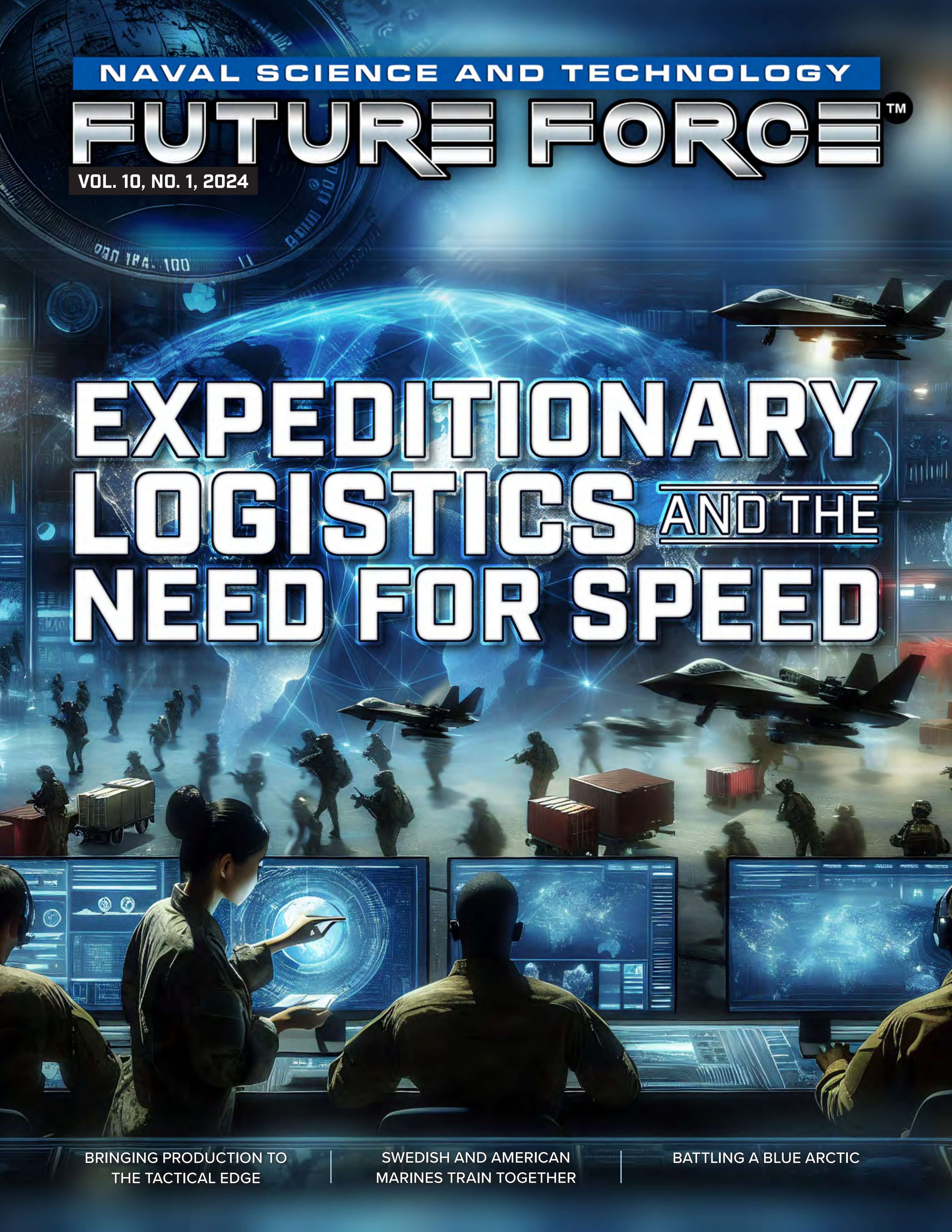
NAVAL SCIENCE AND TECHNOLOGY

FUTURE FORCE™

VOL. 10, NO. 1, 2024



EXPEDITIONARY LOGISTICS AND THE NEED FOR SPEED

BRINGING PRODUCTION TO THE TACTICAL EDGE

SWEDISH AND AMERICAN MARINES TRAIN TOGETHER

BATTLING A BLUE ARCTIC

VOLUME 10
#01
2024

FUTURE FORCE

NAVAL SCIENCE AND TECHNOLOGY MAGAZINE




IN THIS ISSUE

COLUMNS

To submit an article or subscribe to *Future Force*, please visit our website or contact the managing editor.

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

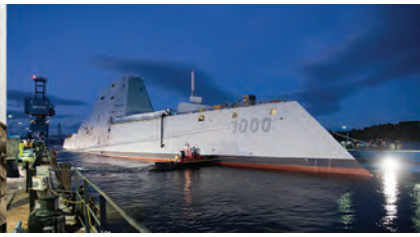
Email: futureforce@navy.mil
Phone: (703) 696-5031
Web: https://www.onr.navy.mil/en/Media-Center/futureforce
Facebook: http://www.facebook.com/navalfutureforce

BEYOND FUTURE FORCE ▼

Interactive features are enabled with the digital copy of Future Force:

https://www.onr.navy.mil/en/Media-Center/futureforce

Mobile Download



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.

This magazine is an authorized publication for members of the Department of Defense and the public. The use of a name of any specific manufacturer, commercial product, commodity, or service in this publication does not imply endorsement by the Department of the Navy. Any opinions herein are those of the authors and do not necessarily represent the views of the US government, the Department of the Navy, or the Department of Defense.

Future Force is an unclassified, online publication. All submissions must be precleared through your command's public release process before being sent to our staff. To subscribe to *Future Force*, contact the managing editor at futureforce@navy.mil, (703) 696-5031, or *Future Force* Magazine, Office of Naval Research, 875 N. Randolph Street, Ste. 1425, Arlington, VA 22203.

All photos are credited to the US Navy unless otherwise noted.

Front Cover: Illustration by Jeff Wright.

SPEAKING OF S&T

▶▶ Rear Adm. Kurt J. Rothenhaus, USN

Photo by Lance Cpl. Zachary Candiani

Greetings from the Office of Naval Research (ONR). We're pleased to bring you a new edition of Future Force magazine—a publication dedicated to exploring past, present and future capabilities that support the great Sailors and Marines who we have the privilege of serving.

As we look around the world, we know that technological prowess is not limited to the United States and our allies. In fact, competitor nations have been on the move for decades, studying our strategies and platforms, and developing forces and tools designed to combat us. In some cases, their capabilities have improved exponentially in the last decade alone. As reflected in the latest Navy's recently released Science and Technology Strategy, areas of critical importance where we must maintain dominance are autonomy and unmanned platforms. From seafloor to space, unmanned underwater, surface, and aerial vehicles are critical enablers to mission success. Several of the articles in this issue touch on progress on those key technologies.

The Navy and Marine Corps team have been leaders in autonomous and uncrewed platforms, with ONR supporting pioneering research around the world. Our early work, with REMUS vessels, among many other efforts, partnered with industry, academia, and the Naval Research and Development Enterprise (NR&DE) early, to support the fleet to establish significantly improved battle space awareness on, below, and above the seas. Within ONR, we look to the present and the future on a daily basis—providing our Sailors and Marines with capabilities they need today, and envisioning the tools they will need in the future to keep the peace, and, if necessary, win the fight and come home safe.

This edition also features groundbreaking work being done by and in support to the Marine Corps. In particular, the opening of a new research center near Marine Corps Base Quantico is truly exciting. We are excited to welcome and partner with Brigadier General Doran, both commanding general of the Marine Corps Warfighting Laboratory at Quantico and our Vice Chief of Naval Research.

Enjoy this edition of Future Force. We hope it informs and inspires you to continue to value and support the fleet and force we are proud to serve.

Rear Adm. Rothenhaus is the Chief of Naval Research.

EXPEDITIONARY LOGISTICS AND THE NEED FOR SPEED

Supplying and sustaining tomorrow's expeditionary battlefield will involve more than just maintaining and defending traditional lines of supply with land, sea, and air transport. The logistical tail of tomorrow's warfighters will have a greater presence and speed as unmanned and autonomous platforms become more important.

HOW WE GOT HERE

▶▶ By Colin E. Babb

THE DEEPEST LIFE

FAMOUS FOR A SINGULAR, HEROIC MOMENT THAT BROUGHT HUMAN BEINGS TO THE BOTTOM OF THE WORLD OCEAN FOR THE FIRST TIME, THE LATE DON WALSH WAS SO MUCH MORE THAN JUST A MAN WHO MADE THE "DEEPEST DIVE."

It's not often you get an email from a Swiss game show. A producer from the show, described as Switzerland's equivalent to "Who Wants to be a Millionaire," had sent it in hopes of answering a rather precise question: how deep did Jacques Piccard and Don Walsh go on their record-setting dive in January 1960? The internet provided conflicting answers; would the historian at the Office of Naval Research (me) be able to give a definitive solution? Let me ask Don Walsh, I replied. He was there.

Few people are lucky enough to have the kind of longevity where they get to see their lives pass from the merely mundane into the realm of legend, but Don Walsh was one of those people. (It is also, I should say, very rare for historians to have a living person handy to answer their historical questions for them.) Before his passing on 12 November 2023, Don was aware of his status as someone who had done something extraordinary as a young man yet lived long enough to see his public fame recede into the rear view mirror. (Chris Wright's 2015 book, *No More Worlds to Conquer*, chronicles this phenomenon with profiles of everyone from Olympic gymnasts to Apollo astronauts; Walsh's story is the first chapter.) Looked at more closely, however, Don had had a certain kind of fame in his youth. Seen in all its breadth, Don's life was in fact profoundly focused, and impactful, on our engagement with the sea from nearly beginning to end—and that was his true notoriety.

Photo by Bobby Cummings

Don will be forever known for his participation, alongside pilot and Swiss citizen Jacques Piccard (hence the particular interest from the game show), in the so-called "Deepest Dive" on 23 January 1960, at the Mariana Trench, more than 35,000 feet below the surface of the Pacific Ocean. Until 2012, these two men were the only human beings to have visited this unique destination, the Challenger Deep. (Since the dives of movie maker James Cameron in that year, those of explorer Victor Vescovo in 2019-22, and a Chinese expedition in 2020, the number of visitors to the world ocean's deepest location is now 27.) The craft used by Walsh and Piccard to descend to the bottom of the ocean, the bathyscaphe *Trieste*, remains one of the most distinctive underwater vehicles in history—visually and mechanically inspired by the balloons the Piccard family had used in the 1930s to reach world-record aerial ascents.

While reaching the deepest part of the world ocean was a heroic act that will likely always be remembered and measured chiefly in terms of feet (the accepted depth, by the way, for the dive has long been 35,814 feet; newer measurements place the spot they reached at slightly less than that), the real achievement of the dive was its clear and unequivocal statement that human beings could now reach any part of the ocean. Like so many firsts, it would take time and patience to make that statement have real meaning—there is so very much ocean to visit of course. In the decades after the dive, Don would dedicate his life to help make exploration of the world ocean a reality and improve our understanding of the sea.

I got to know Don in the early evening of his career some 25 years ago, when I was assigned as editor for his six-times-a-year column "Oceans" at the beginning of my own career when I was at the US Naval Institute *Proceedings*. Each column was intended to showcase an aspect of the world's oceans that escaped the other pages of the sea-service-focused magazine. In that respect Don was about the best person to tell that story.

Graduating from the Naval Academy in 1954, Don would go on to sub school and qualify for service in conventional submarines—just at the time when the Navy's submarine fleet was shifting to nuclear power (he never got an interview with Adm. Rickover, the infamously difficult gateway to nuke school, he once told me). He would serve in several mostly World War II-era boats before being associated with the *Trieste*, and eventually commanded USS *Bashaw* (AGSS 241) in the late 1960s. (At the time, it was probably the oldest active submarine in the world.) When he became a part of Project Nekton and the *Trieste* team to make the Deepest Dive in 1960, at a stroke he became the Navy's foremost submersible pilot. He would serve with *Trieste* for several more years and would go on to get an MS and PhD from Texas A&M University, with a focus on remote sensing of the oceans from space—at the time an area of science in its infancy.

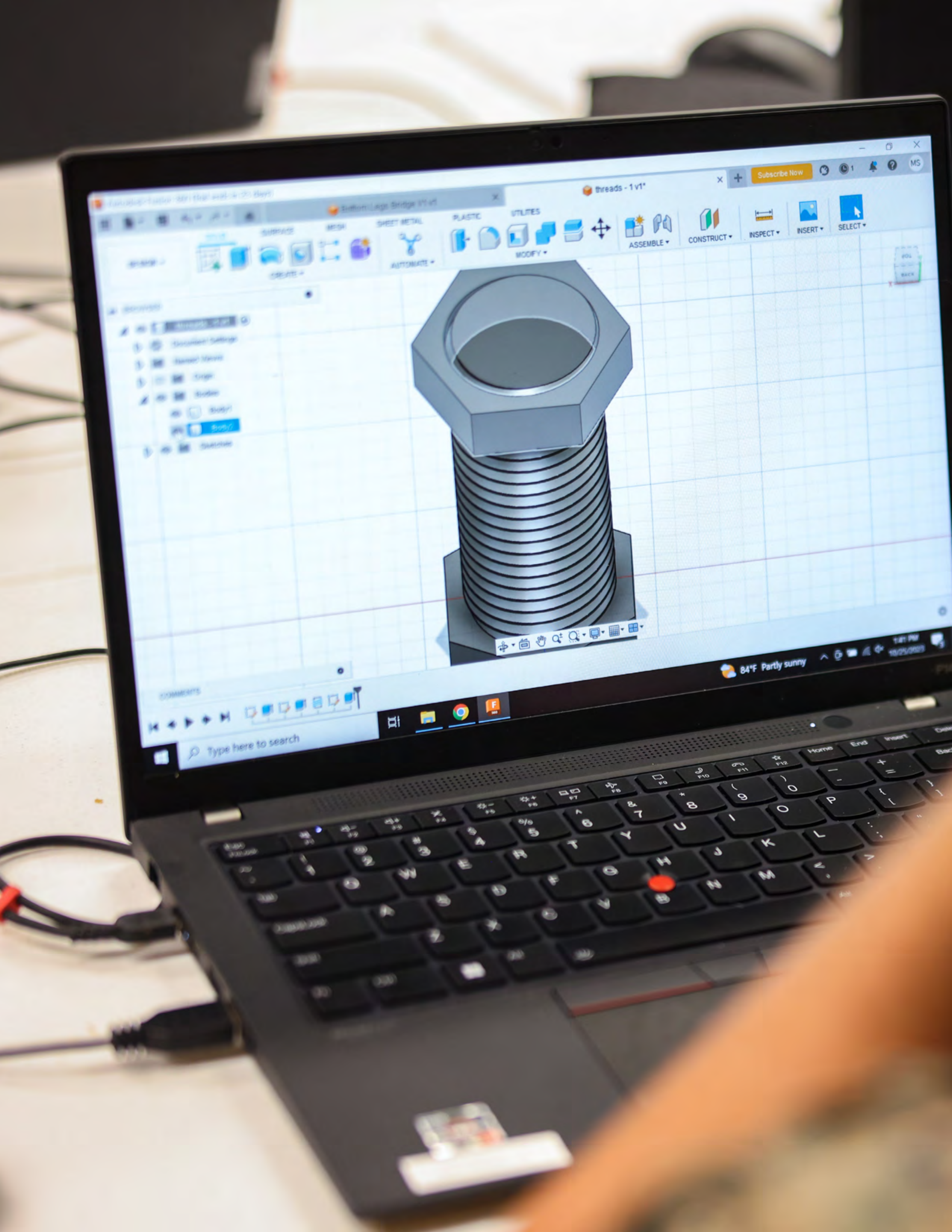
Don retired from the Navy as a captain in 1975, but in many respects his career had only begun. With his practical and professional experience, Walsh was appointed by two presidents to serve on the National Advisory Committee on Oceans and Atmosphere, from 1979 to 1985, and during this time also served on the Law of the Sea Advisory Committee during a crucial period when the current iteration of the United Nations Convention on the Law of the Sea was being negotiated. Although never ratified by the United States, the Convention on the Law of the Sea remains one of the most important foundations of current international maritime law and is recognized by 168 countries as well as the European Union.

