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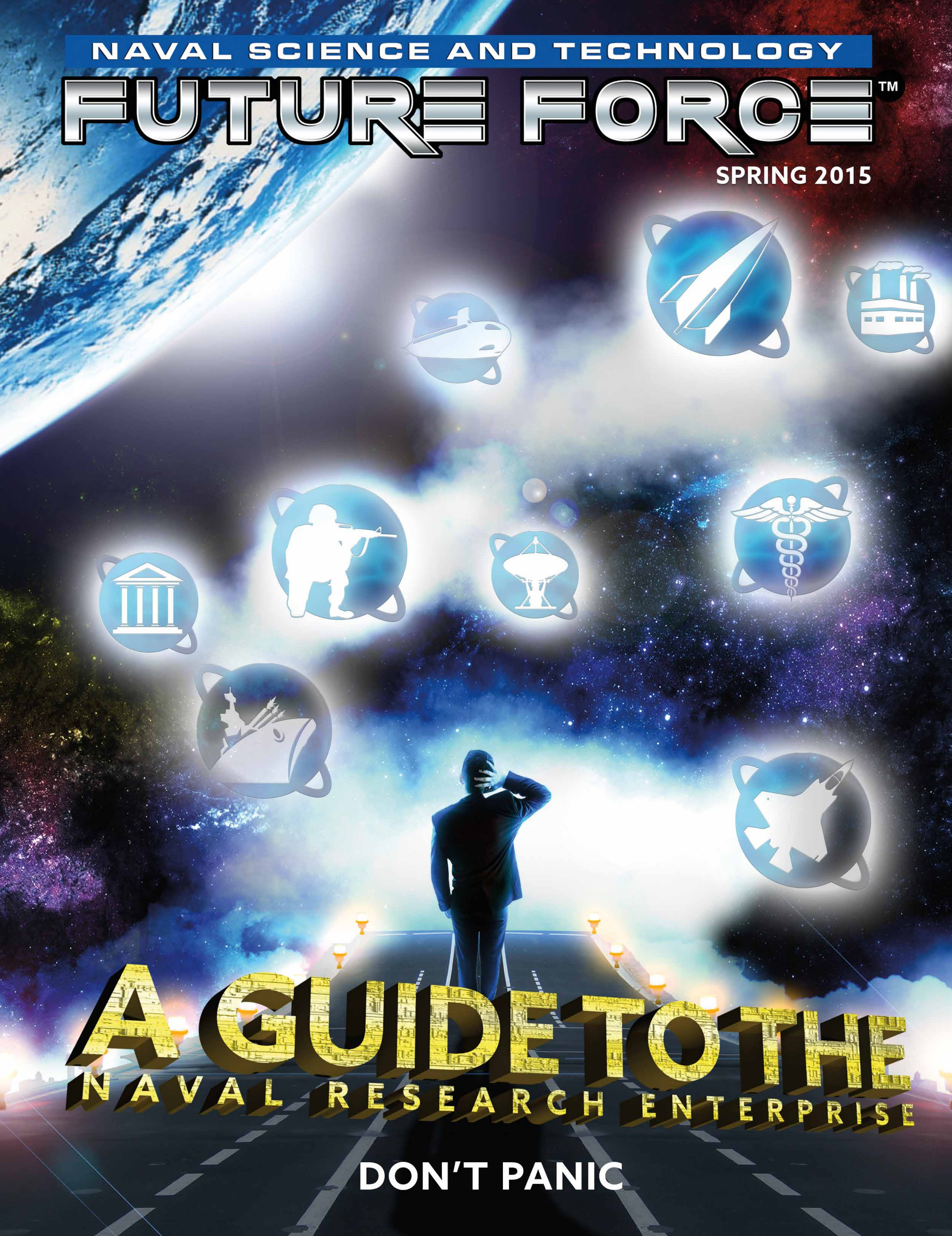

A GUIDE TO THE NAVAL RESEARCH ENTERPRISE

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FUTURE FORCE

NAVAL SCIENCE AND TECHNOLOGY MAGAZINE

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Future Force Magazine
Office of Naval Research
875 N. Randolph Street, Suite 1425
Arlington, VA 22203-1995

Email: futureforce@navy.mil
Phone: (703) 696-5031
Web: http://futureforce.navylive.dodlive.mil
Facebook: http://www.facebook.com/navalfutureforce

Future Force is a professional magazine of the naval science and technology community. Published quarterly by the Office of Naval Research, its purpose is to inform readers about basic and applied research and advanced technology development efforts funded by the Department of the Navy. The mission of this publication is to enhance awareness of the decisive naval capabilities that are being discovered, developed, and demonstrated by scientists and engineers for the Navy, Marine Corps, and nation.

Front Cover: *Hitchhiker's Guide to the NRE,* Illustration by Alvin Quiambao

SPEAKING OF S&T

By Rear Adm. Mathias W. Winter, USN

Chief of Naval Operations Adm. Jonathan Greenert (left) and Chief of Naval Research Rear Adm. Mat Winter discuss the Shipboard Firefighting Autonomous Robot, SAFFiR, at the Naval Future Force Science and Technology Expo on 4 February 2015. Photo by John F. Williams.

In February, I rolled out the latest Naval S&T Strategy at the Future Force Naval S&T Expo, held at the Washington, D.C., Convention Center. The event provided an important opportunity for participants to interact with program officers from the Office of Naval Research (ONR) and to discuss technical challenges facing the Navy and Marine Corps with leaders from across the Naval Research Enterprise (NRE).

This spring issue of *Future Force* provides a "guide" to the NRE to keep that conversation going. It is fundamental for everyone involved in the discovery, development, and delivery of naval S&T to understand just what the NRE is and how it relates to the broader Naval Research and Development Establishment (NR&DE), which is focused on maturing new technologies from naval S&T into acquisition programs of record. This continuum of science, research, development, testing, and evaluation ultimately fosters good ideas in the lab to become new capabilities for naval warfighters.

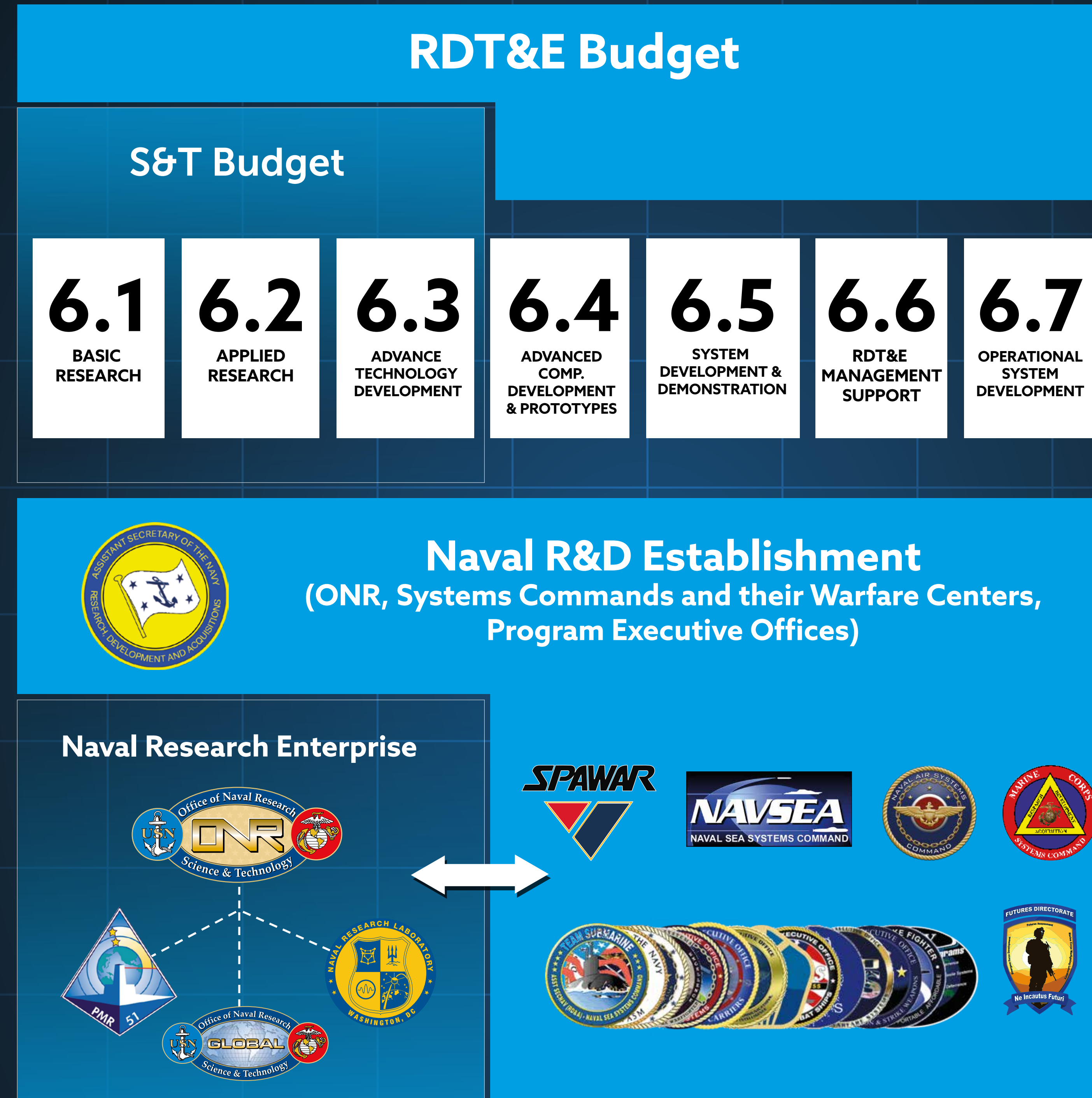
As the Chief of Naval Research, I am responsible for the Department of the Navy's S&T funding and its execution by the NRE, which includes ONR, ONR Global, the Naval Research Laboratory, PMR-51, and our industry and academia partners. It all begins with funds in basic research (6.1)—the seed corn of new discoveries necessary for technology breakthroughs. Applied research (6.2) and advance technology development (6.3) funds develop and deliver working prototypes from the NRE to the NR&DE (see below graphic).

S&T is about 1 percent of the Navy's budget. It is the "venture capital" of the Navy and Marine Corps. High return on these investments is enabled by efficiently consolidating these funds and activities under one roof at ONR. The NR&DE manages the entire continuum to advance new technologies through the acquisition process and into the fleet/force. Dr. John Burrow is the Deputy Assistant Secretary of the Navy, for Research Development, Test and Evaluation, and oversees the NR&DE.

This issue of *Future Force* helps illustrate how our people and organizations enable mission success. First among them is the Secretary of the Navy, the Honorable Ray Mabus, who discusses how Task Force Innovation is harnessing new technologies and the talent of our people to accelerate good ideas. Additional articles provide insight from the founding of ONR as an S&T organization established by law, to collaboration with NRL, to profiles of all nine naval warfare centers and their unique mission focus, to how educational partnerships are growing the next generation of great naval scientists and engineers.

Together, all of us in the NRE and NR&DE work hard to support the discovery, development, and delivery of technological advantages for our Sailors and Marines.

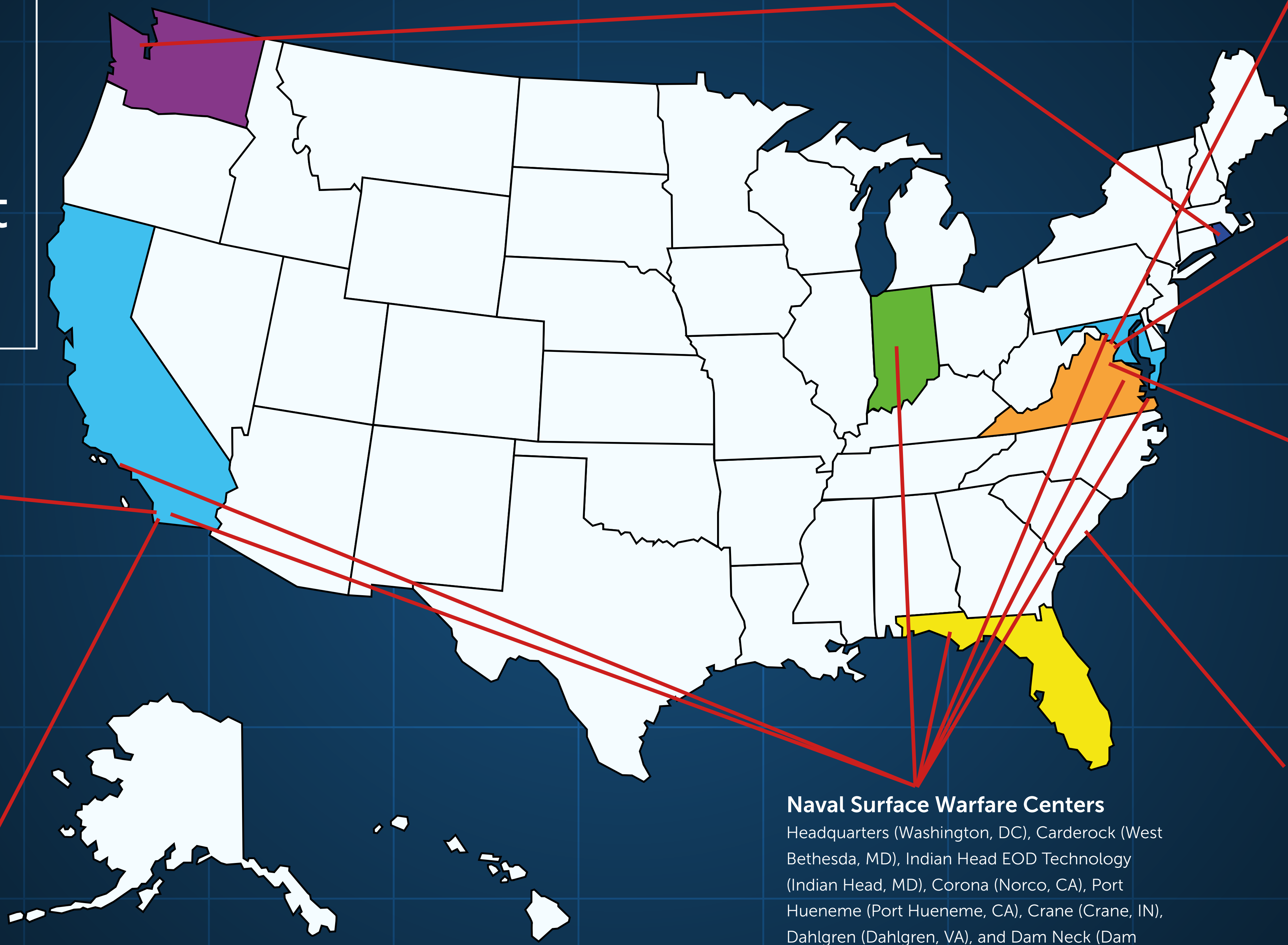
Rear Adm. Winter is the Chief of Naval Research.



The Naval Research Enterprise and the Naval Research & Development Establishment

The Naval Research Enterprise manages and executes the Navy and Marine Corps' science and technology, while the Naval Research & Development Establishment matures naval science and technology to programs of record.

Components of the Naval Research and Development Establishment in this Issue



Naval Undersea Warfare Centers
Keyport (Keyport, WA) and Newport (Newport, RI)
- Submarine Systems and Torpedoes
- Undersea Warfare Systems
- Autonomous Undersea Vehicles

Naval Research Laboratory
Washington, DC
- Radar
- Information Technology
- Optical Sciences
- Electronic Warfare
- Material Sciences
- Plasma Physics
- Electronics Science
- Biomolecular Science
- Acoustics
- Remote Sensing
- Oceanography
- Chemistry
- Marine Meteorology
- Space Science and Technology

Office of Naval Research
Arlington, VA
- Expeditionary Maneuver Warfare and Combating Terrorism
- Command, Control, Communications, Intelligence, Surveillance, and Reconnaissance
- Ocean Battlespace Sensing
- Sea Warfare and Weapons
- Warfighter Performance
- Naval Air Warfare and Weapons

Marine Corps Systems Command
Quantico, VA
- Intelligence
- Ammunition
- Light Armored Vehicles
- Training Systems
- Information Systems and Infrastructure
- Command, Control, and Communications
- Infantry Weapon Systems
- Army and Fire Support Systems
- Combat Support Systems

Space and Naval Warfare Systems Center Pacific
San Diego, CA
- Command, Control Communications
- Computers Intelligence, Surveillance, and Reconnaissance

Naval Health Research Center
San Diego, CA
- Operational Readiness
- Operational Infectious Diseases
- Military Population Health
- HIV/AIDS Prevention

Naval Surface Warfare Centers
Headquarters (Washington, DC), Carderock (West Bethesda, MD), Indian Head EOD Technology (Indian Head, MD), Corona (Norco, CA), Port Hueneme (Port Hueneme, CA), Crane (Crane, IN), Dahlgren (Dahlgren, VA), and Dam Neck (Dam Neck, VA), and Panama City (Panama City, FL)
- Ships and Ship Systems
- Warfare Systems Readiness and Assessment
- Sensors
- Electronics and Electronic Warfare Systems
- Surface Ship and Expeditionary Warfare Systems
- Surface Warfare Logistics and Maintenance
- Energetics
- Explosive Ordnance Disposal
- Mines and Mine Countermeasures
- Diving Systems

Space and Naval Warfare Systems Atlantic
Charleston, SC
- Communications
- Intel Collection/Processing
- Info Management
- Business Information

By Colin E. Babb

The Genesis of the Office of Naval Research

Rear Adm. Julius Furer assumed the role of coordinator of research and development in December 1941 and would oversee much of the Navy's science and technology research during World War II.

Vice Adm. Harold Bowen had been director of the Naval Research Laboratory in 1939-42, and became the chief of the Office of Research and Inventions in May 1945. He became the first chief of naval research the following year. Much of his initial efforts in the new office centered on his longtime interest in promoting naval nuclear propulsion.

With the stroke of a pen in August 1946, President Harry Truman created a new government organization that would—for the first time in U.S. history—fund and manage peacetime scientific research conducted mostly outside of the government itself. In all honesty, however, the signing of the law merely gave the "new" organization an additional level of authority for a job it already had been doing for more than a year. The agency's chief, Vice Adm. Harold Bowen, had to do little more than change the office stationery and the title on the front door, from the Office of Research and Invention—to the Office of Naval Research (ONR).

ONR was a progeny of the burning embers of history's bloodiest war, a compromise born of the necessity to facilitate what many hoped would eventually be a civilian-led national organization that could fund all science and technology, not merely research of interest to the Navy. The government had been involved in promoting, conducting, and advising on research for generations, and the Navy had been conducting its own research since the establishment of the Naval Observatory in 1830 and the Naval Research Laboratory in 1923. World War II, however, saw the rise of new levels of government involvement in science and technology research.

The effort to provide some federal direction to research started in June 1940, well before bombs began falling at Pearl Harbor. Building on a tradition of World War I organizations such as the Naval Consulting Board and the National Research Council, the National Defense Research Committee (NDRC), headed by Vannevar Bush, coordinated civilian research toward military ends. Unlike the many advisory groups of the past, however, the NDRC (and its wartime successor, the Office of Scientific Research and Development [OSRD]) had both the power of the purse—with the means to contract for research as well as to provide grants—and the ear of the president. The Manhattan project would be the most famous product of OSRD's efforts during the war, but the agency became the clearing house for new technology in nearly every area of science, from proximity fuzes to penicillin (at the height of the war effort in 1944, OSRD was funding more than $135 million in research). Divided into departments and offices, OSRD's comprehensive portfolio eventually would be replicated in ONR's structured approach to research.

