. WHAT IF THE JOB OF MOVING THOSE SUPPLIES COULD BE MADE EASIER AND SAFER?

In their October 2019 article in *Future Force*, "Unmanned and Unafraid: The Transformation of Naval Oceanography," Dr. William Burnett and Dr. K. Todd Holland opened their piece with a provocative statement: "The question is not will the Navy use unmanned maritime systems in military operations, but rather how many will the Navy operate." They note that "unmanned systems take the place of operations considered dull, dirty, or dangerous."[1]

While their article focuses primarily on "dull" operations such as ocean observation, they suggest that the US military would be well served to consider them for "dirty" and "dangerous" roles in high-end warfare.[2] As the US military pivots from wars in the Middle East and South Asia and addresses the need to be prepared for conflicts with peer competitors, it is time to consider unmanned vehicles in a new light and consider new ways that these emerging technologies can support US military operators.

While there are many types of unmanned systems—air, ground, surface, and subsurface—this article will focus on unmanned maritime systems (surface and subsurface), as they have not received as much attention. Today, the unmanned systems are finally emerging as systems that can keep warfighters out of harm's way by taking on much of the dull, dirty, and dangerous work that previously put Sailors and Marines at risk.

The Technology-Based Unmanned Renaissance

"My view is that technology sets the parameters of the possible," writes military historian Max Boot in his book *War Made New*, "it creates the potential for a military revolution."[3] He supports his argument with historical examples to show how technology-driven "revolutions in military affairs" have transformed warfare at different times. He points out the importance of technology in giving militarily innovative nations war-winning advantages.

In his book *Wired for War: The Robotics Revolution and Conflict in the 21st Century*, P.W. Singer makes the argument that robots (unmanned systems) will change the character of warfare. He offers examples of how these systems are already transforming the way that the United States wages war, describing the military application of everything from the practice of having unmanned PackBots deal with deadly improvised explosive devices, to the employment of large unmanned aerial vehicles such as Global Hawk to provide comprehensive surveillance of wide swaths of territory, to the use of a wide variety of drones such as Predator and Reaper to kill terrorists from a distance.[4] His assertions regarding the potential and promise of the use of unmanned systems in future wars have not been lost on US defense and military officials who have expressed an increasing interest in unmanned systems.

The 2018 *National Defense Strategy* has an intense focus on technology and notes that the United States will not achieve the security and prosperity it seeks without harnessing advancing technologies to support its warfighters, noting:

> The security environment is also affected by *rapid technological advancements and the changing character of war*. The drive to develop new technologies is relentless, expanding to more actors with lower barriers of entry, and moving at accelerating speed. New technologies include advanced computing, big data analytics, artificial intelligence, autonomy, robotics, directed energy, hypersonics, and biotechnology—the very technologies that ensure we will be able to fight and win the wars of the future.[5]

One of the most rapidly growing areas of innovative technology adoption by the military involves unmanned systems. In the past several decades, the US military's use of unmanned aerial vehicles (UAVs) has increased from only a handful to more than 10,000, while the use of unmanned ground vehicles (UGVs) has exploded from zero to more than 12,000. The use of unmanned surface vehicles (USVs) and unmanned underwater vehicles (UUVs) also is growing, as both of these are proving to be increasingly useful for a wide range of military applications.[6] These systems have been used in the conflicts in Iraq and Afghanistan, and will continue to be equally relevant—if not more so—as strategic focus shifts toward the Asia-Pacific region.[7]

Most military officials agree that unmanned systems have a crucial role in providing the United States with dominance on the battlefield. The Department of Defense's vision for unmanned systems is to integrate these systems into the joint force for a number of reasons, but especially to reduce the risk to human life in high-threat areas, to deliver persistent surveillance over areas of interest, and to provide options to warfighters that derive from the inherent advantages of unmanned technologies—especially their ability to operate autonomously.

The importance of unmanned systems to the US Navy's future has been highlighted in a series of documents, ranging from the revised *A Cooperative Strategy for 21st Century Seapower*, to *A Design for Maintaining Maritime Superiority*, to a chief of naval operations *The Future Navy* white paper. The latter document presents a compelling case for the rapid integration of unmanned systems into the fleet, noting:

> There is no question that unmanned systems must also be an integral part of the future fleet. The advantages such systems offer are even greater when they incorporate autonomy and machine learning . . . . Shifting more heavily to unmanned surface, undersea, and aircraft will help us to further drive down unit costs.[8]

The Navy is making an enormous commitment to unmanned systems—especially unmanned surface systems. For example, the Navy is establishing a Surface Development Squadron, to experiment with unmanned ships.[9] Future development ideas call for a "ghost fleet" of autonomous unmanned surface ships that could operate against an enemy force without putting Sailors in harm's way.[10] Fortunately for the US military, under the stewardship of organizations such as the Defense Advanced Research Projects Agency, ONR, and the nation's military laboratories, decades of work have resulted in the development of unmanned systems that have been delivered to warfighters. While the exigencies of the wars in Afghanistan and Iraq necessitated the accelerated development and fielding of aerial and ground systems, the potential for conflict against high-end adversaries has meant the development of unmanned maritime vehicles has grown in importance.