Perhaps the most notable part of Don's "second career" was the time he spent as a cruise ship lecturer, something that kept him away from home for as many as six months of every year into his 90s. (He once estimated, in the early 2000s, that he probably had gone on the equivalent of several million dollars' worth of cruises.) Many of these were to some of the most isolated and difficult to get to regions of the world, especially the polar regions. From the many thousands of people he touched in lectures, talks, on committees, and in his association with organizations such as the Explorers Club, Don was a tireless advocate for greater engagement with and understanding of the oceans.

With Don's passing, one of the last living connections to ocean exploration's "heroic age" is gone. In the future, most of the exploration of the seas, like in so many other arenas, will be done remotely without humans having to risk life and limb sealed in steel spheres as Don and Jacques Piccard did more than 60 years ago. We all, however, live in their shadow, and can be grateful for all that they did in service to our connections to the sea.

About the author:

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


threads - 1 v1*
Subscribe Now
ASSEMBLE
CONSTRUCT
INSPECT
INSERT
SELECT
84°F Partly sunny
Type here to search

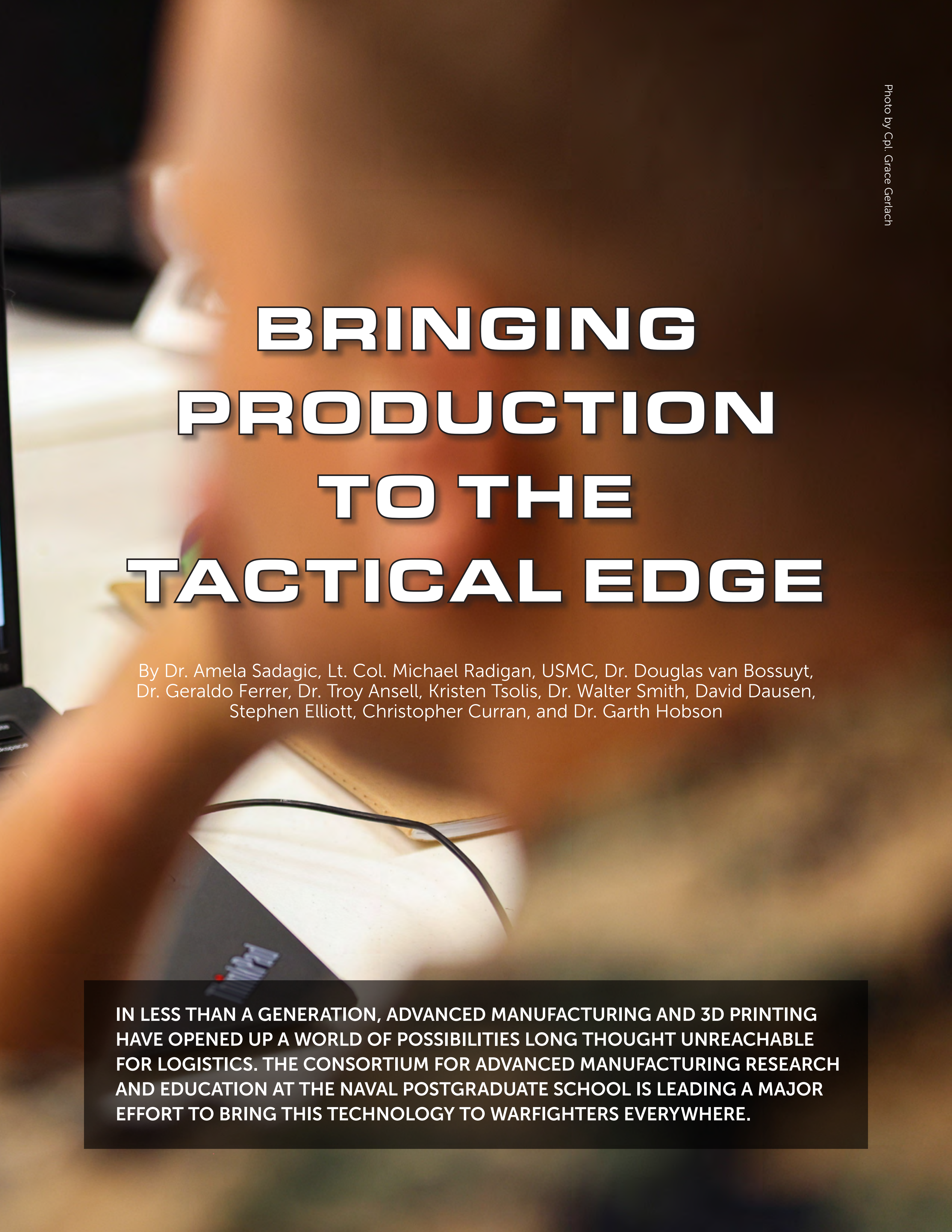


Photo by Cpl. Grace Gerlach

BRINGING PRODUCTION TO THE TACTICAL EDGE

By Dr. Amela Sadagic, Lt. Col. Michael Radigan, USMC, Dr. Douglas van Bossuyt, Dr. Geraldo Ferrer, Dr. Troy Ansell, Kristen Tsolis, Dr. Walter Smith, David Dausen, Stephen Elliott, Christopher Curran, and Dr. Garth Hobson

IN LESS THAN A GENERATION, ADVANCED MANUFACTURING AND 3D PRINTING HAVE OPENED UP A WORLD OF POSSIBILITIES LONG THOUGHT UNREACHABLE FOR LOGISTICS. THE CONSORTIUM FOR ADVANCED MANUFACTURING RESEARCH AND EDUCATION AT THE NAVAL POSTGRADUATE SCHOOL IS LEADING A MAJOR EFFORT TO BRING THIS TECHNOLOGY TO WARFIGHTERS EVERYWHERE.

The old adage, "amateurs talk strategy; professionals talk logistics," may soon need to be revised with "and experts talk advanced manufacturing." Operating in the Indo-Pacific region presents a time-distance equation we have not experienced since World War II. The needs and challenges of expeditionary logistics are, however, well known in the military domain. The challenge is that there are entire industries in the defense industrial base that have nearly halted production and some companies that do not exist anymore due to loss of demand. The military's issues also define its contemporary needs: flexibility, agility, adaptability, redundancy, and modularity while operating in a variety of environments. The inherent fragility of supply networks and transportation instability to the points of need all contribute to growing challenges that expeditionary logistics must address in novel ways.

The ability to produce parts on demand at the tactical edge will enable warfighters to outmaneuver an enemy and complement existing supply systems. It is only recently that advanced manufacturing (AM) machines are beginning to catch up with warfighters' imaginations. Modern 3D printing solutions are robust, and they can now deliver parts larger than the previously limited desktop lab environments with acceptable materials and properties. The available materials list is ever increasing, and these additive machines can even be integrated with subtractive solutions in a hybrid, multi-axis system. While temporarily redeploying service members from their primary duties in the middle of battle may seem counterintuitive, their operation of those systems to produce autonomous capabilities and accelerate field repairs could be the necessary force multiplier to win in combat.

Advanced Manufacturing

AM will bolster (though not replace) the supply system, and it may induce unintended consequences and different kinds of stress. If multiple components, however, can be made of the same raw material, why not inventory that material in a single spool, powered with a digital repository, allowing warfighters to build these components as needed? Thanks to AM, supply ships will have the capability to produce parts that would take too long to fulfill from the mainland. The realization of this vision requires two significant developments: identifying in advance the parts that have the potential to be produced by AM, and generating a library of those parts—which will become available whenever a part needs to be built on a supply ship. It is, therefore, vital for the domestic industrial base to integrate traditional manufacturing with AM methods, feeding on each other in an iterative fashion, to enable sustained maintenance on the field without the need for extensive inventories of spare parts that are seldom used.

Because AM can reduce dependency on complex and often fragile supply chains, it is especially valuable for naval operations. Logistics ships could be given AM technology to produce a large set of critical components locally, reducing vulnerability to supply chain disruptions—which can be a particularly useful capability in a contested environment or in remote operational theaters.

To maximize the power of AM, its function must be more than just to print repair parts that look and feel identical to the ones that failed. Critical thinkers on the battlefield cannot apply changes to the design in real-time and reduce the opportunity of the same failure. Most important, the same systems allow warfighters to create new solutions that have never existed before. These solutions can then be fed back to the domestic industrial base for mass production with economies of scale, and thus, the feedback loop that includes industry is complete.

To maximize the power of AM, its function must be more than just to print repair parts that look and feel identical to the ones that failed.

Success Depends on Affiliated Domains

The success of expeditionary logistics depends on achievements in many domains, and AM is one part of that complex solution. Materials development and parts validation are another part of the solution. Although Sailors or Marines can print temporary replacement parts during deployment, long-term application of printed parts will require validation of mechanical properties (e.g., tensile strength), fatigue testing, analysis of corrosion behavior, and materials characterization. A critical factor is being able to link material properties in the printed part to the part being replaced.

The first step is to create a digital twin that captures not only the part dimensions but also the simulated part behavior. Then, through the proper application of AM technology and postprocessing, we can print a part with high fidelity and replicate geometry and material properties. The same digital artifacts must be stored and transmitted to the point in need using the infrastructure that satisfies stringent cybersecurity measures and protection. The personnel working with 3D printing systems require training in operating and maintaining those systems; that may also include expertise with 3D modeling software needed to create or manipulate 3D models of known or new parts and tools. In addition, all solutions that are to be operated by humans need to have an interface that is easy to learn and use to avoid being an obstacle in the technology adoption process.

An ElemX 3D printing machine in a 20-foot containerized system was deployed aboard USS *San Diego* (LPD 22) in September 2023. Photo by Kevin Demesa

Despite its advantages, AM technology remains susceptible to cyber threats. Tampering with digital twin files can compromise component integrity, leading to accidents or catastrophic failures. Cyber attackers can also create counterfeit products, compromising weapon systems. Intentional flaws introduced in the manufacturing process can compromise part integrity, posing significant risks in critical operations. And in contested environments, cyber attackers might isolate design locations from manufacturing sites, disrupting the entire production process.

To mitigate these risks, strong cybersecurity measures are paramount. Safeguarding digital twin files, employing encryption, securing communication protocols, and implementing access controls are crucial steps. Adequate employee training to recognize and respond to cyber threats is essential for secure integration of AM technology in the logistics systems. By focusing on these strategies, naval operations can harness the benefits of AM while maintaining security and operational readiness, even in contested environments.

AM capabilities also need to be well integrated into acquisition and logistics enterprises with programs of record backing them up. Having a set of one-off solutions sparsely acquired across the fleet is neither scalable nor sustainable, and, as a result, such a situation does not bring the critical advantage needed in contemporary warfare.

CAMRE Initiatives and Research Efforts

The Consortium for Advanced Manufacturing Research and Education (CAMRE) at the Naval Postgraduate School (NPS) is a coalition of stakeholders with the mission to "accelerate widespread adoption of additive manufacturing across the Department of Defense," in support of the tri-service maritime strategy, Advantage at Sea.

To that end, CAMRE researchers identified and selected several high-gain initiatives aimed at accelerating the adoption of AM. These can be classified into three groups, the efforts that: get the AM and affiliated systems ready, get the personnel ready, and engage in early experimentation and deployment of AM across the fleet.

CAMRE researchers have tested printed parts and demonstrated that those parts could be used to replace traditional parts. An example included an investigation of the properties of printed maraging steel (a high-strength steel used by the Marine Corps for parts in motor transport assets). It was found that the strength of both as-printed and precipitation-hardened maraging steel exceeded that found for traditionally fabricated maraging steel, something that has been observed in the AM community for other 3D printed materials. CAMRE has been experimenting with alternative AM approaches as well, such as liquid metal printing to produce parts that cannot be manufactured using other techniques, including metal foams and thermal components. These technologies allow the use of alloys such as AA7075, which is a very high-performance aluminum alloy used in aerospace applications.

CAMRE researchers also have developed digital twin templates for 3D printers, allowing the rapid development and deployment of digital twins for AM. The digital twins can monitor 3D printers in real time and determine when maintenance needs to be performed and whether parts coming off printers may not meet quality standards. Having a digital twin stereotype, a generic digital twin that can be adapted to specific makes and models of printers, allows for a centralized understanding of the overall health of the fleet of 3D printers.

Metal AM forms bulk material differently from classical subtractive manufacturing techniques. As a result, material properties differ from subtractive manufactured parts. In ideal conditions, it is possible to embark on a materials characterization campaign to fully understand these differences. In the case of forward-deployed manufacturing, this sort of scientific endeavor is less feasible. In these cases, it is vital to develop an understanding of the bounding box of acceptable conditions for manufacture. These can include atmospheric as well as adverse accelerations and vibrations. In an effort to better understand the conditions these machines will be exposed to, NPS has developed a physical twin experiment with AM being deployed at sea and compared it to AM in the lab. NPS has designed a data acquisition system to fully monitor the environmental conditions of each print in both locations. Monitored conditions include pressure, temperature, oxygen concentration, humidity, vibrations, and inclinations. These are all monitored at high speed to ensure that each part of the print process is appropriately characterized.

To gain an understanding of materials characterization and develop training for future operators, NPS has forward deployed various printers with data acquisition capability. This effort began by encapsulating large-scale metal printers for deployment. NPS worked with Navy salvage and diving to generate a containerized version of a liquid metal aluminum printer. This containerized solution has been sent to sea aboard USS *Essex* (LHD 2) for RIMPAC 2022, then sent to the Marines at Camp Pendleton for training and exercises, and finally to USS *San Diego* (LPD 22) for further at-sea testing. In addition, these efforts have been expanded to the icebreaker USCG *Healy* (WAGB 20) using advanced plastic printers.

Change agents are the vanguards of progress; they are individuals and institutions that drive innovation and transformation. In the realm of AM within the Department of Defense (DoD), these agents play a pivotal role in propelling the military's capabilities into the future. Innovators and adopters are two critical categories within the framework of technology adoption. Innovators are trailblazers, envisioning and developing cutting-edge technologies and methodologies. They create the blueprints for the future. Conversely, adopters are the pragmatists who recognize the value of innovation and translate it into practical implementation. They are essential in ensuring that transformative ideas find their way into tangible applications within the DoD's operational context.

