NAVAL SCIENCE AND TECHNOLOGY

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NATO, INNOVATION, AND RESEARCH COLLABORATION

LEARNING TO NAVIGATE WITH THE SWEDES

AUSTRALIA AT FOREFRONT OF HUMAN-MACHINE INTERACTION

INTERNATIONAL NAVAL SCIENCE AND TECHNOLOGY

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IN THIS ISSUE

COLUMNS

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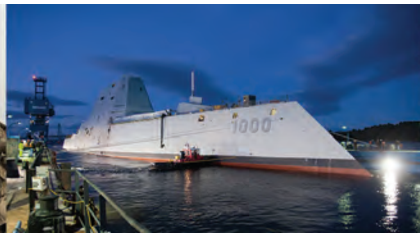

Future Force is a professional magazine of the naval science and technology community. Published quarterly by the Office of Naval Research, its purpose is to inform readers about basic and applied research and advanced technology development efforts funded by the Department of the Navy. The mission of 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.

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Front Cover: Illustration by Jeff Wright.

SPEAKING OF S&T

▶▶ By Rear Adm. Lorin Selby, USN

Photo courtesy of Standing NATO Maritime Group 1

Greetings and welcome to the newest edition of *Future Force* Magazine. While each issue focuses on topics critical to the US Navy and Marine Corps, I can't think of many subjects more important than accelerating the international partnerships that power our science and technology (S&T) work around the world.

We are working hard to find, foster, and deliver naval advantage wherever it may be.

As chief of naval research, I have emphasized to the Naval Research Enterprise (NRE) that "business as usual" is not an option for how we do naval S&T. We either try new ways of doing business and increase our return on investments, or we fall behind—including potentially to nation-states of malign intent. Potential adversaries are going all-in on technological catch-up with the United States—and in some cases, they are succeeding. We cannot allow that to happen. The world depends on open ocean commons, guided by the rule of law and ensured by a powerful United States and our allies. However, the access to cutting-edge technology is far easier today than it once was. Artificial intelligence, autonomy, quantum computing and more are not the exclusive province of the democratic world. We dare not imagine that the technological edge we enjoyed in much of the post-World War II era is set in stone.

So how do we maintain our edge? In many ways, but one of the most important is by working in innovative ways with our allies. The NRE is laser-focused on discovering and advancing S&T from around the world to provide capabilities for our fleet and force. Led by an incredible team of professionals at ONR Global, our science directors sponsor research from Asia to South America, and from Europe to Africa. Our ONR Global science advisors are directly embedded with US Navy and Marine Corps commands around the world, seeing what technologies are needed, what's working, and frankly, learning to view things from a different lens.

Seeing things from different perspectives is a crucial part of success, and another key benefit to working with partners around the world.

ONR "knows" international partnerships. Our first international office was established in London in 1946, and it serves today as ONR Global headquarters. We have established offices in Santiago, São Paulo, Prague, Singapore, Melbourne, and Tokyo. We also recently opened a Naval Tech Bridge in London, cosponsored with the Royal Navy. That Tech Bridge will be a place where industry and academics from around the world can—virtually or in-person —collaborate freely with American and British officials on new ways to solve our toughest challenges.

We are lowering barriers to inspiration, and increasing the power of collaboration.

I also serve as the Navy's senior national naval representative. In that role, I work with my peer officers in different countries. One of the great ideas bubbling up today is interchangeability. (That is distinct from interoperability, a concept we've long enjoyed of nations working together to advance a common front. Interchangeability, however, is Interoperability on overdrive.) In this concept, we are looking to work together from the very beginning of system design, using common specs and standards to make it easy to have fully-shared technologies that work on any platform of either partner, right from the get-go. We are already engaged in this effort with our partners in the Royal Navy in the United Kingdom.

In addition to theaters of operations, we're also working with international partners in the Arctic—a region whose importance has grown as climate change brings new challenges, opening up new passageways and bringing new competition to everything from new bases to mineral extraction. And ICE-PPR, or the International Cooperative Engagement Program for Polar Research, is bringing together defense departments from the United States, Canada, Denmark, Finland, New Zealand, Norway, and Sweden to share polar research and advance polar science and technology.

We're in this for the long-haul with sponsored research, but we're also on the deckplates of America's fleets. A growing part of our work with allies is led by ONR Global's Experimentation and Analysis (E&A) team. Experiments taking place on, below or above the sea are an important path to research success and to long-lasting, viable partnerships in the international arena. The E&A team is just one of many ways that we are providing direct services to today's fleet. ONR Global's TechSolutions program – which takes requests directly from Sailors and Marines and provides technology prototypes in 12 months – is the epitome of quick-reaction to naval needs.

The importance of international collaboration is clear. To keep the peace, advance new capabilities for our Navy and Marine Corps, and win the fight if need be, we must leave no stone unturned in our effort to discover great ideas.

Enjoy this issue of *Future Force*!

Rear Adm. Selby is the chief of naval research.

INTERNATIONAL NAVAL SCIENCE AND TECHNOLOGY

Multinational exercises such as the annual Baltops provide opportunities for partners and allies to learn how to work together at sea. They are also one of the best among many venues to develop and test new shared technologies. From experiments at sea to collaboration in the laboratory, naval science and technology flourishes when shared among nations.

▶▶ By Colin Babb

The Crucible of War Gave Birth to ONR LONDON


Frederick Hovde (left) served as the first head of the London Mission. He would later go on after the war to be president of Purdue University. Bennett Archambault (right) headed the mission for the rest of the war, and would later become chief executive officer of Stewart-Warner Corporation. Photo (left) courtesy of Purdue University Libraries, Archives and Special Collections
Photo (right) courtesy of New York City College of Technology

CONCEIVED DURING BRITAIN'S DARKEST DAYS DURING THE BLITZ IN 1940 AS A WAY TO QUIETLY ASSIST THE ALLIED WAR EFFORT THROUGH SCIENCE, THE LONDON MISSION OF THE OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT WOULD GO ON TO BE A KEY CONTRIBUTOR TO VICTORY IN WORLD WAR II.

Months before the Japanese attack on Pearl Harbor brought the United States into World War II in December 1941, American scientists already were hard at work collaborating with their British colleagues. Originally sent as representatives of the National Defense Research Committee in what was for the Americans a time of peace, the London mission would go on during the war under the Office of Scientific Research and Development (OSRD) to be a major contributor to the Allied effort in the European theater. Considered a success in international science and technology partnership, OSRD's London office would be transferred to the care of the Navy after the war—and continues today as the longest-serving location of the Office of Naval Research (ONR) Global.

The London office originated in the immediate aftermath of the famous Tizard Mission in 1940, when a team of British scientists was sent to the United States in the midst of the Battle of Britain to bring a host of advanced technologies—most notably the cavity magnetron and other inventions related to radar—to the United States. The group's intention was to take advantage of American production capabilities to augment the already overstrained British industrial capacity, as the Commonwealth faced the Germans alone. During a meeting with the National Defense Research Committee (NDRC) on 27 September 1940, Sir Henry Tizard proposed that there be a continuing exchange of technological and scientific information between the United Kingdom, the United States, and Canada. Later that same year, it was decided to send an American team to London to facilitate this exchange and establish a permanent presence in London. President Franklin Roosevelt selected Harvard president and NDRC member James B. Conant to head this mission, which reached London in March 1941. Formally established in August 1941 as a part of OSRD—the new name of the NDRC—the permanent London Mission already had been working for several months informally under Frederick L. Hovde, a member of the initial Conant Mission. OSRD London operated throughout the war with permanent staff as well as a large number of temporary visitors (mostly technical experts) sent by divisions and projects in the United States to interact with their British counterparts. A companion organization, the British Central Scientific Office, was established in Washington, DC, in early 1941 and served a similar role for the British war effort. The duties of the London office included exchanging technical reports, arranging for travel to and from England for personnel involved with numerous projects, handling of cables on technical topics between the two countries, and arranging for clearance of foreign scientists for OSRD projects. The London Mission also had responsibility for the more limited technical interactions between other "Lend-Lease" countries (such as Australia, New Zealand, and South Africa, and medical technology exchanges with the Soviet Union). After leading the mission during its first year, Hovde returned to the United States and was replaced by Bennett Archambault in April 1942. The office would remain under Archambault's leadership for the rest of the war.

With American entry into the war and the vast increase in the number of transatlantic research projects, the mission quickly discovered that its initial charter to be a conduit of technical reports between London and Washington was extremely difficult to fulfill. Many project teams, pressed to produce useful technology, had little time for completing formal reports on their progress. With many reports backlogged and delayed, it was the mission's personnel exchange program that proved to be London office's most useful function. Field technical aides, each of whom was responsible for coordinating a particular area of research, would travel between OSRD's Washington headquarters and various projects in the United Kingdom, becoming among OSRD's most knowledgeable experts in their fields during the war. Other on-the-ground activities of London office personnel included participating in scientific intelligence teams that accompanied forward units in France and Germany after D-Day (this role proved so expansive that by December 1944 a London satellite office was opened in Paris to coordinate these teams' activities).

Over the course of the war, the London Mission was responsible for ensuring the delivery to the United States of more than 59,000 technical reports from the United Kingdom and Canada, as well as the sending of more than 82,000 American technical reports to the British and Canadian governments. The mission also coordinated the visits of more than 1,800 technical experts on foreign travel (both to and from the United States), and handled nearly 7,800 cables of a technical nature. As an official procuring agency for the Lend-Lease program, the London Mission also arranged for the physical transfer of completed technical equipment to Britain and Canada. In this regard there was a special emphasis to facilitate the transfer of radar equipment in particular, by special agreement between OSRD and various British and American companies.

Most of the London Mission was closed down in July 1945 after the surrender of Germany, but the liaison part of the mission was continued until the remaining staff and offices were formally transferred to the Navy's Office of Research and Invention (ORI) in March 1946, with Commodore Robert E. Robinson Jr. as the first commanding officer. Several months later, in August, ORI would be formally reorganized as the Office of Naval Research. ONR London remained the only international office within ONR until the addition of the office in Tokyo in 1974.

About the author:
Colin Babb is a contractor serving as the historian for the Office of Naval Research, and the managing editor of Future Force.

BUILDING TRUST WITHIN THE GLOBAL RESEARCH COMMUNITY

By Capt. James Borghardt, USN

IN A WORLD WHERE THE RULES FOR WHAT "PRESENCE" MEANS ARE CHANGING CONSTANTLY, OFFICE OF NAVAL RESEARCH GLOBAL IS CONTINUING TO CONNECT PEOPLE, IDEAS, TECHNOLOGY, AND SCIENCE ACROSS OCEANS AND BORDERS.