Evaluating Unmanned Surface Vehicles

The Navy and Marine Corps have a lot to learn about unmanned surface vehicles, and there is a palpable desire to put them in the hands of Sailors and Marines. Navy-Marine Corps exercises, experiments, and demonstrations—such as a series of advanced naval technology exercise events and the annual Bold Alligator series—have looked at a wide range of emerging technologies, including unmanned vehicles that can make expeditionary assault forces more lethal, agile, and survivable. Other events have examined different missions conducted by the Navy-Marine Corps team, specifically the logistics and sustainment function.

Logistics have been central to warfare for many millennia. For the Navy-Marine Corps team, this plays out most prominently during an amphibious assault. The Valiant Shield exercise, overseen by Marine Forces Pacific and conducted on the Marianas Island Range Complex, experimented with using this emerging technology to provide sustainment to Marines on the beachhead during this critical juncture of an amphibious assault.

Marines in the fight use enormous quantities of fuel, food, ammunition, and other materiel as they attempt to move off the beachhead. While many functions are important in an amphibious operation, once the assault is under way and Marines are on the beach, sustainment is crucial in ensuring their success. Two researchers at the Royal United Services Institute put it this way, "The capacity of Marines to push inland must depend on the security of their logistical support."[11]

Using manned naval craft for this sustainment mission puts operators at unnecessary risk of enemy fire, and in proximity to near-shore obstacles that were not cleared prior to the assault phase. Using scarce manned craft to perform this mission also takes them away from more important roles. That is why this major Navy-Marine Corps amphibious exercise evaluated the ability of unmanned surface vehicles to conduct this sustainment mission.

Marine Forces Pacific used USVs during Valiant Shield to resupply the landing force. The exercise coordinator used a catamaran-hulled, 12-foot MANTAS USV to provide rapid ship-to-shore logistics sustainment. This small, autonomously operated USV carried just 120 pounds of cargo, but the proof of concept worked and demonstrated that unmanned surface vehicles could effectively resupply troops ashore.

Using unmanned vehicles for the sustainment mission can be a game changer for expeditionary assault forces. Beyond taking operators out of harm's way, using USVs in this role frees manned craft for other missions. In addition, having a continuous, preprogrammed logistics resupply process to perform one of the dull, dirty, and dangerous functions important in an amphibious assault means there is one less thing for commanders to have to manage during these operations.

This proof of concept with a 12-foot MANTAS USV achieved positive results. Resupply in 120-pound increments, however, is far less than is required to provide what is needed by Marines on the beach. The Valiant Shield exercise provided the impetus and inspiration to continue to explore the use of USVs for amphibious force sustainment. The Navy and Marine Corps are looking to scale up small USVs and continue to experiment with using larger USVs to provide greater sustainment quantities.

Scaling Up to Deliver Logistics Capabilities

To undertake this effort, the maker of the MANTAS family of vehicles (Maritime Tactical Systems) was asked by the Navy and Marine Corps to develop larger proof-of-concept USVs for this logistics sustainment mission using the same catamaran hull design as the smaller vessel used in Valiant Shield.

This shows several MANTAS T12 unmanned surface vehicles before deployment during an offshore exercise. Photo courtesy of Maritime Tactical Systems, Inc.

Larger MANTAS unmanned surface vehicles from 38 to 50 feet long are being constructed for further review by Navy and Marine Corps officials during upcoming exercises, experiments, and demonstrations such as Trident Warrior 2020. This may not be the ultimate size for the USV the expeditionary assault force needs as a long-term solution, but it will go a long way to advancing the state of the art in unmanned semiautonomous or autonomous logistics support.

There are larger USVs that can be evaluated by the Navy and Marine Corps, but the basic specifications of the 38-foot (T38) and 50-foot (T50) MANTAS will provide an indication of the ability of USVs to provide a continuous stream of logistics support to Marines on the beach. The T38

The MANTAS T12 during a Valiant Shield exercise off the shore of Guam in the Pacific. Photo courtesy of Maritime Tactical Systems, Inc.

can carry a payload up to 4,500 pounds, while the T50 can carry a payload of up to 10,000 pounds. The vessels travel at cruise speeds greater than 25 knots. Given the speed and carrying capacity these USVs, it is readily apparent how it can fulfill this, as well as other, important logistics functions.