Preparing warfighters for using AM requires training, iterative exploration, and an appetite for productive failures.

Preparing warfighters for using AM requires training, iterative exploration, and an appetite for productive failures. NPS students can explore AM in class or during workshops in our multidisciplinary campus maker space. Whether or not they use computer-aided design, students learn how the military has used AM to date, how to find a 3D model, prepare it for a printer, and print in inexpensive and forgiving materials. They also learn about various printing technologies and the pros and cons of 3D scanning. Once they gain confidence with the basics, they can explore printing with other more expensive and complex materials that require additional training. Our students, newly returned from operational experience, have a unique perspective on military problems and how they might solve them, and several have even helped the local US Coast Guard group design and fabricate noncritical boat parts that are either difficult to procure, do not yet exist, or might lend themselves to design improvement. Our students have also produced parts as part of their AM class to 3D print training aids, new designs for military equipment, and tools. Many of our nontechnical officers are eager to adopt AM as well as to understand the risks to which they expose their colleagues and their careers by choosing AM-printed parts. Classes will often discuss the differences between military services' tolerance for AM risk and the scope of risks in adopting (or not adopting) AM. Students from NPS have gone on to fill many leadership positions in the military AM space. CAMRE also maintains ties to other military and service academy maker spaces to share lessons learned, best practices, and use cases for AM adoption.

NPS stands as a beacon of excellence in this landscape. With its rigorous academic programs, world-class faculty with expertise in diverse domains, and extensive research facilities, NPS is uniquely poised to serve as a catalyst for accelerating AM within DoD. The institution's focus on interdisciplinary collaboration fosters an environment where experts from different domains, innovators, and adopters can come together, bridging the gap between theoretical advancements and real-world application. NPS's strategic location close to key defense industry hubs provides an invaluable opportunity for meaningful industry partnerships, ensuring that the innovations developed within its walls find a seamless path to integration within the broader defense ecosystem.

The task of technology adoption is an endeavor of significant complexity and a number of active participants who need to make strategic decisions and support that process. CAMRE has been reaching out to many groups and individuals and it has well-established working relationships and collaborations with Naval Sea Systems Command, including the repair Centers in Norfolk and San Diego, the Marine Corps, and the Coast Guard. The mission that

Marine explosive ordnance disposal technicians look at models made from 3D printers during an explosive ordnance disposal additive manufacturing course at Marine Corps Base Hawaii. Photo by Cpl. Grace Gerlach

CAMRE has is a compelling one, and it will be achieved only with persistent work over an extended period and in collaboration with all stakeholders whose actions affect the adoption of AM.

The Future

AM is already in use in the defense sector and has seen limited deployment afloat and ashore, but the future of expeditionary logistics lies in the full embrace of AM. An ecosystem of 3D printers from the tip of the spear all the way back to logistics hubs in North America will allow components and assemblies to be rapidly produced when and where needed and keep us in the fight. We must, however, not lose sight of the greater logistics and sustainment ecosystem that includes the many other technological advancements that are happening today, such as artificial intelligence and machine learning, data science and data mining, computer vision, cybersecurity and cyberwarfare, virtual and augmented reality, robotics, and many of the classical and newer engineering disciplines that contribute to these technologies. The military that integrates all these technologies into their logistics and supply chain, as well as their design and manufacturing processes, will be enabled to perform more challenging missions more rapidly in contested or denied environments.

The rapidly evolving nexus of these technologies requires extreme inter- and transdisciplinary cooperation. Traditionally siloed science and engineering disciplines must work seamlessly across long-held boundaries to integrate and iterate their combined knowledge. The CAMRE effort has demonstrated this already within the domain of AM by successfully integrating mechanical engineers, systems engineers, computer scientists, operations researchers, and many other disciplines. That has allowed CAMRE to advance the field of AM for warfighters rapidly.

About the authors:

Dr. Sadagic is a research associate professor in the Computer Science Department and the Modeling, Virtual Environments and Simulation Institute at the Naval Postgraduate School. She serves as a co-director for CAMRE and the Center for Additive Manufacturing.

Lt. Col. Radigan is a member of the Marine Innovation Unit and a liaison from the Marine Corps Warfighting Laboratory to the Naval Postgraduate School.

Dr. van Bossuyt is an associate professor in the Systems Engineering Department at the Naval Postgraduate School.

Dr. Ferrer is the Chair of Naval Supply Chain Management at the Naval Postgraduate School.

Dr. Ansel is an assistant professor in the Mechanical and Aerospace Engineering Department at the Naval Postgraduate School.

Kristen Tsolis is a lecturer in the Defense Analysis Department and a director of the RoboDojo Laboratory at the Naval Postgraduate School.

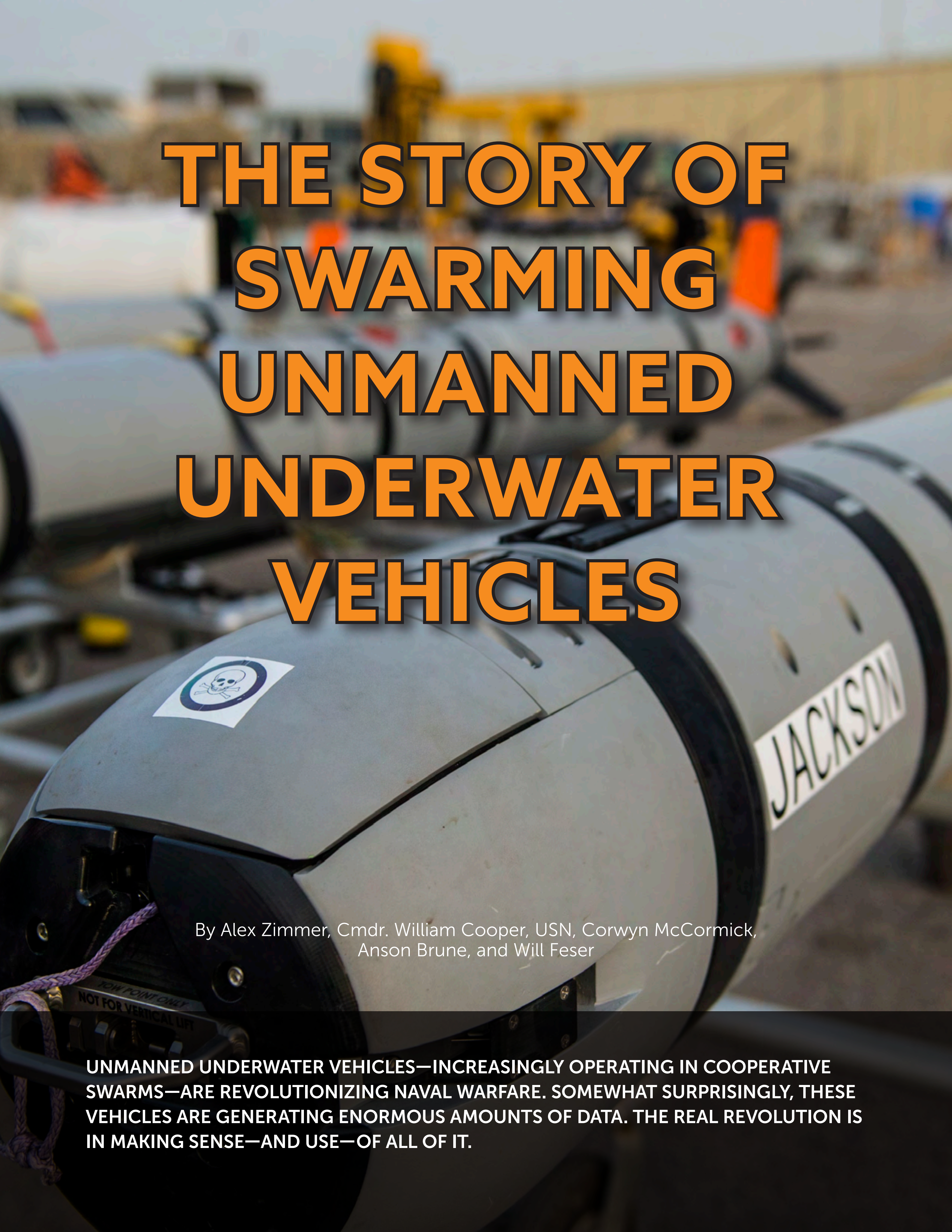
Dr. Smith is a research associate professor in the Mechanical and Aerospace Engineering Department at the Naval Postgraduate School.

David Dausen is a faculty associate (research) in the Mechanical and Aerospace Engineering Department at the Naval Postgraduate School.

Stephen Elliott is an associate director of FLEETWERX.

Christopher Curran is a program manager for CAMRE.

Dr. Hobson is a professor in the Mechanical and Aerospace Engineering Department at the Naval Postgraduate School. He serves as a director of CAMRE.



THE STORY OF SWARMING UNMANNED UNDERWATER VEHICLES

By Alex Zimmer, Cmdr. William Cooper, USN, Corwyn McCormick, Anson Brune, and Will Feser

UNMANNED UNDERWATER VEHICLES—INCREASINGLY OPERATING IN COOPERATIVE SWARMS—ARE REVOLUTIONIZING NAVAL WARFARE. SOMEWHAT SURPRISINGLY, THESE VEHICLES ARE GENERATING ENORMOUS AMOUNTS OF DATA. THE REAL REVOLUTION IS IN MAKING SENSE—AND USE—OF ALL OF IT.

Naval Warfare Information Center Pacific's MK-18 program has delivered advanced capabilities to the Navy's explosive ordnance disposal community in the form of unmanned underwater vehicles (UUVs) that exhibit intelligent and autonomous behavior. These systems originated as commercial solutions that used human-based mission planning and objectives. Developments in advanced sensors combined with artificial intelligence and machine learning aided perception in the form of automatic target recognition have enabled these UUVs to operate in swarms or squads to best achieve their mission objectives. These UUVs leverage embedded target recognition and create dynamic objectives "on the fly" within the autonomy framework. This behavior results in decreased mission timelines, and the autonomy engine also perpetuates a shared world model ensuring that in a situation where a single UUV fails, the mission can still be accomplished by other UUVs in the swarm.

Expeditionary Mine Countermeasures

On 18 February 1991, USS *Tripoli* (LPH 10), an amphibious assault ship operating in the Persian Gulf, struck a moored mine. The damage was extensive—the blast had blown a 16-foot-by-25-foot hole ten feet below the water line in the ship's bow. Thankfully, no one was killed. At the time of the strike, *Tripoli* carried a minesweeping force composed of six MH-53 helicopters. These aircraft, however, were not deployed while the ship was under way. Less than three hours later, reports came in of a second damaged ship, the guided-missile cruiser USS *Princeton* (CG 59).

In less than a day, three naval mines (two influence and one contact mine) had dramatically altered the ability of the United States to project power ashore with acceptable losses. As a result, the Navy began to look hard at how to close the capabilities gap in littoral operations. Operating near shore in contested environments was recognized as a high-level requirement. In addition, the Marine Corps needed a way to conduct an amphibious assault through a suspected minefield when contemporary, conventional mine countermeasure forces were not fast enough. In 1996, the Chief of Naval Operations directed the establishment of a Very Shallow Water mine countermeasures detachment, and soon after Naval Special Warfare, Marine Force Reconnaissance, and Navy Explosive Ordnance Disposal (EOD) formed a test detachment. The mission was to develop and test tactics, techniques, and procedures to clear assault lanes for amphibious forces. This unit was also tasked to investigate new technologies as they became available.

Origins of NSCT 1

Technology and concept of operations development warranted the detachment being commissioned into a full unit designated as Naval Special Clearance Team (NSCT) 1 in 2002. The unit provided requirements for (among other things) an unmanned UUV very shallow water mine countermeasures system based on lessons learned. The Navy's EOD program office, PMS 408, contracted for a three UUV prototype system based on Hydroid's Sculpin to be acquired for further development of tactics, techniques, and procedures. Before the new system arrived, the unit was deployed to Iraq for the assault phase of Operation Iraqi Freedom in 2003. Navy EOD was able to assemble four prototype REMUS 100s for the effort and conducted their first wartime use to map the Iraqi ports of Umm Qasr and Al Zubair. Over the next several years, these prototype REMUS systems (including the larger, deeper-diving, higher-duration REMUS 600) were evaluated across a series of missions and different environments with direct input from both government engineers and military end users. The designation MK-18 was applied to the program.

Fielding a Capability

In late 2011, Iran threatened to close the Strait of Hormuz. The American response was to increase mine countermeasures (MCM) capabilities in the 5th Fleet dramatically. Eight MCM ships and a MH-53 mine hunting helicopter squadron were forward deployed to Bahrain. Although the MK-18 Mod 2 systems (based on the REMUS 600 platform) were being developed specifically for very shallow water missions at that time, they were more than capable of deeper and longer-duration missions for open-water mine countermeasures. As a result, the Secretary of Defense approved a "Fastlane" initiative, an accelerated acquisition program to field 12 medium-class REMUS 600 Kingfish UUVs to 5th Fleet. In 2012, the first MK-18 Mod 2s and contractor operators arrived in Bahrain and were attached with Commander, Task Force 56 (Navy Expeditionary Combat Forces Central Command). Within a few months of deployment, the UUVs, through a number of exercises, proved to be a reliable and flexible options for mine detection and classification.

In 2013, the Navy Expeditionary Combat Command began forming a new unit of action: the expeditionary MCM company. The plan was to eventually provide two forward-deployed companies in both 5th Fleet and 7th Fleet at all times. In 2014, a MK-18 UUV operations and maintenance training course was established at the Naval Mine Warfare Training Center in San Diego to help meet the demand for trained operators. To date, more than 700 fleet personnel have been trained to operate the MK-18 family of systems.

Big Data...We Have a Problem

The introduction of the MK-18 UUVs into operations heralded a new age of mine countermeasures. Sailors could deploy these expeditionary systems from rigid-hull inflatable boats and collect high-quality sonar imagery. It quickly became apparent, however, that with the high data collection rates and strong endurance of the battery cells onboard, something unanticipated happened: managing the large amounts of data became a challenge.

Multiple vehicles in an area of operations conducting long-duration missions generate copious amounts of

Photo by PO1 Julian Olivari

sonar imagery that need to be reviewed. This process, known as postmission analysis, is time and labor-intensive. First, UUVs are recovered and returned to the ship or shore, where data is extracted and uploaded to a postmission analysis computer. Finally, operators trained to locate mine-like objects by combining key features, such as shape, shadow, dimensions, and volume, review the data and identify targets of interest. Since operator training and postmission analysis experience levels vary, these large amounts of data became the MK-18's most valuable asset—as well as potentially its biggest headache.

Where Do We Go from Here?

Early techniques for detecting targets of interest in sonar imagery collected on the UUVs were called computer-aided detection/computer-aided classification (CADCAC). These image-processing techniques were integrated into the command-and-control software located on the analysis computer. The output of these techniques was visualized in the form of a white-dotted circle overlaid on the sonar imagery, directing the operator's eyes to the target of interest. This was important because operators, with their varying levels of experience, often had highly variable processes. In contrast, CADCAC was consistent, even if performance was not optimal.