Much military research during the war remained with the technical branches and bureaus within both services, and it was the desire to supplement this research that led to the creation of the Navy's Office of the Coordinator of Research and Development in July 1941. This office, headed from December 1941 by Rear Adm. Julius Furer, had limited authority compared to the peacetime organization that would succeed it. Nominally, Furer's role was to act as a liaison with all the bureaus, but missing was a direct role in contracting for research outside the Navy. This was done indirectly; Furer also was a member of OSRD, which funded research at the Navy's request and direction.

By the end of the war, there was tremendous momentum for the continuation of the research model of civilian-led, government-funded, militarily useful research embodied in OSRD's approach. This led to a number of efforts to create a national science funding organization. One was led by West Virginia Senator Harvey Kilgore, whose wartime hearings on the funding of scientific research and development eventually led to the "Kilgore Report" in 1945, which called for a national science agency. Another voice for government-funded science was Vannevar Bush, who, at the request of President Franklin Roosevelt, wrote a manifesto for a national science foundation, *Science—The Endless Frontier*, also in 1945. Disagreements between these two plans over control, geographical distribution of research, and other matters delayed the creation of the National Science Foundation until 1950. In the meantime, the Navy had its own plans for combining the structures and experiences of OSRD with those of Furer's office into a new organization.

> Seven decades ago, a new government science-funding agency arose that helped change the Navy's research into a research enterprise.

In May 1945, as the war was winding down, Secretary of the Navy James Forrestal established the Office of Research and Inventions (ORI), which combined the Office of the Coordinator of Research and Development, the Special Devices Section (a component of the Bureau of Aeronautics), the Naval Research Laboratory, and the Office of Patents and Inventions. Vice Adm. Bowen, who had previously headed the two latter organizations, was made the director of the new agency. The basic outlines of ORI came from a group now known as the "Bird Dogs"—a group of young officers who had worked under Furer and his predecessor, Jerome Hunsaker—and Capt. Robert D. Conrad. The main attributes of the Bird Dogs' plan involved placing a flag officer at the head of the organization and providing two advisory committees to support that person, one on research and another on research and development (eventually, ONR would require only that an officer of lieutenant commander or above be appointed chief, and the committees would be narrowed to one, what would become the Naval Research Advisory Committee).

Missing from ORI was a stamp of approval from congress, since it was presumed that as an organization created in wartime by the secretary of the navy under the war powers act it may not have had the authority to commit public funds in peacetime. Submitted to the House Committee on Naval Affairs on 27 March 1946, a bill establishing an Office of Naval Research, HR 5911, was introduced by committee chairman Carl Vinson. After some debate and minor revisions, the legislation passed the Senate and was signed into law in August 1946 as Public Law 588.

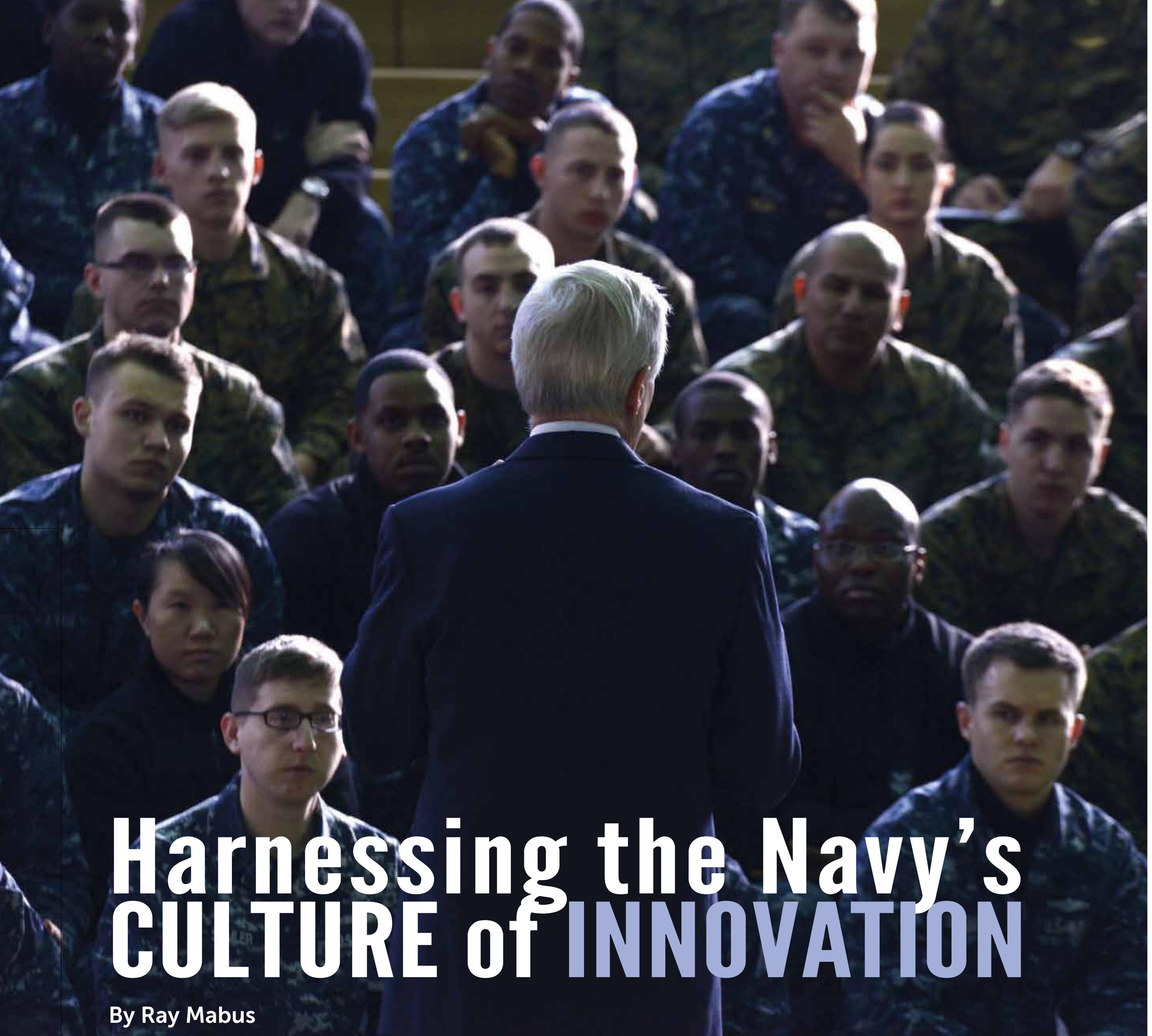
The new Office of Naval Research was immediately at the nexus of the growing Cold War, the only government agency able to maintain the connections between academia, industry, and the military services in the pursuit of new science and technology. Less than three months after the establishment of ONR, Conrad, who had been so instrumental during the war years in helping to formulate the policies embodied in the agency's approach to research, described before an audience at the University of Illinois ONR's already considerable portfolio, which consisted of "about 200 research contracts covering over 400 projects, totaling about $22,000,000. More than three-quarters of this volume is placed with universities and colleges. Considerably more than half these projects are under $25,000 apiece." It was a strong beginning for a research model that soon would be replicated throughout the government.

The founding of ONR did not necessarily make what would later be called the "Naval Research Enterprise" an inevitable development. Important pieces of that enterprise were already in place in 1946 (such as the Navy laboratory structure in the various bureaus), but other vital components would come much later (such as the legal capability to provide grants, and partnerships with future organizations such as the Defense Advanced Research Projects Agency, the National Science Foundation, and others). What the founding of ONR represented most was a transition point between wartime and peacetime, between a paradigm of research that had tolerated serious government funding of science as an activity mainly in times of crisis, to one increasingly where government, academia, and industry were to become permanent partners in pursuit of science and technology—regardless of war or peace. In truth, it was a part of a transformation into a new kind of "peacetime," one where the boundaries separating the beginning and ending of war have become blurred or indistinguishable. ONR, and the research enterprise that now surrounds it, has become an enduring and inseparable part of national science and technology—as well as of national defense.

In this issue, authors from around the Naval Research Enterprise provide a rough guide that explores the processes and projects of many of its constituent organizations.

About the author:

Colin Babb is a support contractor serving as the historian for the Office of Naval Research and managing editor of *Future Force*.



Harnessing the Navy's CULTURE of INNOVATION

By Ray Mabus

Secretary of the Navy Ray Mabus speaks with Sailors and Marines during an all-hands call in Seoul, Republic of Korea, in December 2014. With the establishment of Task Force Innovation, the secretary wants the dialogue to work both ways in the search for new ideas for how to improve the Navy and Marine Corps. Photo by MCC Sam Shavers.

The U.S. Navy and Marine Corps uniquely provide presence around the globe to promote stability, deter adversaries, and assure our nation's leaders full range of options in times of crisis. In past conflicts, our attention often was focused on one defined adversary; today, with the onset of the information age, technology has been democratized and our adversaries come in all shapes and sizes. They are unhindered by processes and policy, let alone the rule of law, and can adapt and employ technology and tactics as fast as the commercial world can develop them.

In the face of these new and dynamic challenges, and with an increasingly constrained fiscal environment, it is critical that we continue to lead the way—across every part of our organization—in innovative thinking.

Strategic thinkers know that leading an organization through times of change requires innovation. In my few short years in uniform I learned something that has been reinforced in the five years I've been Secretary of the Navy. The Navy and Marine Corps are always changing, evolving, and advancing to meet the latest in technology and warfighting developments. Innovation is part of our tradition, and it will continue to define us and drive our capabilities into the future.

In January, I established the Navy's Task Force Innovation, a group from across the department composed of innovative thinkers, experts, and warfighters with diverse backgrounds and from every level. I've charged them with identifying changes we could make to amplify the power of the innovative workforce that comprises the Navy and Marine Corps. Our talented Sailors, Marines, and civilians have proven their ingenuity throughout our history, whether it's bringing our ships from sail power to the steam-driven ironclads of the Civil War, or the Marines' development of amphibious warfare. Our people have been and will always be our most innovative resource. What we're doing is harnessing the creative energy they already have, and finding ways to infuse those ideas back into our operations.

Innovation isn't just producing some new platform or weapon. Innovation must mean taking a new look at our culture, our policies, and our operations and challenging ourselves to think differently. Promoting a culture of innovation means repurposing resources to endorse a new idea; it means removing bureaucratic roadblocks to allow for change more quickly. It also means accepting the risk associated with coming up with new ideas, some of which will not work. I challenge the Sailors, Marines, and civilians of the fleet to bring their ideas forward, and I challenge the Navy leadership to encourage that innovation—whether it be concepts, tactics, policies, processes, or technologies. The challenges of the present and future require that we aggressively press forward with emerging capabilities and operating concepts that exist within the intellectual capital of our remarkable workforce.

For seven decades, the Navy and Marine Corps have kept the sea lanes open, maintaining stability and security around the world. Today, increasing global demands coupled with tighter budgets force the Navy and Marine Corps to maintain our global presence in the midst of decreasing resources. There is no better time than now to embolden our innovators and reinvigorate the culture of innovation that is intrinsic in our people, and has, throughout our history, inspired some of the greatest achievements our world has seen.

Our people, information, and systems are all part of a constantly transforming information era that must adapt with the times to stay at the forefront.

A majority of our Sailors and Marines come from a generation native to this information world; they have grown up with mobile technology and social media at their fingertips. They bring new and unforeseen skills to our fleet, and it's our responsibility to attract, develop, and retain the best talent.

In today's information environment, data provide us an unparalleled military advantage—but data in the wrong hands can be catastrophic. The platforms of the future are increasingly reliant on the ability to collect, analyze, and disseminate data. This requires understanding that data has intrinsic value outside of the systems and platforms that contain it. With the large quantity of information and data we collect, we must take advantage of the great leaps that have been made in advanced computing and analytics and ensure we treat our information as a strategic asset while preventing our adversaries from using it against us.

{ There is no better time than now to embolden our innovators and reinvigorate that culture of innovation that is intrinsic in our people. }

Our ships, aircraft, and submarines, along with the incredible systems we have developed to enhance these platforms, make us the most advanced Navy in the world. Looking ahead, unmanned systems and advanced manufacturing are the future. Now is the time to look at all of our platforms and systems and make sure we are asking ourselves what the future fleet looks like, and how we can best use the capabilities we have today to remain a superior maritime force in the decades ahead.

About the author:

Ray Mabus is the Secretary of the Navy.

ASSESSING WARFIGHTER PERFORMANCE WITH VIRTUAL REALITY

By Amanda Markham

The Physical and Cognitive Operational Research Environment uses a Computer Assisted Rehabilitation Environment and additional immersion capabilities to create a realistic virtual environment that can visually imitate any environmental scene such as an Afghanistan mountain range or a bustling city street.

Researchers at the Naval Health Research Center are using the technology of video games to study warfighters and provide physical therapy.

To wounded warriors, participating in a virtual task in the Physical and Cognitive Operational Research Environment (PhyCORE) at the Naval Health Research Center (NHRC) in San Diego may just seem like playing a big video game. This unique environment, however, provides researchers and clinicians with the capability to conduct training and validation of physical and cognitive training programs for rehabilitation of wounded warriors with a high degree of scientific and clinical accuracy, while keeping patients engaged and enthusiastic about their recovery.

As the Department of Defense's premier deployment health research center, NHRC's cutting-edge research and development is used to optimize the operational health and readiness of the nation's armed forces. Within proximity to more than 95,000 uniformed service members, world-class universities, and industry partners, NHRC's expert team sets the standards in joint ventures, innovation, and practical application.

Researchers at NHRC are using novel immersive virtual environments such as PhyCORE, in addition to smaller virtual reality systems and conventional clinical and laboratory tools, to understand physical and cognitive performance in healthy and injured warfighters with the goal of improving programs and techniques for wounded warrior rehabilitation. The immersive virtual environment at the PhyCORE laboratory is a novel and effective means to support research and clinical studies that aim to understand and assess physical and cognitive performance factors of warfighters.

PhyCORE uses a state-of-the-art technological system called the Computer Assisted Rehabilitation Environment (CAREN) and additional immersion capabilities to create a realistic virtual environment that can visually imitate any environmental scene. It includes a six-degrees-of-freedom motion platform, 16 optical cameras for 3D motion capture, a dual-belt treadmill, embedded force plates, and a 180-degree, 10-foot-tall panoramic screen, which NHRC scientists use to recreate scenes such as a mountain range in Afghanistan or a bustling city street. CAREN has been expanded beyond many similar systems to include a high-performance treadmill, driving and laser rifle simulators, 3-D projection, and realistic sounds and scents. It is all of these components working simultaneously that create lifelike virtual scenarios for patients and the state-of-the-art clinical research laboratory for the PhyCORE team.

Current clinical work in the PhyCORE includes assessment of rehabilitation training programs for wounded warriors such as using the CAREN for vestibular physical therapy (restoring patients' sense of balance). After a six-week training program on the CAREN, vestibular patients show improvement in CAREN-based functional tests and in traditional clinical tests for dizziness, balance, and gait. In other work, outcomes of a two-week, clinical-based fall-prevention program are being assessed on the CAREN, and patients with lower-limb amputation are showing significant improvement in their ability to prevent a fall, increased confidence in their prostheses, and increased confidence with activities of daily living. Patients are retaining these outcomes three and six months following training.

Additional work related to the warfighter in the PhyCORE has assessed the performance of warfighters wearing different personal protective equipment. The PhyCORE research team is also one of the first groups to establish norms describing how healthy individuals perform in the CAREN. Preliminary results from this work suggest that multi-tasking training programs conducted in the PhyCORE lead to improvements in both physical and cognitive performance of injured populations.

The team of scientists and researchers at NHRC will continue to develop and assess rehabilitation programs for the wounded warrior and training programs for the healthy warfighter. PhyCORE researchers also plan to transition the lessons learned within the virtual system to the clinic or the field to reduce rehabilitation times and improve outcomes for the wounded warrior and provide performance feedback measurements to help healthy warfighters.

About the author:

Amanda Markham is a project manager with the Naval Health Research Center.

"A Valuable Commodity": Talking about Naval Sea Systems Command's Warfare Centers

Donald McCormack, executive director of the Naval Surface and Undersea Warfare Centers, sat down to discuss the centers' science and technology portfolio.

Q: Why do the warfare centers do science and technology?

A: Since the early 1960s, there have been numerous studies and commissions to examine the effectiveness of Department of Defense (DoD) and Navy research and development organizations. A recurring conclusion is the government must maintain strong in-house technical knowledge to retain "smart buyer" and "honest broker" capabilities. These responsibilities include helping the Navy translate warfighting needs into technology requirements, performing warfare analyses, and verifying the quality and effectiveness of platforms and systems—all inherent governmental responsibilities that cannot be performed by industry or academia. The primary role of the warfare centers is to help make naval programs successful by providing unbiased technical advice and solutions to our partners, namely the program executive offices (PEOs), the fleet, the Marine Corps, the Office of Naval Research (ONR), DoD, and the Defense Advanced Research Projects Agency (DARPA). Our scientists, engineers, and technicians provide technical advice and solutions across the entire full spectrum lifecycle of platforms and systems—from cradle to grave. Overall, our science and technology (S&T) portfolio across all nine divisions is small in the context of our "full spectrum" portfolio, but it is a critical part of what we do. In addition, the ability to do science and technology helps us attract and retain our talented scientists and engineers.

Q: What do you mean by a "full spectrum" portfolio?

A: The entire lifecycle of a platform or system may span 40 to 50 years. At the beginning stages of S&T, one of our divisions may design and build a prototype system in partnership with ONR, the PEOs, the fleet, Marine Corps, academia, or and/or industry. If the prototype meets Navy requirements, then the Navy may decide to transition the technology into a formal program of record and ultimately onto a ship, platform, or system. Once a program is established, our industry partners generally manufacture the platform or system and the warfare center division's responsibility becomes a technical oversight role throughout its remaining lifecycle. Data shows when the centers participate in S&T at the beginning stages of the platform or system lifecycle, the transition from S&T to a fielded system through the proverbial "valley of death," where programs don't make it all the way through the process, is more effective and consistent. I also want to point out—I often hear people use the words "S&T" and "innovation" synonymously, but I think it is important to understand "innovation" happens across the entire lifecycle, not just in S&T.

Q: Are the warfare centers' S&T investments generally focused on next-generation technologies?

A: No. In fact, the Naval Sea Systems Command's warfare centers are equally invested in reducing total ownership costs for fielded platforms and systems toward the end of the acquisition lifecycle, specifically in maintenance and obsolescence management. A great example of this is a recent Naval Innovative Science and Engineering Section 219 research project at Naval Undersea Warfare Center Keyport Division in a plasma thermal spray process for submarine components. Within the warfare centers, Keyport Division specializes in maintenance and industrial base support, fleet material readiness, and obsolescence management for undersea warfare. Keyport successfully developed a plasma thermal spray process for applying chromium oxide ceramic coatings to a submarine brine pump shaft aboard a Los Angeles-class submarine. The spray provides significant protection against wear and corrosion and exceeded all metallurgical and mechanical testing criteria. Currently a grinding process is being developed to fully qualify the pump shafts components as "A" condition assets—ready for issue to the fleet. The S&T project was done in partnership with Trident Refit Facility Kings Bay, Puget Sound Naval Shipyard, and Applied Research Lab Penn State and aligns with the total ownership cost focus area in the ONR S&T plan. Ultimately, this research shows real promise for increasing the operational availability of our fleet platforms.