Delivering Logistics Sustainment to Troops Ashore

As any observer can see from a hilltop near one of several Marine Corps bases, an amphibious formation typically stands no more than 15-25 nautical miles off the beach being assaulted. Using a notional stand-off distance of 20 nautical miles, an amphibious formation equipped with four T38s traveling at their conservative cruise speed of 25 knots could deliver 18,000 pounds of material from the amphibious ships to the beach per hour, allowing the short time needed for loading and unloading the craft. Multiply that by 24 hours and you get a buildup of greater than 400,000 pounds of vital material per day, enough to support a substantial force of troops ashore. For four T50s, the number is even higher, more than 800,000 pounds per day.

Both T38 and T50 are modular and can keep cargo dry in the turbulent surf zone. In addition, given the fact that an adversary will endeavor to fire on unmanned craft attempting to resupply the landing force, each vessel can operate in "gator mode," where the main deck is awash and only equipment such as cameras and radar are exposed above the water surface, making each USV much harder to target.

In addition to the upcoming Trident Warrior and RIMPAC exercises in the summer of 2020, the Navy is planning an ambitious range of exercises in the years ahead: several advanced naval technology exercises, Sea Dragon, Bold Alligator, Valiant Shield, Valiant Blitz, Large Scale Exercise 2020, and others. Based on the promising performance of small unmanned surface vessels in support of expeditionary assault forces, the Navy and Marine Corps would be well served to experiment further with larger USVs to perform this vital logistics sustainment mission.

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[1] William Burnett and K. Todd Holland, "Unmanned and Unafraid: The Transformation of Naval Oceanography," *Future Force*, vol. 6, no. 1 (2019): 18-21 (accessed at: https://futureforce.navylive.dodlive.mil/files/2019/10/FF_2019_Vol6-No1.pdf).

[2] The authors note that "these lessons should not be lost on the Navy as it begins large-scale production and operation of unmanned systems. As more and more autonomous vehicles maturate and integrate with the fleet, unmanned systems will assume key roles in defensive and offensive operations."

[3] Max Boot, *War Made New: Technology, Warfare, and the Course of History 1500 to Today* (New York: Gotham Books, 2006). Boot does not present technology as the only element determining victory or defeat, giving full acknowledgement to a host of other factors, from geography, to demography, to economics, to culture, to leadership. He is firm, however, in his contention of technology's huge impact, noting: "Some analysts may discount the importance of technology in determining the outcome of battles, but there is no denying the central importance of advanced weaponry in the rise of the West . . . . The way to gain military advantage, therefore, is not necessarily to be the first to produce a new tool or weapon. Often it is to figure out better than anyone else how to utilize a widely available tool or weapon."

[4] P.W. Singer, *Wired for War: The Robotics Revolution and Conflict in the 21st Century* (New York: Penguin Press, 2009).

[5] *Summary of the 2018 National Defense Strategy of the United States of America* (Washington, DC: Department of Defense, 2018), accessed at: https://dod.defense.gov/Portals/1/Documents/pubs/2018-National-Defense-Strategy-Summary.pdf.

[6] There has been extensive reporting regarding the emphasis on unmanned surface vehicles (including the substantial funding for these craft in the Navy's FY2020 budget submission) in the defense media. See, for example, Justin Katz and Mallory Shelboure, "Navy Seeks Accelerated Move into Unmanned Systems," *Inside the Navy* (1 July 2019).

[7] For some of the best work regarding unmanned systems, see, for example, P.W. Singer, *Wired for War*; Bradley Jay Strawser, ed., *Killing by Remote Control: The Ethics of an Unmanned Military* (Oxford: Oxford University Press, 2013); William Arkin, *Unmanned: Drones, Data, and the Illusion of Perfect Warfare* (New York: Little, Brown and Company, 2015); Larry Lewis and Dianne Vavrichek, *Rethinking the Drone War* (Quantico, VA: Marine Corps University Press, 2016); Paul Scharre, *Army of None: Autonomous Weapons and the Future of War* (New York: W.W. Norton and Company, 2018); and John Jackson, ed., *One Nation Under Drones* (Annapolis, MD: Naval Institute Press, 2018).

[8] *The Future Navy* (Washington, DC: Department of the Navy, 2017), accessed at: http://www.navy.mil/navydata/people/cno/Richardson/Resource/TheFutureNavy.pdf.

[9] Megan Eckstein, "Navy Pursuing 'Surface Development Squadron,' to Experiment with Zumwalt DDGs, Unmanned Ships," *USNI News* (28 January 2019).

[10] Kris Osborn, "Navy to Test 'Ghost Fleet' Attack Drone Boats in War Scenarios," *Defense Maven* (22 January 2019).