I recently heard a lecture claiming that 90 percent of the scientists our planet has ever hosted are still working in science today. That is a remarkable number. The lecture went on to demonstrate that number was a reasonable estimate by using compelling mathematical modeling. R&D Magazine's 2017 Global R&D Funding Forecast illustrated that while total research and development spending in the United States has increased since 2010, the number of scientists per capita decreased significantly. The same report also showed that 80 percent of the world's researchers are outside of the United States. In addition, according to the Congressional Research Service's Global Research and Development Expenditures: Fact Sheet, the United States' percentage share of global research and development funding has shifted significantly from 69 percent in 1960 to 28 percent in 2018.

According to the Times Higher Education World University Rankings 2021, 25 of the top 50 universities (and 63 of the top 100) are outside the United States. Of the $2.1 trillion in global research funding, the US Department of Defense basic research funding accounts for just 0.1 percent. The United States, and specifically the Department of Defense, is no longer driving global basic research through direct funding.

Although many might find this significant shift in global research resources and influence disheartening, by shifting its focus from basic research investments for specific capabilities to research investments that establish trusted partnerships and collaborations, Office of Naval Research (ONR) Global and its co-investors and collaborators have instead created opportunities for accelerated discovery with a system of research networks. By focusing on these networks of trusted partnerships, the funding imbalance has less influence than our ability to connect researchers to other motivated and influential researchers who can accelerate discovery through collaboration. Like any other significant human endeavor, these trusted partnerships are neither accidental nor easy to establish. Creating a network of connections is certainly a part of the journey, but it is a very small part. The secret to establishing, maintaining, and expanding these trusted partnerships is an enduring presence.

Presence, in every sense of the word, is what can turn a contact into a trusted partner. Presence includes being physically present in their country or in their time zone. Presence is a familiar rapport supported by common interests. Presence is sharing a meal, an idea, or even a connection. Anthropological research indicates Homo sapiens tend to trust what they know and what they experience. Many of us are driven or motivated by funding, but we don't trust someone simply because they have money. ONR Global invests 0.3 percent of the Department of Defense basic research funding to connect with leading international researchers. Once connected, our globally disbursed team of 50 scientists and engineers use our enduring presence in two offices and 25 deployment sites to transition our network of connections into a community of trusted partners. As retired Adm. James Stavridis eloquently articulated in his August 2020 *Proceedings* article, "You can surge forces, but you must build trust one interaction at a time."

By spending time in their labs, with their students, and at conferences, ONR Global scientists create and strengthen the bonds of trust with our partners. These bonds persist when after their three-year deployment overseas, our scientists return to naval research and development labs, federally funded research and development centers, and university affiliated research centers that are their home commands. These bonds persist as our trusted partners are recognized as Nobel

Laureates or are promoted to senior positions within their governments. These bonds allow us to leverage an ever-expanding network of intellectual capital to accelerate discoveries and make the world a better and safer place through maritime security.

The age of the US government dominating global research and development resources is gone. By focusing its 0.3 percent of the 0.1 percent Department of Defense share of global research and development funding and its 50 deployed science directors and advisors on creating, maintaining, and expanding our network of trusted partners, ONR Global is leading the Navy and Marine Corps' efforts to leverage international research resources into future US naval power and maritime security.

About the author:

Capt. Borghardt is the commanding officer at Office of Naval Research Global.

Global-X Challenge Awards More Than $1 Million

The International Global-X Challenge, launched in April 2020 by the Office of Naval Research (ONR) Global, has selected four winning projects that will demonstrate revolutionary capabilities for the US Navy, Marine Corps, commercial marketplace, and the public.

The awards, totaling more than $1.1 million, fall under two challenge areas. The selected international teams of researchers will have nine months to demonstrate that their concepts meet objectives.

Global-X Challenge is designed to discover, disrupt, and ultimately provide a catalyst for development and delivery of new capabilities. Following successful concept demonstrations by the four winning teams in June 2021, ONR Global may support an additional nine months of research, while transition partners prepare to implement technology maturation for insertion into the fleet.

"We are very excited about the level of interest generated by this initial stage of the first-ever edition of Global-X," said ONR Global's executive officer, Capt. Matthew Farr. "We received groundbreaking proposals from all around the world—highly capable ideas with the potential to deliver value throughout the US Navy and Marine Corps.

"We expect great things from the teams we selected for the next phase of capability demonstration."

After evaluating 11 full proposals—chosen from 385 highly competitive white papers from 33 different countries—ONR Global selected four teams, with members from Australia, Denmark, Spain, Switzerland, the United Kingdom, and the United States. Under the challenge topic "Multifunctional Maritime Films for Persistent and Survivable Platforms and Warfighters," Dr. Nick Aldred and his team from the University of Essex will demonstrate a sample biofilm that will resist biofouling with the goal of eventually replacing traditional hull coatings.

The concepts of the remaining three winning teams address the challenge topic "Object Detection and Identification in any Medium." Dr. Brant Gibson and his team at RMIT University in Melbourne, Australia, will demonstrate a robust quantum-limited diamond-fiber magnetometer that may achieve nanotesla sensitivity for long-term, wide area maritime surveillance.

At the same time, Dr. Teuta Pilizota, University of Edinburgh, and her team will explore whether a self-sustained electrical bio-chip can detect flow and small traces of chemicals.

Finally, Professor Gregory Cohen, Western Sydney University, and his team will demonstrate neuromorphic event-based sensors that can quickly detect submerged vehicles and objects—and enable celestial navigation without breaking the water surface.

ONR Global's technical director, Dr. Rhett Jefferies, stated, "Global-X has already stimulated novel, high-risk multidisciplinary research ideas with both military and commercial value and that may address current and future Navy and Marine Corps technology needs. We are confident the winning projects we selected will provide a glimpse of new capabilities, forever changing how we operate."

More information can be found on the Global-X website: https://www.onr.navy.mil/Global-X/ ONR Global sponsors scientific efforts outside of the United States, working with scientists and partners worldwide to discover and advance naval capabilities.

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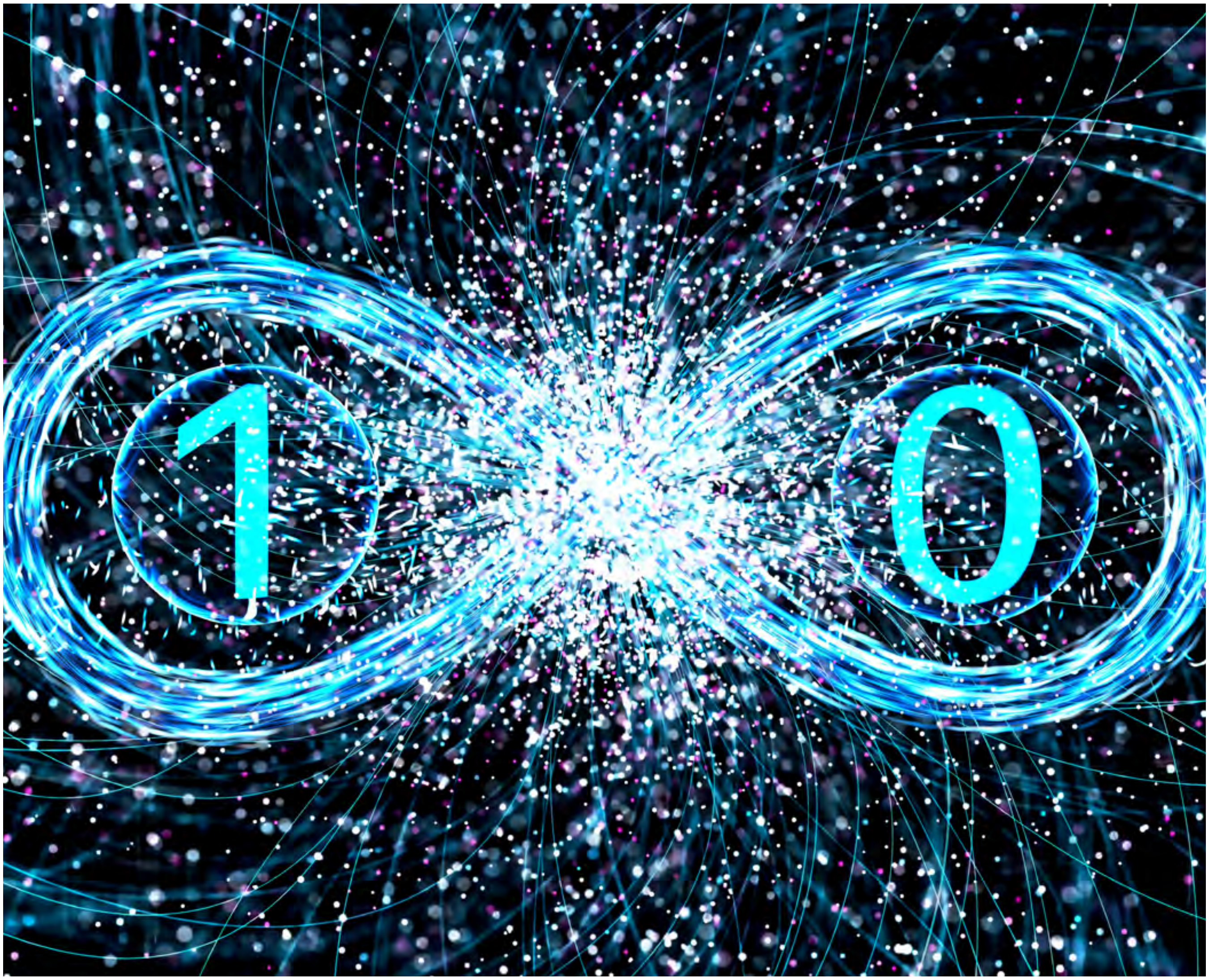

QUANTUM COMPUTING:
EARLY FUNDING SUPPORTS GROUNDBREAKING TECH

By Felipe Reisch

FOR MORE THAN 70 YEARS, THE BASIC BUILDING BLOCK OF MOST COMPUTERS HAS BEEN THE BIT—WHICH CAN BE ENCODED AS EITHER A 1 OR 0. QUANTUM COMPUTERS USE QUBITS, WHICH CAN BE A 1 AND A 0 AT THE SAME TIME. THIS DECEPTIVELY SIMPLE DISTINCTION IS RIFE WITH REVOLUTIONARY POTENTIAL.

Quantum computers may be able to help create new pharmaceuticals, understand chemical reactions, solve certain problems that are otherwise intractable, create new materials, and allow for highly disruptive applications in numerous sectors.

In this world of opportunities, Universal Quantum, a disruptive new player on the global quantum computing stage, recently announced it raised $4.5 million in funding. The company is set to develop its groundbreaking new quantum computing approach and compete with the world's biggest quantum computing companies, with backing from highly influential tech investors.

The University of Sussex (Brighton, United Kingdom) spin-off company, founded by quantum computing experts Professor Winfried Hensinger and Dr. Sebastian Weidt in 2018, has the goal of building the world's first large-scale quantum computer with Hensinger as the chief scientist and chairman and Weidt as the chief executive officer. The Office of Naval Research (ONR) Global and the Army Research Office (ARO)—an element of the US Army Combat Capabilities Development Command's Army Research Laboratory—both support Hensinger's basic research in the department of physics and astronomy at the University of Sussex.