Q: How much of the centers' portfolio is S&T?

A: If you look at our overall workload in fiscal year 2014 across our seven surface warfare center divisions and two undersea warfare divisions, the preponderance of our workload is in research and development through fleet support. In '14, seven percent of our workload was in S&T. The majority of our S&T funding is acquired through ONR, DARPA, and the Office of the Secretary of Defense. In addition, the divisions execute S&T under the Section 219 program as well as independent applied research and in-house laboratory independent research funding from ONR. Historically, our divisions at Dahlgren, Carderock, Newport, Panama City, and Indian Head execute larger S&T portfolios than some of our other divisions.

Q: How do the centers determine their S&T investments?

A: Across the warfare centers, we base our S&T investments on several factors. First, we look at naval requirements, which are driven by the needs of our warfighters. Our scientists and engineers work with warfighters in the field, program managers within the PEOs and the Chief of Naval Operations/Marine Corps staffs to help determine, translate, and shape naval requirements. We also align S&T investments with guiding documents such as ONR's Naval S&T Strategy, the Naval Sea Systems Command Strategic Business Plan, and the Surface Warfare Enterprise S&T objectives—strategic plans that are also based on naval requirements. Second, we look at S&T portfolios across industry, academia, and other warfare centers/systems centers to identify unique research opportunities within the division's mission areas. This reduces the duplication of effort across the government. A good example is Indian Head's Explosive Ordnance Disposal Technology Division. They are DoD's leading experts in the field of energetics—no one else is developing next-generation energetics material our warfighters need for current and future weapons systems. Third, we align our S&T investments with our 125 technical capabilities across the nine divisions. Our capabilities are essentially defined areas of expertise; each one includes people with knowledge, skills, and experience and requisite facilities and equipment. Overall, every division has a chief technology officer who works closely with the division technical director to identify technology investment areas and then lead S&T efforts that deliver cutting-edge technologies into the hands of our warfighters.

Q: How have the centers benefitted from the Naval Innovative Science and Engineering Section 219 authority?

A: Since Section 219 authority was established, we have made significant improvements in the health of our technical workforce by providing opportunities for our scientists and engineers to work on relevant research projects. Section 219 authority also provides more flexibility to support advanced degrees, rotational assignments, and certifications for our workforce as well as invest in aging facilities and equipment. Most importantly, Section 219 provides more opportunity for the warfare centers to participate in cross-organizational, multidisciplinary teams (including industry and academia) to mature technologies and transition them into formal programs of record. We were very excited when the 219 authority was recently extended by Congress until 2020 and hope it will become a permanent authorization.

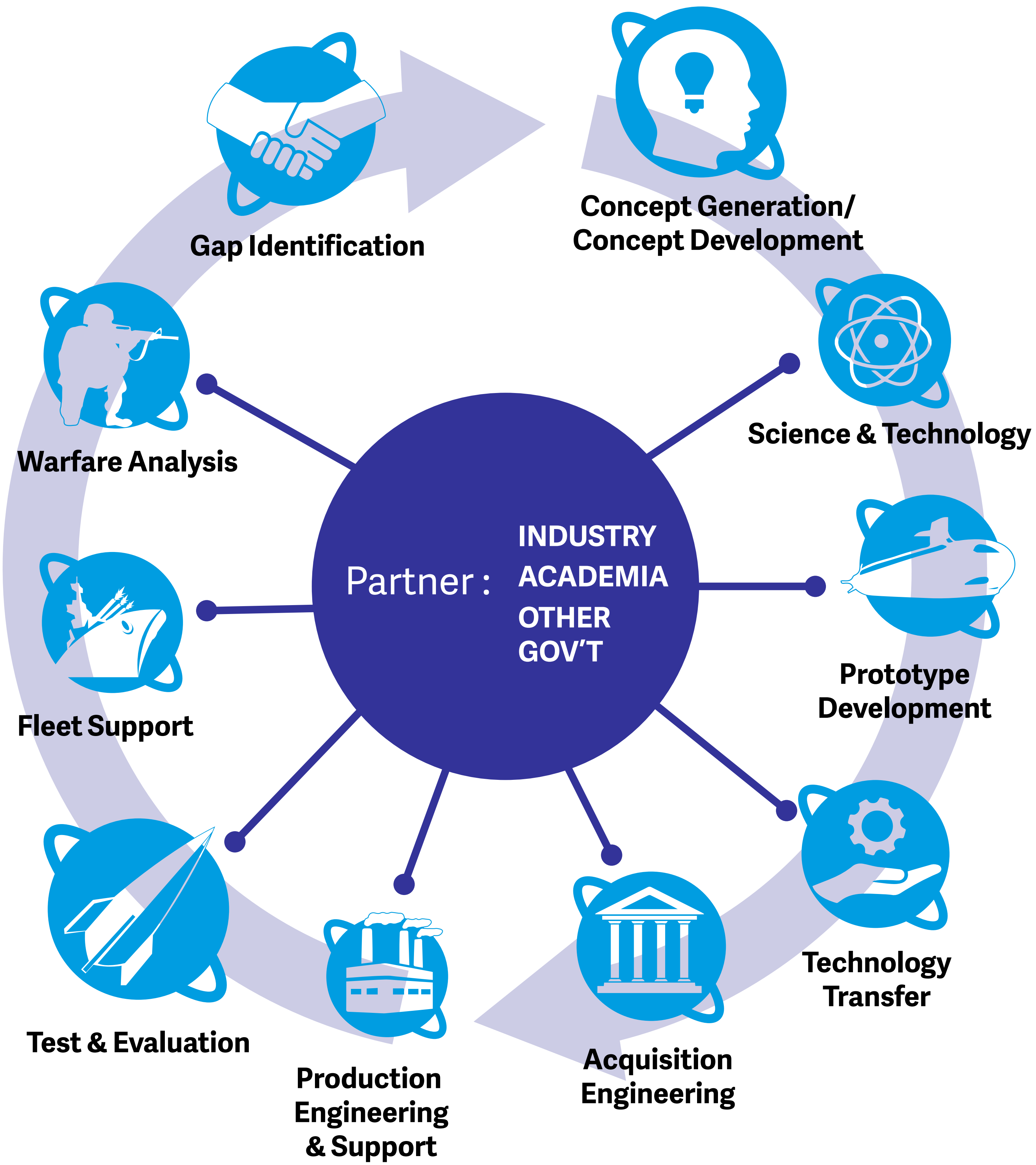
Q: What do you see as the biggest S&T challenges?

A: As Navy leadership continues to make tough decisions in this budget-constrained environment, it is easy to become shortsighted with S&T investments. These investments are a valuable commodity for the Navy's future; it's our seed corn. Remember, it often takes decades to develop, mature, and transition breakthrough technologies like the laser weapon system, or for our chemists at Indian Head to synthesize new molecules and then develop and field energetics materials. At the same time, the demand signal for Navy operations and presence is increasing as the DoD strategy pivots towards the Pacific. To address this challenge, we need to aggressively innovate across the entire lifecycle now. If we don't, the funding may be there, but I'm concerned we won't have time to develop the necessary technologies. Another related challenge we face is the number of leading scientists in key research areas who are retiring faster than they can be replaced. For example, it takes about 10 years of hands-on experience and dedicated mentoring by a senior chemist to reach a journeyman level in energetics. To address this challenge, we need to continue to improve our processes for hiring, retention, and knowledge management.

Q: Any closing thoughts?

A: The Naval Sea Systems Command warfare centers have long and distinguished legacies in S&T—some divisions date back to the 1800s. More than 100 years ago, Rear Adm. John Dahlgren began a tradition of proving naval ordnance that is carried on today at Indian Head Explosive Ordnance Disposal Technology Division (founded in 1890) and Dahlgren Division (1918). Newport Division's historical roots trace back to 1869 when the Newport Torpedo station was established. From these roots, the surface and undersea warfare centers were formed in 1992—today, we provide technical expertise across multiple portfolios in multiple warfare areas. Our Dahlgren scientists and engineers are leading the technical design and testing of the railgun and the Navy's first laser weapons system deployed aboard USS Ponce (AFSB[I] 15), working in partnership with Naval Sea Systems Command and ONR. These are just a few examples of the warfare centers' S&T contributions that are helping to ensure our Sailors and Marines stay on the right side of an unfair fight.

Full-Spectrum Life Cycle for Platforms and Systems



S&T Funding within Naval Sea Systems Command's Warfare Centers

All the systems commands—e.g., Space and Naval Warfare Systems Command, Naval Air Systems Command, Marine Corps Systems Command, and Naval Sea Systems Command—have systems centers or warfare centers that operate as Navy Working Capital Fund activities, which means work is contractual in nature and funding must be received before the work is performed. Unlike the systems centers or warfare centers, the majority of the Navy is "mission funded" with congressionally appropriated budgets that are executed over the course of a fiscal year. Within the warfare centers, S&T is funded in several key ways:

- **S&T Program Office Funding**
  Some warfare center divisions receive S&T funding directly from program offices within ONR and DARPA. Generally, doctorate-level scientists identify a need, develop an idea, and present a proposed solution to an ONR, DARPA, or DoD program manager for funding consideration.
- **The Naval Innovative Science and Engineering Section 219**
  This program was established in the FY09 National Defense Authorization Act and authorizes Department of the Navy laboratories, warfare centers, and systems centers to fund innovative basic and applied research that supports naval missions, develop programs that transition technologies into operational use, and invest in workforce development and recruiting. In FY14, the Naval Sea Systems Command warfare centers invested more than $49 million using Section 219 authorization.
- **In-house Laboratory Independent Research**
  This is an ONR program within discovery and invention that funds basic research to develop fundamental knowledge and to train the scientist and engineer workforce.
- **Independent Applied Research**
  This is an ONR program within discovery and invention that funds applied research to develop fundamental knowledge and to train the scientist and engineer workforce.
- **Warfare Center Overhead**
  All warfare centers invest a percentage of their division overhead funds to support S&T efforts.

MARINE CORPS SYSTEMS COMMAND:

Keeping an Eye on the Future

By John Stroud

There are endless paths a new technology can take from a developer to the hands of a Marine in the field. Charting and navigating those paths is what the scientists and engineers of the Marine Corps Systems Command (MCSC) Technology Transition Office (TTO) do every day. As the Department of the Navy's systems command for Marine Corps ground combat and information technology systems, MCSC has an eye on the future to ensure it is fielding the most advanced, affordable, and relevant technology to give Marines an operational advantage.

Under the direction of MCSC Chief Technology Officer Jim Smerchansky, TTO transitions technology to acquisition programs where it can be delivered to Marines and supported for its life cycle. Many in the technology transition business will tell you it is a contact sport. This means there are many players with whom we must engage frequently—and in a variety of venues. Those players encompass the Naval Research Enterprise (NRE), including the Office of Naval Research (ONR), systems commands, warfare centers, laboratories, federally funded research and development centers, university-affiliated research centers, and other naval organizations, as well as industry partners, our financial and requirements communities, and various organizations with the entire Department of Defense.

Transition through Communication

The key to successful technology transition is early and frequent communication among developers, program managers, the requirements and financial communities, and the end users. TTO ensures that MCSC program managers are involved in the technology transition process. In general, acquisition program managers are risk averse because they are balancing requirements, schedules, and costs—and they understand that anything introducing risk can affect one or all of those parameters and send a program off track. New technology, by its nature, often introduces risk to an acquisition program. That's why anything that can reduce risk for the program manager increases the chances for successful transition.

One way TTO enhances the collaboration between technology and materiel developers is by embedding advanced technology integrators (ATIs) in MCSC program offices. ATIs are senior scientists or engineers who report to TTO but are physically placed with the program management teams. Having ATIs sit within the program offices helps managers stay engaged with technology development efforts and provides a link from the technology development community to the program managers. Reporting to the TTO director provides an enterprise perspective and shapes MCSC technology priorities and engagement with the broader research enterprise.

The key partner on the technology side of the equation is ONR and its Expeditionary and Maneuver Warfare and Combating Terrorism department. MCSC does not receive any science and technology funding to conduct basic research, applied research, or advanced technology development and therefore relies on ONR to conduct those activities and then transition the results to acquisition programs. ONR has a myriad of initiatives available to carry out research and technology development for the Marine Corps and—through TTO (in general) and ATIs (specifically)—MCSC is engaged in all of them. Other prominent technology partners include the Marine Corps Warfighting Laboratory, Naval Research Laboratory, Defense Advanced Research Projects Agency, and other service laboratories.

The Capabilities Development directorate within Deputy Commandant, Capabilities Development and Integration, is the Marine Corps' combat developer (requirements and financial partner), which lays the groundwork for technology transition to acquisition. The directorate's portfolio managers ensure that technologies slated for transition to acquisition programs have the appropriate funding and that the new technologies are supported by warfighter requirements. If there is no requirement or funding to acquire and sustain a capability, there is no viable transition path. The "three circles" of technology developer, materiel developer, and combat developer (together with end-user involvement) comprise the recipe for successful transition to warfighters. Technology transition is definitely a contact sport.

Modernization Planning

Technology developers often ask us, "What do you need?" The answer to this question should be easy, but it is often difficult to express. With dozens of programs and hundreds of products, including everything Marines drive, shoot, wear, or use for communication, it is easy to answer "everything." This may be true, but the reality is we must prioritize technology investments. MCSC does this through modernization planning. Program managers, through their ATIs, prepare and maintain modernization plans for their program portfolios that show how and when they plan to upgrade capabilities.

ATIs develop roadmaps that show the technology development efforts under way or planned, along with the corresponding acquisition program and timeline. These roadmaps provide a way to communicate to stakeholders how MCSC is modernizing our programs, as well as assist in identifying where we need more technology investment. MCSC has a modernization order that codifies this process and communicates the commander's intent and commitment to finding the best technology to maintain our tactical advantage.

Since MCSC provides the eventual transition path for technology development efforts from ONR and other basic and applied research organizations, it is important that program managers are engaged in the planning and execution of science and technology efforts. If the target manager is not on board with the strategy then transition will be both difficult and time consuming. TTO represents MCSC interests to the NRE and communicates command priorities and plans. There are several avenues available for science and technology investment to modernize Marine Corps capabilities; each one has distinct advantages and a place in modernization planning.

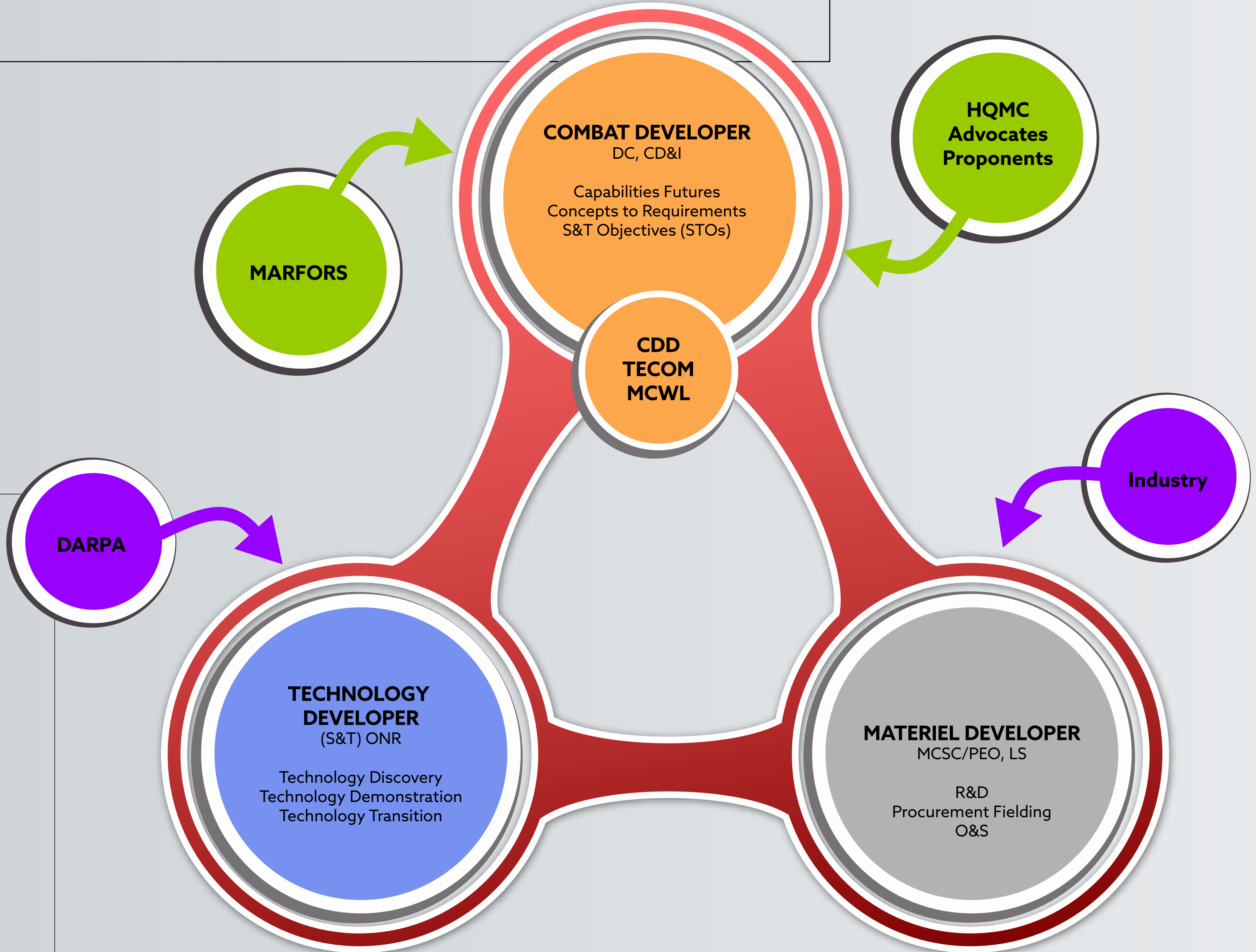
The Future Naval Capabilities program managed by ONR is the most significant science and technology investment program for MCSC. This program's products have one of the highest probabilities to transition to acquisition. That's because there is significant funding to make a real impact, and high-level oversight to ensure efforts are focused on needs and drive formal coordination between materiel, technology, and combat developers through technology transition agreements. This program is ideal for high-impact, long-term modernization strategies where programs have several years to plan, execute, and transition.

Lance Cpl. Nick Foss looks down the sights of his M249 squad automatic weapon during a Korean Marine exchange program exercise in Pohang, Republic of Korea. Photo by Pfc. Cedric Haller.

Small Business Innovation Research (SBIR) and the Rapid Innovation Fund (RIF) are two ONR-managed programs where we engage with our small-business industry partners. Both programs are designed to solicit ideas from industry to address specific topic areas and use the art of the possible to solve ongoing problems. SBIR has the advantage of tapping into a broad array of otherwise innovative companies that may be marginally or infrequently engaged with the Defense Department. It also is a relatively low-risk approach with distinct stages of technology development and incremental levels of investment. This provides off ramps if a technology is not panning out—or allows the opportunity to elevate quickly a promising technology to the next level of development. RIF efforts often build on SBIR projects to transition mature technologies to programs of record. In less than two years, a technology can go from mature to ready for transition into a program for fielding. The deliberate planning and use of these and many other science and technology tools enable program managers to develop long-term strategies to modernize their programs.