While the idea of applying current technology to solve the problem at hand was sound in theory, the primitive detection software often resulted in hundreds of CADCAC calls per mission. This led to fleet users reporting that the technology was a detriment to the analysis workflow and cluttered the screens they had available. A new solution was needed.

The application of deep learning to this problem proved revolutionary. Training the automatic target recognition models using neural networks showed a tremendous increase in the probability of detection/classification and a dramatic lowering in false alarms. Individual models from Johns Hopkins University's DeepMine, Northrop Grumman's MineHunter, SeeByte's ATR, and Naval Surface Warfare Center Panama City Division's XATR were fused into the generalized automatic target recognition framework. Each model has its own strengths and weaknesses (higher probabilities, or lower false alarms) yet fusing them together optimized the system's performance. In addition, the application of automatic target recognition significantly increased the speed with which operators could conduct analysis, resulting in a shorter detect-to-engage timeline. Topside target recognition had become a capability for the end user instead of just another tool.

Distributed Sensor Networks Coalescing Together

Advancements in embedded processing enabled the next stage of the evolution of mine countermeasures UUVs. Previously, the vehicles could operate and conduct their missions with a predetermined course and objective planned by operators. Data were then collected and downloaded postmission, initiating the analysis process. Integrating powerful Nvidia graphics processing units onboard the vehicle and the parallel integration of the Neptune autonomy product opened a new range of possibilities.

Operators were able to plan a set of objectives, similar to before. Each UUV participating in the mission would be integrated into a squad of vehicles and be aware of the objectives assigned to the other vehicles in the squad. This concept of a persistent "World Model," where teams of vehicles could work together on multiple objectives, became critical.

The MK-18 Mod 2 Kingsfish, now a standard unmanned underwater vehicle used by mobile diving and salvage, explosive ordnance disposal, and mine countermeasures units, is a modified version of the REMUS unmanned vehicle originally developed by Woods Hole Oceanographic Institution with the support of the Office of Naval Research. The first major use of this technology occurred in 2003 with the clearing of Iraqi ports in the aftermath of Operation Iraqi Freedom. Photo by MC2 Benjamin Wooddy

Once the UUVs are launched, this World Model is updated by acoustic communications between vehicles while they complete their assigned objectives. If one vehicle fails, the other vehicle takes over. If one vehicle completes its primary objectives early, it will assume secondary objectives from the other vehicle.

In addition to the autonomy functionality, automatic target recognition was brought to the "wet edge," a paradigm where systems must operate disconnected from any sort of network or high-powered cloud computing center. The wet edge is an inhospitable

The introduction of MK-18 unmanned underwater vehicles heralded a new age of mine countermeasures and other naval warfare areas. It quickly became apparent, however, that with the high data collection rates and strong endurance of the battery cells onboard, something unanticipated happened: managing the large amounts of data became a challenge. Photo by Chief MCS Travis Simmons

environment demanding the vehicle use its onboard sensors to the greatest extent for decision making, with little to no communication back to a monitoring station. Imagery collected from vehicle sensors is processed using multiple algorithms onboard the vehicle. Targets of interest are identified and assigned a confidence level, after which they will be added to the World Model. This allows automatic target recognition to queue autonomy and add dynamic objectives to the squad. When one vehicle finds a target of interest, it can task another vehicle with a higher-fidelity sensor to get a better look. In effect, a distributed sensor network was implemented using UUVs with various capabilities.

Continuous Machine Learning Operations Pipeline

Looking toward the future, the next stage is rapid deployment and learning of automatic target recognition models based on data collected by forward-deployed units. To achieve the next stage of artificial intelligence/machine learning capabilities, these systems will need to be able to collect data and funnel it from the tactical edge back to developers, who will train additional models and get those models back to the fleet in rapid fashion.

This involves model monitoring onboard the "wet edge" to determine when the predeployed model is no longer optimal for the target environment. This can mean the automatic target recognition is no longer able to detect targets of interest or distinguish bottom features based on the data on which it was trained previously. To achieve this vision of a machine learning operations pipeline, a new set of tools is being developed in conjunction with Project AMMO (Automatic target recognition Machine learning operations for Mine countermeasures Operations) and Project Overmatch, the prioritized effort to build the naval operational architecture to fully enable distributed maritime operations, expeditionary advanced base operations, and littoral operations in a contested environment. MK-18 is actively involved in demonstrating the culmination of these efforts and remains on the cutting edge of automatic target recognition development.

MK-18 UUVs must be able to operate, sense, and adapt their way through the undersea domain, which can greatly constrain intervehicle communications, all while providing tactically relevant information back to the Sailors monitoring the mission. The challenges faced in this environment are unique, planetwide, and cannot be understated. It is clear, however, that furthering artificial intelligence/machine learning capabilities to aid in intelligent decision making and leveraging autonomy to execute the follow-on behaviors is the path forward for more capable UUVs. While there are still leaps forward to be made and the future does look bright, we have to step back and recognize how far we have come. Anytime a UUV is deployed and a ship full of Sailors is removed from the threat of minefields, the threat to human life is reduced.

About the authors:

Alex Zimmer is the program lead supporting underwater explosive ordnance disposal and artificial intelligence/machine learning within the Program Office for Expeditionary Missions, PMS 408.

Cmdr. Cooper is a Navy explosive ordnance disposal officer and the fleet product director for underwater explosive ordnance disposal within PMS 408.

Corwyn McCormick is a contractor from Orca Maritime supporting PMS 408.

Anson Brune is head of the Expeditionary Unmanned Systems Technology Development Branch at Naval Information Warfare Center Pacific.

Will Feser is head of the Expeditionary Unmanned Systems Fleet Support Branch at Naval Information Warfare Center Pacific.

SWEDISH AND AMERICAN MARINES TRAIN TOGETHER IN THE "EXTREME LITTORALS"

By Capt. Edward Lundquist, USN (Ret.)

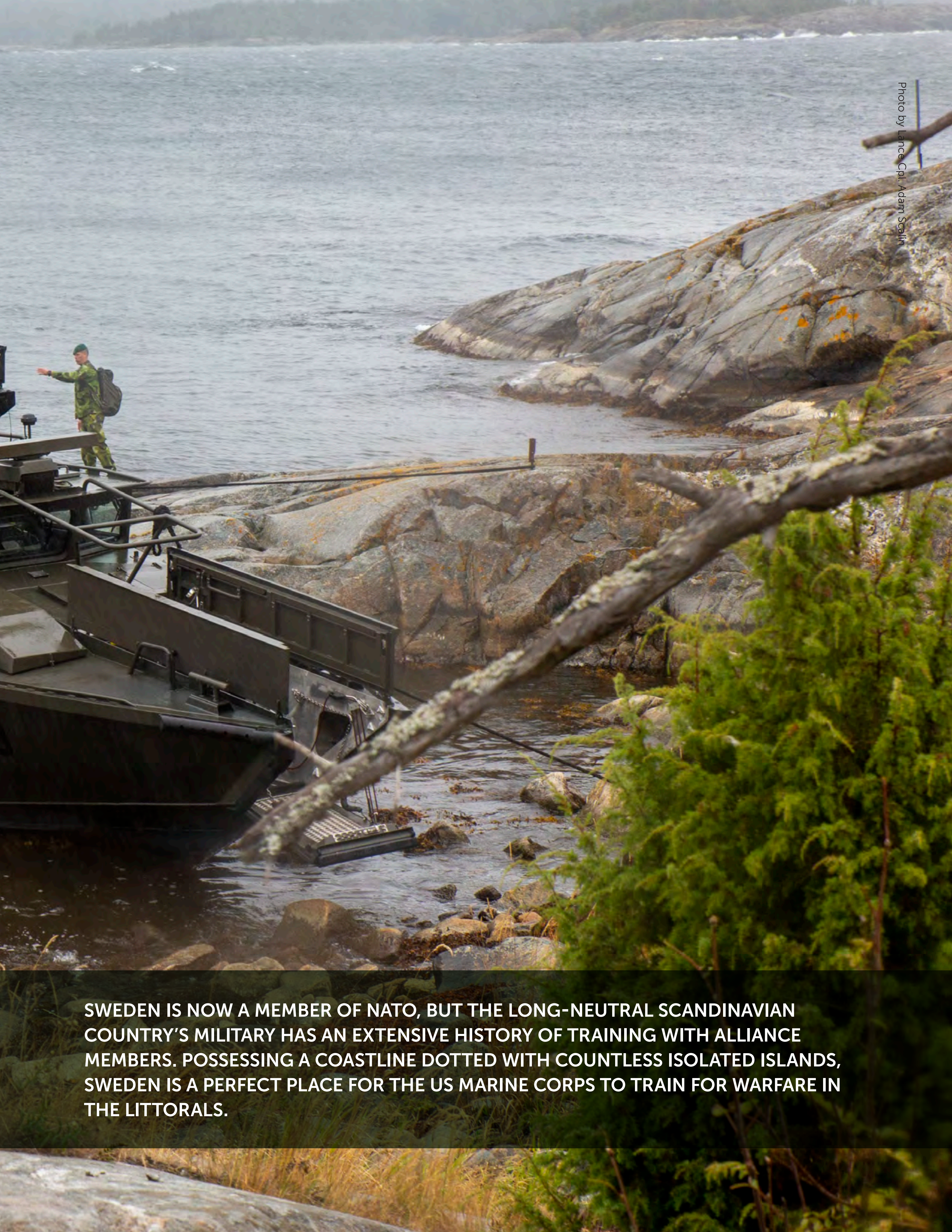


Photo by Lance Cpl. Adam Scalin

SWEDEN IS NOW A MEMBER OF NATO, BUT THE LONG-NEUTRAL SCANDINAVIAN COUNTRY'S MILITARY HAS AN EXTENSIVE HISTORY OF TRAINING WITH ALLIANCE MEMBERS. POSSESSING A COASTLINE DOTTED WITH COUNTLESS ISOLATED ISLANDS, SWEDEN IS A PERFECT PLACE FOR THE US MARINE CORPS TO TRAIN FOR WARFARE IN THE LITTORALS.

The US Marine Corps is sharpening its skills to conduct distributed maritime operations and expeditionary advance base operations in a contested environment. That's why they teamed up with Swedish marines for the Archipelago Endeavor 2022 exercise near the Berga Naval Base along the rugged Swedish coastline.

Brigadier Gen. Andrew T. Priddy, deputy commanding general of II Marine Expeditionary Force, said the exercise was very important. "The Swedes have about 100,000 islands, so being able to operate in this type of environment—in the archipelago and in the littorals—for the Swedish forces, it's extremely important. For us, as a Marine Corps, we have a lot of lessons we can learn."

The Swedish archipelago is about as different as you can get from Iraq and Afghanistan, and the Swedish marines are experts in exploiting the environment to their advantage. It's their front yard, and they know it very well. At the same time, the US Marines have their own knowledge and tactics to share.

"We have some tactics, techniques and procedures that are different between our services. We're learning a lot from each other," Priddy said.

The forces moved around the many islands to practice securing objectives and then practiced sustaining their forces spread out in the austere environment.

Priddy explained the tactical scenario for the morning. "We've got an enemy on one of the islands. We're suppressing their fire with mortars and heavy machine guns, and we'll follow up with an amphibious landing and take the island with a platoon of about 40 US and Swedish marines in two combat boats."

The blustery rain, along with choppy seas and rugged rocky terrain challenged the warfighters. But it also made for a good training environment. According to Priddy, that's the way Marines like it.

"I think you can see its very Marine Corps friendly," he said with a smile while talking with reporters out on windswept Lilla Skogsskar Island.

The US Navy and Marine Corps Distributed Maritime Operations, Littoral Operations in a Contested Environment, Concept for Stand-in Forces, and Tentative Manual for Expeditionary Advanced Base Operations (TM-EABO) underscore the importance of providing the resources of combat power where and when needed.

According to TM-EABO, "Littoral forces rely on resilient and agile logistics that adapt to changing environments and conditions to conduct EABO. Effective sustainment provides the means to enable freedom of action

US Marines with Littoral Engineer Reconnaissance Team, 8th Engineer Support Battalion, II Marine Expeditionary Force, conduct a patrol to recon a potential beach landing site during exercise Archipelago Endeavor. Photo by 1st Lt. William Reckley and endurance while extending operational reach. Sustainment determines the depth to which a force can conduct decisive operations, allowing a commander to seize, retain, and exploit the initiative."

The Marines understand that distributed maritime operations (DMO) and EABO required new ways of thinking about supporting small units, which may be constantly on the move, at remote locations. Archipelago Endeavor provided an excellent warfighting environment in which to experiment and train and put the new concepts to the test.

"In this exercise, we're operating in a littoral environment, with water standing between us here and the objective," Priddy said. "I think our biggest challenge is sustaining ourselves forward, being able to both operate inside of the littoral region and being able to project logistics forward to sustain that force. We have a lot to work to do."

Sgt. David Swinton of the US 2nd Light Armored Reconnaissance Battalion said the joint training improved the Marines' ability to operate in the archipelago. He said the US Marines were "disaggregated," and working in smaller teams. He said the Marines used their Puma unmanned aerial system to "livestream everything we're doing back to the fleet," and to "help the Swedes walk their mortars onto the target."

"This is a difficult environment to operate in, both from the weather but also from being in all the different islands and the littorals," Swinton said.

Swinton's communications team used a commercially available Simrad Halo 24 radar that can be found on fishing boats and adapted it to provide surveillance data into the classified network. This way, Marines distributed throughout the archipelago would have access to contact information on hostile vessels.

Swinton said it is important to establish relationships in time of peace, before a crisis and needing to have those relationships. "Working with our Swedish partners here to develop those relationships now is exactly what we're doing," said Swinton. "We're both professional forces that work very well together."

Capt. Brandon Klewicki commanded the Mobile Reconnaissance Company, 2nd Light Armored Reconnaissance Battalion, 2nd Marine Division. "We exemplify the warfighting concept of distributed maritime operations and expeditionary advance base operations explained in the Marine Corps Force Design 2030. We operate much like small, mobile guerilla forces that can target and track vessels moving within the contested littoral, and avoid those counter measures traditionally used by naval forces. Using small tactical vehicles, commercial off-the-shelf boat radars, and small unmanned aerial systems, we can enhance the maritime domain awareness for fleet forces. Our secure tactical

"US and Swedish marines recover an AMY unmanned surface vehicle (an ONR-supported technology) aboard a Combat Boat 90, a small high-performance light craft of Swedish manufacture. To the right is the larger Reckless unmanned surface vehicle, which is being used for logistics support of small units in austere littoral environments. Photo by Edward Lundquist

data links connect our sensor data with the network to provide targeting information to the appropriate shooters.

Klewicki said Archipelago Endeavor was an opportunity to "further demonstrate and refine the concepts and technologies in the company in a very challenging maritime terrain, alongside a key regional partner—and soon to be ally."

During Archipelago Endeavor, the US Marines got familiarized with the Swedish watercraft platforms—specifically the Group Boat (also known as the G boat), Combat Boat 90 (CB 90), and Hovercraft 2000, which the Swedes use to move people, equipment, and supplies around the islands.

The Americans brought unmanned systems, including a pair of unmanned surface vessels (USVs), to integrate into their operations. A Sonar Amy and Reckless USV, both made by Arizona-based Hydronalix, were used to provide reconnaissance of the underwater environment in and around the areas where the Marines would be operating, as well as to move supplies such as food, water, ammunition, and batteries from the boats to the Marines ashore on the islands.