"Practical quantum computers have been described as one of the holy grails of science," Hensinger said, "due to their disruptive capabilities across a wide range of sectors such as finance, drug discovery, and chemical reactions, intelligence, and defense, to name a few.

"The answer to cure Alzheimer's, Huntington's, Parkinson's disease, dementia, and some cancers may come from a better understanding of protein folding," he added. "Unfortunately, simulating protein folding on conventional computers or even supercomputers is extremely challenging due to the limited computational resources available. Quantum computers may enable us to understand protein folding, and contribute to solving one of the biggest of all human challenges—our aging society."

Revolutionary Approach

Hensinger and Weidt have developed a radical new approach to building a quantum computer. While some companies have created small quantum machines, Universal Quantum believes that only its technology, on a reasonable time scale, has a realistic opportunity of being scaled up into machines large enough to unleash the huge potential of quantum computing on a worldwide basis.

Key to Universal Quantum's appeal are some fundamental differences in its approach to building a large-scale trapped ion quantum computer. All of the leading platforms for quantum computers have challenges related to scaling them up to the large number of qubits needed for meaningful computations. For many trapped ion systems, one of these challenges is that number of laser beams required in the system grows linearly with the number of qubits. At small numbers of qubits, this is tractable, but as the systems grow in size the number of lasers becomes a challenge. The approach the Hensinger group has developed eliminates the need for many of those lasers by manipulating the qubits in a different way.

"This new approach allows much better scaling of the numbers of qubits," said Dr. Andrey Kanaev, ONR Global London science director, "since there is no need for multiple very high-quality lasers focused with micron scale accuracy per qubit. Additionally, the global microwave tones needed can be generated using widely available RF technology borrowed from cell phone technology."

Hensinger added, "We recently invented a method for trapped ion quantum computing where this scaling vanishes, significantly reducing the difficulty of producing a practical quantum computer. Instead of using laser beams for quantum gate execution, our approach makes use of proven microwave technology, such as that used in mobile phones."

"When the Army first started supporting Professor Hensinger's research at the University of Sussex in 2012, it was a very high-risk method to potentially achieve scalable quantum computing," said Dr. Sara Gamble, quantum information science program manager at the ARO. "The research progress made over the past several years has been excellent, and we look forward to continuing research aimed at overcoming the many remaining scientific challenges facing the quantum computing community in developing scalable systems."

In the next decade, quantum computation will become a very disruptive technology in many areas, including in several crucial defense applications. The areas likely to be the first to feel the effects of quantum computation will be materials science, chemistry, and (potentially) artificial intelligence/deep learning.

In the case of material science and chemistry, the inherent capability to model large and highly complex quantum mechanical systems efficiently will enable much higher-fidelity calculations and prediction of the physical characteristics of new materials and chemical processes. Using even state-of-the-art supercomputers (classical), there are currently many approximations and assumptions needed to simplify the numerical calculations performed when modeling new materials and complex chemical processes.

"Quantum computation is known to enable breakthroughs in such modeling and simulation," said Kanaev. "Such capabilities will have many applications relevant to the Navy—for example, cost-effective and rapid computational exploration of new materials. In AI/deep learning, there are indications, both theory and early experimentation, that a large-scale, high-fidelity quantum computation will provide advantages in performance with respect to classical computers."

About the author:

Felipe Reisch is a strategic communications specialist with Office of Naval Research Global.

AUSTRALIA AT FOREFRONT OF

HUMAN-MACHINE INTERACTION RESEARCH

By Dr. Yoko Furukawa

RESEARCHERS FROM THE UNIVERSITY OF NEW SOUTH WALES IN SYDNEY ARE FINDING WAYS TO INCREASE THE CAPABILITY OF HUMAN-MACHINE COOPERATION, BY EXPLORING A NOVEL LINE OF RESEARCH BASED IN FUTURE INTENT PREDICTION.

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Developing interpretable data mining, machine learning, and deep learning algorithms—as well as designing systems and interfaces—to enable novel ways of human-machine interactions, including an improved understanding of challenges such as trust, explainability, and resilience that improve human-autonomy partnership—is the work being led by Dr. Lina Yao, senior lecturer at the University of New South Wales, with her group of researchers.

Thanks to funding provided by the Office of Naval Research (ONR) Global, Yao's team is boosting the capability of human-machine interactions—which serve as the core of interactive intelligent systems—by exploring a new line of research based in future intent prediction. Most existing research focuses on detecting, rather than predicting, intent. Future intent prediction is crucial in real-life scenarios, where anticipatory response is required such as active sensing and autonomous navigation to make responses actively.

Collaborating with machines will become an essential part of how humans live, work, learn, and play in the near future, as intelligent machines have the potential to seamlessly augment and boost humans' physical and cognitive capabilities. For machines to become our collaborators rather than mere tools in a wide range of settings, however, many science and technology breakthroughs still need to occur. ONR Global is facilitating these future breakthroughs with its support of international research communities. Australian research communities are particularly advanced in the field of human-machine interaction (HMI) science.

This ONR Global-funded project aims to develop theoretical foundations and a data-efficient intent prediction paradigm that can capture human-machine interactions and temporal relational mining of intents and contexts, analyze and predict future intents from both explicit and implicit contexts, discover and recognize new unseen intents with limited examples, and provide effective mitigation strategies to improve performance (such as adjusting levels of automation or adapting visualizations)

"Generally speaking, the core objective of human-machine cooperation is to create mutual understandings between the behaviors of humans and artificial intelligence [AI] systems, to improve human welfare and well-being, enhance the human decision-making process and maximally reap the benefits of AI systems," said Yao. "This project is one of the pillars towards this goal." To predict intent, her project is addressing such technical challenges as the extraction and representation of heterogeneous and entangled data that are evolving with time, as well as machine learning from limited samples.

The ability of human beings to recognize others' intents accurately is a significant mental activity that involves reasoning about objectives such as what other people are doing, why they are doing it, and what they will do next. The quality of interpersonal and human-machine communications can be enhanced by employing predictive intent analysis to identify other human beings as peers, competitors, or bystanders, and to forecast their future activities. In the meanwhile, the situated courses of actions could be employed.

Present and Future Applicability

Previous research has revealed that human intent could be inferred by measuring human multifaceted activities from multiple heterogeneous information sources, such as body and brain sensors (e.g., echocardiograms, electroencephalograms, and inertial measurement unit sensors such as accelerometers and gyros). Nevertheless, many of the existing studies focus on detecting rather than predicting intent, or recognize intent's predefined variables. Intent prediction remains largely unexplored when only partial observations or few clues for intent have been observed.

With theoretical foundations and a data-efficient intent prediction paradigm, this project aims to boost the capability of human-machine interactions, which serve as the core of interactive intelligent systems (e.g., robots, logistics units, or other sophisticated military systems). Such systems aim to meet increasingly complicated defense demands, such as improved operators' performance and training techniques, autonomous weapons, casualty reduction, casualty recovery, and mental health management.

For instance, future intent prediction could help autonomous vehicles to decide how to maneuver depending on the next predicted intent or assist robots to make future decisions. In these scenarios, existing systems can only detect intent when it has already occurred or partially occurred, which may not give operators sufficient time to respond.

"The ultimate goal the community are keen to achieve is to enable AI to act like a human, artificial general intelligence, with which humans can partner up," said Yao. "Therefore, it would be wise to look it up from the perspective of human behavioral and cognitive science. Actually, many major findings are inspired by them. For example, reinforcement learning and learning to learn are inspired by neuroscience and behavioral science. In my opinion, developing hybrid solutions integrating the different streams of AI developments might be a promising way to realize AI's superiority and ever-increasing capabilities, and further to merge and work together with human beings to transform into a new level of joint/collective intelligence and super mind. This project lays a solid foundation to support our future explorations and effort."

This research will be a critical piece in a wide range of human-machine collaboration applications in the near future, both in defense and in civilian applications including recommender systems, brain-machine interfaces, and the internet of things. Particularly in defense, this line of research will lead to decision-support tools for teams of machines and human warfighters that are fast, accurate, and highly relevant to the mission and task context.

About the author:

Dr. Furukawa is the science director at ONR Global Melbourne.

INTERVIEW:
ALLIED COMMAND TRANSFORMATION AND INNOVATION

By Capt. Edward Lundquist, USN (Ret.)

CAPT. LUNDQUIST SPOKE IN 2020 WITH LEADERS—REAR ADM. RENE T.P. TAS, ROYAL NETHERLANDS NAVY, DR. ERIC POULIQUEN, AND BRIG. GEN. POUL PRIMDAHL, ROYAL DANISH ARMY—AT THE NATO ALLIED COMMAND TRANSFORMATION (ACT) IN NORFOLK, VIRGINIA, ABOUT TRANSFORMATION AND INNOVATION. THE DISCUSSION FOCUSED ON HOW INDUSTRY AND ACADEMIA CAN WORK WITH NATO AND THE MILITARY SERVICES OF MEMBER NATIONS TO MAKE NEW TECHNOLOGIES AND CONCEPTS AVAILABLE TO WARFIGHTERS. FORMED IN 2003 AS THE SUCCESSOR TO ALLIED COMMAND ATLANTIC, ACT'S MISSION IS "TO CONTRIBUTE TO PRESERVING THE PEACE, SECURITY AND TERRITORIAL INTEGRITY OF ALLIANCE MEMBER STATES BY LEADING THE WARFARE DEVELOPMENT OF MILITARY STRUCTURES, CAPABILITIES AND DOCTRINES."

Photo by PO1 Adrian Melendez

LUNDQUIST
Admiral, what's your job here at ACT?

TAS
I'm assistant chief of staff for capability development. Basically, what we do in one sentence is develop common-funded capabilities. As you know, the NATO nations have ships, battalions, and aircraft. That's all being funded by the nations themselves. But there are some capabilities that are owned by NATO itself. It amounts to less than 1 percent in investment money, and includes programs like the AWACs [Airborne Warning and Control System] and AGS [Alliance Ground Surveillance], which are owned by NATO itself.

LUNDQUIST: Your team is responsible for NATO's requirements and capability development. Do you wait for a requirement to come your way, or are you scanning the environment to see what technologies are coming along that might be useful, and you try to help develop something innovative that NATO doesn't know about or fully understand yet? Do you invest in future technologies and capabilities before someone asks for it?

TAS
In years past, NATO and the militaries were the driving force in technology. Today, it's industry and the commercial market that drives innovation. Because of competition in the market place, industry is moving fast and developing remarkable technologies. Now, when we need a new capability, we need to reach out to industry and find out what's out there. We try to be as innovative as possible, and we ask industry and academia what are the possibilities.

LUNDQUIST
So how do you engage with academic institutions? Is there a consortium that has said "we are interested in working with NATO"?