Technology Experimentation

Our most important goals in technology transition are to ensure our technologies work when we give them



to Marines. Along with the "three circles" of technology, materiel, and combat developers, end-user involvement is critical for successful transition. One way MCSC involves end users is through its technology experimentation initiative. Technology experimentation seeks to put prototypes into the hands of end users, in relevant environments, to collect feedback on how well those prototypes meet the users' needs. Technology often works well in the laboratory but fails to accomplish its mission when exposed to an operational environment.

There are distinct advantages to end user involvement in technology experimentation: End users get the opportunity to influence system requirements and design early in the acquisition process, so technology is relevant when fielded; direct feedback from end users helps developers correct deficiencies early and avoid surprises after transition—and risk to the target acquisition program is reduced by informing program managers on how well technology works and what managers might need to do to ensure it works after transition.

To ensure that prototypes are introduced into the right venue for experimentation, MCSC works with ONR science advisors at Marine expeditionary forces and Marine forces to match prototypes with the appropriate fleet exercises or training venues. Since science advisors are part of command staffs and know the technology community, they are in a unique position to connect technology developers to members of the operational community. Planning for inserting prototypes into an operational venue often starts more than a year prior to a specific test event or exercise. MCSC enlists support from naval laboratories to conduct the planning, execution, and reporting for prototypes it evaluates with the operational community.

Lance Cpl Trent Martin, with 3d Battalion, 1st Marine Regiment, 15th Marine Expeditionary Unit, aims in on a target during an exercise at Twentynine Palms, California. Photo by Sgt. Emmanuel Ramos.

There is one initiative that MCSC is working on with the ONR small business office as a pilot project. This will use a small portion of SBIR administrative funding to provide small businesses with the opportunity to get feedback on their prototypes through fleet experimentation. This initiative is important for SBIR success because small businesses often lack the connection to the operational community and there is no other funding available to conduct technology experimentation with end users. Ultimately the same advantages are realized for program managers, technology developers, and end users.

There are many examples of how field experimentation has paid off for the acquisition, technology, and operational communities. The III Marine Expeditionary Force made technology experimentation a priority for the major amphibious exercise Ssang Yong 2014 in the Republic of Korea. The expeditionary force's science advisor sent out a solicitation for mature technologies to address several operational needs for the exercise. In response, the MCSC program manager for Marine air-ground task force command, control, and communications provided secure communications controller technology prototypes for the exercise. This technology allows disparate radio networks to operate with each other.

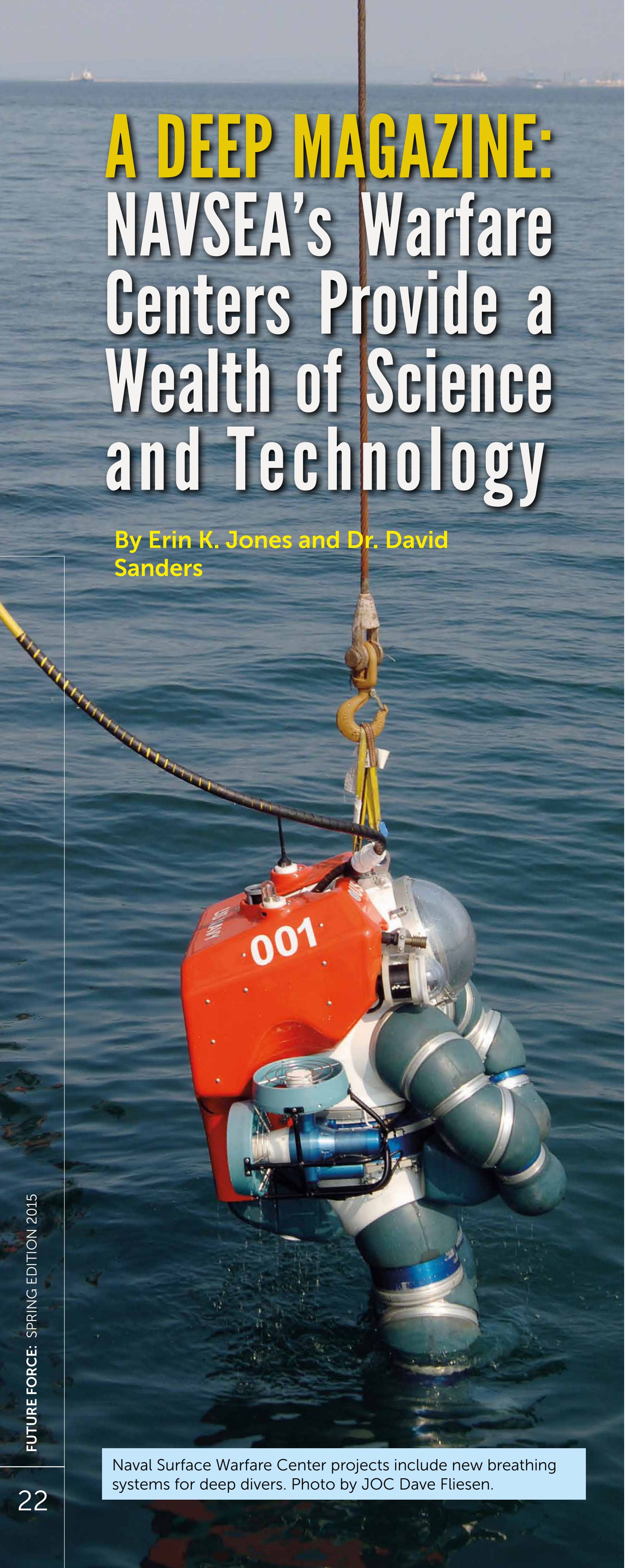
The controller performed well and, on seeing the operational payoff, the expeditionary force's commanding general directed that a deliberate universal needs statement be written for the capability and transmitted to the Marine Corps requirements community. The experimentation team documented operator feedback, areas where the capability could be improved, and reported the information to all stakeholders. The end result was the development of a detailed and achievable warfighter requirement, improved technology specifications (that will result in a superior end product), and a known technology transition path into future acquisition.

The Way Ahead

It can be difficult to navigate the many paths to successful technology transition because there is not a single prescribed path to do so. At the end of the day, it is about providing an operational advantage to Marines so they can accomplish their missions. There is a wide variety of tools technologists can use to modernize capabilities—and deliberate planning to employ those tools communicates the strategy for transitioning a given technology. That communication with all of the stakeholders is the difference between technology development that simply advances technology and technology development that provides enduring capabilities to warfighters. MCSC has an eye on the future and will continue to collaborate with the Naval Research Enterprise and other stakeholders to get there.

About the author:

John Stroud is the deputy director of the MCSC Technology Transition Office.



A DEEP MAGAZINE: NAVSEA's Warfare Centers Provide a Wealth of Science and Technology

By Erin K. Jones and Dr. David Sanders

Naval Surface Warfare Center projects include new breathing systems for deep divers. Photo by JOC Dave Fliesen.

The Naval Sea Systems Command (NAVSEA) warfare centers consist of seven Naval Surface Warfare Center (NSWC) divisions and two Naval Undersea Warfare Center (NUWC) divisions, representing approximately 30 percent of the Navy's engineering and scientific expertise. The primary role of the warfare centers is to help make naval programs successful by providing unbiased technical advice and solutions to their partners, including the program executive offices, the Office of Naval Research (ONR), the fleet, the Marine Corps, the Department of Defense, and the Defense Advanced Research Projects Agency. Warfare center scientists, engineers, and technicians provide technical advice and solutions across the complete lifecycle of platforms and systems.

At Navy science and technology laboratories, the warfare centers develop capabilities that are adaptable and mission-relevant and capitalize on the changing nature of technology and warfare. Their portfolio generates foundational research at the beginning stages of a platform or system lifecycle to increase the effectiveness and consistency of technology transition into a fielded system. These investments are aligned with 125 technical capabilities across all nine divisions; each capability is a defined area of expertise that includes the people with the right knowledge, skills, and experience as well as the requisite facilities and equipment. Aligned with the Naval S&T Strategy and the NAVSEA Strategic Business Plan, the warfare centers' investments are wide ranging, yet highly focused on ensuring warfighters maintain a dominant position in any battle and against all threats at all times. In 2014, NAVSEA scientists and engineers contributed a number of advances that align with the nine focus areas within the Naval S&T Strategy.

FOCUS AREA: INFORMATION DOMINANCE-CYBER

NSWC Dahlgren Division—Cybersecurity

The capstone of Dahlgren Division's cyber portfolio is USS *Secure*, a cyber test bed composed of dedicated lab space as well as connections to the Joint Information Operations Range and the Department of Defense's Cyber Range. USS *Secure* is used to develop and test cybersecurity capabilities and tactics, techniques, and procedures prior to fleet transition and concepts of operation training. A noteworthy solution produced and deployed from USS *Secure* is the common architecture system assurance tool, which enables real-time vulnerability monitoring of ships' combat systems and provides crews with the capability to address emergent cyber threats. There are a number of other projects within the portfolio covering activities such as supply chain risk management, securing operation systems, quantum encryption, securing industrial control systems and supervisory control and data acquisition systems, and shipboard cyber situational awareness, as well as cyber activities directed at cyber workforce development and training. To accomplish this effort, Dahlgren partnered with sister divisions Carderock, Corona, and Crane as well as Applied Physics Laboratory Johns Hopkins University, Naval Air Systems Command, National Security Agency, ONR, Space and Naval Warfare Systems Command, Fleet Cyber Command/10th Fleet, and US Pacific Fleet.

Currently, several warfare center divisions are collaborating to expand the USS *Secure* concept with the goal of developing a "whole ship, system of systems" cyber test bed. The expanded test bed will be accessed through the Joint Information Operations Range to enable cyber research, development, test, and evaluation across combat and weapon systems as well as hull, mechanical, and electrical systems.

NUWC Newport Division—Time-Domain Interference Cancellation for Active Communication and Sonar Systems

In partnership with ONR, this project applies recent developments in time-domain coherent cancellation of structured interference to improve the performance of active and passive sonar receivers operating in cluttered acoustic environments. Structured interference refers to unknown waveforms that exhibit some structure, allowing them to be estimated and described with fewer degrees of freedom than purely random waveforms. This class contains most man-made sonar waveforms as well as some marine mammal vocalizations. Ship and machinery noise would be examples of "unstructured waveforms," which means they are difficult to describe fully with a small number of parameters. This research develops signal processing algorithms that will greatly enhance digital undersea communications as well as improve sonar application performance.

FOCUS AREA: PLATFORM DESIGN & SURVIVABILITY

NSWC Carderock Division—Phonon Interactions of Aluminum during Sensitization

Working in partnership with the University of Louisiana, Carderock Division explored the sensitization of "5XXX" aluminum (magnesium-rich alloys), which is well documented but not well understood. Sensitization can be described as changes in the chemical structure of the material as a result of exposure to environmental factors such as heat. This project advances the fundamental understanding of changes in marine aluminum alloy during sensitization, which leads to significant cracks and degradation of ship superstructures. The goal is to determine transformation kinetics and to propose changes in aluminum processing to slow the sensitization process of aluminum alloys. This project advances the understanding of maintenance and maintainability of naval platforms and systems.

NUWC Newport Division—Improving the Damage Tolerance of Laminated, Woven Composite Materials

Newport Division's research improves energy absorption in laminated, woven composite materials to limit damage during violent impacts. A modeling technique to predict the performance of the composite materials based on critical parameters also is being developed. Working with ONR, the University of Massachusetts at Lowell, Natick Army Research Laboratory, and NASA Langley Research Center, this research will help provide better armor and protective structures for warfighters.

FOCUS AREA: POWER PROJECTION AND INTEGRATED DEFENSE

NSWC Dahlgren Division—Future Electric Weapons Ship Design

Directed-energy weapons are an emerging, high-interest area of naval warfare offering significant increases in engagement capability to counter dense threat concentrations. Electric weapon systems such as solid-state lasers, railguns, electronic warfare systems, and new radars will place significant demands on ship power systems. While these systems offer a wide range of new capabilities, they require unprecedented integration with ships' machinery control systems. Ships' power machinery effectively provides the "deep magazine" for electric weapons capabilities. For effective command and control throughout the kill chain, combat systems need a real-time presentation of the available electrical power to perform weapon selection and engagement scheduling. With weapon capability and mission performance so closely coupled to available power, new integration pathways between combat and machinery control systems must be developed. In the fleet, this type of integration does not exist, as today's kinetic weapons do not have the same power-to-capability dependencies. Real-time knowledge of power availability, however, provides combat systems with an effective method to use available power throughout the kill chain to properly sequence engagements in a threat-saturated, anti-access/area denial environment.

To transition electric weapons into fielded platforms, Dahlgren Division is conducting active distributed experiments with Carderock Division's Ship Systems Engineering Station in Philadelphia to integrate ship power systems with combat systems. By laying the foundation for distributed network testing, follow-on efforts will have the opportunity to perform more robust verification prior to implementation and integration testing to reduce technical and integration risk. Follow-on phases will focus on incorporating higher-fidelity representations and models for systems on both ends of the interface for more realistic system representations. Starting with simulators and message generators, the goal is eventually to undertake the design and prototyping necessary to involve complete systems (such as the Aegis combat system) to provide increasing levels of realism and operational validity. This groundwork for connecting complete tactical systems affords the occasion to continue performing total ship systems engineering, as well as whole-ship testing in the laboratory. In addition, network connectivity between tactical combat and power systems is forward-focused by providing an environment to support hardware-in-the-loop testing, operator training, and a better understanding of system performance.

FOCUS AREA: WARFIGHTER PERFORMANCE

NSWC Corona Division—Corrosion Resistant Coatings

The Navy's annual cost of corrosion mitigation is about $2.4 billion. Many corrosion-resistant coatings in use today are toxic to humans and are environmentally hazardous (hexavalent chromium, for instance, is a known carcinogen). The purpose of this research is to develop anodic coatings resistant to corrosion and erosion while reducing hexavalent chromium in the environment. In this project, amorphous alloys were assessed for galvanic potential in simulated seawater and initial coating methods were tested. Working with ONR-supported visiting professors from California State Polytechnic University-Pomona, University of California Riverside, and the California Institute of Technology, this research mitigates the effects of corrosion on military assets.

Naval Undersea Warfare Center Newport Division is working on science and technology that investigates how sound impacts beaked whales, among the most deep diving of all whale species. Photo by NOAA.

NUWC Keyport Division—Thermal Spray of Submarine Components

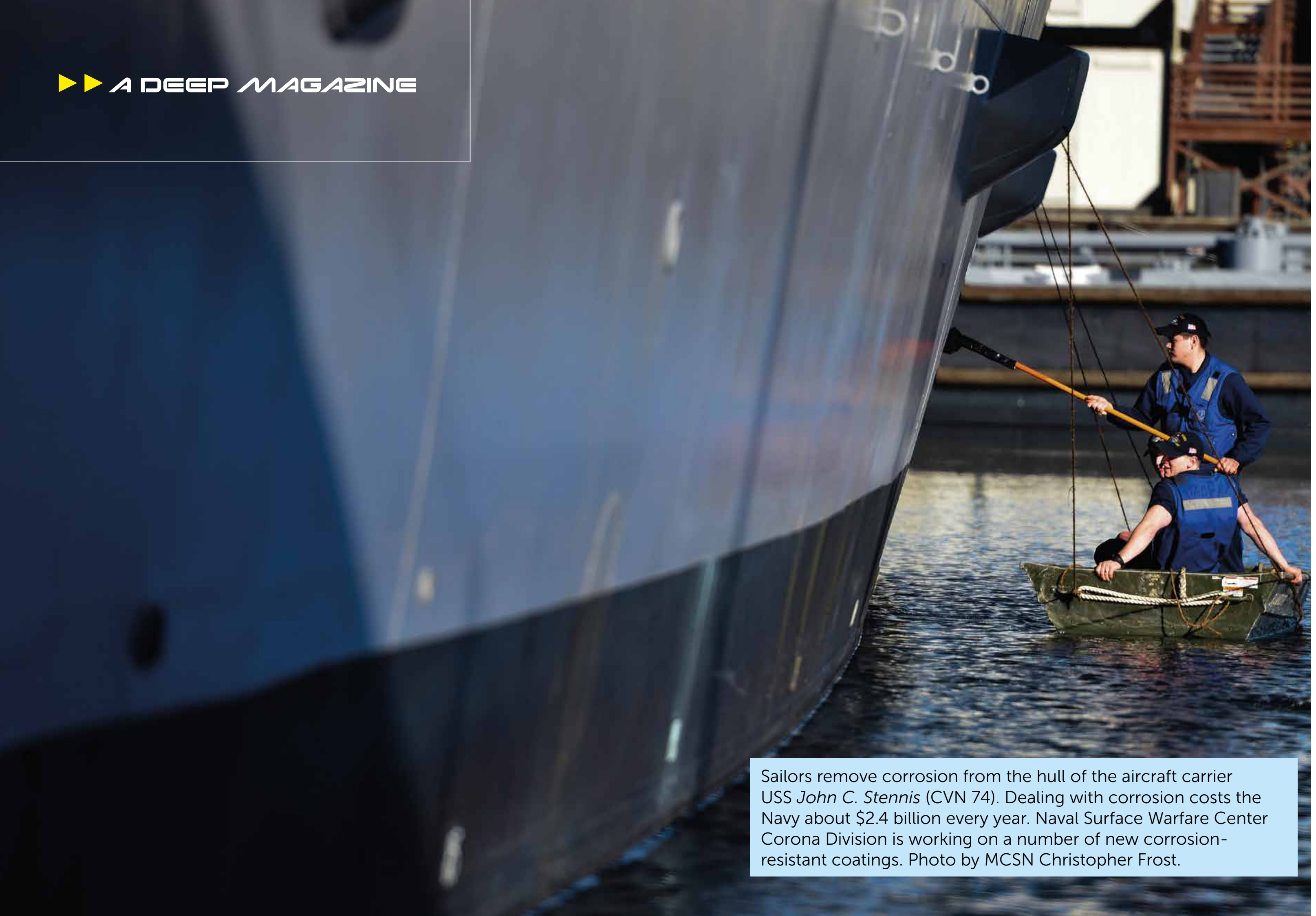
This project successfully developed a plasma thermal spray process for applying chromium oxide ceramic coatings on fleet components. This work successfully applied the chromium oxide coating to brine pump shafts aboard a *Los Angeles* (SSN 688)-class submarine. All metallurgical and mechanical testing criteria were exceeded and a grinding process is being developed to fully qualify the pump shafts components as "A" condition assets (i.e., ready for issue to the fleet). In partnership with the Trident Refit Facility at Kings Bay, Georgia, the Puget Sound Naval Shipyard, and the Applied Research Laboratory at Pennsylvania State University, this research provides significant protection against wear and corrosion of submarine components.