"How they would be used depends on the tactical situation," said 1st Lt. Terrence Rohmeyer of Combat Logistics Battalion 6 Littoral Tactical Logistics Section. "It depends on the problem set were faced with. USVs could be the answer. You could get several hundred pounds on [the Reckless], which would be enough to forward-sustain a rifle platoon. If we need a larger sustainment model, we might be looking at a G Boat or CB90, due to the added capacity. With the manned boats, we need operators, as well as people to manage the cargo. The unmanned autonomous boats allow us to load the boats and set the destination and then it gets there without dedicated manning.

"We're practicing deploying the USVs from the G-boats and CB90s, as well as our typical shore-based deployment," Rohmeyer said. "We program it for mission and send it to a forward location along with a route to get there. After it arrives at its destination and unloaded, it would be sent back to us where it can be loaded for the next mission. Conceivably, large numbers of the Reckless USVs could be loaded as needed for different small teams of Marines at dispersed locations."

The Amy and Reckless vehicles were developed with the investment of Navy Small Business Innovation Research (SBIR) funding. Hydronalix has been able to derive and extend their SBIR projects to develop new vehicles to support evolving mission requirements. The SBIR funding also assisted in getting Marines trained to use the vehicles as well as to ship them to Sweden for Archipelago Endeavor.

Hydronalix CEO Tony Mulligan said that his company learns a great deal when operators get to use their vehicles and help assess how well the vehicles perform in realistic situations. "We couldn't get this kind of feedback another way. It helps us to improve the vehicles to deliver the capabilities our warfighters need."

Eva Huie, a mechanical engineer with Hydronalix, said that Archipelago Endeavor provides Marines with a unique opportunity to experiment with Amy and Reckless to conduct underwater surveys and environmental assessments prior to a landing, and to provide logistics and sustainment support to forward locations. "They can test how much water, food, batteries, ammunition, medical supplies and whatever they need, into the boats and see how quickly they can move that material ashore remotely or autonomously and do all that in this very challenging environment."

A Swedish marine with the 2nd Swedish Marine Battalion sights in during live fire exercise during exercise Archipelago Endeavor. Photo by Lance Cpl. Adam Scalin

Swedish marine Sgt. Boris Zelanda with 4th Boat Training Company, 2nd Swedish Marine Battalion, briefs US and Swedish marines on navigational features of the Hovercraft 2000 during exercise Archipelago Endeavor. Photo by Lance Cpl. Adam Scalin

Not only can the Reckless' 20-cubic foot interior be stuffed with supplies, the vehicle also has more storage that can be strapped on top, a capability that came about when testing the system with operators. "We take their input and find ways to integrate the systems with more of what the operators want," Huie said.

Huie said Hydronalix provides the Marines with a week-long training program to learn how to use the vehicles, conduct the maintenance, and capture and understand sensor data. But, she said, someone can learn the basic operations of the vehicles pretty quickly.

Priddy remarked that the Swedish CB 90 combat craft, the country's sophisticated training ranges in the archipelago, and their forces' ability to sustain themselves in an expeditionary and distributed way means Sweden's military is optimized for littoral operations in the Baltic. "The big takeaway for us is how they operate. They're great partners, and this is a great opportunity to work with one of our allies in the Baltic region."

"It's extremely important that we continue to work with our allies and partners, and being here in Sweden is just another example of that," Priddy said. "Both of our countries have a lot to learn from one another. We're both professional forces that work very well together.

Priddy said that it's important to establish relationships in time of peace, before a crisis. "Working with our Swedish partners here to develop those relationships now is exactly what we're doing."

Col. Adam Camel, commander of the Swedish Navy's First Marine Regiment, said the Swedes are gaining a lot as well. "The US has a high technical level. They have some interesting weapons, good cyber capabilities, and some sensors that we're interested in. They also brought some unmanned vehicles. So, I think this training is mutually beneficial."

The Marines are no strangers to the Baltic and have trained with their counterparts from Sweden and Finland before. With these countries now members of NATO, the training is even more relevant, and has taken on added urgency because of Russia's invasion of Ukraine.

"We are sending a message, as well. We are showing Russia that we are training, we have partners, and we're united," said Camel. "We are building up our capabilities, and we are very eager to defend our country and this region."

About the author:

Capt. Lundquist writes on naval, maritime, and defense issues, including developing science and technology for warfighters.

Coast Guard photo by PO2 Eric J. Chandler

BATTLING A BLUE ARCTIC

By Sarena Padilla and Lt. (j.g.) Garner Fleming, USN

THE ARCTIC—WHERE THE PHYSICAL ENVIRONMENT POSES A GREATER THREAT TO ACHIEVING STRATEGIC DOMINANCE, MANAGING ASSETS, AND ENSURING FREEDOM OF THE SEAS—WILL BE THE NEXT FRONTIER FOR US MILITARY OPERATIONS.

The time has come to shift our mindset toward our northernmost body of water. The Arctic Ocean is in many ways an uncharted domain for conducting military operations. It will be no easy feat to operate in this region—its ice-infested waters present a hostile environment for human beings as well as modern ships. Currently, the United States has a limited icebreaking capability, making it completely reliant on the Coast Guard and its vessels USCGC *Healy* (WAGB 20) and USCGC *Polar Star* (WAGB 10) handling all polar pathfinding needed to ensure safe transit in this region. This shortfall is driving the production of the next generation of polar security cutters, a joint Navy/Coast Guard effort to address the dire necessity for increased icebreaking operations in the near future. The first polar security cutter is expected to be delivered in 2025.

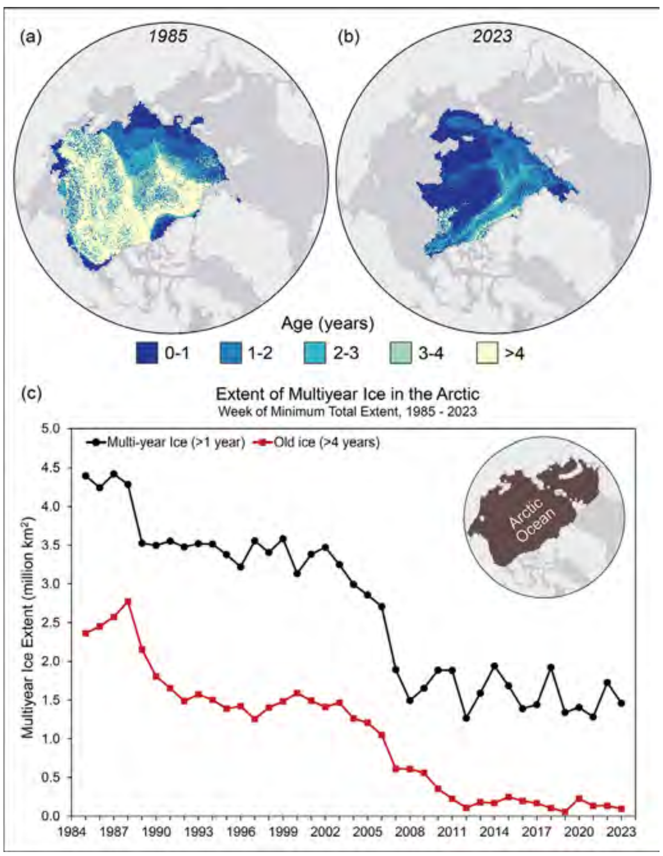
Any future naval conflict will require leveraging the latest technological advancements made since World War II—the last time the United States was truly challenged at sea. The North Atlantic and the Pacific, the regions where that war was fought, are both vastly different operational realms than what the Arctic presents. The future of warfighting will demand means beyond globally-deployed strike groups and a prominent physical presence. The information warfare community will be of greater importance as the challenges facing battlespace awareness, assured command and control, and integrated fires are heightened in the austere environment of the Arctic. Successful intelligence preparation of the operational environment, mastery of the electromagnetic spectrum, and solid communications could very well be deciding factors for any conflicts in the high latitudes. Any future conflict is likely to be settled in large part by how well information (including environmental intelligence) is gained, exploited, and disseminated. Technology that utilizes artificial intelligence/machine learning methods could yield a warfighting advantage in predicting the physical battlespace.

Current projects are under way across the fleet, many led by the Office of Naval Research and Naval Research Laboratory, to address the need for advanced multiplatform data assimilation to improve high-latitude numerical environmental models for forecasting and predictions. A variety of environmental data collected through in situ or remote means is necessary for these modeling efforts to be successful. The sea ice edge can vary by hundreds of miles overnight when faced with the dynamic meteorology present in the region. Many analytical intelligence challenges can be partially to fully automated, but even these innovative efforts require substantial data, among other resources, as a driving mechanism. It will be essential to fill the current environmental data gaps in the Arctic if the United States is to harness the technical advances made in computing and successfully exploit technologies such as more sophisticated models and innovative artificial intelligence projects. Some small but mighty naval commands have started paving a path forward to meet these shortfalls.

The US National Ice Center (USNIC) is a tri-agency organization of the Navy, the National Oceanic and Atmospheric Administration (NOAA), and the Coast Guard whose mission is to provide global-to-tactical-scale ice and snow products, ice forecasting, and related environmental intelligence services for the government. Fewer than 50 uniformed, civilian, and contract personnel comprise USNIC on a daily basis, with only a dozen of those individuals performing the duty of creating a variety of routine ice analyses for the Arctic and Antarctic, the Great Lakes, and other geostrategic locations where ice may form. USNIC also compiles a daily analysis of northern hemisphere snow and ice products to support assets and personnel in the field. With such a small team, providing environmental intelligence to ensure safety of navigation in treacherous polar waters and economic prosperity within and along high latitude commercial routes and port regions is a significant task.

Anticipating Change

Sea ice affects not only its local surroundings but also contributes to global ocean temperatures and currents.



Sea ice age coverage map for the week before minimum total extent (when age values are incremented to one year older) in (a) 1985, and (b) 2023; (c) shows the extent of multiyear ice (black) and ice greater than four years old (red) within the Arctic Ocean region (inset) for the week of the minimum total extent. NOAA graphic

An air-deployable expendable ice buoy is deployed in the high Arctic near the North Pole from a Royal Danish Air Force C-130 aircraft operating out of Thule Air Force Base in Greenland, as part of the International Arctic Buoy Program. Photo by John F. Williams

Sea ice generally forms during the winter months and recedes in the summertime, leaving some ice to linger until the following summer. As sea ice has a high albedo (a bright surface), much of the solar radiation received by sea ice will be reflected away from the earth, assisting in keeping the polar regions cold. As temperatures warm either seasonally or climatologically, less sea ice remains to reflect this solar energy, creating a positive feedback cycle that further exposes ocean waters to insolation and the absorption of energy. This cycle, intertwined with sea ice cover, is one reason the polar regions are sensitive to even the slightest fluctuations in global temperature.

Several portions of the Arctic Ocean that have historically been covered with sea ice through at least parts of the winter will become increasingly ice-free in the coming years. This decrease in ice presents the possibility of shorter maritime trade routes, or even completely new transpolar routes, becoming available—significantly increasing the amount of Arctic maritime Arctic traffic. The great power competition's intrinsic threats to the Arctic region are expected to grow as economic and geopolitical opportunity grows. It should be noted that the Arctic is the sole shared battlespace with a peer competitor. There is no doubt rapid change is occurring in the Arctic, making now the opportune time to form strategic war plans that include solutions from the information warfare community.

A Way Forward

The US National Strategy for the Arctic Region was most recently updated in 2022 with a new ten-year scope that seeks a peaceful, stable, prosperous, and cooperative Arctic while acknowledging the heightened strategic competition alongside corresponding strategic objectives that share commonalities with the USNIC mission. The geostrategic importance of the Arctic will only increase each year as the decline of the perennial sea ice continues and the ice edge shifts. It is imperative to increase awareness of the unique operating environment that the Arctic presents and strengthen actions that will yield a strategic advantage there. This effort includes investing in technology that detects and tracks potential threats and improves our own capabilities in the region. This is not a simple task because of the dominant role that Russia has in the Arctic as well as the growing desire by China for a role in the region.

The Arctic remains largely unfamiliar in its delicate environmental complexities. The need for increased and enhanced observations continuously grows as the sea ice left behind year after year becomes more fragile, thin, and diminishes in extent, losing an equivalent area the size of South Carolina annually. Characterizing the ice in the region requires various input sources whether it be satellite-derived data, in situ sensing platforms, or occasionally deployed personnel feedback while onboard icebreaking operations in the region. The limited in situ observations help increase near-real-time environmental knowledge in the Arctic, but at current numbers they form an incomplete picture and are not enough for fully forecasting and safely operating within such a complex, harsh domain. USNIC and partners are able to sense atmospheric and sea state conditions by using a network of buoys through the US Interagency Arctic Buoy program, but the unforgiving surroundings that the Arctic poses degrade any deployed hardware quickly. The resulting data gaps require routine sensor replacements and drive the demand for development of tailored equipment for this cold, icy region.

USNIC relies mostly on satellite imagery to fulfill its mission. As the sea ice extent continues to be influenced by climate change, the workload for operational centers such as USNIC rises with increased vessel traffic near ice-infested waters. USNIC is pursuing automated solutions to combat the increase in vessel traffic needing ice products and expertise. This will improve sea ice characterization from its current standards that are reliant on manual analytical methods by trained ice analysts. By bringing artificial intelligence and machine learning into the analytical workflow for making sea ice products, USNIC is able to provide enhanced qualitative and quantitative sea ice products and support the safety of navigation.

The northern lights illuminate the Arctic sky over the Navy's Ice Camp Queenfish during Ice Exercise 2022. Ice Camp Queenfish was built on a sheet of floating ice approximately 160 nautical miles offshore in the Arctic Ocean, and included sleeping tents for about 60 personnel, a command center, a dining tent, and a runway for aircraft. Photo by MC1 Cameron Stoner

Domain Detection

In situ sensors deliver invaluable information on the scene utilized for reporting near-real-time atmospheric and sea state conditions, initialization, and forcing of global weather models, validation of satellite-derived environmental data, and identifying long-term trends in the region. Buoys are routinely deployed from either shipborne or airborne platforms. In collaboration with 12 nations across the globe, American-deployed buoy observations contribute to the broader International Arctic Buoy program network. In situ sensor deployments can be costly and require careful planning, but the data they collect is necessary to achieve a prosperous and peaceful Arctic region. Since deploying buoys, USNIC and other partners have been able to validate environmental predictions and to identify vital trends in the Arctic for large-scale operations such as ice exercises held every two years on the Beaufort Sea. Deployed buoys are subject to the harsh environment of the Arctic and may become dormant for weeks or months in detrimental weather, if not destroyed completely by the force of shifting ice. Buoys typically only survive a few years at best before requiring complete replacement. Data gaps are also formed from the sensors drifting south of the Arctic Circle, no longer reporting conditions that are useful for Arctic operations.