TAS
Our innovation branch has what we call an "innovation hub," and that's a system where we can reach out to more than 5,000 experts in academia at a time, from all over the world. It's all unclassified, as well. We reach out and say, "We have a problem we have to solve. How can you help us?" It's an open question. Our traditional approach might be to build a new version of the same stuff we've been using. But using open innovation, we're reaching out to people who think outside the box and are looking at technologies that may be five or ten years out in the future and beyond.

LUNDQUIST
If I am a researcher at an academic institution and I see one of your queries, what's in it for me if I respond? Would I get some funding to conduct research on that topic? Could I be placed on a team or a committee that's going to be brought together to investigate or examine that issue further? Or is it just, "'Send us your thoughts,' and we send you a thank you note"?

TAS
There is a process. When we start collecting the ideas, we look at the different skills and disciplines, and who would be the best people we could bring together to be on a team to examine this problem or opportunity.

LUNDQUIST
Do you have some funding to resource those efforts?

TAS
We do have resources for innovation. And in the programs of work for each one of the capabilities we are developing there is money, as well. We can hire people and contractors. We do that all the time. When we invite people from academia, it's not an issue, but if we invite people from industry to help develop that capability then they would not later be able to bid for that program work.

LUNDQUIST
For the newer and smaller nations in NATO—compared to the original countries that have been doing this a long time—does this open up a lot of opportunities for them and their industries and academic institutions? Does it give them exposure to ideas from all over the world that maybe they would not have had otherwise?

TAS
Yes. They can get involved in helping us in developing existing capabilities, of solving problems that we have articulated, and participating in our innovation challenges. For example, we conduct "hack-a-thons" twice a year. We have competitions and invite people who just subscribe and say, "Hey, I have a good idea, you should have a look at it." We have some standups, as well, with people who have thought about a particular issue in some university or one of the naval or military academies or war colleges among the nations, where they can tell us, "I have something you should know about it." So we invite them as well. We do reach out to a list of people all over the world. We could reach out to an even broader group but we have limited resources.

LUNDQUIST
What is ACT's relationship with the NATO Centre for Maritime Research and Experimentation [CMRE] in La Spezia, Italy?

TAS
CMRE is a NATO-nations-owned facility. It's part of the NATO Science and Technology Organization. They are customer funded, so nations pay for it, but we here at ACT are their biggest customer. We're spending USD $20 million in 2020 and we're going to increase that in 2021 if our budget gets approved. There had been a decline in funding, but we've turned that around. They have a tremendous group of people over there. CMRE is important for us for several reasons. The first is the support of capability development, whether it's a national capability development, a multinational capability development, or common funded capability development. They are great at doing that. For the individual nations to develop these capabilities themselves would be more costly. So, it contributes to capability development; it makes that capability more affordable in the end, and you assure interoperability right from the start. And that's important because if every nation is developing something similar, and you don't have interoperability already built into the design, you're going to pay for it later both in terms of effectiveness and in terms of cost.

Another is making sure that we can keep the maritime technological edge. Over the past 70 years, we have been the front-runners. We were ahead of our peer competitors, but that's changing now. Our adversaries have become smarter as well, so we need to keep the technological edge, and CMRE contributes to that.

> "If you want to operate somewhere, you have to know the environment. And we need to have experience working in that environment."

Another reason is that investing in emerging and disruptive technologies makes us smarter—not just the maritime world, but NATO as an enterprise. That's a big spin-off from CMRE's maritime work. It has a huge impact on everything we do, like managing big data, machine learning and artificial intelligence, and modeling and simulation. Beyond what CMRE is doing in the maritime domain, there's a huge spinoff to other domains as well.

LUNDQUIST
CMRE has a lot of experience in collecting, storing analyzing huge amounts of data. How you do that is a problem set for any NATO endeavor.

TAS
Yes, they're tremendously important. NATO understands the importance of the maritime domain, and it is growing in importance for the entire world. History has proven that if you lose the maritime, it's hard to do everything else. The maritime environment has even greater importance than in the past. We have the traditional sea lines of communications, but not just the shipping lanes, but the seabed is also is becoming more and more important because of all of the communication lines that connect nations and continents. We may have forgotten it a little bit after the Cold War, but the sea is back. The threat has become more complex. We now have to worry about everything from the littoral to the blue ocean. When the Cold War ended, our peer competitor fell away. We shifted focus to the littoral and piracy, transnational crime and terrorism. That hasn't gone away. But now we also have a near-peer competitor back again. It's not one or the other. Its additive. We now have to contend with all of it. The maritime is becoming more important and more complex. Not just ship against ship or submarine against ship, but there are hybrid threats.

LUNDQUIST
There is a renewed interest in the high north, in part because of the resurging peer competitor. A lot of the knowledge of the Arctic, the high north, and the GIUK [Greenland-Iceland-United Kingdom] gap, that we learned during the Cold War, is actually different because of climate change. You can't just go back and look at your data from 40 years ago.

TAS
If you want to operate somewhere, you have to know the environment. And we need to have experience working in that environment. Back during the Cold War, we had major ASW [antisubmarine warfare] exercises, with many surface ships, submarines, and maritime patrol aircraft. In the last 20 years, we have done fewer big ASW exercises, and we have

lost some of the knowledge and experience. We're getting that back fortunately. But we have fewer assets now, we didn't collect the data for many years; and we didn't train as extensively, so we have to compensate for that. CMRE is helping with that, collecting data, developing knowledge, and creating technology that will give us the expertise we need to maintain our edge.

CMRE is experimenting with new equipment that can provide new data, like the underwater vehicles, buoyancy gliders, and wave gliders. It's far less costly to collect data with unmanned systems than large numbers of maritime patrol aircraft (and we don't have large numbers of them anymore) and networks of those unmanned sensors provide better persistence. Everybody will agree that we need the CMRE, and if we didn't have it, then we should invent it yesterday.

We are dealing with new domains, such as space and cyber. So as technology is changing, we also have changes in policies and strategies. That is what is driving us. We are showing a coherent military instrument of power. That edge is not only based on technology, but also processes and people, so that the whole is greater than the sum of the parts.

And lastly, and very importantly, we need to ensure that we have "Day-Zero Interoperability." That means that we are fully interoperable even before we commence a conflict or war. If we can't link all or our systems at day one, it's going to cost a couple of months to become interoperable and we don't have those months. So that's why we call it "Day-Zero interoperability." Here at ACT, we help the alliance by scanning and investigating the future, to see the art of the possible and embrace promising technologies. CMRE is doing that every day. They are acquiring commercially available sensors and platforms, and trying them, modifying them, and networking them together to find potential solutions to warfighting requirements.

Here we innovate and challenge, which is something CMRE is also doing as well. As ACT, we deliver common-funded capabilities, and CMRE is contributing to that, not just in ASW and mine countermeasures, but also ISR [information, surveillance, and reconnaissance] and maritime situational awareness.

POULIQUEN
For maritime ISR, the nations are interested in finding new, more effective, affordable, and less risky ways to meet targets.

TAS
That's where CMRE's work can really benefit the nations. For instance, a capability like an ASW barrier with underwater gliders or collaborative MCM [mine countermeasures] with UUVs [unmanned underwater vehicles] and USVs [unmanned surface vehicles] contributes to NATO's maritime capabilities. One could argue that it should be a NATO-owned or multinational pool, or to keep it national. It's already multinational, I think, because the nations that are contributing to CMRE are working on it together. But one could also argue, make it a NATO pool, owned by 29 nations so everybody can contribute. But that's for nations to decide, of course.

"Here at ACT, we help the alliance by scanning and investigating the future, to see the art of the possible and embrace promising technologies. CMRE is doing that every day."

LUNDQUIST
I want to talk more about how ACT is sponsoring opportunities for academic and industry researchers to propose issues, concepts, problems, subjects, and topics where they can say, "I might have a solution for that." How do you encourage that?

POULIQUEN
We're breaking ground, actually. We are now able to develop, quickly fund, and produce what we call "minimum viable products," or MVPs, to the forces. That's a way of saying that it's not perfect, but it will actually get something that's a bit more than a prototype into the hands of users that they can actually try it and test it out. The approach is a spiral development, where an MVP user can suggest changes or modifications to make it better. We usually start from a pain point. Maybe we have an operator who has difficulties properly planning a mission, or is frustrated with the available tools. We quickly bring experts together to develop that.

LUNDQUIST
Who identifies those pain points? Who comes to you and says, "This is a problem"?

POULIQUEN
As part of the innovation process, we knock on the doors of the various activities within the NATO command structure—the NCS [NATO Codification System]—and we ask them, "Is there something that you cannot do? Is there something that you're frustrated about doing, or that you do but it's not very efficient?" They will describe that pain point, and explain the users' experience, and we work with those users to address those pain points by producing an MVP. This model is very new—it's only about a year old—but we have allocated some funds for the process, and we are getting ready to deliver our first two MVPs to AIRCOM [Allied Air Command].

TAS
We are also looking forward and seeing needs. We're developing a new command-and-control system at the request of the NATO command structure. But we know that 5G will play a huge role in the future. So we are reaching

out to industry to find out what they think 5G can do for us in the future. This is closely related to what the innovation branch is doing, so we combine the innovation with the capability development because we want a product that will be used by our warfighters.

LUNDQUIST
So we're actually looking at two different things: science and technology [S&T] on one end of the spectrum and research and development on the other.

POULIQUEN
They're closely related. The directed innovation is more the S&T part. And then there's the open innovation, which arises from specific pain points, where we're looking for solutions that we can adopt quickly.

LUNDQUIST
Would those be more mature technologies?

POULIQUEN
Yes, but S&T sometimes, as you know, produces opportunities. A lot of the work CMRE has done recently could be quickly turned into a solution for operators. Like CMRE's collaborative MCM with the BlackCAT and MUSCLE UUVs. Or the multistatic tactical prediction aid. And some of the software that they are using for collaborative MCM could actually be reengineered for ASW or maritime ISR.

We can leverage their work with big data into entering all the AIS [Automatic Identification System] data into the new command-and-control system. The data that are collected by gliders could be installed into the maritime command-and-control system and used to provide commanders with enhanced planning capabilities. And we could do this relatively quickly, with not much money.

PRIMDAHL
Our challenge is actually to see the S&T at very low technology readiness levels and actually bring it forward so we transition to a capability in the end. We have a five-year program for the "vision," but it's a constant dialog.

TAS
Our vision has five main parts. We want to make sure that we have multidomain secure command and control; a network of secure ASW unmanned systems; the same for MCM unmanned systems and maritime ISR, and, of course it overlaps a little bit; and the fifth one is to build a shared, coherent ISR picture of maritime situational awareness, so that is broader than just the underwater part.

As operations become more and more complex, we look to CMRE to help us combine modeling and simulation, machine learning, and artificial intelligence with getting real-time data, such as from gliders and other distributed ISR sensors. I think that will give us a huge advantage. We will be much faster than an enemy that doesn't have that in their decision loop.