[11] Sidharth Kaushal and Jack Watling, "Amphibious Assault Is Over," *RUSI Defence* (January 2019), accessed at: https://rusi.org/publication/rusi-deence-systems/amphibious-assault-over

About the authors:

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A NEW MINE COUNTERMEASURES CONCEPT FOR AMPHIBIOUS OPERATIONS

By Dr. Joong Kim

THE AMPHIBIOUS ASSAULT REMAINS ONE OF THE MOST COMPLEX AND DANGEROUS FORMS OF MODERN WARFARE. DANGER CAN LURK IN THE WATERS OFFSHORE EVEN BEFORE THE FIRST MARINE HITS THE BEACH. ENSURING THAT THE FORCE GETS ASHORE SAFELY CALLS FOR A NEW MINE COUNTERMEASURES CONCEPT THAT MATCHES THE CURRENT THREAT.

With the reemergence of long-term, strategic competion in a security environment that is defined by rapid technological change, we must develop technologies that influence our operational approach to defeat explosive hazards throughout the naval battlespace, from the deep water to the inland objective. Large-scale combat operations and forcible entry are still the last resort in this strategic security calculus. That being said, given the increasing likelihood of small-scale contingencies, the United States more than ever requires a flexible and agile maritime crisis response force.

The ability to put a ground force ashore quickly is a strategic necessity, but the increased range and lethality of antiaccess/area-denial weapons likely will expose our naval forces to a higher risk of mission failure. These weapons include both waterborne and ground-based mines, improvised explosive devices, and other explosive hazards that can be deployed rapidly and effectively over a great area. These hazards impede operational tempo and freedom of maneuver from the deep water through the littorals and inland to the objective. To support naval expeditionary maneuver, the existing process of mine countermeasure (MCM) actions must be streamlined to a flexible and rapid capability continuum from the deep water to the objective, at sea and on land.

MCM today is a Navy mission that: requires human-intensive activities that extend the timeline and increase mission risk; is overt, which increases mission risk and risk to personnel; uses often older systems that are reaching the end of their service lives; lacks the capacity to complete the mission unless the mission is limited in scope. Since USS *Tripoli* (LPH 10) and USS *Princeton* (CG 59) struck mines 1991, the Navy has made significant investments into its MCM program—but the program still faces many challenges. Budget constraints arose because of other capabilities gaps and need, resulting in technology transitions being delayed or cancelled and creating both technology and capacity gaps. In addition, after tranistioning the Coastal Battlefield Reconnaissance and Analysis program to the Navy's mine warfare program in the late 1990s, the Marine Corps has not subsequently addressed MCM challenges in an amphibious environment, being focused on fighting improvised explosive devices. This has left the Department of the Navy with inadequate MCM capability, especially in the most challenging environment: from very shallow water through the beach.

The Integrated Countermeasures and Hazard Defeat Concept

Modern distributed forces cannot be constrained by a requirement to attack along traditionally prescribed lanes. Elements of the landing force must possess the freedom to maneuver at will, conducting "detect and avoid" or "hasty breaching" operations at the individual connector, platform, or small-unit level. Capabilities that allow for reconnaissance, breaching, clearing, proofing, and marking/reporting along avenues of approach and ashore will enable warfighters to execute missions across the full spectrum of conflicts in the complex littoral environment. In this proposed concept, the landing force will be required to conduct some level of mine and obstacle detection and avoidance or breaching from the very shallow water (40 to 10 feet in depth), through the surf zone (10 to 0 feet depth) and beach zone, and on to inland objectives. As a result, the Marine Corps has identified a need for an organic explosive hazard detection, neutralization and marking capability from very shallow water and beyond and is exploring various technologies to meet this requirement.

These are the key areas for the concept:

- Operators will only supervise and monitor decisions made by machines as they execute the mission
- Networked platforms, sensors, and neutralization systems work together to improve performance (time, probability of detection, and reduction of false alarms) from deep water to the objective
- Systems must provide capability and operational flexibility through all operational phases and the range of military operations
- The Marine Corps' organic capability to detect and mitigate explosive hazards from very shallow water forward is complementary to Navy capabilities up to the beach zone.

Relevant Technical Investments and Enablers

Modular, Scalable Detection and Neutralization

The process of detection and neutralization in MCM and explosive hazard defeat (EHD) is an interrelated and interconnected operation. An effective neutralization system can tolerate inaccuracy of the detection system or bypass the detection process altogether. The "detect and avoid" concept, the result of the high probability of detection and identification of threat objects, can reduce the neutralization burden by providing an option to avoid threats. In addition, this concept requires electronic marking, reporting, and a precision navigation capability to become reality. Therefore, the MCM/EHD solution must consider the systematic approach to the balance between the neutralization, detection marking, and reporting capabilities.