NSWC Corona Division—Shock Stop

Working in partnership with ONR, Indian Head Division's Explosive Ordnance Disposal Technology Division, Dahlgren Division, the University of California Riverside, and industry, Corona Division developed Amorphous Bubble Bonding (ABB), a technique to produce foams and cellular materials with a range of densities, strengths, and stiffnesses. Such materials are used in a wide variety of lightweight structural, energy-absorption, and insulation applications in aerospace, automotive, and other industries. Silicate glass bonded by the ABB process has one of the highest energy absorbing capacities for any foam. To put it into context, a half-ton pickup traveling at 30 miles per hour could be brought to a complete stop with a 20-pound bumper of this material. The ABB technique produces tailored material performance through fine control over physical material characteristics such as cell size, wall thickness, and internal cell pressure. The cellular structures are tailorable for multiple applications and already have been optimized to absorb more energy per pound than any other material. This benchmark material may be a valuable component for composite solutions designed to protect warfighters from improvised explosive devices and other explosive impacts. The properties of the new material may have applications for enhancing lightweight armor and blast-mitigating materials.

NUWC Newport Division—Determining the Effects of Acoustic Transmission to Beaked Whales

Working in partnership with ONR and the University of St. Andrew, Newport Division conducted extensive data



Sailors remove corrosion from the hull of the aircraft carrier USS *John C. Stennis* (CVN 74). Dealing with corrosion costs the Navy about $2.4 billion every year. Naval Surface Warfare Center Corona Division is working on a number of new corrosion-resistant coatings. Photo by MCSN Christopher Frost.

collection and analysis to develop a risk function that defines the likelihood that a given sonar event on a Navy test range will produce a behavioral change in the resident beaked whale population. The quantification of biological impacts from naval sonar and acoustic testing is of critical importance to maintaining environmental compliance while balancing test requirements and objectives. This research completed the final development of the risk function, which will significantly affect future marine mammal range safety predictions. This research provides more accurate predictions of marine mammal effects on Navy ranges, and thereby allows for more efficient use of range and range assets to support naval training exercises.

NSWC Panama City Division—Initial Response Diving

Panama City Division is exploring manned intervention to depths of 380 feet worldwide with hands-on-target within 36 hours of deployment, in collaboration with NAVSEA's Supervisor of Salvage and Diving, the Navy Experimental Diving Unit, Mobile Diving and Salvage Unit 2, the Naval Submarine Medical Research Laboratory, and the US Coast Guard. The safety and reliability must meet or exceed the safety and reliability of current Navy surface-supplied diving to minimize risk for free swimming divers. This research identifies technology gaps and pursues novel solutions to increase capability when a divers' situational awareness, adaptability, agility, and dexterity are required in response to time sensitive subsea casualties of national interest.

NSWC Crane Division—Laser Texturing for Enhanced Mechanical Properties

Current bonding preparation procedures for metal coatings can be intensive and present challenges in the scaling process as well as controlling the end state surface. Working with Corona Division, Port Hueneme Division, Carderock Division, Naval Research Laboratory, Naval Medical Research Unit-San Antonio, and Walter Reed National Military Medical Center-Bethesda, Crane Division investigated the effects of laser treatment on mechanical adhesion of adherent surfaces. Research demonstrates that laser-textured surfaces are more adhesive because of increased surface area for adhesion and improved opportunity for mechanical interlocking. It appears that texturing surfaces with an ultra-short pulsed laser could have positive effects in the medical field as well in texturing metal plates for head injuries and other medical applications. This research reduces hazardous materials, provides increased adhesion when applying coatings to metals, decreases surface preparation, and provides longer lasting bonds.

NSWC Panama City Division—Life Support Helium Conservation for Surface-Supplied Deep Diving

Mobile diving and salvage units conduct manned diving operations at depths of more than 300 feet with the Fly-Away Mixed Gas System (FMGS). When diving deeper than 190 feet, the nitrogen in air becomes a narcotic and helium-oxygen breathing gas is necessary. The FMGS currently provides breathing gas through an umbilical to a demand-regulated, open circuit helmet. In each breathing cycle all inhalation is from surface-supplied gas and all exhalant vents to the sea. As a result, large amounts of oxygen and helium are wasted. This project modifies a Navy semiclosed circuit rebreather and a commercial "demand-open circuit" diving helmet and integrates them into a hybrid system. This system recycles the majority of the breathing gas while adding helium-oxygen mixture consistent with metabolic consumption. The hybrid system reduces helium consumption up to 80% and improves life support performance. In partnership with Mobile Diving and Salvage Unit 2, ONR, and NAVSEA's Office of the Director of Ocean Engineering Supervisor Salvage and Diving, this research reduces the work of breathing, carbon dioxide, and flow noise for Navy divers. Helium is a costly nonrenewable resource—this effort reduces helium consumption and increases capability.

NUWC Keyport Division—AMCAST Submarine Casting Development

Submarine castings typically have high unit costs and very long lead times for procurement. This project successfully used additive manufacturing technology to produce three types of metal castings for *Los Angeles*-class submarines: a torpedo tube intake grid, a low-pressure air compressor rotor, and a trim and drain vacuum/priming pump lobe. In comparison with most additive manufacturing technologies for use aboard submarines, the components produced with the AMCAST process met all drawing requirements and could be designated as "A" condition hardware—ready for fleet issue. A partnership with Pearl Harbor Naval Shipyard, this effort rapidly delivers less expensive submarine components to warfighters.

FOCUS AREA: POWER AND ENERGY

NSWC Carderock Division—Underwater Wireless Energy Transfer and Storage

This project develops a capability to evaluate concepts for wireless power transfer in seawater for unmanned underwater vehicles. In addition, this project explores the design and optimal systems for wireless power transfer, including architectural dependencies, the effects of the interaction of the electromagnetic fields with the environment, and maximum transfer rates based on size and geometries. This research will increase the resilience, endurance, and station-keeping capacity of unmanned vehicles to minimize the time required for it to transit to a "mother ship" for recharging.

FOCUS AREA: EXPEDITIONARY AND IRREGULAR WARFARE

NSWC Crane Division—Wide Field of View Performance Validation

This project addressed wide field of view (WFOV) systems challenges by performing comparative test and evaluation on a prototyped Foveal WFOV night vision goggle technology. Existing goggle technology is limited to a narrow field of view of 40 degrees. The Foveal WFOV goggles mimic human vision to double this field of view to about 80 degrees and provide five times the situational awareness over current systems. Current testing to date has demonstrated an improvement of 20-40 percent with the WFOV goggles on combat efficiency and mobility tasks. The project validated the predicted performance benefits of Foveal WFOV technology by testing it in real-world conditions and establishing better metrics for future evaluations of similar systems. This enhanced resolution technology is designed to accommodate the next several generations of night vision goggle technological improvements including digital goggles, white phosphor tubes, and short-wave infrared goggles. This technology continues to exceed human vision resolution requirements and will be used by special mission operators and other Defense Department communities as a lighter, cheaper, and more capable technology than previous night vision goggles.

NSWC Indian Head Division—High Reliability, Dual-Purpose Improved Conventional Munition Replacement Program

This program will provide warfighters with a highly reliable, 155-mm cluster munition that is compliant with the Defense Department's unexploded ordnance policy and weapon safety standards, while also maintaining effectiveness against widely dispersed light, medium, and heavy targets. The program will replace the M483A1 and M864 projectiles, and provide Marines with an improved capability to shape the battlefield in future conflicts. This effort aligns with both the expeditionary and irregular warfare and warfighter performance focus areas by providing a viable replacement to ensure Marines maintain capability as less reliable rounds are removed from inventory.

NSWC Dahlgren Division—Surface Plasmon Resonance

This project develops surface plasmon resonance (SPR) technology for label-free identification of biological warfare agents and other biological organisms of operational or public health concern. The current solution to test for biological agents and other organisms uses polymerase chain reaction technology in devices installed in medical spaces aboard large-deck amphibious ships and hospital ships. This project is developing three aspects of SPR technology: surface chemistry, nanosurface construct, and optics. The goal is to optimize and integrate SPR technology for select biological targets. Once this is demonstrated, the technology can be developed for additional biological targets, as well as expanded to include chemicals and explosives. SPR based devices have the potential to decrease the logistics burden, reduce training and reagent costs, provide quantitative (vs. qualitative) results, and detect toxins in addition to the DNA and RNA of bacteria and viruses. This research was done in partnership with ONR, Virginia Tech, Vanderbilt University, and the Institute of Photonics and Electronics at the Academy of Sciences of the Czech Republic.

FOCUS AREA: EXPEDITIONARY AND IRREGULAR WARFARE

NSWC Indian Head EOD Technology Division—Development of an Adaptive Spatiotemporal Positioning Algorithm for a Small Autonomous Aerial Radio Frequency Repeater

Explosive ordnance disposal technicians need robots with advanced arms and manipulators for improvised explosive device operations. Dual-arm manipulators with multiple degrees of freedom provide capability similar to the dexterity of a human arm and hand. To control a high degree of freedom and dexterity, a semi-autonomous control system is required to command each of the joints to position the manipulators to a designated location. Without the semi-autonomous solution, the workload of the operator to position each joint manually would be overwhelming. Although other solutions to semi-autonomous manipulation have been studied, this unique research explores using modular sensors and an octree data structure (where every data node has eight subcomponents). The octree data structure algorithms in development reduce the computation time of estimating points of interest, thus freeing up computer resources aboard the robot for other computing tasks. In addition, the method is insensitive to sensor noise and is constructed in a modular manner that does not rely on a specific 3D sensor, manipulator, camera, or number of cameras. This research advances robotic capability to keep warfighters out of harm's way.

FOCUS AREA: ELECTROMAGNETIC MANEUVER WARFARE

NSWC Port Hueneme Division—C-Band Tracking Experiment to Determine Appropriate Radio Spectrum for In-Flight Communications

Today, we rely heavily on cell phone coverage, wireless internet, and instant communications. These applications enable users to access the electromagnetic spectrum and the use of a wide range of broadband/radio frequencies specific to those individual applications. To make the frequencies more available, existing users of the various frequencies had to be identified and moved to other frequencies before reapplying the use of the freed-up spectrum to broadband users and applications. The Federal Communications Commission, the agency responsible for managing the entire radio spectrum, is transitioning the Department of Defense to new frequencies.

This project studied the migration process from S-Band, which has been in use since the 1960s, to C-Band telemetry frequency. It includes offering new perspectives for existing components currently in operation such as antennas used for broadcasting and receiving as well as determining if missile, aircraft and ground systems can "talk to each other" when using a different portion of the radio spectrum. The division's White Sands detachment built a test rocket called the C-Band Tracking Experiment that provides hard data to help determine future radio spectrum requirements. The division invited a broad cross section of partners, including representatives from the Test Resource Management Center, Missile Defense Agency, Naval Air Systems Command, Edwards Air Force Base, and NSWC Corona Division to test their respective hardware using the experiment. Overall, seven organizations collaborated to test seven different systems that provided data to directly compare S-Band and C-Band frequencies. The missile was fired on 17 December 2014 and provided a high-acceleration rolling vehicle that went approximately 30 miles up and 50 miles down range, all the while broadcasting onboard data from two telemetry (S-Band and C-Band) links. The data collected from that flight is being evaluated and shared with partners responsible for determining the future path of radio frequencies. Following the flight, the missile safely parachuted back to earth for reuse.

These are just a few examples of the science and technology contributions from Naval Sea Systems Command warfare centers that are helping to ensure our Sailors and Marines stay on the right side of an unfair fight.

About the authors:

Erin Jones is the director of corporate communications for the Naval Surface Warfare Center. She previously served on active duty as a public affairs officer at the Chief of Information in the Pentagon and is a qualified surface warfare officer.

Dr. David Sanders is the director of corporate communications for the Naval Undersea Warfare Center. He has served as the public affairs officer at Naval Station Newport and NUWC Newport Division, as well as a congressional press secretary.

A spectacular firing of the Naval Research Laboratory's test railgun. Basic research in this area has contributed to what will soon be a full weapon system deployed at sea for testing in 2016. Photo courtesy of Naval Research Laboratory.

"This Great Laboratory":

THE U.S. NAVAL RESEARCH LABORATORY

By Don J. DeYoung

One hundred years ago the world was changing—rapidly and violently. It was springtime, 1915. The first great war of the 20th century was raging across Europe and into Asia and Africa. Trenches and barbed wire, stretching from the English Channel to Switzerland, had locked the combatants in a bloody stalemate for months. Artillery, machine guns, and flamethrowers pounded, raked, and scorched "no man's land," ending thousands of lives in just hours. More than a million men were already dead. Offensives were futile, so increasingly brutal measures were taken to break the impasse. On 22 April, in Flanders fields, a yellow-green cloud of chlorine gas drifted among choking, dying men. Days later, on 7 May, a U-boat torpedoed a passenger liner, RMS *Lusitania*. The big ship sank in 18 minutes, claiming 1,195 lives, including 123 Americans. The first tank had not yet rumbled over the trenches, but that day was fast approaching.

Watching the spreading destruction from afar, Thomas Alva Edison had an idea that grew out of the great inventor's concern that America would be pulled into the war. On 30 May, when asked by a New York Times correspondent to comment on the conflict, he urged the government to:

"Maintain a great research laboratory, jointly under military and civilian control. In this could be developed . . . all the technique of military and naval progression, without any vast expense. . . . At this great laboratory we should keep abreast with every advanced thought."

The Congress soon approved the Naval Act of 1916 with the goal of a "Navy second to none." Among its provisions were funds to create what would become—through the combined efforts of Edison, Assistant Secretary of the Navy Franklin D. Roosevelt, and the Naval Consulting Board—the U.S. Naval Research Laboratory (NRL). On 2 July 1923, NRL was officially established. The principal speaker at the new facility's opening was Theodore Roosevelt, Jr., who had followed his father, Theodore, and cousin, Franklin, into the job of assistant secretary of the Navy. As the Naval Consulting Board wished, NRL was placed administratively in the secretary's office, under the assistant secretary. This was done to allow it to become a research establishment for the whole Navy.

Edison's idea was that a government laboratory, working in league with industry, and knowledgeable of naval needs, would help build American sea power through long-term, mission-related research and development, all with the purpose of defending the republic. For more than 90 years now, NRL has fulfilled the inventor's vision. This was affirmed in 2005 when the Navy League's New York Council bestowed the laboratory with the Roosevelts Gold Medal for Science. The council noted that NRL had "helped make the U.S. Fleet the most formidable naval fighting force in the world," and called it "the Government's premier defense research laboratory."

NRL continues to fulfill Edison's vision by contributing to what may become the most revolutionary advances in naval power projection in decades; laser weapons and railguns. NRL scientists were the first to propose and simulate the use of incoherently combined, high-power fiber lasers as the architecture for the Navy's new Laser Weapon System (LaWS). In 2014, LaWS was deployed in the Persian Gulf aboard the USS *Ponce* (AFSB[I] 15). At less than one dollar a shot, in testing it has downed an unmanned aerial vehicle and destroyed moving targets at sea. NRL's railgun program began in 2003 and has since become a critical element in the efforts to develop hypervelocity electric weapons for long-range fire support and ship defense. When the Navy deploys its first hypervelocity electric launcher, its success will be partially because of NRL's work.

Why NRL Works

As the corporate laboratory of the Department of the Navy, NRL conducts basic research, translates the results of this research into technologies, and assists in the transfer of these technologies to other Navy Department, Defense Department, federal, and industrial organizations for incorporation into effective operational military systems. The successful transition of these technologies supports NRL's corporate philosophy that a sustained and well-managed investment in multidisciplinary research and development leads to continual improvements to the nation's defense, helps prevent technological surprise by potential adversaries, and can lead to revolutionary and world-changing capabilities, such as sonar, radar, satellites, GPS, and, maybe soon, laser weapons and railguns. The reasons for NRL's success certainly include basic imperatives such as a high-quality workforce, challenging programs, and satisfactory facilities, but there are other factors of vital importance:

Broadly Based Multidisciplinary Program

NRL's program includes more than 15 scientific disciplines and applied technology areas, including optics, chemistry, plasma physics, materials science, oceanography, acoustics, electronic warfare, radar, and space science and technology. This approach allows a better understanding of a problem and taps the creative synergy of diverse disciplines. Moreover, technical problems are becoming increasingly complex in nature. For such reasons, NRL established its Nanoscience Institute, which conducts research at the intersections of materials, electronics, and biology. Later, NRL created its Laboratory for Autonomous Systems Research to support research in intelligent autonomy, sensor systems, power and energy systems, human-system interaction, and more. Recently, using a methodology reminiscent of Project Hindsight, the Office of the Secretary of Defense led a survey that confirms the benefits of a multidisciplinary program: NRL made 181 contributions to 52 of 83 current major defense acquisition programs. NRL was found to have affected 26 of 35 Navy major programs (74 percent) and 17 of 48 non-Navy programs (35 percent). The survey, however, likely undercounts contributions from early basic and applied research that found their way into these programs outside the knowledge of the survey respondents, which replicates Project Hindsight's chief weakness.

Organizational Position

Public Law 79-588 created ONR and placed it, along with NRL, within the Office of the Secretary of the Navy in 1946. Since then NRL has reported directly to the Chief of Naval Research (CNR). This preserved the original guidance from Edison and the Naval Consulting Board that NRL be placed where it could focus on the long-term needs of the Navy, rather than on short-term operational requirements.

Strategic Guidance and Funding

NRL's programs address the capability gaps identified in the Naval S&T Strategic Plan. Department of Defense and Department of the Navy strategic documents provide the foundation for this plan. It is a broad strategy that articulates a general direction for the future, while retaining sufficient flexibility and freedom of action to meet emerging challenges. For its base program, NRL receives broad guidance from the CNR that also establishes level of effort. Using a rigorous internal review process, NRL then develops an annual comprehensive base program plan that is proposed to the CNR. The base program, funded directly by the CNR, is a vital key to NRL's success. Indeed, the importance of a supportive CNR to an innovative NRL program cannot be overstated.