LUNDQUIST
You mentioned that ACT is CMRE's biggest customer?

TAS
Yes. We provide funding for 13 different programs, coming to more than $20 million.

POULIQUEN
And, we're far more than just a source of funding. We are involved in the planning, execution, reporting, and sharing with the nations of that maritime S&T program that CMRE conducts for us. It's a team effort.

PRIMDAHL
Some nations design their own S&T program as a function of what CMRE is doing or not doing. They complement each other. The sharing is very important for us, because we don't necessarily utilize all the things that CMRE comes up with. We deliver that technology to nations so they can take it even further. They benefit immensely. And I think they are seeing the value of it. CMRE is more of a catalyst of something that nations can take further themselves. Some of these solutions would be very difficult for the nations to investigate and develop on their own. There is a lot of risk taking. But, together with CMRE, the nations can exploit that technology for acquisition of their own capabilities.

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Rear Adm. Tas is the assistant chief of staff for capability development at Allied Command Transformation.

Brig. Gen. Primdahl is the assistant chief of staff, requirements division, at Allied Command Transformation.

Dr. Pouliquen is the head of the future solutions branch at Allied Command Transformation.

A MODEL FOR SUCCESSFUL INTERNATIONAL COLLABORATION IN MARITIME RESEARCH

By Dr. T. B. Curtin and Dr. S.E. Ramberg

ESTABLISHED IN THE EARLY DAYS OF NATO, THE CENTRE FOR MARITIME RESEARCH AND EXPERIMENTATION—SEEN HERE ARE ITS TWO RESEARCH VESSELS, NRV *ALLIANCE* AND CRV *LEONARDO*—IS A SHARED SCIENCE AND TECHNOLOGY ORGANIZATION THAT REMAINS A MODEL FOR 21-CENTURY RESEARCH.

In response to Cold War threats in the mid-1950s, the US Naval Research Advisory Committee recommended that Western allied nations collaborate on antisubmarine warfare (ASW) research to sustain a common competitive advantage. Subsequently, in May 1959, the NATO Supreme Allied Commander Atlantic (SACLANT) established the "SACLANT ASW Research Centre" with nine participating North Atlantic Treaty Organization (NATO) nations—Canada, Denmark, France, Germany, Italy, the Netherlands, Norway, the United Kingdom, and the United States. Italy offered to host the laboratory in La Spezia. During its first four years, the centre was managed by an Italian nonprofit company (Società Internazionale Ricerche Marine), initially a subsidiary of Raytheon and later owned and managed by Pennsylvania State University. In 1962, the North Atlantic Council established the centre as a NATO organization under direction of SACLANT by adopting a charter.

A Scientific Advisory Council, which provided advice to SACLANT on the scientific program of work in the early years, evolved into the still-existing Scientific Committee of National Representatives (SCNR). In 2003, the SACLANT Undersea Research Centre was renamed the NATO Undersea Research Centre (NURC), and more recently became the Centre for Maritime Research and Experimentation (CMRE), an executive body of NATO's Science and Technology Organization.

The scientific accomplishments of the centre over the decades have been well-documented and have proven to be very valuable in many ways.[1] Examples include:

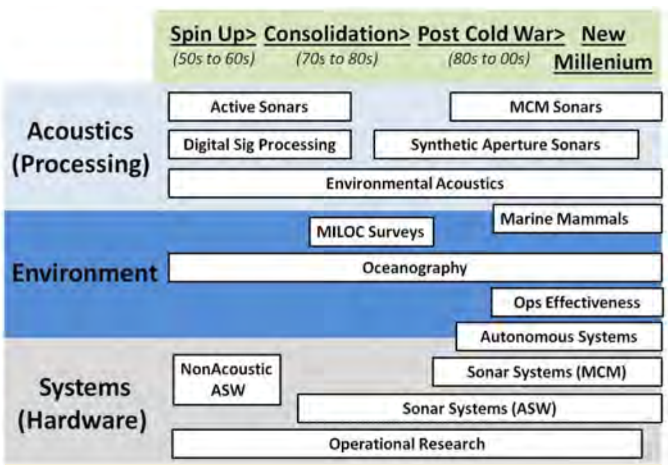
- Digital signal recording and processing fundamentals
- Long-range reliable ASW detection in deep water
- Synthetic aperture sonar that advanced mine countermeasures (MCM) with unmanned vehicles
- Algorithms for ASW towed arrays and sources to eliminate ambiguities and multipath effects
- Acoustic propagation models that continue to be used today by NATO nations
- Internationally recognized marine mammal impact mitigation
- Demonstrations of autonomous underwater vehicles for MCM and port-protection missions.

The special combination of oceanography and acoustics was termed environmental acoustics, and its focus evolved over the years in response to changing maritime missions.

Key Organizational Ingredients

The objective of this paper is to examine the key organizational ingredients that have made the centre successful and the implications of lessons learned that will ensure success in the future. The original ingredients of the centre's organizational model are:

- Diversity of rotating national research scientists on staff from government laboratories and academia (typically three- to six-year tenures)
- Permanent engineering support staff (for seagoing work and for unique maritime IT systems)
- Seagoing capabilities (a number of research vessels over the years—typically one large plus one small vessel available at all times)
- Base funding by NATO common funds (scientific program of work)
- Collaboration with national programs and sharing of all centre products across NATO
- Balance between bottom-up ideas from centre scientists and top-down guidance from the member nations
- An SCNR oversight body whose members are "card-carrying" research managers in their own nations who could also control/influence their national programs and resources (many served as senior managers of the centre over the years)
- Desirable and strategic host location enables a wide range of relevant field operations.



The evolution of the centre's program of work.

Evolution

For the first decades of the centre's existence, geopolitical change was gradual, and perceived NATO security threats were well defined. A stable financial commitment to the centre by mostly maritime NATO nations enabled researchers to focus on technical efforts and collaboration among members rather than annual funding searches. Change has accelerated in recent decades, however. The break-up of the Soviet Union shifted NATO's raison d'etre, altered perceptions of threats to the member nations, and increased NATO membership. The acceleration and globalization of technological change, and new geopolitical realities that include both major power and nonstate threats, have resulted in a challenging environment three decades after the end of the Cold War.

The centre has adapted to most of these changes, but it cannot evolve sustainably in several areas without further guidance from member nations through NATO. The need for better understanding and coordination of ASW and MCM, accounting for the effects of the changing environment on maritime system performance, remains highly relevant. The centre was an early adopter of unmanned undersea platforms that are now prevalent in NATO across many mission areas. Several geographic areas of previous concern have re-emerged with an increase of Russian submarine operations in the Arctic and the Mediterranean, even though the nature of military and other security operations in these regions has changed. The number of quiet diesel-electric submarines is growing rapidly throughout the world. Recent US Navy initiatives such as Task Force Ocean are reminiscent of early motivations for the establishment of the centre: a need for greater knowledge of the ocean in support of undersea operations, and a need for reinvigorated expertise that generates such knowledge. Just as in the past, a centre-like institution in NATO may have an important role to play in addressing these needs. Given that need, can the centre's proven organizational model be adapted to meet today's challenges, or is a new model in order? The key ingredients listed above will be discussed in this context in the following sections.

Rotating National Research Scientists

A rotation of research scientists from academia and national laboratories (as well as occasionally from industry) for periods of about three to six years has been the norm because it aligns well with a timeframe for well-focused scientific research projects as well as manageable sabbatical and leave-of-absence constraints. Since its inception, the centre has attracted nearly 1,000 scientists from 15 different nations. This science flux remains a viable and effective concept. Many researchers value an opportunity to concentrate on their research for a few years with international colleagues while having access to state-of-the-art engineering support and seagoing resources. In addition to innovative technical advances, lasting relationships among researchers have fostered mutual respect and trust that often last for entire careers.

Interoperability of hardware and software among national assets has also been a benefit. In today's increasingly virtual world, the value of in-person interaction for a period of months to years might, ironically, be more important than it was in the past. In addition, the role of diversity in fostering and accelerating innovation is now well-established.[2] From its early days, the centre implicitly understood the value of diversity. To recapture this value, research institutions in member nations need to revitalize and incentivize tours of residency at the centre.

Permanent Engineering Staff

Science experimentation at sea requires a robust engineering capability with a "critical mass" of staff accounting for areas of technical expertise, sea-going experience, and personnel succession. Such a staff also provides institutional memory for technical achievements that exceeds the terms of rotating research staff. Advances in science depend on well-engineered new tools. Experiments at sea require engineering support for instrumentation and data acquisition. Most institutions, especially maritime research organizations such as the centre, cannot sustain a stable in-house infrastructure in a highly variable and uncertain customer-funded regime. Perhaps NATO members with subcritical capabilities in selected infrastructure areas can begin to rotate engineering staff with the centre at some level. Engineering staff rotation might go in either direction depending on particular projects.

In the early 2000s, NATO sought to centralize its networking functions and IT staffs. The underlying assumption was that all NATO organizations would have the same basic IT needs and therefore costs could be reduced by centralization. For the centre this was not the case, and the result was a serious challenge to the full spectrum of science networking, computing, and other IT needs. When it comes to shared resources such as engineering services, there is an optimum balance between the specific needs of each project and generic expertise applicable across projects. Maintaining this balance in the context of the technical and operations changes requires a high level of managerial skill. The addition of a high degree of annual funding uncertainty tends to render the challenge intractable. To realize the proven benefits of an organization such as the centre, a sustained investment in engineering talent and infrastructure will be necessary as in the past.

Seagoing Capabilities

A distinguishing and very attractive feature of the centre is its seagoing capabilities. In the past, this has involved highly capable research vessels such as NRV *Alliance*. Operations with naval units have also been a common feature of the centre's program of work.

The seagoing core of the centre's efforts is essential to retain. Maintaining and operating ships, however, is expensive. There is an opportunity today to shift from traditional crewed vessels to networks of autonomous systems. This shift is itself a potential research area increasingly relevant to NATO. The centre could be an attractive and accessible testbed for autonomous ocean (and multidomain) experimentation for alliance and national operations. This could take the form of a common-funded, long-term program that supports advancement of the technology and methods on behalf of all NATO members and sustains an inventory of platforms for common use. Focused projects by individual nations or in smaller partnership groups to expand and coordinate national expertise would seem particularly cost effective.

Centre staff circa 2005. Photo courtesy of CMRE

Ships become obsolete as onboard systems and equipment age. Fifty-year lifetimes for research ships without aggressive maintenance and upgrades are unusual. Ships can be given major midlife refits to extend their useful lives. At some point soon, NRV *Alliance* will need a refit/replacement whose cost is well beyond a customer-funded program of work. A plan for seagoing experimentation in current and foreseeable geographic areas of interest with a view toward emergent technology and globalized operations is clearly in order and will require visionary leadership in NATO.