Having additional sensing platforms in the Arctic and enhancing their performance and design is beneficial not only to global researchers and USNIC, but these actions also fulfill a pillar of the US National Strategy for the Arctic Region, which calls for "invest[ing] in modernized domain awareness to detect and track potential airborne and maritime threats and improve sensing and observational capabilities, including for sea ice, ship traffic, and weather." The future of the Arctic and its stability depends on how effectively we depict battlespace awareness in the region. Well-equipped sensors and novel computing methods will allow the United States to reach that goal.

USNIC primarily examines synthetic aperture radar satellite imagery because of its ability to penetrate clouds and provide reliable, high-resolution coverage throughout day and night. This imagery, in conjunction with artificial intelligence algorithms, is a powerful tool that will allow operational users—such as USNIC, the Coast Guard's International Ice Patrol, the Canadian Ice Service, and the Danish Meteorological Institute—to form better environmental products and predictions of the polar regions. The embedded potential in using artificial intelligence and machine learning processes will further increase the efficiency of USNIC to support mariners, to save ice analysts time and effort as support requests increase, and to lead to increased comprehension of a changing polar environment.

Even the most advanced models at first require substantial data sets to be trained on before becoming a part of the operational workflow to characterize sea ice. Environmental machine learning models that intake satellite imagery can vary in output based on several factors, including fluctuations in season, viewing angle, weather conditions, and which region of the Arctic being imaged. While machine learning applications ideally make manual processes more streamlined and of higher quality, there is significant effort involved initially to ensure the model is producing accurate and meaningful results for the mission, such as classifying multiple stages of sea ice from a single satellite image.

A Joint Effort

It requires a team effort to fully utilize aforementioned technological advancements to better predict the Arctic battlespace. Industry partners continue to provide cutting-edge business models and oceanographic sensors that aid decision-makers in mission planning and execution above and beyond what the Department of Defense is capable of alone. The observational gaps can be filled with multitudes of smaller, satisfactory instruments rather than just a single highly precise, expensive unit—yielding minimized temporal latencies when viewing data from every angle. USNIC has recently taken part in the cooperative research and development agreement between Naval Meteorology and Oceanography Command and Sofar Ocean Technologies. This partnership allows further testing of buoy-based sensors in high-latitude operating environments for longevity in severe weather conditions faced in the Arctic.

An ongoing effort exists to bring currently available data from shipboard and unmanned platforms into global weather models and decision support services such as USNIC sea ice products. A joint force of all Department of Defense players operating within the Arctic will determine mission success as conflicts arise. The Navy's Arctic Submarine Laboratory coordinates periodic ice exercises to challenge naval operational readiness, boost experience and understanding, and develop partnerships further with like-minded nations, other armed service branches, and research partners. Northern Command holds the Arctic Edge exercise biannually across the Alaskan landscape, in order to gain agility training in a cold-weather environment for both US and Canadian defense personnel. These exercises require improved coordination and communication between all service branches in the coming years to test and maximize joint capabilities in the region.

A Sailor launches a Mark 18 Mod I Swordfish unmanned underwater vehicle to conduct a mine countermeasures survey in the Gastineau Channel near Juneau, Alaska, during Arctic Edge 2022.

Naval special warfare members perform a high-altitude, low-opening jump during the 2022 Arctic Edge exercise. Arctic Edge is a US Northern Command biennial defense exercise designed to demonstrate and exercise the ability to rapidly deploy and operate in the Arctic. Photo by MC2 Trey Hutcheson

Most recently, the Navy's Strategic Blueprint for the Arctic was released, which acknowledges that the vast majority of global trade—which is expected to double over the next two decades—travels across the world's oceans, on the order of 90 percent. The Arctic Ocean has the potential to connect more than 75 percent of the world's population as melting sea ice opens up timelier maritime trade routes between North America, Europe, and Asia.

An opening of the Arctic Ocean brings the United States closer to northern neighbors to provide mutual assistance in times of need, enable allied nations to defend the homeland, deter aggression, and coercion, and protect sea lines of communication. The Navy's resilience in the Arctic is embodied by the late Rear Adm. Robert Peary, credited as possibly the first to reach the North Pole in 1909, "I will find a way or make one." Building a more capable Arctic naval force is critical to securing our national security.

About the authors:

Serena Padilla is a former naval meteorology and oceanography officer and **Lt. Fleming** is an active meteorology and oceanography officer currently stationed at USNIC within the Science and Technology Department.

A DAUGHTER'S STORY: 2037

By Alan Lemon and Aaron Hubbard

IN THIS IMAGINATIVE LOOK AT THE FUTURE, THE AUTHORS ENVISION A NAVY WHERE SAILORS, AND THE PLATFORMS THEY USE IN THE AIR AND UNDER AND ON THE SEA, WILL BE CONNECTED IN WAYS MORE POWERFUL THAN EVER.

Standing her first solo mid-watch on Father's Day 2037, Lt. Cmdr. Alessandra Kitchen (call sign Ditch'N), is a newly qualified tactical action officer (TAO) on board USS *Thomas Paine* (LSC 151, call sign Reason).

Ditch'N's father, retired Navy Cmdr. James Archer, was a surface warfare officer who, after 9/11, decided he would foster his children's interest in the STEM (science, technology, engineering, and math) fields. He had taken Alessa and her brother on several Tiger cruises during their formative years. Cmdr. Archer introduced Alessa to the finer aspects of the extensive science and engineering that went into the development of the Aegis weapon system. At the time, looking through the eyes of a young teen, Ditch'N thought her dad's console in the Combat Information Center (CIC) was cutting-edge technology. Years later, after graduating from San Diego State University with a bachelor of science in human factors engineering (HFE), Lt. Cmdr. Kitchen now knows better. As a naval aviator, she appreciates the finer aspects of the HFE efforts that went into the design of her P-8's cockpit.

While her time aboard Reason has given her a newfound respect for the surface community—the pace, the complex decision threads, the attention management, and the task coordination of working with larger teams within the surface action group (SAG)—she is pleasantly surprised to find her curved multitouch display console so intuitive; it is simple and easy to use. It is designed with an understanding of usability and the nature of human cognition, taking advantage of human-centered design (HCD) and cognitive engineering (CE).

It gives her pause, though, to wonder how her father did it all with the functionally designed user interfaces (UIs) that were all too common back then. Those function-based designs required incessant voice reports over NET 15 just to maintain situational awareness of the track picture and didn't easily facilitate timely and efficient decision-making. Without the cognitively engineered designs of today, how could they possibly fight the battle, managing so much info, through so many windows?

Displacing 13,100 tons, Reason is the fifth large surface combatant (LSC) within the Future Surface Combatant Force (FSCF). As TAO, Kitchen has unprecedented command and control of a fleet of 600 unmanned vehicles (UxVs ground, air, surface, or undersea) deployed from the three optionally manned and unmanned surface vessels (O/USV) within Surface Action Group U-1. The intuitive task-based design of her curved multitouch display console of the Integrated Combat System (ICS) provides uniform command and control and incorporates the tactical employment of all connected kinetic and nonkinetic systems and UxVs to great effect. *Thomas Paine* is the Positive Identification and Radar Advisory Zone (PIRAZ) ship, currently active in the Navy Cybernetic Network with passive beyond-line-of-sight radar picket provided by USVs. These netted services are managed by the Central Track Services (CTS) and coordinate tasking across the ICS and within the FSCF. *Thomas Paine* is tracking and reporting 11 commercial air tracks within the immediate sector and all are within engagement range.

As a "brown shoe," Ditch'N particularly likes the novel application of the autonomous UAVs there to support the surface action group. Near the end of her disassociated tour, Ditch'N has had to learn all the surface Navy jargon. Kitchen is standing watch as TAO in the Ship Command Center (SCC) with four other team members: two on the bridge, two in the Situation and Analysis Center (SAC), two engineers, and two for the combat systems. This is a much smaller and far more capable crew than that of her father's era with a watch team of 25 operators just in CIC. Kitchen really digs her augmented situational awareness provided by her Secure Personal Enhanced Coordination Device (SPECD). Looking like expensive safety glasses—and certainly more stylish than the standard issue "birth control devices" (BCDs)—the sailors decided to drop the "D" and just call them SPECs.

Her SPEC's flash a red indications and warning alert from the SAC as NET 15 comes alive for once with an excited voice report from the ship signal exploitation coordinator (SSEC) about possible hostile aircraft from the south, new track 6001. She acknowledges the indications and warnings alert on her TAO console, the heightened alert status of "Yellow 'N' Tight" warning order and weapon control status depicted by the posture and condition frame around all tactical displays. The corresponding icon in her SPECs disappears. The high-side details of the inbound threat are now presented in concert on her display console. Perfect high-side fusion. With her action, the ICS aboard Reason immediately alerts the commanding officer. With his own SPECs and his tactical tablet, the captain is now immediately aware of the current tactical situation in his at-sea cabin.

The advancements in human-computer interaction aboard Reason provides seamless task coordination between the crew members of "Team Reason." More important, these designs have allowed recent innovations in artificial intelligence to be seamlessly integrated, allowing the optimally manned crew to manage the multiple UxVs, deployed from the large USVs in a screen formation, with ease. Such advances permit the employment of the netted sensors and weapons of the FSCF with much greater combat effectiveness.

Reason's next-generation warfare system, the ICS, fully interconnects all shipboard systems (navigation, hull mechanical and electrical, main propulsion, etc.) and fuses all the multisource organic and external sensors, data links, and nets that crews had to manage in the past. In response to possible "hostile Air, Track 6001"

All photos by Naval Information Warfare Center Pacific from the south, Reason alerts Ditch'N with a Condition 1 recommendation on her console as well as her glasses. The ICS immediately computes the composite track picture provided by the USV, in the van of the action group, with all the pertinent data, course, speed, size, and possible identity, and based upon the closest point of approach and predicted intercept.

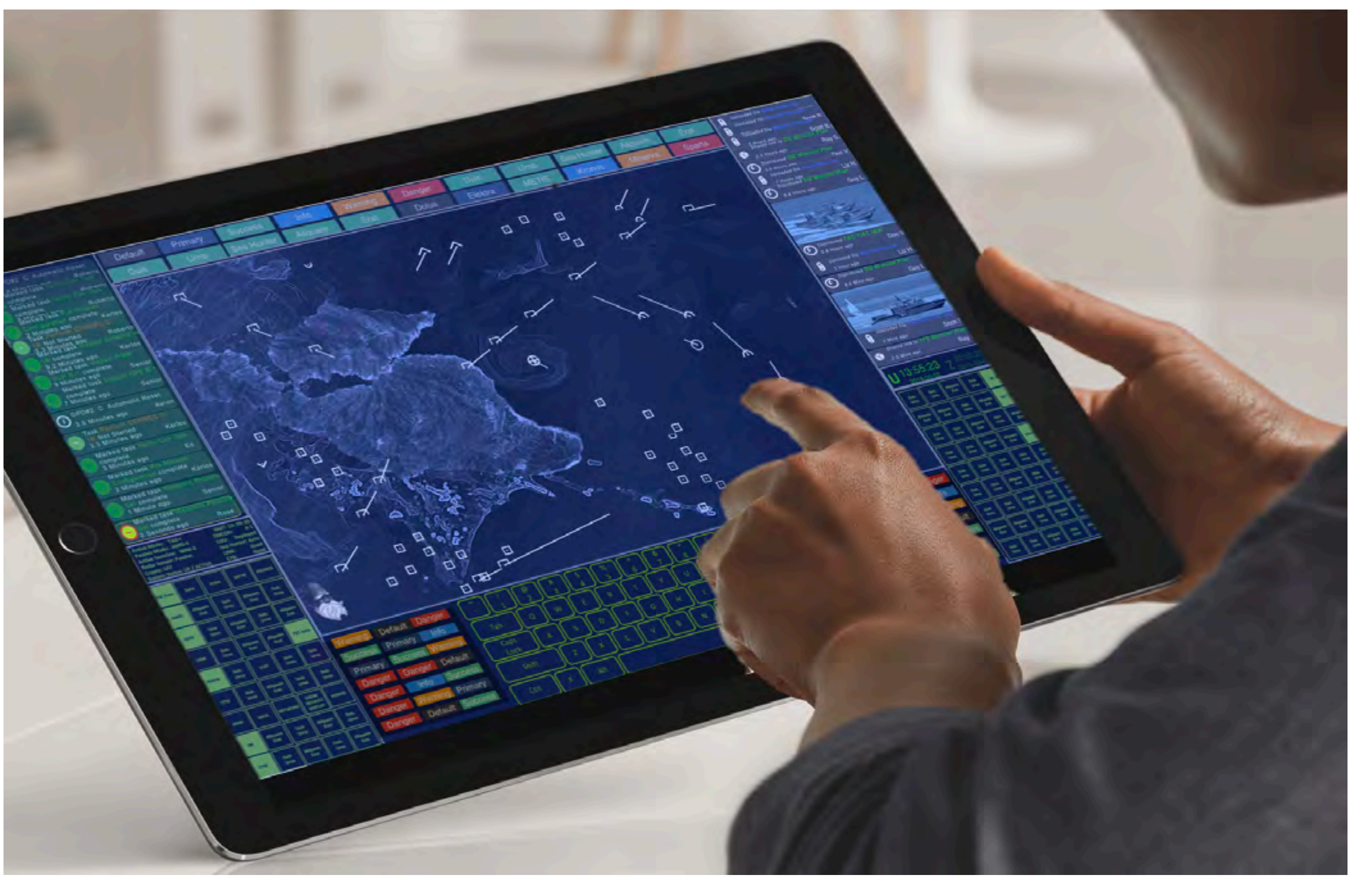
With two easy and yet purposeful depressions of the general quarters quick action button, Ditch'N selects "Set Condition 1" from her console and confirms the action. Reason sounds the claxon and passes "General Quarters, General Quarters, General Quarters, All Hands Man your Battle Stations." At the command to set general quarters, the automation algorithms aboard Reason have suboptimized the dynamics of the ship's system and the ICS has already calculated multiple courses of action. The combat systems officer of the watch has already seen his control console indicate the automatic system reconfiguration in preparation of defensive actions.

The engineering officer of the watch, called upon to immediately reset Gas Turbine Set No. 3, steps out to the open well deck and accesses the starboard bulkhead mounted J display. She quickly resets turbine set with three quick actions on the touch screen. Even though she still has her welding gloves on and with the sea spray covering the screen with the winds deep on the port quarter, however, it is simply not a problem with the Zytronic PCT (projected capacitive touch) screens found throughout the ship.

The engine plant comes to full power as the electrical zone distribution reconfigures to a split configuration, bringing the solid electrolyte power banks online for full power and sends a remote acknowledgement to the UxVs. Reason's ICS alerts the crew of USS *Long Beach* (FSC 11, call sign Alcoa), a newly upgraded next-generation future surface combatant Flight II ICS cruiser, and provides them with immediate situation awareness.

With the threat still inbound, Ditch'N selects track 6001 for engagement on her console's dashboard and the entire action group shifts to "Red 'N' Tight," the posture and condition frame of tactical displays disseminating the status change. The relevant secret data associated with the track is displayed on her console, and the visuals are complemented with the acoustical illusion of a rising Shepard-Risset Glissando tone. The indications and warnings data from SSEC in SAC is providing her with an augmented visualization of the threat, a nice sensitive compartmented information overlay through her SPECs.