Navy Working Capital Fund

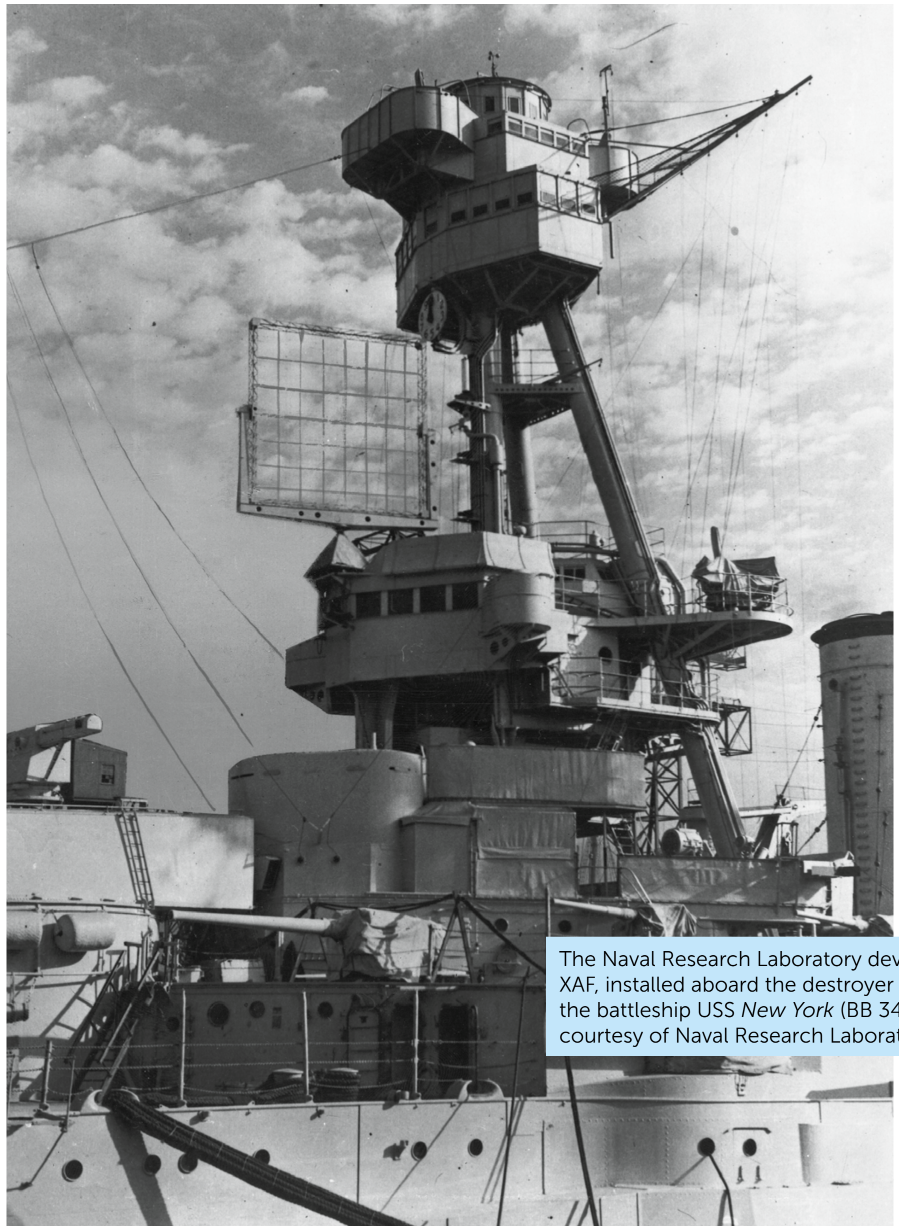
Reimbursable funding provided by Navy, Defense, and non-Defense sponsors through the Navy Working Capital Fund helps to produce world-class research results at the lowest possible cost. The system works as follows. All costs of doing business are distributed proportionately as overhead charges added to the cost of a research work year and are paid by the sponsors of each project. Sponsors have the choice of funding or not funding individual projects on the basis of cost, scientific quality, and responsiveness to their needs, so it follows that NRL's researchers must compete by satisfying those needs. The capital fund also fosters decentralized decision making by placing the responsibility for program success on the technical abilities of each division superintendent and branch head. This is proper because technical decisions are best made at a level of authority closest to the expertise of the researchers.

Continuity of Civilian Technical Leadership

A landmark White House study, chaired by David Packard in 1983, stressed that, "The quality of management is crucial to a laboratory's performance. Federal agencies must insist on highly competent laboratory directors." Indeed, the job of NRL's senior management is to choose areas in which to work, divest work that has become appropriate for other performers, serve as the final arbiter of scientific merit, and foster the basic conditions necessary for innovation. The latter includes a high-quality staff, challenging programs, productive partnerships, effective support services, satisfactory facilities, state-of-the-art equipment, and a reasonable degree of autonomy. History has shown that the stable continuity of NRL's senior civilian management is a key to ensuring those conditions—just six civilian directors have guided the program since 1949. This stability is most vital for nurturing the laboratory's long-term basic research programs.

A Collaborative Naval Research Enterprise

In a three-year period (2012-14), there were 507 "interactions" between NRL and other Navy laboratories. The interactions included, but were not limited to, panel and committee participation, shared research, and funded collaborations. There also were 266 interactions with Army laboratories and 188 with Air Force laboratories. Over a similar three-year period (2010-12) NRL researchers had 1,019 collaborations with 232 U.S. universities and research institutions in 48 states, and 193 with foreign universities and research institutions in 34 countries. NRL also has a relationship with the private sector that is characterized by a high level of productive collaboration and mutual respect. Charles Townes, Nobel Laureate and former vice president of the Institute for Defense Analyses, commented on that relationship when he said, "NRL is important to all of us--to defense industry and to science."



The Naval Research Laboratory developed the first U.S. radar, the XAF, installed aboard the destroyer USS *Leary* (DD 158) in 1937 and the battleship USS *New York* (BB 34), shown here, in 1938. Photo courtesy of Naval Research Laboratory.

An Indispensable Nature

NRL is important to all of us because of what it does, but it is indispensable for what it is—a government laboratory. The federal government ultimately bears sole accountability for national missions and public expenditures, so decisions concerning the types of work to be undertaken, when, by whom, and at what cost should be made by government officials responsible to the president. The government therefore must be a smart buyer and be capable of overseeing its contracted work. For this the government uses its "yardstick," a term introduced by political scientist H.L. Nieburg. In technical matters, this measure is the collective competence of its scientists and engineers. Their advice must be technically authoritative, knowledgeable of the mission, and accountable to the public interest.

One example of NRL's impact as a yardstick was described in *Joint Forces Quarterly* (October 2009). During construction of USS *Seawolf* (SSN 21), the contractors chose a titanium alloy for the boat's muzzle and breech doors instead of the usual steel. Because Seawolf's torpedo tubes were larger than those of the older *Los Angeles* (SSN 688)–class boats, the contractors, quite reasonably, wanted to use a material as strong as steel but only about half the weight. The alloy, however, has another property. Under certain conditions it becomes brittle. Cracks can form by the simultaneous action of tensile stress and a corrosive environment, such as seawater. The phenomenon is called stress corrosion cracking and it will fracture some titanium alloys, at times fast enough for one to "stand there and watch it happen."

NRL had quantified the sensitivity of titanium alloys to stress corrosion cracking in seawater many years before Seawolf was designed. One paper cautioned that, "no prudent program manager would schedule a program in which [stress corrosion cracking] of new materials might be a problem without provision for a sound experimental characterization of stress-corrosion properties in the pertinent environment." Unfortunately, NRL experts were not asked their opinion on using this alloy, nor were they consulted until after the mistake was detected—by chance. The stroke of luck occurred when, during Seawolf's construction, a hinge pin fractured while being straightened by a hydraulic press. It was made from the same titanium alloy as the muzzle door that it was intended to support. The Navy quickly formed a team with the best available experts on process and material technology. The panel of government scientists from ONR and NRL determined that the contractors' decision had "placed a material with risk of unstable, catastrophic failure at the pressure hull boundary," and they proposed improvements to the process of selecting materials. The Navy implemented their proposals and commended its "unbiased technical experts" for contributing to Seawolf's safe operation.

"The Government Should Maintain a Great Research Laboratory"

Thomas Edison envisioned what would become NRL as he watched the bloody clash of six empires and then proposed what he believed was necessary to defend the American republic. Since that time, alongside industry and the other elements of national power, NRL has helped to transform the U.S. Navy, protect national security, and improve everyday life in ways the great inventor could not have imagined during that tragic springtime, 100 years ago.

About the author:

Don DeYoung is the executive assistant to NRL's director of research.

Ingenuity Leads the Search for Underwater Munitions

By Dr. Ted R. Clem, Dr. Daniel D. Sternlicht, and Stephen A. Hurff

{ A collaborative effort is delivering advanced sensors to seek out unexploded ordnance. }

Since the advent of gunpowder warfare, expended and discarded ordnance has been making its way into our oceans, lakes, and rivers. Aside from military engagements, munitions contamination is caused by weapons testing and training, accidents, and dumping. Worldwide, the expansion of population centers and increasing economic and recreational activity along coastal and inland waters will require the reuse of prior war zones, as well as active and formerly used defense sites.

There is, however, a significant technological shortfall in our ability to detect and localize seabed unexploded ordnance (UXO), especially in discriminating this material from other natural and man-made objects. Considering the large quantity of items of all types often found in such areas, the rejection of "clutter" is essential to minimizing unnecessary diver inspections during remedial activities. Current commercial sensors have a limited capability to detect UXO (especially those that are buried) and to reject clutter.

There are significant parallels between the technical requirements for hunting sea mines and UXO; in fact, lost sea mines from past generations are part of today's UXO complement. Sidescan and ahead-looking sonars are used in mine hunting to search for, classify, and map sea mines over relatively large areas. Afterward, close-up camera or diver inspections (known as reacquisition-identification missions) are conducted to determine whether or not a contact is indeed a mine. Environmental conditions in shallow coastal and inland waters, however, pose significant technical challenges to existing capabilities.

Commercial survey sonars operating at high acoustic frequencies have difficulty resolving distant object features and provide limited bottom penetration for resolving buried mines. In addition, identifying a sea mine by visual inspection is problematic if the mine is obscured in low-visibility waters, masked by biological growth, or buried. Increased use of unmanned systems in maritime environments will reduce the number of diver inspections, as well as the cost and risk associated with remediating underwater munitions sites.

The Office of Naval Research (ONR) has sponsored the development of mine-hunting sensors, which are being evaluated for preliminary site assessments for munitions contamination. This article will highlight two such technologies: the second generation of the Small Synthetic Aperture Minehunter (SSAM) and a magnetic classification system hosting the Laser Scalar Gradiometer (LSG). The Naval Facilities Engineering Command has employed these advanced mine-hunting systems to conduct UXO surveys, including assessments at Naval Air Station Patuxent River, Maryland, in April 2012; Naval Support Activity Panama City, Florida, in August 2012; Marine Corp Base Quantico, Virginia, in October 2012; and the Naval Weapons Station Earle, New Jersey, in August 2013.

Acoustic Situational Awareness and Contact Imaging

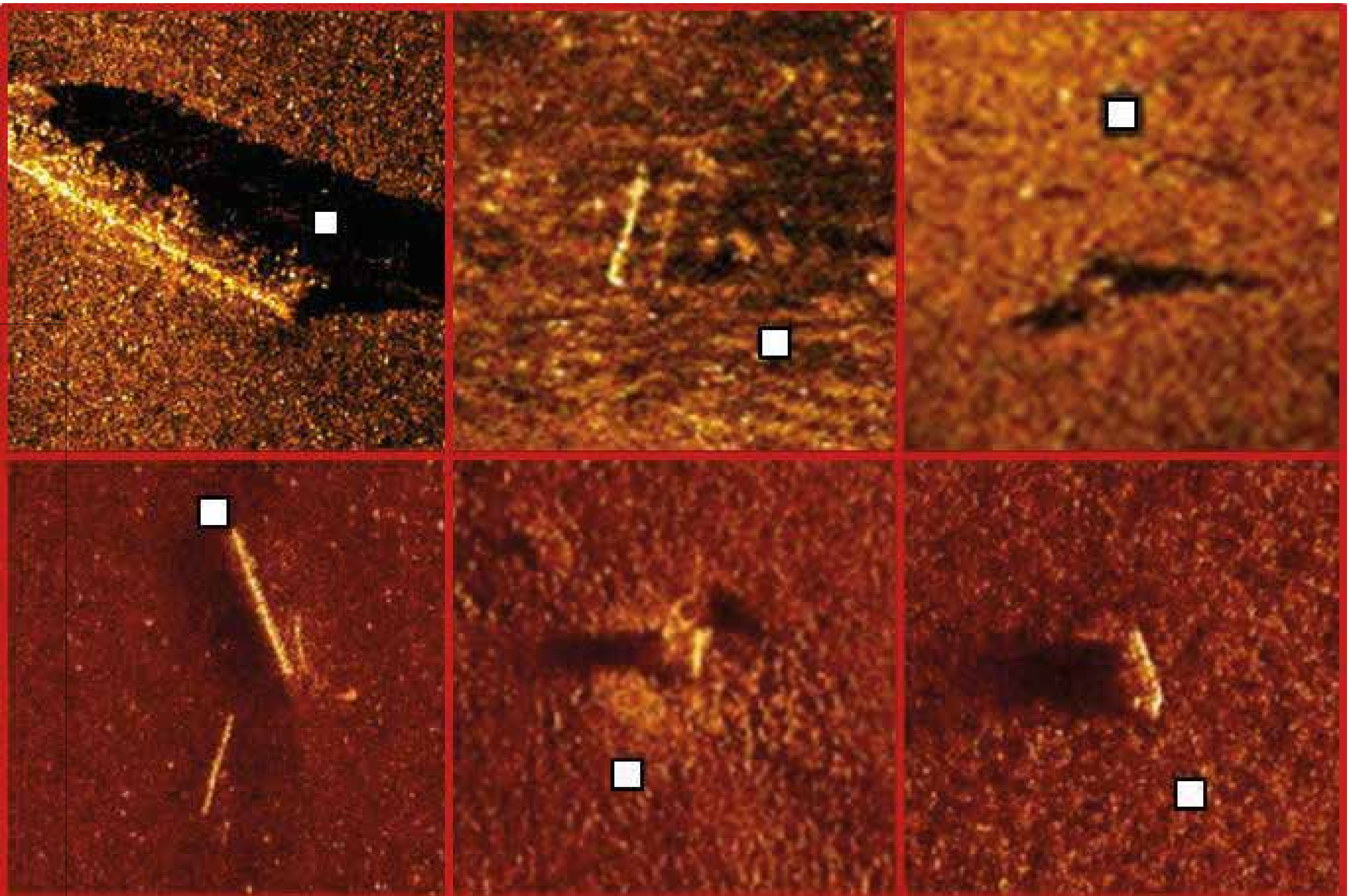
The SSAM technology was developed by the Naval Surface Warfare Center Panama City Division located in Panama City, Florida, and the Applied Research Laboratory at Pennsylvania State University in State College, Pennsylvania, for hunting mines in highly cluttered and dynamic shallow water environments. It consists of two synthetic aperture sonar systems: a high-frequency sonar and a long-wavelength broadband sonar, wherein two separate projectors share a common hydrophone array. This array has multiple vertical staves for shallow-water, multipath suppression, and interferometric processing to provide fine-resolution seafloor bathymetry. The SSAM sonar is integrated on a REMUS 600 unmanned underwater vehicle developed by Woods Hole Oceanographic Institution in Woods Hole, Massachusetts.

The valuable situational awareness obtained from airborne optical imaging and operator visualization often is taken for granted in land-based UXO surveys. It is an entirely different situation underwater, where optics and commercial sonars are usually less effective. High-fidelity synthetic aperture sonar sensors, however, have led to revolutionary improvements in underwater visualization. SSAM has been used to reveal changes in seabed structure and to locate hitherto unknown navigation obstructions. It produces sharp images of complex bottom terrain such as vegetation coverings, coral and rock formations, and remnants of man-made construction. But it is the fine-scale imaging capability developed for mine hunting in dynamic shallow-water environments that makes the system especially well-suited to wide-area scanning for UXO-like objects.

Reacquisition and Identification

As is often the case in coastal and inland areas, poor visibility limits the effectiveness of optical sensors or excludes them entirely for further target discrimination. Even when visibility permits, munitions encrusted with biological growth may not be identifiable. Recently, the SSAM has employed a new reacquisition-identification technique known as circular synthetic aperture sonar (CSAS). CSAS involves circling the sonar about a detected object to create a fused, very high-resolution image from all aspects. Although falling short of optical imagery, CSAS imaging far exceeds the quality obtained with conventional sonars. This imaging modality has been used to confirm the identity of UXO-like objects, and has been key to determining when and where to employ divers.

Just as on land, magnetic anomaly detection can play a significant role in underwater munitions surveys since a majority of UXO types have steel casings and/or parts. In particular, passive multichannel magnetic gradiometers add the magnetic moment vector as a classification feature complementary to object visualization. By the early 1990s, Panama City Division developed and demonstrated a straightforward fusion of acoustic and



Sample acoustic images from sidescan sonar (top row) and synthetic aperture sonar (bottom row) co-registered with magnetic contact localizations displayed by white squares. Photo courtesy of Naval Surface Warfare Center Panama City Division.

magnetic data for mine classification. A target detected by sonar was classified as a mine only if both the sonar and the gradiometer independently indicated that the target was a mine. Users obtained an acoustic clutter rejection rate better than 98 percent, and the effectiveness of this data fusion approach has been validated repeatedly since then for both mine hunting and UXO surveys.

The magnetic classification system, also deployed on a REMUS 600 vehicle, was developed by Panama City Division and Woods Hole to reacquisition-identify "proud" (i.e., sitting on the sea bed) and buried sea mines and to reduce acoustic clutter. This system hosts the LSG, a high-performance, multichannel magnetic gradiometer developed by Polatomic in Richardson, Texas. The LSG can provide predictions of contact position, burial depth, and magnetic-dipole moment vector. Once the LSG was demonstrated, this system was outfitted with a 900/1800-kHz commercial sidescan sonar and a Pike F-421 electronic still camera to establish a fusion of multiple sensing modalities.

During these surveys, LSG data was fused with images coregistered from both the sidescan sonar on the LSG and from the SSAM operating on an independent platform. The LSG effectively indicated which objects were ferrous. Based on various studies comparing contact locations from the LSG and its companion sidescan sonar, we found that the LSG's automated target recognition provides more accurate contact localizations than the more commonly used technique of magnetic intensity mapping. Moreover, contact size, shape, and orientation features automatically extracted from the magnetic moment vector can be correlated with comparable acoustic classification features. The automated target recognition also provides a rough estimate of contact burial depth. From the inspection of sidescan sonar images coregistered with LSG contacts, we have confirmed that the automated target recognition provides reliable predictions of burial state. More significant, we have been able to shed light on the preponderance of buried UXO-like objects in these environments.

Summary

Mine-hunting technologies developed by ONR have provided new capabilities for the detection and localization of unexploded ordnance in challenging shallow-water environments. The SSAM has been used for high-resolution acoustic imaging both for panoramic situational awareness and for the classification of UXO-like objects. CSAS missions have provided strikingly distinct images of UXO-like contacts. The LSG, in fusion with its sidescan sonar and with the SSAM, rejected a high percentage of acoustic clutter anomalies and detected a large number of buried UXO-like anomalies not imaged by either sonar. Poor visibility excluded the use of optics during these surveys.

Many contaminated sites are located in sedimentary environments with strong currents that can result in burial, mobility, or subsequent exposure of unexploded ordnance. That munitions come in a variety of sizes, shapes, and states of fragmentation further complicates the problem. Remediation of these sites will require further advances in underwater sensors (acoustic, magnetic, and others) and instrumentation platforms, as well as the development of excavation technologies to aid in the process of ordnance disposal.