Some of the obvious features already have been pursued for explosive hazards detection systems, such as: high probability of detection, low false alarm rate, low manufacturing cost, low maintenance cost, simple and easy operation, interoperability with other systems, small size, reliability, and low logical burden. There are two additional key features for future operations: scalability and modularity. These will play increasing roles as remote platforms continue to shrink while the mission space continues to grow. Scalability will be necessary to maintain the same or increased coverage rates in order to maintain operational tempo. Modularity will be necessary for systems to adapt to a variety of platforms and environmental changes, as well as to reduce the logistical burden of maintaining and carrying separate platforms for each mission. Amphibious operations will include platforms such as ships, boats, ground vehicles, amphibians, and airborne platforms.

To have a detection system that can be modular and able to perform in the relevant environments, it must have the following attributes:

Photo by Lance Cpl. Andrew Cortez

Today's mine countermeasures, centered on the 1980s-era Avenger-class mine hunters (such as USS *Pioneer* [MCM 9] see here during an exercise with 7th Fleet), still place personnel and equipment unnecessarily in harm's way—even with technology such as the Mine Neutralization Vehicle seen here, since it operates using a tether that limits its range and flexibility. Photo by Lt. j.g. Alexander Fairbanks

- Modular, scalable, reconfigurable, and integrated to provide an on-the-move, multiplatform, standoff EHD capability that fulfills multiple missions
- Targeted platforms for sensors and neutralization systems include all ground vehicles, unmanned aerial systems, unmanned underwater systems, unmanned amphibious vehicles, and Marine Corps amphibious connectors
- Uses remote/autonomous amphibious systems in the unmanned lead vehicle or unmanned first wave concept to provide remote capability until true standoff technologies can be developed
- Must address additional challenges of sensing/neutralization in the surf zone and very shallow water and of coordination/communication between land/air/maritime forces and manned/unmanned systems.

Detection system performance is highly dependent on sensor component performance. Environmental factors, such as wind, dirt, sand, water, vegetation, etc., make detection much more challenging. This is why there have been many research-and-development efforts in highly sensitive spectroscopic methods for detection at greater distances. A compact modular system, however, bypasses the challenging standoff issue by examining the threats in proximity typically hosted by an unmanned system. As a result, atmospheric attenuation becomes manageable. Optical systems no longer require large collection optics for high-resolution imaging or reflection spectroscopy. Instead of a single large system to reach a high probability of detection and low probability of false alarm, multiple fused systems in close proximity may be able to raise the chance of detection and lower false alarms.

Even with the potential benefits of unmanned vehicles, there is no single modality that can address all explosive threats from very shallow water to the inland objective. This system requires multiple detection sensors. For example, magnetic sensors are capable of detecting metallic threats, but the coverage rate and detection range are limited. Other sensing modalities can only cover a part of the range of explosive threats under specific conditions, but no single modality can cover both at the sea and ground regions. The solution will reside with multimodal or multisystem systems. This is another important reason for the emphasis on small size, modularity, and scalability.

Information Analysis, Decision Making, and Distribution

The complexity of littoral combat and increased flow of information through various sensors will inevitably demand real-time data collection and processing. Information consolidation, analysis, and distribution is a critical component in developing an integrated MCM/EHD capability. This tool becomes the hub of a system of meshed networked platforms, sensors, and neutralization systems that work together to provide expanded capability and improve performance in the area of detection, marking, and reporting explosive hazards from DW to the objective.

This critical element provides analysis and distribution of sensor information through the force using artificial intelligence that feeds operational and tactical planning systems used in ingesting sensor data for the planning and analysis for the naval MCM program. This tool should address the ability to link and analyze intelligence, surveillance, and reconnaissance systems (strategic, operational, and tactical) and explosive detection information. The analyzed information should provide an appropriate level of information needed to perform missions to commanders, operators, and sensor platforms. It is the centerpiece of the integrated MCM/EHD system's ability to detect, cue, reacquire, confirm, neutralize, mark, report, analyze, and distribute information—increasing the system's probability of detection and decreasing the probability of false alarms far beyond what one simple sensor will ever achieve, as well as providing obstacle avoidance information to both manned and unmanned platforms.

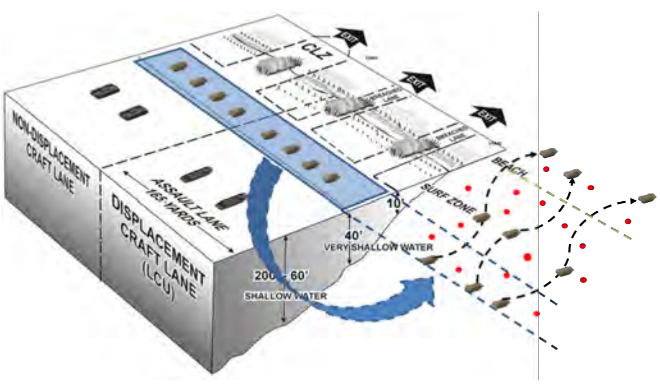
The Role of Big Data in Automatic Target Recognition

MCM/EHD automatic target recognition (ATR) algorithms can drastically compress the detect-to-neutralize timeline by vastly reducing the amount of data that human operators must review and annotate, or even enabling fully autonomous clearance operations. Accuracy is central to effectiveness in any ATR task, and it has improved markedly because of deep neural network approaches that rely on large, labeled datasets. Curating and storing data needed for highly accurate ATR using stand-alone hardware is a formidable task for even one sensor, let alone the myriad sensors the Navy employs on its surface and underwater survey platforms.