Base Funding for a Scientific Program of Work

NATO commitment to the centre has shifted toward two similar but separate funding methods: an entirely customer reimbursable program of work (determined by customer/project), making the centre similar to other commercial or many government laboratories for hire; or some combination of a NATO common-funded program of work and a supplementary work program that is customer-funded on a project basis (this combination was recommended by the NATO Research and Technology Board in 2005).

These funding regimes shift many key ingredients of the original centre model that were responsible for its success during the Cold War. Under common funding, all NATO members share in the scientific program of work outputs equally. This is obviously most relevant to members with maritime forces. For the supplemental work program, this becomes complex because ownership and protection of customer-funded products must be addressed in the best interests of NATO.

A transformed centre with a common-funded program of work could also be supported by a consortium of nations with common maritime concerns in both the Atlantic and Pacific (such as the United States, United Kingdom, Canada, Norway, Netherlands, Germany, Japan, Korea, and Singapore), independent of or in partnership with NATO.

Are a group of like-minded nations willing to provide support for a collaborative laboratory as they did in the past? In particular, can oversight by "card-carrying" national scientists—critical to a vibrant program of work wherein scientific areas of interest to nations are aligned with their own research—be reconstituted? Does senior leadership recognize and appreciate the added value of such a partnership?

Beneficiaries of Centre Products

Common funded work of the centre has been available to all member nations. This will be true for common funded program of work products as well as any supplemental work projects sponsored in this way. The value of such products may be seen in the agreement NATO reached with France for it to receive centre products even after France left full NATO membership in 1966. France could dine "a la carte" from the centre's work by paying a share for the costs of the corresponding projects retroactively over the preceding three years. This arrangement continued until France returned to full NATO membership in the early 2000s when it paid the cost of its share for the preceding entire program of work in accordance with the agreement. Thus, precedents exist for a structure to handle funding and possibly intellectual property issues for projects that are outside the common funding regime.

It must be clear that supplemental work projects are fully costed to support their use of centre resources so the common-funded program of work does not subsidize the supplemental work or vice versa. Indeed, an independently supported supplemental work program should have the effect of reducing overhead and other infrastructure costs borne by the program of work. In the United States, Department of Defense labs are permitted to charge an additional indirect fee on externally sponsored programs to fund internal independent research and development not unlike the centre's program of work activities. In the same sense, co-locating a joint ocean research facility with the centre can allow a program of research to share infrastructure costs benefiting all partners. It is not clear that such a partner laboratory must be physically co-located with the centre and, in fact, could be far away. The challenges to these sorts of arrangements will be accurate costing and rules for isolating intellectual property for some period of time.

NRV *Alliance* participated in a 2017 NATO ASW exercise in the strategic gap between Iceland and Norway.
Photo courtesy of CMRE

For the centre to operate professionally in such a hybrid funding environment, it must substantially expand its contracting, accounting, and legal departments to support such an operation, and the associated indirect costs will need to be included in project budgets. The new billets to staff these departments will need to be established by NATO and be compliant with existing treaty work-permit arrangements.

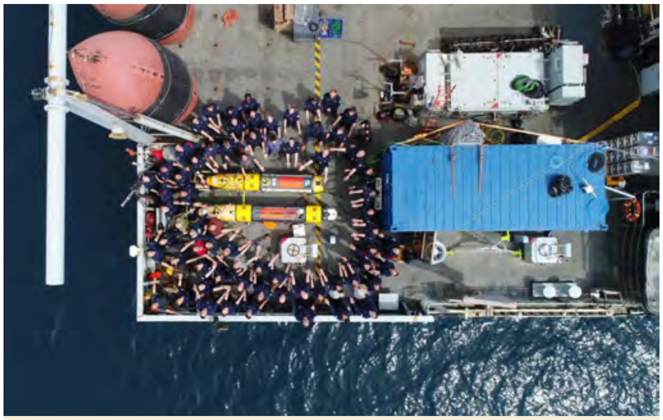
Balance between Bottom-up and Top-down

This key ingredient for success of the centre over many years is seriously affected by a total customer-funded regime. Moreover, customer funding effectively eliminates any elements of fundamental research while often limiting the ability of the centre to anticipate shifts of NATO military priorities. The shift of ASW research from deep to shallow water, the changes in MCM to autonomous systems, and the need for marine mammal mitigation research are but three examples wherein the centre, with advice from the SCNR, made such anticipatory adjustments to the common funded program of work that proved prescient. This balancing process between near-term customer requirements and future customer needs only works well if the top and bottom participants share a common base of knowledge and expertise that serves to ground assessments on a well-understood technical basis.

The process of prioritizing the research in a common forum with a diversity of experienced partners is critical for all participants.[3] A common funded program of work to assure these attributes together with a supplemental work program meeting specific near-term customer needs may be manageable with skillful, hands-on leadership and advice from a seriously reconstituted SCNR. An updated charter for the centre as well as terms of reference for the SCNR may be required at this point. If undertaken, these updates also could reconcile the combined roles of Supreme Allied Commander Transformation and Maritime Command, with the SCNR and the centre for the greater benefit of NATO.

"Card-Carrying" Research Managers

To be effective, the SCNR members must be carefully chosen by the nations on a par with each other as originally conceived and implemented. They should be "card-carrying" researchers/managers who can handle the balancing process described above for the program of



Standing NATO Mine Countermeasures Group 2 staff with centre staff and autonomous underwater vehicles aboard HMS *Enterprise* during a 2018 exercise. Photo courtesy of CMRE

work and who also control/influence their corresponding national programs and resources. In addition, such SCNR members can find opportunities and resolve any issues that might arise with more mature national programs (e.g., early armament procurement efforts/acquisition). During the early years, the SCNR functioned as envisioned. As NATO expanded, Cold War priorities waned and bureaucracies grew, SCNR membership degraded. Annual meetings became powerpoint exercises and residual formalities. This evolution reflected a reduced willingness of nations to commit knowledgeable people to serve and provide informed guidance. With proper, uniform credentials, the SCNR can advise the centre and NATO on tuning the balance required for the centre's work and on fostering fruitful collaborations. Lastly, it could reestablish a useful tradition wherein former SCNR members sometimes go on to serve as senior managers of the centre.

Desirable and Strategic Host Location

The centre's current location in LaSpezia has served NATO very well, and can continue to address a growing array of security and related concerns for the NATO alliance in the larger Mediterranean area. Moreover, the centre's location and activities are attracting a number of Italian maritime research, education, and commercial activities to the LaSpezia area. In the future, multiple locations could be considered on a rotating basis, including a virtual component. Host countries/alliances could contribute by sharing infrastructure. NATO affiliation does provide a number of practical advantages (e.g., visas, work permits) that come with being under the umbrella of an international treaty. An equivalent multilateral diplomatic agreement among participating nations could provide similar benefits that reduce infrastructure and overhead costs for all. The avenues and technologies for "hosting" and collaboration have expanded dramatically since the founding of the centre in the 1950s. Exploiting these advances must be part of a reimagined centre.

Conclusion

To maintain competitive advantage in today's complex maritime world, advances in science and technology are critical. Such advances have never been the purview of just one nation. Collaborative research among like-minded partners has proven to be effective in driving innovation. A successful model for such research has been established at the centre, but some of its key ingredients have eroded in recent years. Can the model be adapted and reinvigorated to pave the way for the future? We recommend that organizations of like-minded nations, such as NATO, build on the proven advantages of the centre's model, and create a transformed centre of the future. The centre, founded with visionary leadership, has provided a large return on investment over the years. Visionary leadership remains the key.

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Photo by MCSN Christine Montgomery

BUILDING RELATIONS THROUGH INTERNATIONAL EXPERIMENTATION

By Dr. Marcus Tepaske

OFFICE OF NAVAL RESEARCH GLOBAL'S EXPERIMENTATION AND ANALYSIS PROGRAM PROVIDES OPPORTUNITIES TO CONDUCT EXPERIMENTS WITH INTERNATION AL PARTNERS IN REALISTIC ENVIRONMENTS—SUCH AS DURING YEARLY JOINT WARRIOR EXERCISES.

At any given point in time there are naval forces from countries around the world training and conducting exercises. Navies do this for any number of reasons, such as to become more proficient in the art of naval warfare, to posture or send a message to the world, or to experiment with new concepts and technologies to improve future capability. The US Navy conducts training and exercises for all these reasons, and in some instances has the opportunity to do so in collaboration with partners and allies. Of particular interest to the Office of Naval Research (ONR) Global is when those international experimentation opportunities revolve around technology development.

Aligning under ONR, whose mission is to plan, foster, and encourage scientific research to maintain future naval power and preserve national security, ONR Global serves as the enduring Navy and Marine Corps global presence in technical and operational communities, investing in trusted partnerships to discover and connect science and technology leaders. The six departments within ONR Global (science advisors, science directors, foreign comparative testing, TechSolutions, international engagement, and experimentation and analysis) all support these common goals, with one of the most effective tools for building trust and capability being international experimentation.

Through international experimentation, ONR Global builds trusted relationships, leverages collective genius, and promotes interoperability between nations. This is not a new concept—the Navy has been conducting joint exercise for decades, and there are countless instances of joint experimentation—but ONR Global experimentation and analysis maintains a constant focus on advanced technology development (6.3) experimentation, both domestically and internationally, in support of ONR and ONR Global missions.

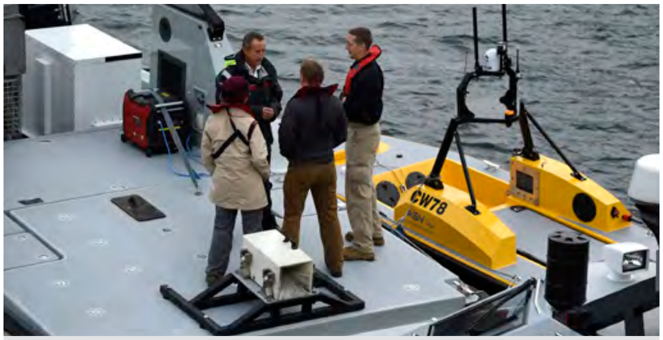
ONR Global experimentation and analysis actively works to take late-stage technology development programs from the Naval Research Enterprise and conduct militarily relevant experimentation with Sailors and Marines. This often takes place in US-only events, but there are situations that warrant international experimentation, whether it be the need to demonstrate interoperability, to gain access to ranges and resources the United States may not have, or to strengthen relationships with our partners.

Some of the larger international naval exercises, such as Rim of the Pacific, Baltic Operations, or Talisman Saber, provided great opportunities for international experimentation. In 2021, ONR Global will take advantage of the forces and assets in the Baltic region to experiment with emerging mine countermeasures capabilities from deep water to the littorals. ONR Global also will be inserting a number of capabilities into Australia's Talisman Saber to demonstrate forward logistics sustainment using laser communications, unmanned systems, and novel sensors.