About the authors:

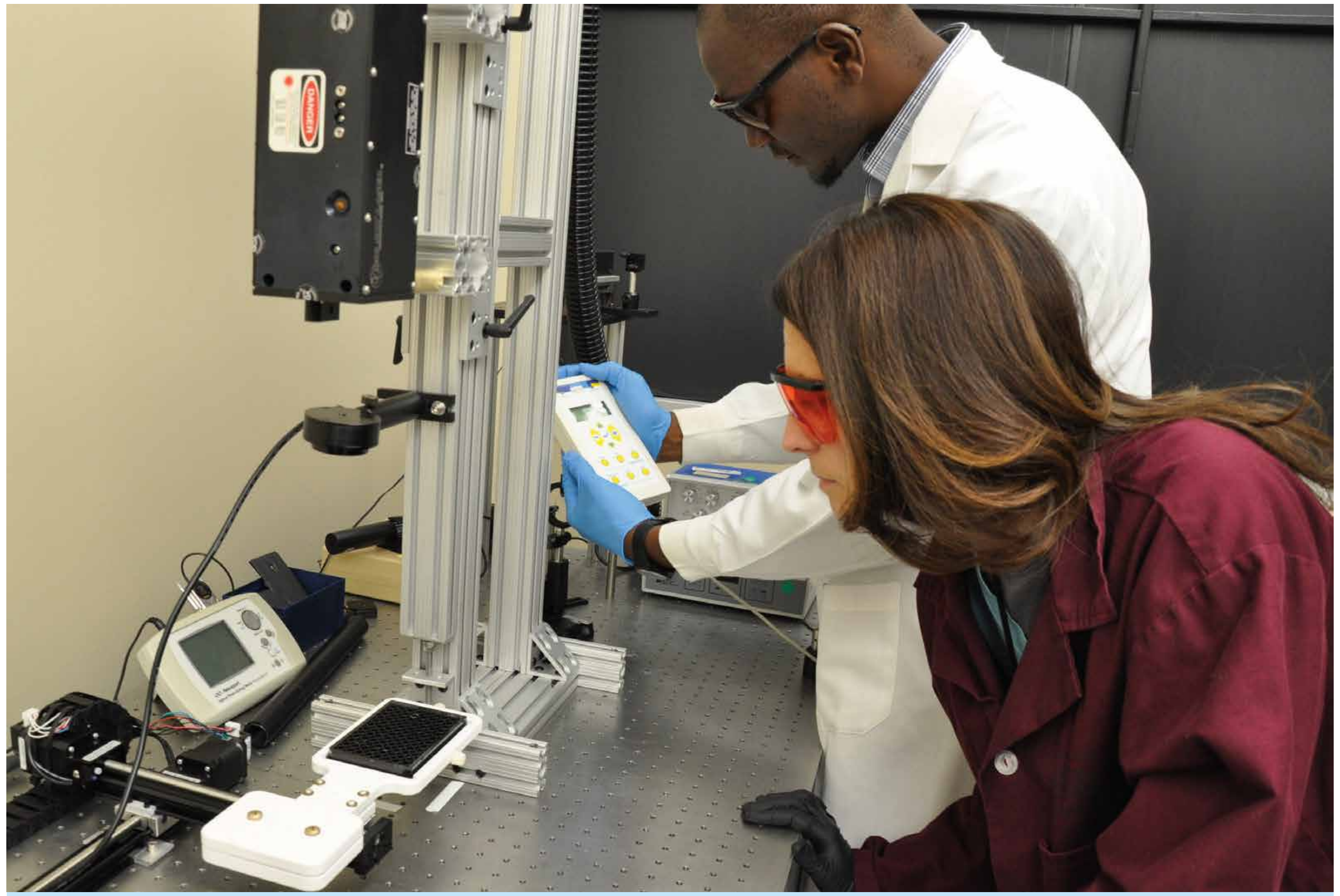
Dr. Clem is a research scientist in the sensing sciences division at the Naval Surface Warfare Center Panama City Division.

Dr. Sternlicht is the head of the sensing sciences division at the Naval Surface Warfare Center Panama City Division.

Stephen Hurff is the radiological and munitions response program manager for the Naval Facilities Engineering Command.

Naval Medical Research Reaches New Level by Being Interdisciplinary

By Dr. John Simecek, Cmdr. David Leal, USN, and Capt. Jonathan Stahl, USN



Dr. Nancy Millenbaugh (front) and Dr. Dickson Kirui (back) investigate how pulsed laser irradiation would maximize bacterial biofilm destruction. Photo by Flisa Stevenson.

The military and civilian medical research communities are acknowledging that even their best individual efforts cannot fully address today's complex and interconnected problems. The research process of lone scientists or small teams solving medical problems with a single-pronged approach is incongruous given our advanced and ever-evolving understanding of the disease process. Nowhere has the need for a change to this paradigm been more evident than in the dynamic realm of military medical research.

Interservice Collaborations

Battlefield injuries often present special challenges to the healing process and demand that relevant research no longer proceeds as a compartmentalized effort. Being located on Joint Base San Antonio, Texas, where many injured warfighters receive care at the San Antonio Military Medical Center, means Navy researchers see first-hand the need for a mindset change—and they have developed a new model for scientific excellence in response. Strategic planning begets thoughtful scientific hiring to create interdisciplinary teams, which are designed to "attack" a problem from numerous pathways. This new approach also encourages scientists to think imaginatively and network with other researchers to form collaborations and leverage resources. Internal collaborations, interservice collaborations, and fiscal efficiency characterize the Naval Medical Research Unit San Antonio (NAMRU-SA) approach to the business of research, and are key reasons why sponsors are excited about their capabilities and what they are accomplishing.

NAMRU-SA is one of eight subordinate research commands in the global network of laboratories operating under the Naval Medical Research Center, Silver Spring, Maryland. To improve medical outcomes related to NAMRU-SA's mission and capabilities in combat casualty care and craniofacial health and restorative medicine, this collaborative approach not only is necessary, it also makes great scientific sense. NAMRU-SA is reengineering wound healing, infection control, and dental treatments with a diverse team of scientists and clinicians from across the United States, encompassing molecular and cellular biologists, biomedical engineers, microbiologists, immunologists, physiologists, and healthcare specialists including surgeons and dentists.

Reengineering Wound Healing

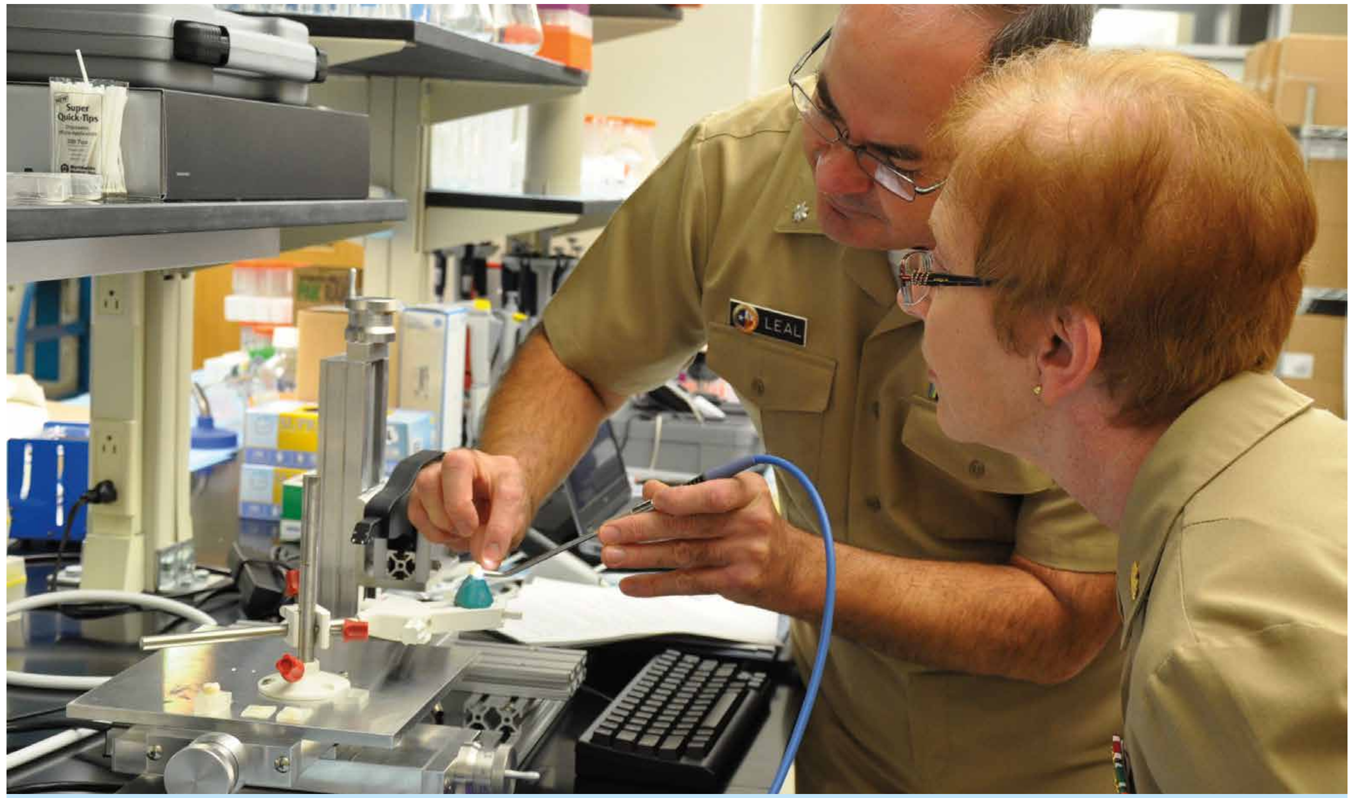
NAMRU-SA's purposeful integration of scientific disciplines and a value-conscious approach to research provides an interdisciplinary view of the problem under investigation and leads to cutting-edge solutions and product-driven research. For example, recent statistics reveal that approximately 65 percent of battlefield injuries are related to head, face, or neck trauma and that antibiotic-resistant infections in these areas increase death, illness, and direct costs of treatment by 30 to 100 percent. Improved craniofacial wound management and infection control is essential for decreased morbidity and mortality in Sailors and Marines, controlling healthcare costs, and improving service members' quality of life in terms of both function and esthetics. To that end, NAMRU-SA launched a collaborative initiative involving biomedical engineers, cell biologists, immunologists, mechanical engineers, biomaterials experts, and dentists. The team developed a novel approach to creating biocompatible nanofibers to enhance wound treatment, especially wounds to the craniofacial region. The biocompatible nanofiber scaffold is designed to promote tissue repair by forming a surface that mimics the natural cellular environment while simultaneously releasing bioactive molecules to accelerate healing and potentially minimize the formation of scar tissue.

To synthesize the nanofibers, NAMRU-SA's biomedical engineering team constructed a custom electrospinning apparatus. The device produces the nanofibers by spraying a polymer solution through a spinneret under an applied electric field. The electric field induces a charge in the polymer solution, leading to the elongation of droplets into a thin, continuous fiber of submicron diameter. The nanofiber composition and structure, including spray pattern and strand size, are readily controlled during the electrospinning process, enabling the user to tailor nanofibers to a wide variety of biomedical applications.

Once the process is optimized, scientists plan to integrate nanofibers into coatings for use on medical materials to improve treatment for craniofacial injuries. These nanofibers can deliver bioactive agents at a sustained rate and can be assembled into a 3D architecture to guide cell behavior. This endeavor has led to a collaborative effort with the US Army Dental and Trauma Research Detachment to develop a novel bandage that will contain therapeutic agents to improve healing and decrease scar formation in military trauma patients.

The success of the electrospinning technology and nanofibrous scaffolding was directly attributable to the comprehensive team approach applied to the problem. Every team member brought a unique perspective and skill set to the issue and resulting end product. Industry has used a similar process to spin plastic and polyvinyl fibers into household items such as air filters, but developing a technique and accompanying device that could transform organic elements into engineered tissue, and then transport and deliver drugs to fight infection and promote proper natural healing, is complex and poses serious challenges. The absence of any one idea or perspective may have derailed the project or resulted in a less-than-optimal outcome.

The electrospinning apparatus can reliably produce nanofibrous scaffold and the fibers can be embedded with growth factors, medications, and other materials of interest. The implications of these new capabilities cannot be overstated. This technology will be increasingly used to fabricate nanofibrous scaffolds for a multitude of tissue-engineering purposes related to tissue repair or regeneration because of its cost-effectiveness, relative simplicity, and ability to scale up scaffold production. Scaffolds of various shapes and sizes can be constructed, while at the same time fiber orientation, composition (blended fibers), and dimensions can be controlled precisely. In addition, these ultrafine fibers can be woven using a variety of natural and synthetic components. Scaffolds generated by this method offer the additional advantage of being able to incorporate bioactive components such as growth factors. Growth factors can then be released in a controlled and continuous manner while the scaffold still possesses adequate mechanical properties to serve as a physical wound dressing. While development of the nanofiber technology is ongoing, these nanofiber materials offer the potential to improve patient outcomes and reduce costs associated with wound treatment.



Cmdr. David Leal (left) demonstrates the Optical Coherence Tomography (OCT) system to Capt. Denise Smith (right). The OCT is a laser device that shows dentists subtle discrepancies and cracks in a tooth that cannot be seen in a regular dental exam. Opposite, electrospinning has become a common technique in the production of polymer nanofibers; the polymer jet is being ejected towards a collector plate. Photos by Flisa Stevenson.

Infection Control that Pushes the Edge of Technology

Another example of NAMRU-SA's contemporary and integrated research approach is in the area of infection control. Bacterial wound infections are problematic for military and civilian populations around the world. Two of the major challenges for successful treatment of maxillofacial (face and mouth) wounds in particular are multidrug resistance and formation of biofilms (bacteria growing in slime-enclosed aggregates). The high level of infection in facial injuries and the difficulties encountered during extended military evacuation procedures contribute to severe soft tissue breakdown that results in delayed healing, increased scarring, scar contracture, deformities, long-term functional deficits, and difficulty with facial reconstruction.

NAMRU-SA is addressing these challenges by assembling an interdisciplinary team with expertise spanning chemistry, virology, molecular immunology, and structural biology to physics, mathematics, and nanomedicine to develop innovative therapeutic strategies as alternatives to conventional antibiotics. This pioneering team proposed a two-phased approach to solving multidrug resistance and biofilms. One arm of the research focuses on using laser-induced opto-acoustic treatment, which is pulsed laser light and energy absorbing nanomaterials to physically damage the infectious agent through generation of heat and shock waves. A major advantage of this approach is that the efficacy of the technique at eradicating pathogens would not depend upon level of antibiotic resistance, growth rate, or metabolic status. Another arm of the study involves developing compounds that can break through biofilms to enhance the activity of antibiotics and help debulk infectious lesions. The ultimate contributions of this research will be new technologies and products for improved treatment of antibiotic resistance and biofilm infections, essential for preservation of soft tissues and optimal cosmetic and functional outcomes following maxillofacial injuries.

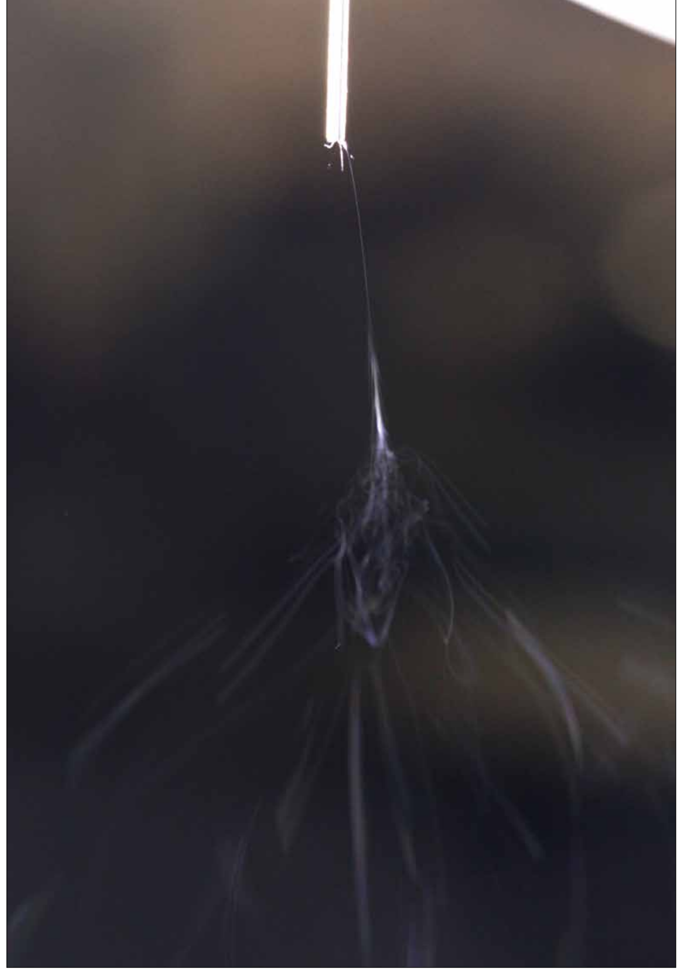
Preventive Dental Care to the Extreme

Preventive dental care is often categorized as routine, but fractured teeth and restorations are the most commonly reported dental emergencies among military personnel. Recent statistics from Soldiers serving in Iraq place the cost of these types of emergencies at more than $20 million a year, not accounting for degradation of unit operational capability. A large number of these emergencies occur because of a gap in current dental diagnostic technology that prevents accurate characterization of enamel cracks. Transillumination, for example, uses visible light to highlight the fracture, but visible light scatters when reflected on enamel and does not allow the clinician to determine the depth or extent of the fracture. In addition, the most basic diagnostic test, X-Ray, is quick but cannot be used to evaluate cracks unless the fracture is grossly displaced.

The disparity between requirement and capability drove NAMRU-SA's craniofacial health research team to explore various industry technologies that could be adapted and other basic technology that was suitable for modification. The team of dentists, engineers, and technicians is evaluating a technology called optical coherence tomography (OCT) that has the potential to provide significant diagnostic images that will aid dentists in evaluating enamel cracks and the need for further intervention. OCT is a laser-based system that allows one to visualize subtle discrepancies and cracks in a tooth not able to be seen during a routine dental exam. The laser uses nonionizing laser light to obtain subsurface images of translucent or semitranslucent materials at a resolution of better than 10 micrometers, and then creates an instant, clear 2D and 3D tissue images by rejecting background scatter signals or light directly reflected from the surface of interest. The most appealing features of OCT are that no special preparation of the biologic sample or subject is needed and images can be obtained in a noninvasive and nonionizing manner. These characteristics translate to a highly effective, quick, easy-to-use instrument with no damage to biologic tissue. The NAMRU-SA team is completing research with the technology by testing extracted restored and nonrestored teeth with simulated chewing stress applied by a mechanical testing device to propagate cracks. Enamel crack propagation will be evaluated using images from a Micro CT scanner and they will be compared to the images produced by the OCT. On successful evaluation and development of a diagnostic predictive model, the research team will work on a hand-held device that would be suitable for use in military dental clinics.

Science with a Purpose

With the current call for improved Sailor and Marine readiness and greater effectiveness for every dollar spent, the philosophy of efficient repurposing of existing technology



and team-driven design of functional devices is an important step forward in a research culture that is traditionally compartmentalized and can labor unnecessarily too early in the research continuum.

The command's goal is science with a purposeful strategic plan designed to approach problems from an interdisciplinary viewpoint while leveraging resources to the greatest extent possible. The NAMRU-SA vision of decreasing time from bench to battlefield is critical to ensuring relevancy, purpose, and longevity in an ever-evolving military landscape.

About the authors:

Dr. Simecek, a dentist with training in epidemiology, serves as head of the Combat Casualty and Operational Medicine Directorate at the Naval Medical Research Unit San Antonio.

Cmdr. Leal, DDS, is the acting head of the Craniofacial Health and Restorative Medicine Directorate at the Naval Medical Research Unit San Antonio.

Capt. Jonathan Stahl, DDS, Ph.D., DC, is head of the Maxillofacial Injury and Disease Department in the Craniofacial Health and Restorative Medicine Directorate at the Naval Medical Research Unit San Antonio.