Future ATR improvements require modern hardware and software approaches that enable continual aggregation, curation, and development. For example, a cloud-based storage strategy would provide large storage capacity, data redundancy/resilience, and developer access to benchmarked and labeled tuning data. Labeled data collected in the field would continually refresh the data store. Modeling and simulation tools running in the cloud environment could augment data-sparse scenarios, providing examples for ATR tuning to new threats and environments. In this continual development paradigm, on-scene system updates would rapidly optimize ATR performance for in-theater conditions.

Autonomy

Remotely controlling and maneuvering many distributed platforms by individual operators is impractical and impossible. Therefore, the integrated MCM/EHD concept must have reliable autonomy to assist efficient navigation



This shows the freedom of maneuver that an organic Marine MCM/EHD capability provides from very shallow water to the objective. Instead confining itself to predetermined lanes, the assault force is free to detect and avoid explosive obstacles while on-board or unmanned teaming neutralization/mitigation systems protect it. During the maneuver, using standoff detection, neutralization, and marking, systems are constantly marking free lanes and automatically reporting those lanes to the follow-on echelons. This concept employs precision standoff neutralization systems to clear the minimal amount of explosive threats speeding the attack and raising the force's operational tempo.

and detection area coverage. Remote and autonomous systems can be launched and recovered by, and controlled from, mounted and dismounted formations. Development of autonomy will allow various small platforms to navigate complex terrain, negotiate obstacles, and operate in all environments under extreme conditions. These systems include capabilities to receive, analyze, disseminate, store, and archive route, terrain, and related geospatial data to facilitate automated electronic reporting. Interchangeable sensors and neutralization systems enable MCM/EHD target acquisition and engagement.

An assault against anti-access and area denial defenses by a swarm of multiple remote and autonomous systems promises to gain localized landing site superiority in time and space sufficient to project distributed forces ashore. The complexities of commoditizing unmanned vehicles for low cost; developing adaptable payloads for intelligence, surveillance, and reconnaissance or weaponization; generating the swarm in a sufficiently short timeframe; and independently targeting and controlling upwards of hundreds of vehicles simultaneously—all of these represent distinct technical challenges. The incorporation of all of these elements into a single concept operating from the sea dramatically increases the difficulty.

Swarming promises to provide an organic, scalable capability to satisfy the conditions of persistent intelligence/surveillance/reconnaissance, MCM/EHD, and time. Swarms of unmanned systems with detection, neutralization, marking, reporting capabilities allows the force to cover great areas at a speed unimaginable today, allowing the standoff detection and neutralization of MCM/EHD that informs commanders in a timely manner to make informed operational decisions.

Buried Object Detection: Ground Penetrating Radar

Ground penetrating radars (GPRs) currently used by the military to detect, locate, and mark buried threats use specialized, large, and dedicated vehicle/sensor platforms. The size, weight, and operational complexity of these systems, however, have limited usefulness for amphibious operations. In addition, their performance is dependent on the skill of trained operators because of the complexity of how these systems display information. The Office of Naval Research has sponsored Lawrence Livermore National Laboratory to create small, adaptable GPR systems that combine novel coherent ultrawideband radar arrays with advanced real-time computed tomographic imaging. The "multistatic" imaging

On the left, field trials with first unmanned aerial multistatic ground penetrating radar system flies in front of a vehicle-mounted prototype array. On the right, a new miniaturized-scalable 16-channel system on a Polaris vehicle is shown prior to its first field test.

arrays focus the radar return energy into three-dimensional images that enable easy interpretation, automatic detection, and threat recognition with machine learning techniques.

The real-time processed GPR image streams, detection features, and their locations are available to multiple clients on a network simultaneously. Operators, commanders, and other integrated systems can all subscribe to selected GPR-processed stream components. The client can tailor the information choices to limit bandwidth to satisfy constraints imposed by communication systems or to maximize the information content. For example, a centralized integrated common operating picture can subscribe to only detection features (low bandwidth), whereas a multisensor/platform fusion system may wish to overlay detection modalities, video, and GPR-based three-dimensional subsurface reconstructions (high bandwidth).