In addition to taking advantage of larger multinational exercises, ONR Global experimentation and analysis also conducts standalone individual experimentation efforts with international partners. ONR Global is currently executing a long-range, high-bandwidth experiment effort with a technology developed at the Wroclaw University of Science and Technology in Poland as well as an experiment with cooperative unmanned vehicles in the maritime environment with the University of Zagreb in Croatia.

On occasion, there are opportunities to conduct much larger technology-focused experimentation efforts with our closest allies. In 2016, ONR participated in Unmanned Warrior off the coast of Scotland, which brought together more than 50 unmanned systems from multiple nations to experiment with interoperability and to feed into the United Kingdom's Joint Warrior fleet exercise. In September 2021, the United States is participating with NATO partners in Robotic Experimentation and Prototyping Maritime Unmanned Systems. This experimentation opportunity, conducted in the North Atlantic Portuguese exercise area, is designed as an experimentation ground for maritime operational communities to work together to develop and test concepts, requirements and technological advances in maritime unmanned systems.

While international experimentation is great for exploring collaborative technology development, the most valuable aspect of it is building trusted relationships that will provide benefits long after the actual experiment concludes. In an August 2020 *Proceedings* article, retired Adm. James



Author Marcus Tepaske, right, and Office of Naval Research Global science advisors Chris Marchefsky and Inez Kelly, left, talk with Vince Dobbin from Autonomous Surface Vehicles, Ltd., about new technologies during the first Unmanned Warrior, a component of the semiannual Joint Warrior exercise held by the United Kingdom. Photo by John Williams

Stavridis recollected how he strove to have human interactions and to build personal trust with leaders because in times of crisis you can surge forces, but you cannot surge trust. ONR Global is both maturating technology and building relationships, and we use those relationships not only in times of crisis but continuously to maintain technological awareness and leverage all of the great minds outside our borders.

The title of Stavridis's article was "You Can't 'Zoom' Trust," which is apropos in this day and age as we continue to work through the COVID-19 pandemic. Virtual connections are an OK way to maintain relationships, but that is only possible as the result of prior face-to-face interactions and that trust bank will dwindle over time. Just as true—if not more so—is that we can't Zoom experimentation. The majority of experimentation involves people physically working on systems, integrating and interacting with the fleet and partners. This past year has greatly slowed experimentation with our international partners, but as the nation and the world become more adept at operating in this environment, ONR Global will continue to promote and leverage opportunities for international experimentation and press on with its vision to be the partner of choice for science and technology leaders.

As globalization continues, the benefit and need for technology experimentation with international partners will continue to grow. Through experimentation, our partners and we can lay the technological and relational foundations so that when the time comes in a future conflict, the United States and our allies will have the best equipment that can interoperate across nations to ensure it is never a fair fight.

For more information or to propose or request an experiment, visit the website https://wiki.nre.navy.mil/display/EandA or contact the appropriate science advisor: https://www.onr.navy.mil/-/media/Files/ONRG/science-advisors-contact-sheet.ashx?la=en

About the author:

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Photo by John Williams

TECHSOLUTIONS PUTS TECH IN THE HANDS OF WARFIGHTERS

By Jason Payne

TECHSOLUTIONS TAKES IDEAS FROM SAILORS AND MARINES AND TURNS THEM INTO PRACTICAL TECHNOLOGY—SUCH AS THIS CARRIER FLIGHT DECK CREW TRAINING SIMULATION—IN 12 MONTHS OR LESS.

In the world of science and technology, getting a newly developed product into the hands of a warfighter in less than five years is nearly unheard of. Unless you are talking about the TechSolutions program, which puts newly developed prototypes into warfighter's hands in 12 months or less. TechSolutions takes requests from Marines and Sailors from around the globe for technology solutions to problems affecting mission effectiveness, and then turns those requests into working prototypes that are tested and turned over to the original requesters and their commands for further use and improvement.

Here are two examples of projects that TechSolutions recently funded in support of the Navy and Marine Corps:

- **Topside Drone Inspection:** TechSolutions recently funded a project based on a request from a Navy lieutenant who pointed out how the Navy spends enormous amounts of money and maintenance man-hours dedicated to simple visual inspections looking for corrosion and other defects on ships. He explained how the development of an autonomous platform that would be capable of detecting material defects, corrosion, warping, and other conditions requiring correction at some maintenance level could potentially save the Navy millions of dollars and thousands of man-hours. Based on this request, TechSolutions funded a Navy warfare center to develop a prototype 3D-scanning system mounted on a small unmanned aerial vehicle that autonomously scanned the entire exterior of a Navy ship for any type of defect. The project took 12 months, and generated interest within the Department of Defense for continued development with government and industry partners for fielding.

- **Energy Training Exercise Game:** TechSolutions is funding a project that started as a request from three Marine Corps captains who were attending the Expeditionary Warfare School in Quantico, Virginia. The project translates Marine Corps fuel logistics/energy training needs into a game design that aligns with learning objectives to target and fill learning gaps with respect to operational energy. This interactive, web-based serious game produces energy-informed planners for operational units by increasing their exposure to, and proficiency in, understanding the operations and logistics relationships in the planning process with respect to energy management. The Energy Training Game came to the attention of TechSolutions when it received an invitation to attend and participate in the Commandant of the Marine Corps' Logistics Innovation Challenge in 2019. The game was one of more than 75 entries to the challenge submitted by Marines of all ranks. There were many outstanding entries, but the Energy Training Game emerged as the overall winner, and TechSolutions was happy to step in and award funding to developers to create the game. Since the project began, the developer has reached out to the three captains to gain operational insight and request feedback on the game's design. The final delivery and demonstration of the game was in September 2020. This project has drawn the attention of Marine Corps operational logistics planners, who are working with the Marine Corps' Expeditionary Energy Office to create an "operational" version of this application. The Office of the Secretary of Defense also has expressed interest.

TechSolutions has been in existence since 2002, and has funded hundreds of requests across the spectrum of functional areas within the Marine Corps and Navy from Sailors and Marines who were located both at home and abroad. One of the interesting aspects of TechSolutions is the fact that it allows any Marine or Sailor from E-1 to flag level officers to submit requests, and there are only a handful of requirements that need to be met for a submission/request to be considered. These requirements include:

- The solution needs to be technology not yet developed. TechSolutions doesn't buy technology off the shelf, or build an updated version of something that already exists. TechSolutions reaches out to world-class scientists and engineers that make up the Naval Research and Development Establishment and asks them to propose solutions to warfighter requests by leveraging state-of-the-art science and technology.
- The technology required to respond to the request needs to be mature enough that a solution/prototype can be developed in 12 months or less.
- The solution needs to fit within our budget (projects average $750,000).

TechSolutions does not require verification of an official "warfighting requirement" to fund a Marine or Sailor's request. Instead, TechSolutions communicates directly with the Marine or Sailor who made the request to further define exactly what the solution needs to do, or what it needs to look like. In addition, it is helpful to the success of the project if the requesting Marine or Sailor participates in the development of the solution. The requestor is asked to participate via telephone, or in person, in selecting the winning proposal, attending the kickoff meeting and in design reviews with the performer. In addition, the requestor's assistance is requested to coordinate end-user feedback sessions and the final prototype demonstration.

If you have an idea on how a new technical capability will increase either your or your unit's mission effectiveness and you want to see a solution developed and delivered to you within a year, then you should give TechSolutions a try. TechSolutions is capable of providing solutions to technical problems no matter what functional area you may work in. If you are a fixed-wing or helicopter mechanic, and you have an idea that will save time or money or will improve your mission effectiveness, then visit TechSolutions online. The same goes if you are an intel type, a weapon system specialist, or a logistician. If you have a good idea, then submit it to TechSolutions. If you're a combat engineer or a communications specialist, and you've thought of a way to accomplish a task in a better way than it's currently being done, then ask TechSolutions to develop a solution.

The easiest way to submit an idea to TechSolutions, and look at some previously funded projects as well, is through its website, https://www.onr.navy.mil/techsolutions, and register for an account. Once you're confirmed as registered, you access the TechSolutions portal, click the "Request a Solution" button and you will be asked to answer three simple questions:

- What is your observation and/or problem?
- What does the solution need to do?
- Do you have any amplifying information or personal ideas to solve the problem

It really is as simple as that to direct funding toward the development of your idea.

If you have questions, or you would like to talk to TechSolutions, you can contact us:
Email: ONR_techsolutions@navy.mil
Phone: (703) 696-0616

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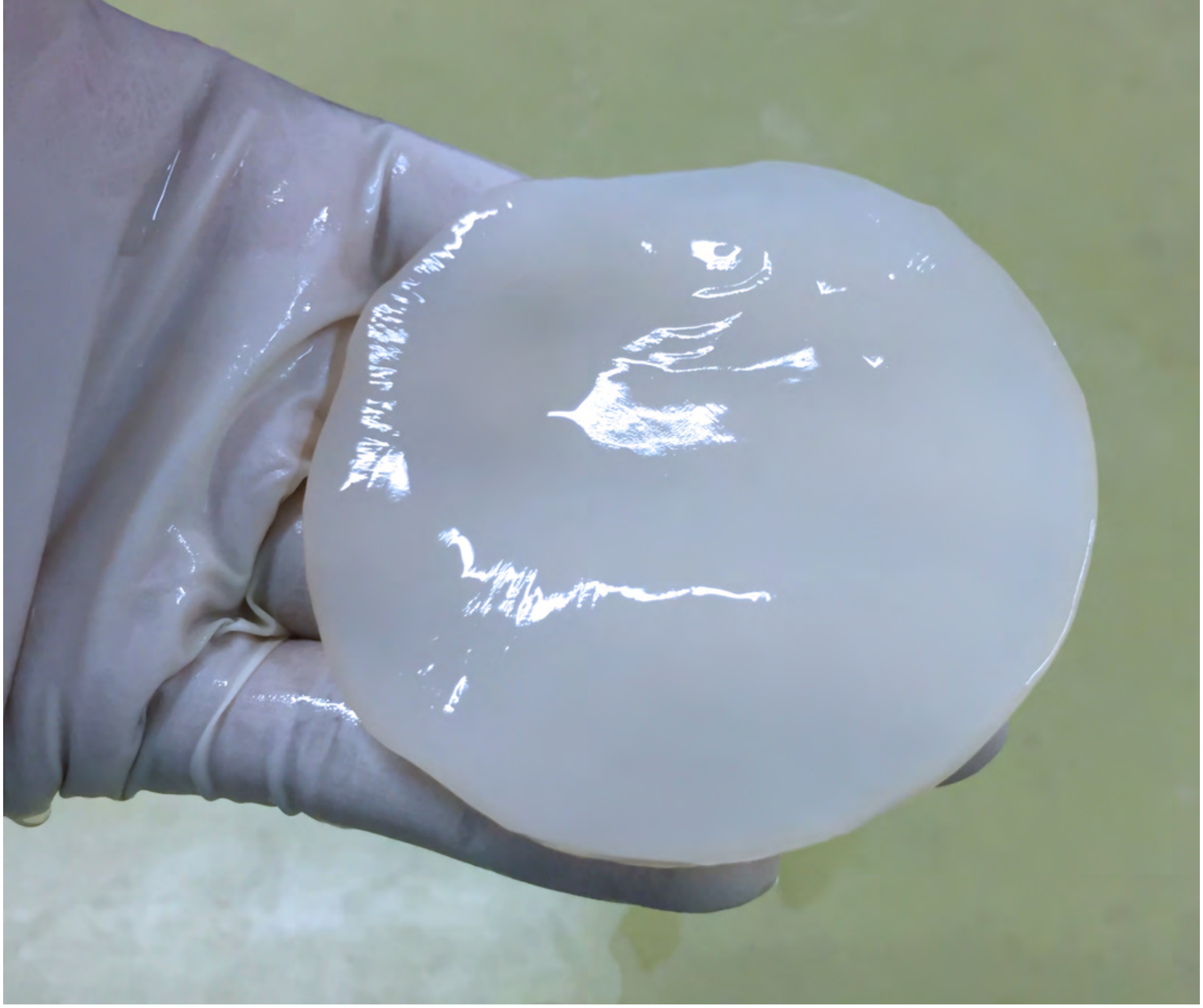