Reason and Alcoa have shared data—composite track picture, doctrine statements, correlated indications and warnings, fire control pairings, weapons load, status, and



state—over the spectral data exchange net simply known as SKYTRK. The dynamic responsiveness of SKYTRK—a secure, high-speed, bi-directional, line-of-sight, and fully networked wireless communication system—ensures connectivity with the UxVs distributed within the FSCF surface action group. SKYTRK defends against service attacks using the spread spectrum algorithm to dynamically shift across the infrared and visible light spectrum of light-fidelity transmission pathways.

Kitchen selects course of action three with a 98-percent efficiency for the lead UAV to conduct a spoofing pull-off maneuver in the outer engagement zone. The ICS provides for secondary intercept displaying what and when to fire on the threat with a solid fire control solution—but only if kinetic action is warranted.

While the ICS assimilates the data of the sea, air, land, space, and cyber domains, the greatest advances of the future combatant ship have been in the human domain: making knowledge visible, and shifting to a sophisticated sense of perspective. These design advances for the FSC have reduced response times allowing for coordination of human action aboard Reason and the remainder of the FSCF. The unified design approach has integrated the crew's propensity for swift and decisive action in the employment of FSCs.

With her selected course of action, the ICS promptly directs the other four command-and-control watch stations in SCC—combat system coordinator (CSC), information warfare supervisor (IWS), air warfare coordinator (AWC), and surface warfare coordinator (SWC)—to action. As TAO, Kitchen also has comms with the ship signal exploitation coordinator (SSEC) and the Strategic Command intel supervisor (SIS) in the Situation and Analysis Center (SAC) as well as the officer of the deck in the pilothouse. Voice channels are seldom used since the cognitive ergonomic solution—of what would provide a pauciloquent (with few words) user experience—for the long hours spent in front of the display assimilates tasking and situational awareness between ICS stations so well.

Kitchen's SPECs light up yellow on the right edge of her glasses indicating a navigation hazard. The TAO console flashes a yellow contour decision aid matching the line displayed for the officer of the deck. Ship's head indicator showing the closest point of approach to *Thomas Paine*, a display has alerted the officer of the deck to the shoal water bearing 255 degrees true, range 16 nautical miles.

In the split second after receiving the shoal water navigation hazard; Kitchen flashes back to a story her father told her of the collision he endured aboard USS *McCampbell* (DDG 85) some 30 years before. The destroyer was in the northern Arabian Gulf, on a dark moonless night, with radar clutter from patrolling in close to coastal waters and a multitude of small fishing boats adding to the clutter. She reflects on how the common decision aids now available on her console could have prevented such a mishap. She can see the visual boundaries relevant to the commanding officer's Night Order no. 4 outlining actions required to maintain safe navigation.

Kitchen, a graduate of military information support operations training, is very familiar with the psychological effects of military operations occurring near fishermen in the patrol area and wonders if the use of USVs is the right option for their situation. In considering the human domain effects, she wants to minimize economic and ideological liability during the tactical situation. The TAO aboard the Alcoa calls up Ditch'N to share an observation on course of action no. 3. The mixed reality headset adjacent to her console riding on Battle Group

Command NET over SKYTRK provides her with the same perspective of the TAO aboard *Long Beach*. Ditch'N can see *Long Beach's* detailed display of the refined tactical course of action options. She sees and agrees.

With the action group composed of three O/USVs, each loaded with multiple nonkinetic (multispectral soft-kill emitters, decoys, active jammers, directed energy weapons) as well as kinetic options that include a multicaliber metalstorm point defense system and the various missile loads within the peripheral vertical launching system the options are diverse. With the advanced HCI's course of action visualization aboard the FSC, the choice is obvious. The discussion is brief and the action decisive; both agree to the repositioning of two assets within Surface Action Group U-1 to slightly modify course of action no. 3.

Kitchen can see the live intelligence, surveillance, and reconnaissance video feed from the Minotaur system aboard the P-8 displayed on her console. The real-time video, once selected with a two-finger tap, plays and displays the intel voice report. To get confirmation she calls up the P-, which confirms the report of an orange-flagged AGI spy ship. Ditch'N and the commanding officer observe the CERT (i.e., certified) sub making a rendezvous with a pair of small boats.

On station "NEO", the unmanned surface vessel SAG U-1 commences to deploy radar cross section enhancement decoys to present a larger profile and lure the track away from the actual aircraft carrier nearby. Reason orders the launch of two organic MQ-18s loaded with new XB-56 HARMs. The reaction time of these distributed assets are possible because of the advancements in artificial intelligence and HCI designs with the FSCF, supported by the increased bandwidth, data, and security assurance provided by SKYTRK.

Kitchen's TAO console exchanges the tactical picture and unit tasking through the ICS, passing indications and warnings, composite track data, and asset tasking across the action group. *Long Beach* receives automatic updates from Reason and both ships have artificial intelligence enhancements activated. Coordinated command of manned and unmanned assets provide the optimal defense in depth for weapons, decoys, and soft-kill electronic attack systems. *Long Beach* is at condition I (general quarters), loaded and ready for bear.

Long Beach's commanding officer enters SCC with his tactical tablet, connected by LiFi (wireless data transmission using LEDs), and orders his TAO to verify "protected unit" is set. *Long Beach* immediately orders "left full rudder," steady course 200 degrees (true) to unmask batteries. Reason maintains current heading of 140, and the large USVs disperse for deception and engageability based on course of action no. 3 modification.

Kitchen's glasses light up bright blue around the edges, indicating a possible blue-on-blue engagement identified by the cyber counter-deception agent. In an instant, Kitchen appreciates the instantaneous challenge and reply on her console with the integrated high side information in her SPECs. She selects the live video feed from MINOTAUR on her TAO console.

The TAO aboard *Long Beach* can see the current evaluation on his console and concurs with the correlation data. They both can see the ongoing attempted cyber deception has led to the false identification of a possible hostile aircraft and the correct reevaluation and confirmation of the track being positively identified as a civilian helicopter. The symbology for the track is changed to assumed-friend helicopter, the action group shifted to "White 'N' Safe," all UxVs within the action group are returned to base. *Thomas Paine's* commanding officer lets loose a big sigh of relief. "Damn that was close" can be heard throughout SCC, only to be followed by "hot mike." Ditch'N selects condition 3 on her console, all systems are reset, and "secure from general quarters" is announced.

After such a close call, she has a newfound appreciation for the system engineering approach taken with the FSCF developed with a holistic design approach, integrating the domains of sea, land, air, space, cyber, and, most importantly, the human domain. With a unified design approach allowing a completely unfettered way of leaping between the domains for a greater perusal of the whole, this new approach allows Kitchen to act with informed restraint—or prescient malice when necessitated. The ICS provided the critical and timely data to make the right decision to break the engagement and prevent a blue-on-blue engagement. The commanding officer updates the crew on the tactical situation over the 1MC and ends with "Good job, Cmdr. Kitchen." What a time for a promotion. She can't wait to call her dad after her watch is done.

About the authors:

Alan Lemon, a retired Navy fire controlman, is a program manager and human-centered design engineer with Naval Information Warfare Center Pacific.

Aaron Hubbard, a retired Navy operations specialist, is a former program manager and test and evaluation engineer with Naval Information Warfare Center Pacific.

The authors would like to recognize **Scott Bewley** who provided the leadership, sponsorship and visionary support for this project known within Naval Information Warfare Center Pacific as Human Systems Integration Concepts of Employment.

Photo by Joe Bullinger

NEW LAB IN QUANTICO ENHANCES MARINE CORPS TEAMING

By Steve Ghiringhelli

WITH THE OPENING OF A NEW LAB FACILITY NEAR ONE OF THE NATION'S MOST IMPORTANT MARINE CORPS BASES, THE NAVAL INFORMATION WARFARE CENTER ATLANTIC CONTINUES TO FIND NEW WAYS TO SUPPORT EXPEDITIONARY WARFARE.

After years of planning, Naval Information Warfare Center (NIWC) Atlantic opened the doors to its new Quantico-area facility in 2023 for the purpose of enhancing the command's longstanding synergy with the Marine Corps.

Situated just minutes from Marine Corps sponsors and decision-makers, the NIWC Atlantic Quantico site will be a key annex of the command's Expeditionary Warfare department, which has a long history of supporting Marines with information warfare solutions.

"Today's environment of strategic competition means we don't have the luxury of time when it comes to developing and fielding capabilities today that the warfighter may need to fight and win tomorrow," said NIWC Atlantic executive director Peter C. Reddy. "As a key partner with Marine Corps Systems Command and Marine Corps Warfighting Lab in the research, development, integration and support for many Marines Corps systems and technologies, I believe this new facility here in the National Capital Region is postured to become a bustling hub of teaming and innovation for the warfighter."

At the forefront of the vision for the new space is the Department of the Navy's concerted effort to connect all networks and systems across the maritime domain. The Marines require an expeditionary force fully integrated with the fleet and ready to operate seamlessly in any contested environment.

"I believe the opening of this facility couldn't have come at a better time," said Dr. Todd Calhoun, Marine Corps Systems Command executive director, during the ribbon-cutting ceremony. "I would like to add my thanks to the NIWC Atlantic project team that worked so hard to make this a reality. Teaming and integration are essential to our new warfighting concepts, and it's very clear to me how important our partnership with NIWC Atlantic is [on that front]."

A large portion of the facility was designed with maximum flexibility in mind using cable trays, configurable electrical busways, and mobile workbenches on casters. Engineers, scientists, logisticians, and other technical experts will use the modular lab to research and develop Marine Corps command, control, communications, computers, intelligence, surveillance and reconnaissance (C4ISR) and information technology systems.

In addition to enhancing collaboration with Marine Corps Systems Command and the Marine Corps

Warfighting Laboratory, the new site will support other Department of the Navy organizations, including Program Executive Office Land Systems, Marine Corps Cyberspace Operations Group, Program Executive Office Manpower Logistics and Business Solutions, Program Executive Office Digital and Enterprise Services, and Headquarters Marine Corps.

The site also will enhance support for NIWC Atlantic's ongoing work with the US Coast Guard.

Ashlee Landreth, who leads NIWC Atlantic's Expeditionary Warfare Department, said the Quantico site will enable closer collaboration between her workforce and their Marine Corps partners.

"I am privileged to lead a department of nearly 700 professionals who pride themselves on the right combination of talent and mission-focused culture," Landreth said. "Along with our industry partners, those working in this facility will be exposed to C4ISR technologies, testing, experimentation and concepts of employment that will drive innovation and make our warfighters more lethal."

NIWC leaders said the opening of the Quantico site took many key players in facilities and operations working tirelessly over the years to complete the task. In the end, it was their creativity, persistence, ingenuity and foresight that made the difference.

"We're grateful for this outcome—and now the most important work begins," Landreth said. "We know this strategic collaboration center will quickly become an enabler for accomplishing critical efforts in support of naval and joint integration."

A Maritime-Based "Live-Fire" Cyber Exercise

In the same way that infantry divisions train hard to be good in land warfare, cyber forces work hard to research and develop the right tools to win the information war.

That was the premise for a unique maritime-based cyber exercise that concluded in September 2022 at NIWC Atlantic called "Cyber ANTX," or advanced naval technology exercise.

Most of Cyber ANTX occurred at the National Cyber Range Complex (NCRC) Charleston, a state-of-the-art facility at NIWC Atlantic headquarters where more than 100 assessors, industry partners, and subject matter experts participated in two weeks of demonstrations.

"To defend deployed networks, you need a strong scheme of cyber support, which can be difficult at sea," said Capt. Nicole Nigro, NIWC Atlantic commanding officer. "With that in mind, this exercise posited, and sought to address, one simple challenge: If a cyberattack knocks out the network on multiple ships at once, what kind of fallback solutions can we develop to support cyber defenders afloat?"

For vendors, Cyber ANTX was an unprecedented opportunity to demonstrate 24 unique innovations in the highly fraught cyber domain using operational vignettes implemented by NCRC Charleston's unique capabilities.

Funded by the Test Resource Management Center under the Office of the Under Secretary of Defense for Research and Engineering, NCRC Charleston allows programmers and hackers to work in a safe and controlled environment.

"I look at this as a live-fire exercise, but in the cyber domain," said Drew York, Cyber ANTX principal investigator. "NCRC Charleston provided an excellent setting, where we could target innovative technologies using real malware and enable the safe exploration of cyberspace defense technologies on multiple fronts."

A total of 29 technology proposals were submitted ahead of the event, according to Dana Rushing, Cyber ANTX execution lead.

Rushing grouped participants into focus areas that included themes like prevention, warning, malware detection and cloud-enabled defense. She said each company was evaluated based on the capability it brought cyber defenders in an afloat environment.

In addition to traditional industry partners, many technologies at Cyber ANTX came from the innovative world of small business.

Two technologies were developed by government labs, through a collaboration between NIWC Pacific and the Office of Naval Research. Their tools involved "debloating" systems overstuffed with non-mission-critical "dead code," such as unused libraries and chat apps, in order to secure networks vulnerable under the weight of too much data.

In the weeks preceding the exercise, Scott West, lead event director at NCRC Charleston, orchestrated the integration and testing of the vendor technologies on the range. Once Cyber ANTX began, the range environment lit

In addition to enhancing collaboration with Marine Corps Systems Command and the Marine Corps Warfighting Laboratory, the new site will support other Department of the Navy organizations, including Program Executive Office Land Systems, Marine Corps Cyberspace Operations Group, Program Executive Office Manpower Logistics and Business Solutions, Program Executive Office Digital and Enterprise Services, and Headquarters Marine Corps. Photo by Joe Bullinger up with activity and dynamic interactions among vendors, active-duty military assessors, and technical assessors from NIWC Atlantic and NIWC Pacific.

"From a mission perspective, this exercise challenged everyone to figure out ways of negating an enemy's 'soft kill' cyberattack and quickly restoring capabilities," said Jeff King, director of NCRC Charleston. "The idea of rear echelon support to forward deployed forces applies to all of the military services and components, since neutralizing a near-real-time cyber effect will be critical in any future conflict."

In other words, cyber solutions harvested at Cyber ANTX can apply to domains other than a shipboard environment.

"If you think about a small expeditionary force like a unit of Marines, which could easily find itself in a disconnected or limited-access environment on an island chain in the Pacific, cyber defense and incident response are crucial as well," said Peter C. Reddy, NIWC Atlantic executive director.

Maintaining readiness to enable "integrated deterrence" around the world were key messages when former Chief of Naval Operations Adm. Mike Gilday released Navigation Plan 2022.

In the document, under force design, "cyber" is named within four priority investment areas.

At NIWC Atlantic, leaders not only hold events like ANTXs but also strive to move away from government-based research and development models that are "isolated, protected and exquisite," said Greg Hays, NIWC Atlantic's senior scientific technology manager for rapid prototyping and fleet exercises.

"Our value proposition is not measured by the number of commercially available widgets or apps that we can procure but rather by the continuous delivery of solutions in response to the changing adversary," Hays said.

The idea for a Cyber ANTX was hatched at Camp Lejeune in 2021, while York and Rushing were working at an isolated outdoor range in a NIWC Atlantic ANTX called "Naval Integration in Contested Environments." York said a discussion about an exercise involving cyber came up with Randy Sharo, who is now the chief technology officer at US Fleet Cyber Command/Commander, US 10th Fleet.