Recently, a significant reduction in the complexity, size, weight, and power requirements of the radar architecture has been achieved. Where previous generations used a large, heavy distributed electronic subsystem, now a single six-by-nine-inch circuit board can drive and control a full 16-element coherent radar array. These new system and antenna architectures enable scalability and deployment of GPR imaging arrays to any available platform. As a result, the GPR system is on a path to a scalable system, down to a small unmanned aerial system or up to a larger military vehicle, or a modular system that can adapt either to a ground or airborne platform.

Conclusion

The amphibious operation is one of the most complex of military operations. It requires coordination not only between the Marine Corps and Navy, but also with joint and combined forces. Freedom of maneuver of our forces has continued to deteriorate as our adversaries' lethality, effectiveness, and range improve. The distributed operation is a natural progression with current technical trends to combat evolving threats.

The Navy and Marine Corps require an expanded capability to conduct standoff detection, neutralization clearing, and marking of buried, surface, and off-route explosive obstacles from deep water to the objective with the following attributes: modular, scalable, reconfigurable, and integrated to provide an on-the-move, multiplatform, standoff explosive hazard defeat capability that meets multiple missions according to commanders' needs. The future capability must address additional challenges of sensing and neutralization in the surf zone and very shallow water.

One way to accomplish this is that Marine Corps organic systems must be complementary to and compatible with Navy MCM/EHD technologies, from very shallow water through to the inland objective. There also must be a single, cloud-based system for coordination, communication, and decision making between land, air, and maritime manned and unmanned systems. The size and sophistication of the distributed sensor input ultimately will limit the effectiveness of artificial-intelligence-based data analysis and decision-making processes. Therefore, continued research and development of explosive hazards threat detection and neutralization sensor and sensing techniques should be emphasized to address future threats and enhance overall mission effectiveness. When this is accomplished, the Department of the Navy will have the cohesive naval MCM system required for success in today's environment as defined by the National Defense Strategy.

About the author:

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Photo by Joe Bullinger

In 2019, Naval Information Warfare Center Pacific completed an important phase of Compile to Combat entitled "Digital Abe," which is a digital representation of a cloud-based information warfare system that will be installed on USS *Abraham Lincoln* (CVN 72) in 2020.

From Waterfall to OASIS: Bringing Development, Security, and Operations to the Corps

By Steve Ghiringhelli

A NEW DEVELOPMENT GROUP AT NAVAL INFORMATION WARFARE CENTER ATLANTIC IS CONNECTING WARFIGHTERS TO INNOVATIVE SOFTWARE SOLUTIONS FASTER THAN EVER BEFORE.

A Naval Information Warfare Center (NIWC) Atlantic enterprise engineering team recently began deploying in earnest its paradigm-shifting methodology for developing software.

Modeled after the US Air Force's software development organization Kessel Run, the newly accredited Operational Application and Service Innovation Site (OASIS) enables NIWC Atlantic's expeditionary warfare department to provide DevSecOps—development, security, and operations—to the US Marine Corps for the first time.

DevSecOps is a commercial best practice that has revolutionized the software industry and only recently made inroads in the military.

"When you look at industries in the commercial sector, you see they are no longer, for example, a logistics company—they are a software company with trucks," said NIWC Atlantic executive director Peter C. Reddy. "The Department of the Navy has to become a software company with warfighters. And because countless software-based battlefield missions can immediately benefit from the DevSecOps approach, the future of OASIS is critically relevant to operations in the information environment."

In the broadest terms, DevSecOps means delivering value to customers faster. It pairs programmers (development) with system administrators (operations) while also embedding security (security) into every step of development.

"Baking feedback into the process allows the end users' thoughts to make it back to the coders building their product," said Erik Gardner, NIWC Atlantic's OASIS director and Palmetto Tech Bridge representative. "Marines have an immediate voice in the development of what will be fielded."

The Air Force was the first service to experience success employing the DevSecOps concept more than two years ago. Named after a smuggling route from the movie Star Wars, Kessel Run has achieved enormous success in efficiencies and attracted the attention of high-level Department of Defense leaders.

In recent years, the DevSecOps model has steadily built on the successes of "agile" and "lean startup," two major software-development methodologies known for shrinking the traditional "waterfall" approach of planning-designing-developing-testing-delivering into small increments called minimum viable products (MVPs).

Instead of taking years to deliver a product that may fail to meet the customer's needs, lean startup promotes a "fail fast" approach, scheduling MVPs every week or two for customers to grade and developers to improve.

Along with agile and lean startup, automation is a key driver in a DevSecOps environment. Automation enables services using artificial intelligence and machine learning to report continuously on a platform's functional health, including key metrics related to cyberattacks, amount of users, outages, and degradation.