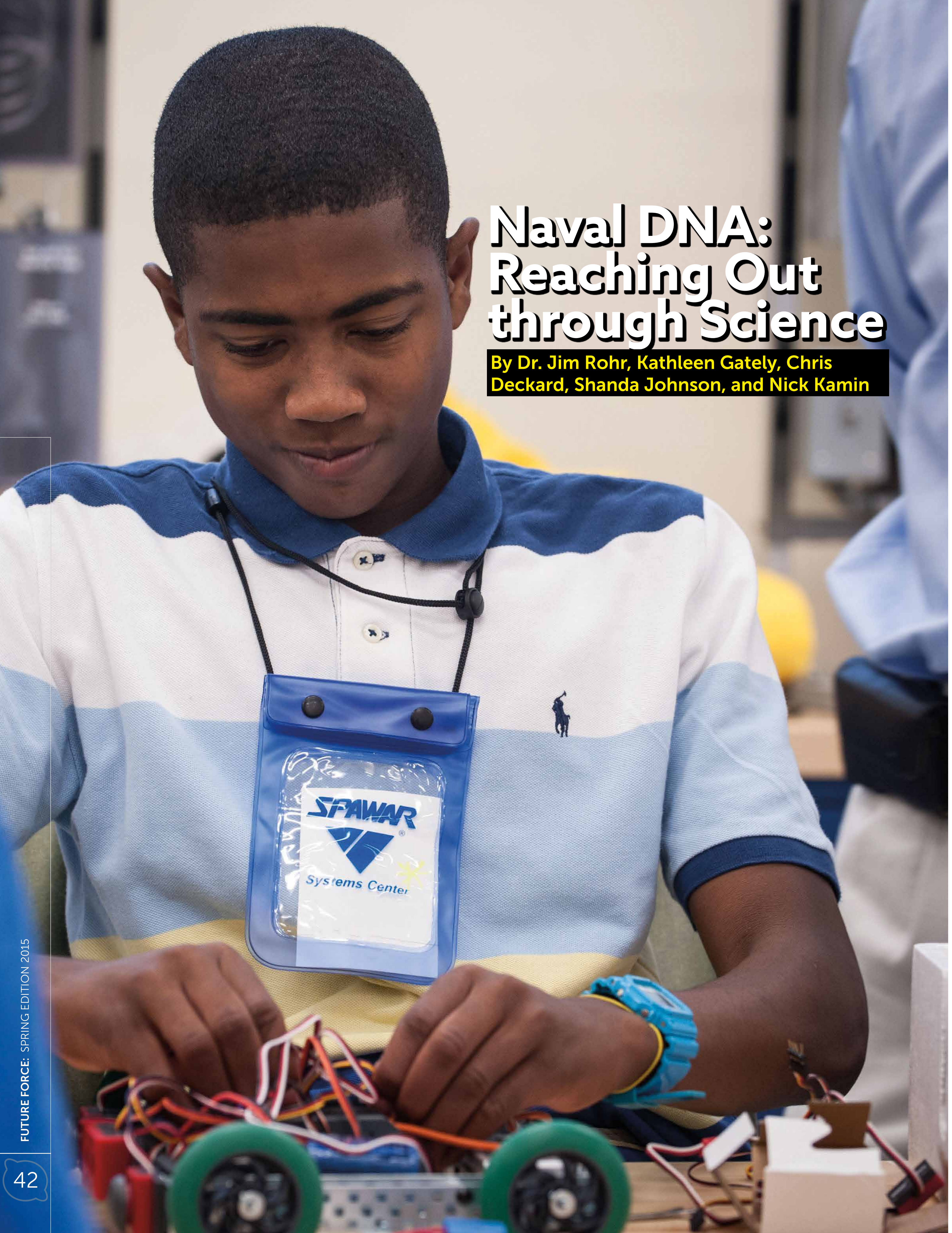


Photo by Joe Bullinger

Naval DNA: Reaching Out through Science

By Dr. Jim Rohr, Kathleen Gately, Chris Deckard, Shanda Johnson, and Nick Kamin

Sometime between 2006 and 2013, a remarkable transformation started occurring among Navy scientists, technologists, engineers, and mathematicians nationwide. They began appearing in unprecedented numbers in classrooms and afterschool learning environments throughout their communities. In 2013, nearly 3,500 Navy science, technology, engineering, and mathematics (STEM) professionals, working with more than 5,100 teachers in 2,000 schools, engaged with more than 120,000 students. Over the past seven years, the K-12 outreach staff for the Space and Naval Warfare Systems Command (SPAWAR) witnessed this transformation, and it is a privilege to provide some context to the above numbers.

For many, what precipitated an increased participation in their local K-12 communities was empowerment through training and materials provided by the National Defense Education Program (NDEP). There was also a shared concern that in order to fulfill SPAWAR's mission—enabling information dominance for the warfighter—we needed to have a stake in cultivating the next generation of STEM professionals at our centers.

At SPAWAR, a large portion of our newly hired personnel consists of computer scientists and engineers. We anticipate that will need to grow. Yet it is estimated that American universities will generate only one-third of the nation's 1.4 million computer specialist job openings through 2020. While the need for computer science and engineering graduates is rapidly growing, the number of introductory secondary school computer science courses is fading from the national curriculum. Introductory secondary school computer science courses have decreased by 17 percent since 2005. The number of Advanced Placement computer science courses has decreased by 33 percent.

NDEP funding—together with a nearly equal internal investment from SPAWAR's research centers, Space and Naval Warfare Systems Center (SSC) Pacific and SSC Atlantic—has made it possible to support a significant STEM outreach effort. We have learned three fundamental lessons, and all of them are equally relevant to the Navy' larger STEM efforts.

First, although some level of funding will always be needed to continue this effort, our greatest strengths are derived from the generosity of SPAWAR's professionals and the examples of senior leadership. In FY14, more than 600 SPAWAR STEM professionals provided almost 25,000 hours to their student communities. Nearly 70 percent of these hours were unpaid volunteer hours.

Second, the partnerships and collaborations established with local K–12 schools, universities, professional societies, industry, and national programs provide our volunteers access to established science education programs such as FIRST Robotics, SeaPerch, Math Counts, Dimension-U, and Material World Science, all of which greatly empower them as STEM ambassadors in our communities.

Third, current efforts are not sufficient to reach historically underrepresented groups (such as women, African Americans, Hispanics, Native Hawaiians, and Pacific Islanders) that are marginally represented as STEM professionals at our commands, but make up nearly three-quarters of the student populations in Charleston, South Carolina, Hawaii, and San Diego, California—the communities that host SPAWAR facilities.

These lessons were integrated to support a single shared vision: to foster a culture that celebrates education—by empowering Navy STEM professionals to bring inspiration to their K-12 communities—and in doing so attract extraordinary students who would not ordinarily have the opportunity to become part of the Navy team. A list of individual outreach initiatives, a fraction of the total, is presented here to help convey the spirit of this vision.

Girls' Day Out

Recognizing the lack of women among engineering graduates and how important middle school is in beginning academic STEM courses of study, the Girls' Day Out program was started in San Diego in 2008.

Middle school girls and their parents are invited to a university campus for a half-day of presentations, lectures, campus tours, and hands-on activities. Keynote speakers are STEM professional women and have included the director of research at the Office of Naval Research as well as the executive director of SSC Pacific. The success of this event has resulted in annual events at other universities throughout the San Diego area. SSC Pacific volunteers have begun a similar program in Hawaii. SSC Atlantic has taken the event to a higher level, arranging for the girls to spend a night on the College of Charleston campus.

Día de Ciencia y Ingeniería en Español

Nearly 50 percent of San Diego's K-12 population is Hispanic, with many parents learning English as a second language. To our knowledge, Día de Ciencia y Ingeniería en Español (Day of Science and Engineering in Spanish) is the first science and engineering event in San Diego entirely in Spanish for the benefit of Spanish-speaking families.

The program started through partnerships with local student chapters of the Society of Hispanic Professional Engineers and Latinos in Science and Engineering. Together with scores of bilingual STEM professionals from SSC Pacific, the Naval Air Warfare Center North Island, and the University of California at San Diego, there have been 14 events, with four more scheduled in 2015.

Robotics Clubs

In 2014, SSC Pacific and SSC Atlantic scientists and engineers provided coaching and materials for 97 FIRST Robotics, 18 SeaPerch, four VEX, and three Micro Robotics teams, providing more than 8,000 volunteer hours of community service. The success of the SeaPerch program—an Office of Naval Research-sponsored underwater robotics program for middle school students—led to local partnerships that brought additional SeaPerch kits and local competitions to our communities. A five-year partnership with the US Coast Guard in Hawaii has led to that state's first regional SeaPerch competition. The explosive growth of the FIRST Robotics program has led to several school partnerships and the hosting of tournaments.

Creating a STEM Pathway

Although an important goal of the SSC Atlantic and SSC Pacific outreach programs is to increase general K-12+ STEM interest and literacy, another crucial long-range goal is to provide a source of highly qualified and diverse professionals for SPAWAR's future workforce. Students and parents are introduced to this idea through stand-alone events, classroom visits, and extended hands-on learning activities.

An example of this is our one-week high school summer camps and academies. Students have an opportunity to work beside STEM professionals who introduce them to current Navy research. SSC Atlantic, in conjunction with the Lowcountry Technical Academy and other local organizations and businesses, provides a week-long cybersecurity camp in Charleston where students participate in hands-on cyber exercises and discussions taught by more than 20 experts. SSC Pacific is preparing to offer a similar cyber camp this year in San Diego.

Typically more than 100 high school, college, and graduate school students engage in a variety of STEM research projects relevant to SPAWAR through eight-to-10-week summer internship programs sponsored by ONR. We are beginning to see students we inspired in middle school camps and academies applying to summer high school programs, summer college internships, and for positions as STEM professionals at our centers.

It is possible for extraordinary students to have their college costs paid for through Department of Defense scholarships such as the Science, Mathematics, and Research for Transformation Scholarship for Service program, which supports undergraduate and graduate students pursuing degrees in STEM disciplines. The program aims to increase the number of civilian scientists and engineers working at Department of Defense laboratories.

However we increase the number of STEM professionals, we need to take advantage of the wealth of talent in those groups currently underrepresented in STEM. How do we recognize leadership potential? A student's participation in robotics teams, summer camps, academies, and internships provides an opportunity to identify such potential. Navy K-12+ outreach programs afford an incredible opportunity to attract and prepare an extraordinary workforce.

Those who have given back as STEM professionals have had a profound effect on both their organizations and their communities. National learning tools such as DimensionU, Material World Modules, SeaPerch, and Math Counts have been integrated into many school curricula across the country. SSC Atlantic, in conjunction with the South Carolina Department of Education, has developed a cybercourse and updated the South Carolina Career and Technology Education curriculum to include a cybersecurity track that has been embraced by several high schools.

SSC Pacific is assisting the San Diego County Board of Education to prepare teachers for the Next Generation Science Standards, which require a greater role by STEM professionals. Inquiry-based presentations and demonstrations developed at SPAWAR centers have been shared with other organizations such as the YMCA and various after school programs such as the Marine Corps Forces Pacific Youth Center and the National Guard Youth Challenge Academy.

Participants and staff from SSC Atlantic's Girl Day Out spend a day and a night at the College of Charleston. Photo by Joe Bullinger.

SSC Atlantic instituted the first professional National Society of Black Engineers chapter in Charleston, which in turn initiated several junior chapters. SSC Pacific established the first professional MAES: Latinos in Science and Engineering chapter in San Diego. The extraordinary success of FIRST Robotics has led the Department of Defense to ask SSC Pacific to start a national program. Last year, that program supported 436 teams throughout the country. Lt. Cmdr. Sean McConnon, officer in charge of Navy's Guam Facility who originally volunteered in San Diego, is initiating Guam's inaugural FIRST robotics competition.

While our STEM professionals' commitment to K-12+ outreach will always depend on resources and need, we believe that giving back to our communities has become part of the Navy's DNA.

About the authors:

Dr. Rohr oversees SPAWAR's K-12+ outreach program.

Chris Deckard is in charge of SSC Pacific's K-12+ outreach program in San Diego.

Kathleen Gately is in charge of the SSC Pacific's summer internship programs.

Shanda Johnson is in charge of SSC Atlantic's K-12+ outreach program.

Nick Kamin is the manager for SSC Pacific's Hawaii's efforts.

A LOOK AHEAD
POWER AND ENERGY

By Capt. Robert E. Palisin, USN

Throughout the ages, mariners have strived to find innovative ways to overcome the hazards of being at sea. The sea often is a dangerous and inhospitable place that requires the utmost creativity and daring to counter the challenges it presents. In ancient times, the earliest seafarers discovered how to capture the power of the wind and mathematical methods to decipher the secrets of the sun, stars, and moon to find their way. Early engineers discovered how to use fossil fuels and steam to propel their vessels when the wind was calm and learned how to use radar and radio waves to safely navigate. In more recent times, modern scientists have mastered how to use the power of the atom to create nearly inexhaustible power and energy for some of the largest and most capable vessels ever to put to sea, while creating a satellite navigation network that can provide modern day mariners pinpoint accuracy for their location anywhere around the globe.

As we look to the future, the nation's top scientists and engineers actively supporting our naval forces are nearing breakthroughs on numerous power and energy fronts that will further revolutionize how our forces maintain technological advantage and operational primacy above, on, and under the seas. Our next issue of *Future Force* will focus on the many technological pursuits associated with power and energy. The Naval Research Enterprise (NRE) and the Naval Research and Development Establishment (NR&DE) outlined in this issue are actively pursuing power and energy breakthroughs that will help our naval forces effectively employ next-generation sensors, weapons, and propulsion sources. We are laser focused on addressing challenges Chief of Naval Operations Admiral Jonathan Greenert made clear at our Naval S&T Future Force expo in February 2015: "Get our Navy off gunpowder," and "Increase the endurance of our unmanned undersea systems."

To answer these technology challenges the NRE and NR&DE team is completing the process of developing unprecedentedly enormous pulse power systems and incorporating unparalleled power density in innovative battery, fuel cell, and hybrid energy systems. The science and technology community is defining new materials and methods to rapidly and fluidly supply these tremendous power requirements while minimizing transmission inefficiency so we can safely and repeatedly supply the exact power required while mitigating wasteful thermal loading. An even larger challenge currently being pursued is the creation of vessels that not only incorporate these new capabilities but open the door for even more innovative systems in the future. The level of innovation taking place will have second- and third-order effects across all naval platforms and is requiring the entire naval science and technology team to rethink the fundamental requirements and core capabilities of naval platforms of the not-too-distant future.

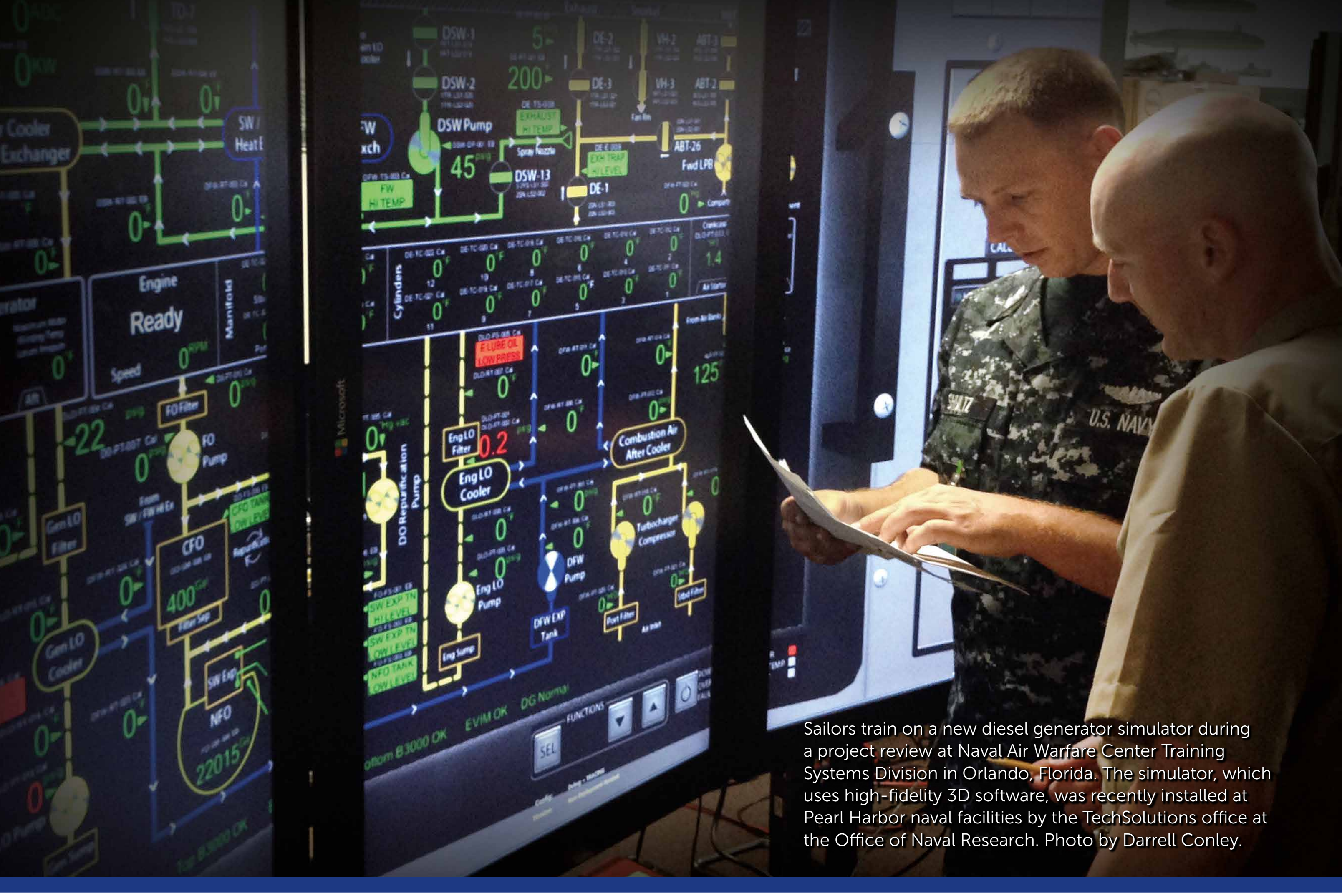
To effectively prepare for design changes enabled by emerging power and energy capabilities, it requires frequent and highly efficient cross-community technical cooperation. Numerous engagement teams and exchange opportunities are under way to ensure the wide-ranging effect of dramatically increased power systems are given proper consideration and able to be fully exploited to the benefit of our future naval forces. Please ensure you obtain a copy of our next issue to see how our naval science and technology community is pursuing this great challenge.

Capt. Palisin is the Assistant Chief of Naval Research and editor of *Future Force.*

The Future of Power

The issues of power and energy are increasingly at the forefront as new ships, aircraft, and other platforms pose design challenges to meet today's propulsion and mission systems needs. New technologies such as the all-electric ship could result in the complete reconceptualization of hull forms and internal layouts, while current limitations on batteries, fuel cells, and engines are awaiting breakthroughs in basic science that could mean larger and longer endurance unmanned systems.

Photo by MC2 Scott Fenaroli.



Sailors train on a new diesel generator simulator during a project review at Naval Air Warfare Center Training Systems Division in Orlando, Florida. The simulator, which uses high-fidelity 3D software, was recently installed at Pearl Harbor naval facilities by the TechSolutions office at the Office of Naval Research. Photo by Darrell Conley.

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Future Force
Office of Naval Research
875 N. Randolph Street, Suite 1425
Arlington, VA 22203-1995

Email: futureforce@navy.mil
Phone: (703) 696-5031
Web: http://futureforce.navylive.dodlive.mil
Facebook: http://www.facebook.com/navalfutureforce