Sharo said he believed the event represented a change in the way the Navy should evaluate cyber technologies.

"With the help of NCRC Charleston, we were able to run realistic scenarios using real tools in an isolated network environment," Sharo said. "This meant operating at a higher level of fidelity than we would have ever considered before on an open network."

Once Cyber ANTX concluded, York praised the strong support of Cyber Command, NIWC Pacific, and NCRC and allocations from Naval Innovative Science and Engineering. He also credited Naval Information Warfighting Development Center, the Navy's Cybersecurity Program Office and US Marine Corps Forces Cyberspace Command for their support.

New Range Facilitates Exploration of Free Space Optics

NIWC Atlantic wrapped up another ANTX in November 2022 aimed at finding free space optics (FSO)-based solutions that enhance warfighter communications in a spectrum-congested or contested environment.

The ANTX—dubbed the "3-Path MONTE" (Multipurpose Optical Communications Naval Technology Exercise)—followed the Cyber ANTX conducted several months before and used NIWC Atlantic's newly certified Laser Communications Experimentation (LCE) range.

A total of four companies were selected under a commercial solutions opportunity (CSO) to demonstrate their products. The four traveled to Charleston on their own dime and spent the week testing out their prototype technologies on the new range.

"What's key here is our aggressive adoption model of using both government and commercial sector funding to search for optical communications solutions," said Greg Hays, NIWC Atlantic's senior scientific technology manager for rapid prototyping and experimentation. "We provided things like manpower, administrative support and the use of our range to create a warfighter-like environment across ground, air and mobile scenarios, while vendors supplied everything else—even their own airplane in one case."

Vendors demonstrate their technologies at Naval Information Warfare Center Atlantic headquarters during an advanced naval technology exercise (ANTX). Dubbed "Cyber ANTX," the two-week event focused on cyberspace defense in denied, degraded, and disconnected environments. Photo by Joe Bullinger

FSO communications, unlike fiber optics in which light runs through a cable, work in open spaces, often through an unseen beam of infrared light traveling from transmitter to receiver.

Through the CSO, Hays said ANTXs can lead to "dual-use technologies" that benefit both the commercial and government sectors by driving affordability and helping each other keep pace with innovation.

While each technology—and the resources to demonstrate each technology — came from the private sector, NIWC Atlantic's Naval Innovative Science and Engineering (NISE) program sponsored the ANTX, which included launching its own aerostat to help facilitate ground-to-air links during the week.

Ahead of the ANTX, NISE funded the laser equipment and certification processes that officially established the new LCE range. Provisions for needed upgrades to the Small Autonomous Unmanned Systems Research range where the laser range resides also came from NISE.

"With the addition of this new range, NIWC Atlantic is in a strong position to support novel communication improvements for the warfighter through events like this optical communications ANTX," said Tom Glaab, an engineer at NIWC Atlantic's science and technology department who serves as team lead for NISE initiatives.

Department of the Navy and other Department of Defense leaders have been focused on FSO technologies ever since information warfare came to play such a key role in military strategy.

Navy Chief Information Officer Aaron Weis's current Information Superiority Vision, which calls for innovation that "rapidly ingests new technologies," is just one example of how ANTXs align with national priorities.

A key technology focus area at NIWC Atlantic is assured communications, and leaders believe FSO capabilities can enable command and control (C2) advantages in a joint, all-domain scenario.

"To really get after this and make those lightning bolts we see on every joint all-domain slide a reality, we know we need to experiment with optical communications, assess their capabilities and connect the dots to ensure our C2 functionality and fallbacks dominate any contested information environment," said Capt. Nicole Nigro, NIWC Atlantic commanding officer. "This is where collaboration with those working in the same space outside of government becomes so vital."

"Representatives from many different organizations observed and/or provided technical assessments during the ANTX, including members of US Army Combat Capabilities Development Command, Marine Corps Systems Command, Office of Naval Research, and US Special Operations Command.

In addition, the maritime platform-electro-optics branch of Naval Surface Warfare Center Crane provided laser system safety support throughout the 3-Path MONTE ANTX.

"Optical communications is a quickly emerging technology requirement needed across the services," said Jason Pizarro, technical lead for Marine Corps communications systems at NIWC Atlantic's expeditionary warfare department. "So we created an opportunity to bring in as many stakeholders as possible."

The field environment was especially important since it provided vendors and government assessors with irregular terrain, temperature modulations and unpredictable weather for evaluating each FSO technology.

"When you shoot a light beam from point A to point B, environmental effects will play a role," Pizarro said. "If there's a tree in the way, you will have an issue. When the morning sun heats up the dew, you will have an issue."

Challenges using the light spectrum, however, do not outweigh the tremendous benefits. Often, traditional forms of communications are more easily jammed or degraded, Pizarro said. FSO communications are by nature difficult to detect and even harder to intercept—a coveted communications component of any operational scenario, especially given the technology's enormous, speed-of-light data throughputs.

Each prototype at the ANTX was evaluated for fixed, mobile and multi-point communications with active pointing, acquisition and tracking systems that can maintain links in dynamic environments. Assessors also tested each optical communication for how well it could resist an adversary's effort to collect on it.

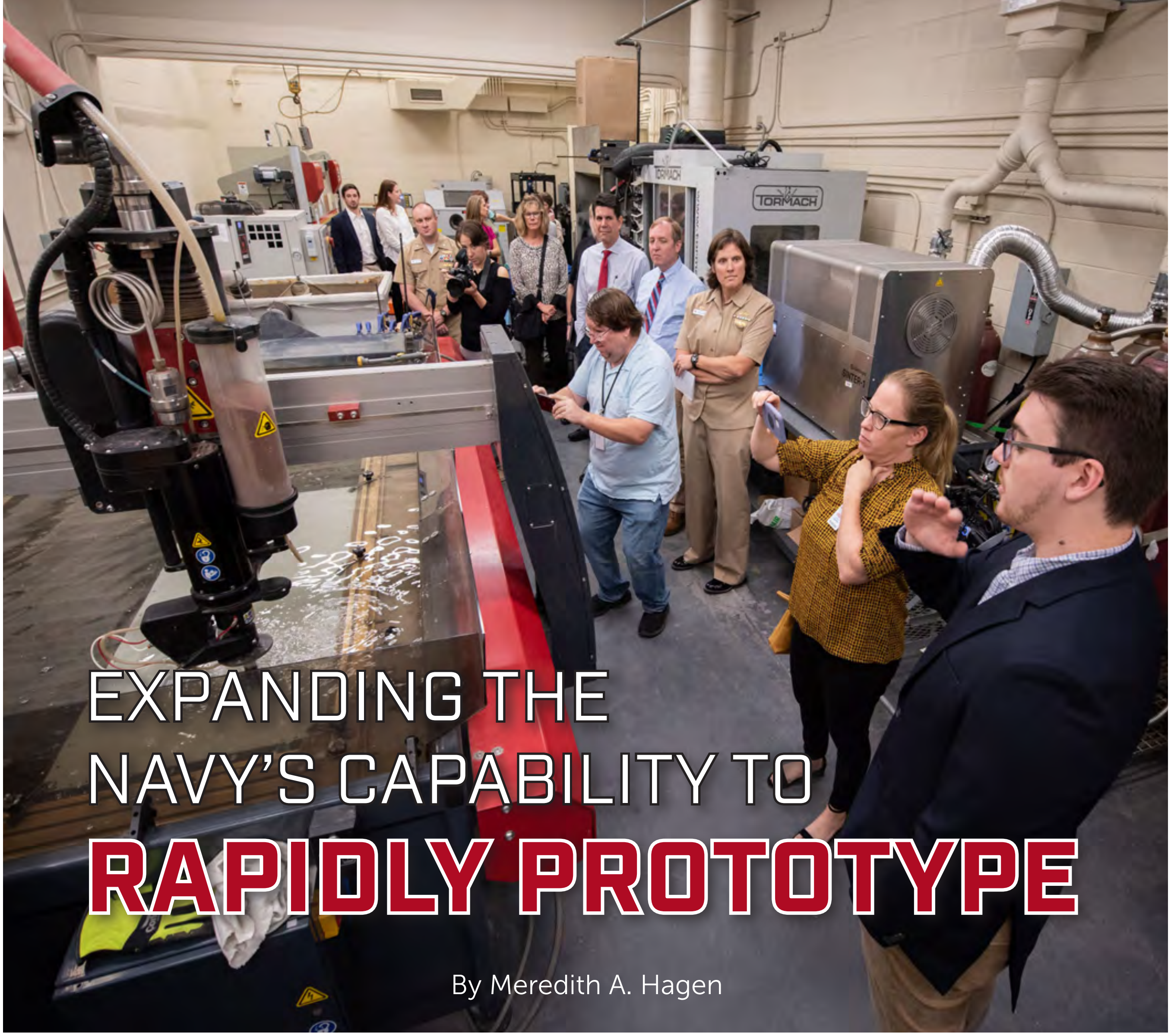
"This ANTX was a perfect example of military-government collaboration with industry and across the NR&DE," said Peter C. Reddy, NIWC Atlantic executive director. "By joining forces across DoD, private sector and other government labs, we can most effectively execute critical experimentation, testing and evaluations to find optical communications solutions that lead to the best outcomes for our warfighters in current and future contested environments."

Following all finalized assessments, vendors will receive a report on how they performed and, as appropriate, what next steps are planned.

About the author:

Steve Ghiringhelli is a writer with Naval Information Warfare Center Atlantic.

Photo by Joe Bullinger



EXPANDING THE NAVY'S CAPABILITY TO RAPIDLY PROTOTYPE

By Meredith A. Hagen

A NEW ON-DEMAND MANUFACTURING FACILITY AT NAVAL INFORMATION WARFARE CENTER ATLANTIC PROVIDES A MUCH-NEEDED RESOURCE FOR THE FLEET AND FORCE.

Naval Information Warfare Center (NIWC) Atlantic celebrated the graduation of on-demand manufacturing (ODM) from a technology focus area to a core proficiency during a ceremony held in October 2022.

ODM is the first of the command's eight focus areas to achieve this notable milestone, which signals the team has completed the training, certifications and technical processes needed to be an established capability and can provide on-demand manufacturing services to the command and the Navy.
NIWC Atlantic has expanded and standardized its ODM capabilities to design and fabricate prototypes in house rapidly with additive, subtractive, and advanced manufacturing processes.

"With the tools and expertise demonstrated here, the ODM lab is able to take a design from idea to physical product in sometimes a matter of just hours or days versus weeks or months," said NIWC Atlantic commanding officer Capt. Nicole Nigro. "That means we have the ability to deliver needed capability to naval forces faster so they can push forward with their mission."

The ODM lab sits on the old Charleston Navy Yard, which closed its doors in 1996 and has now been mostly inhabited and retrofitted by private companies. The 3,000-square-foot, government-owned space houses 15 3D printers and includes two machine shops that hold 15 traditional metal-working and advanced manufacturing machines—overall a $2.5-million investment by the Navy. The team covers down on a wide variety of printing solutions such as metals and polymers, as well as manufacturing capabilities that include laser etching and metal cutting, drilling, milling and bending. A recently added advanced manufacturing water jet can cut up to four-inch-thick titanium and has more than doubled the lab's output of custom-designed parts since its installation.

"We were surprised at how much we've been able to use the water jet," said Aaron Ross, deputy senior competency manager for the 4.7 Production Quality and Manufacturing Competency at NIWC Atlantic.

“It can quickly machine parts that would take hours by hand using traditional methods and the parts are highly repeatable. We can perfect a product here using government resources before sending it to industry for mass production to the specifications we outline. It’s been very effective and saves our project teams both time and money in the long term.”

The lab also has proven its worth as an invaluable resource by producing legacy parts that are no longer being manufactured and mitigating the impacts of recent supply chain issues that delay the delivery of critical items. ODM engineers can reproduce parts and design new parts to serve specific needs such as custom tooling, enclosures and bracketry to support command, control, computers, communications, information, surveillance and reconnaissance (C4ISR) integrated systems, for use aboard assets such as tactical vehicles and shipboard platforms. In the past six years, the lab has fabricated more than 17,000 individual parts that support approximately 35 teams across the command as well as other federal agencies.

Early in the COVID-19 pandemic the shop was called upon to retool and shift their focus toward producing personal protective equipment such as face masks and face shields for the NIWC Atlantic workforce in the absence of available products through traditional logistics channels.

“In line with our command strategic goals, this team is enabling our sailors and marines to keep up with the demands of modern warfare,” said NIWC Atlantic technical director Andrew Mansfield. “The Marine Corps’ Force Design 2030 and the Chief of Naval Operations’ NavPlan Implementation Framework both focus heavily on warfighter self-sufficiency and sustainability. In the modern battlefield, our warfighters will encounter sustainment challenges with getting parts to the field. Our committed group of engineers, scientists, and technicians are training our military members to design and produce their own products remotely using these on-demand manufacturing techniques. They have also built a capability for iterative physical and manufacturing design that is unmatched in the Navy today. This is essential for the Navy to win the future fight.”

The ODM lab is strategically positioned to solve almost any problem thrown their way. It requires a blend of design know-how and understanding the manufacturing technology and processes which allow the team to rapidly provide custom solutions.

As part of their endeavor to become a solution provider toward the improvement of military self-sustainment and reducing the need for onboard technical assistance, the ODM team has developed an award-winning five-day training curriculum, “Design for Manufacturability,” that provides an overview of advanced manufacturing concepts and best practices, modeling software, operation and maintenance, and print optimization training. The team recently deployed this training, along with two 3D printers, to Forward Deployed Regional Maintenance Center (FDRMC) Bahrain and the Navy’s Fifth Fleet Task Force 59 for a months-long naval experiment where they offered solutions for common repair parts that are difficult to source and challenging to fabricate with traditional manufacturing methods.

The ODM lab is strategically positioned to solve almost any problem thrown their way. It requires a blend of design know-how and understanding the manufacturing technology and processes which allow the team to rapidly provide custom solutions.

Lab engineers also use a Model Based Engineering (MBE) approach which focuses on creating digital models also known as digital twins which can be updated throughout a part or products life cycle. This ensures the iterative designs are created, saved and shared across the full systems engineering design from concept to sustainment for future needs including modification, reproduction or logistics support.

In just six years, what started as a six-person ODM action team with a few 3D printers and hobbyist machines has now transformed into a full core proficiency. They were also recently established as a command service center and expect utilization to expand even further in the future.

“This is an amazing accomplishment,” said Nigro. “The knowledge and expertise that has been brought to the command in this growth area keeps us on the cutting-edge of what’s possible as we support our Navy in winning the information war. I am very proud of the capability we have realized here.”

About the author:

Meredith Hagen is a writer with Naval Information Warfare Center Atlantic public affairs.

Marines with Combat Logistics Company 33, 3rd Marine Logistic Group, 3rd Marine Expeditionary Force, participate in the company's first additive manufacturing course at Marine Corps Base Hawaii. The program is designed to equip Marines with skills in computer-assisted design, 3D printing, advanced manufacturing, coding, and electronics. Photo by Sgt. Brandon Aultman

FUTURE FORCE is a professional magazine of the naval science and technology community published quarterly by the Office of Naval Research.

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