"Software factories are popping up all over U.S. military organizations, but OASIS is unique," said Jeff Hays, a NIWC Atlantic enterprise engineering team lead. "By not focusing on a single pipeline, or single platform, OASIS is giving technology professionals the power of the latest mainstream tools, coupled with the power of choice."

Another major draw of DevSecOps is the enormous potential in savings. Unlike the monolithic "waterfall" processes of the past, if an MVP fails, there isn't a huge impact in terms of resources, and program risk is actually reduced, said Robert Neuman, a NIWC Atlantic technical lead in enterprise engineering and integration services.

"You roll back maybe a week," Neuman said. "It's not this multimillion-dollar failure in acquisitions."

Tony Stafford, NIWC Atlantic's DevSecOps command coach, said the software factory concept is, in many ways, about reducing the friction between the team providing the solution and the user, while also minimizing the time and steps to get a tool into the warfighters' hands.

"Generally speaking," Stafford said, "government bureaucracy tends to be additive, growing the distance between builders and users. That is why OASIS is designed as a central hub for the naval enterprise, to find and minimize inefficiencies."

About a year ago, the NIWC Atlantic's expeditionary enterprise systems and services division initiated OASIS in support of a Marine Corps request by the Deputy Commandant for Planning and Resources to improve enterprise software development.

OASIS began operations in summer 2019, cementing the status of DevSecOps at NIWC Atlantic by implementing nearly 30 inherited automated platform services and nine automated application development services—prospective solutions for everything from business operations to tactical systems.

The Marine Corps Business Operations Support Services (or MCBOSS) was the very first DevSecOps capability developed by the OASIS team. DevSecOps is made possible within the MCBOSS multiplatform environment by the Application, Development and Test Services (ADTS) team, which creates the majority of the automated testing and building.

"If the MCBOSS platforms were cars, the ADTS services would be the gasoline, oil, and electricity," noted Jason Anderson, a NIWC Atlantic cloud engineer and DevSecOps lead.

Soon after MCBOSS was established, the Marine Corps went live with its first OASIS-developed application, the Inspector General's Case Action Management program, which provides real-time tracking of data related to investigations.

More recently, OASIS executed a Naval Innovative Science and Engineering project to verify the interoperability of Marine Corps applications developed in OASIS with the Navy's Consolidated Afloat Network and Enterprise Services (CANES).

Bringing DevSecOps to a traditional organization for the first time has required considerable shifts in culture and philosophy, according to Anderson. He said real software that addresses real problems in real time requires not only strong automation but good listening skills as well.

"In a DevSecOps culture, it's better to have 20 different interviews with 20 different people who all have the same problem than reading a requirements document," Anderson said. "We will probably hear that 12 of the 20 are saying something totally different than what's on paper. Each perspective matters."

In time, with its secure cloud-computing architecture ready to host applications, the OASIS team will be well positioned to integrate critical enterprise-level initiatives that seek to modernize the Department of Defense network.

"We continue working with our NIWC Pacific peers in driving DevSecOps solutions across the Navy enterprise and DoD as well," said Kathryn Murphy, a senior scientific technical manager in software development. "The key to our continued success with initiatives such as OASIS will be in creating an awareness of available software factories and preparing the workforce to successfully use them."

Neuman pointed out that getting the best technologies onto the modern battlefield has been the mission of the Defense Innovation Board, which was established in 2016 to bring the technological innovations of Silicon Valley to the military.

Last year, the board released an important study called "Software Acquisition and Practices," which not only highlighted the need for a new acquisition pathway but also addressed the sluggish pace of software development in government.

"They basically pointed out how we had been told since the 1980s that we needed to change the way we did software," Neuman explained. "They told us the problem wasn't that we didn't know that. It was that we didn't act."

As a whole, proponents of the DevSecOps method say traditional procurement processes are fundamentally incapable of putting the latest software-powered equipment on the modern battlefield, where rapidly changing technologies alter the landscape at lightning speeds. They say mindsets must be challenged, and change is more than just inevitable—it is constant.

Gardner, who has driven the OASIS initiative from the beginning, said the bottom line is that radical cultural shifts in practice and thinking are needed in software development to speed solutions to warfighters.

"It's not just that old processes and regulations translate into later delivery times," he said. "It's that the status quo in just about any area of technology will, in the end, put the wrong thing in the hands of the warfighter. We just can't afford to make that mistake."

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The Marine Corps Warfighting Laboratory conducted Project Metropolis II, a dense urban operations limited operational experiment, at Muscatatuck Urban Training Center, Indiana. The event combined robotics, sensors, manned/unmanned vehicles, and dismounted Marines with a focus on improving the ability to sense and locate threats, observe the speed of decision making and action, and determine lethality when employing traditional and surrogate equipment versus an enemy force in an urban environment. Photo by Matt Lyman

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