Shutterstock photo by Kallayanee Naloka

BRITISH SCIENTISTS CREATE SELF-HEALING MATERIALS

By Felipe Reisch

RESEARCHERS IN THE UNITED KINGDOM ARE EXPLORING NEW WAYS TO MANUFACTURE AND USE BACTERIAL CELLULOSE—AN ORGANIC MATERIAL THAT COULD PROVIDE A WAY TO PRODUCE TECHNOLOGIES THAT CAN REPAIR THEMSELVES.

Biology has spent billions of years honing a response system to create healing features in many types of material. From human scarring capacity to the formation and mineralization of mollusk shells to fix cracks, biology has designed diverse ways to have a fast sense-and-respond system for damage. Today, researchers from the Department of Bioengineering at Imperial College London, led by Dr. Tom Ellis, are exploring modularity in engineered living materials, which are based on bacterially made cellulose.

The core objective of this groundbreaking effort is to exploit biology's distinct ability to sustainably heal and replenish material and respond to constant damage while existing in harsh environments. Researchers are looking to make materials more functional than they are today. While sensors can be incorporated into material, they only send information. In this project, the sense-and-response system is one and the same. When damage occurs and is sensed, the response system kicks in and repairs the material.

In the same way that architecture uses modular pieces that can be assembled into completely different buildings, this research has demonstrated the same principle can be applied to the design and construction of bacterial cellulose-based materials. The Office of Naval Research (ONR) Global, Air Force Office of Scientific Research, and Army Research Office are funding this research project.

Bacterial cellulose is produced naturally by several types of bacteria. Discovered in the 19th century, bacterial cellulose has been used in everything from food products, such as the candy nata de piña—or pineapple gelatin—in the Philippines, to wound dressings for burn patients.

"Using genetic engineering methods, we made bacteria produce fluorescent spheroids to prove the concept of DNA-encoded functionalization," said lead researcher Ellis. "With these spheroids, we built different shapes and patterns, demonstrating the potential of spheroids as building blocks. We also used these modular pieces to repair the material, restoring damage in a piece of bacterial cellulose just by placing the spheres within the damage and incubating the bacteria to regrow the material."

The growth in popularity of bacterial cellulose for its outstanding properties is the response to the worldwide challenge to find new materials with better-tailored functional behaviors. "The challenge is to mimic and combine the distinct features biology has to offer," said Dr. Patrick Rose, ONR Global London science director. "We are not only trying to emulate those systems, but engineer biology to have additional features that are more amenable to the needs we seek (e.g., fixing a crack in a windshield, a tear in the fuselage of an aircraft or a pothole in the road) without direct intervention. Ultimately, we want to increase the lifetime of a product, prevent failures of systems before the problem is visible to the naked eye and have the material think for itself. We engineer biological systems to do these things by exploiting the platform of synthetic biology."

Challenges and Opportunities

The next step for this group of researchers is to develop new spheroid-like building blocks with different properties. The more types of blocks they can design and make, the more applications they can explore. One existing direction for this research is creating spheroids that are composites of bacterial cellulose with other materials, as this will help to create more-complex designs.

"This research effort has significant potential to open up a new materials synthesis platform," said Dr. Stephanie McElhinny, a program manager at the Army Research Office, an element of the US Army Combat Capabilities Development Command's Army Research Laboratory. "The system Dr. Ellis' team has developed provides an opportunity to achieve synthesis of highly tunable cellulose networks that could serve as structural reinforcement in future composite materials—for example, reinforced transparent polymeric materials for vehicle windows or windshields or face shields."

Combining different types of cellulose blocks with other materials as well could be another way to make interesting composites with different properties. It might also be a possibility to think about designing a 3D printer to assemble the spheroids into the structures automatically.

"Bacterial cellulose is already attracting a lot of interest in many industries, including textiles, cosmetics, electronics, health, food, and architecture and design," said Ellis. "For example, cellulose cosmetic face masks could be made from these cellulose blocks and designed to contain different active ingredients placed in patterns, so they activate different parts of the face skin. This same approach would also be appropriate for wound-healing dressings, which can also be made from bacterial cellulose."

Dr. Jung-Hwa Gimm, Air Force Office of Scientific Research program officer for natural materials, systems, and extremophiles, said, "Controlling size, size distribution, and mechanical properties of the [bacterial cellulose] spheroids may allow them to be used as a bio-ink for 3D printing. It may be also possible to engineer spheroids themselves to be inexpensive stand-alone biosensors with more robust mechanical properties, like 'growing' living biosensors on the go."

In other words, instead of having material as a one-off use, or requiring it to undergo regular maintenance cycles, this material can be integrated into windshields, composite materials, and clothing. All of it undergoes self-healing—extending use and usefulness.

"The hard part is engineering a sense-and-response system into biology that is novel to biology," said Rose. "It requires fine-tuning genetic circuits and understanding how the system responds. Once those pieces are in place, we can integrate the engineered biological pieces into existing materials and demonstrate that the system senses damage (e.g., cracks, crevices) and subsequently heals them within hours without any human intervention. It takes the concept of smart materials to a whole new playing field."

About the author:

Felipe Reisch is a strategic communications specialist with Office of Naval Research Global.

HARBOR DEFENSE PROGRAM AIDS INTERNATIONAL INTEROPERABILITY

By Susan Farley

THE AUTONOMOUS MARITIME ASSET PROTECTION SYSTEM IS A COLLABORATION BETWEEN TEAMS AT THE AMERICAN NAVAL UNDERSEA WARFARE CENTER AND THE BRITISH DEFENCE SCIENCE AND TECHNOLOGY LABORATORY.

In December 2019, Chief of Naval Operations Adm. Michael Gilday issued a fragmentary order calling for building alliances and partnerships with US allies.

"Operating and exercising together with allies and partners, our Fleet commanders will focus on full interoperability at the high end of naval warfare," it states. "We will build on existing maritime intelligence and logistics partnerships with allied nations, and expand relationships with partner nations to broaden and strengthen global maritime awareness and access."

One existing program is providing a vital connection from the United States to the United Kingdom: the Autonomous Maritime Asset Protection System (AMAPS), a port and harbor security system that has the ability to detect possible threats, determine what those threats may be, deny access to restricted areas, and provide a defeat capability. This cross-domain solution to harbor defense with enhanced autonomy is part of a joint program between the Naval Undersea Warfare Center (NUWC) Division Newport and the Defence Science and Technology Laboratory (DSTL), which is part of the UK's Ministry of Defence. The AMAPS program seeks to develop a unified system that can respond to both surface and underwater threats and enhance the autonomy of system components wherever possible.

James McIntyre is team leader for surface warfare at DSTL and has been collaborating with NUWC's Division Newport on AMAPS.

"From a UK perspective, the NUWC program has a legacy of delivering significant capability in the underwater domain," said McIntyre. "Teaming with the US provided the UK with a unique opportunity to learn from this experience and combining this with UK expertise in above-water autonomous systems meant we had a highly capable team. At the beginning of this program, DSTL set out to understand the role that maritime autonomous systems could play in augmenting harbour protection systems. Over the course of the program this became even more important as the Royal Navy took control of the new Queen Elizabeth-class aircraft carriers. [Maritime autonomous systems] provide an opportunity to provide a persistent and responsive capability that—married with sensor systems and appropriate [command and control]—provide a holistic capability that can enhance our ability to keep our platforms and people safe.

"The team have come up with some innovative approaches and although COVID has impacted our ability to come together as we had originally envisaged, we have learnt from each other and have developed an interoperable system that both nations can build on. The program has helped inform the wider UK and US interoperability-to-interchangeability initiative and as we go forward, AMAPS is an example of how our two nations can work effectively together to meet common goals."

When COVID restrictions prevented in-person testing of AMAPS, the teams developed a way to carry out testing using the Defense Research and Engineering Network, the first time this type of interoperability had been conducted.

The first step was for NUWC Division Newport's harborside security program, known as Argus, to participate in a live, virtual, constructive (LVC) event—a hybrid of live and simulated components operating together in a simulated environment. The Argus security system provided the "live" component of the testing. The successful integration of Argus' live piece with the virtual environment provided the risk reduction needed for the next phase of the project.

Following the LVC event, the Argus system operating from Newport, Rhode Island, connected over the Defense Research and Engineering Network with DSTL's command-and-control system in Portsmouth, UK, to conduct an AMAPS exercise. Originally, this event was scheduled for in-person testing with the Newport team traveling to Portsmouth to integrate the two systems. As travel restrictions forced the cancellation of testing, the teams will continue to prepare for virtual testing over the network to demonstrate remote interoperability.

This type of interoperability is essential for the future Navy, and employing virtual environments during COVID was a necessity that will likely become commonplace.

Christian Schumacher, the technical program manager for the Argus program, has been working to develop enhanced interoperability between NUWC and its UK partners.

"This three-year effort culminated in a marriage between British surface detect systems and the US undersea detect system resulting in a cross-domain solution for port and harbor security," said Schumacher. "Our data messaging and track information was passed to the UK and then they can task their [unmanned surface vessels] to autonomously deploy US deterrence and effectors to mitigate threats. Additionally, the autonomy allows security forces to be a continuous presence and to safety monitor from the command. COVID restrictions forced us to rethink how we integrate with the UK. Instead of traveling to the UK with our enclave computer system, we performed risk buy down by passing messaging and data through the Navy network during an LVC event in September [2020]. The cybersecurity and information assurance approvals obtained during that event was an important stop on our way to full US-UK interoperability."

How AMAPS Evolved

In 2009, NUWC Division Newport was tasked by the Office of Naval Research (ONR) to conduct an expeditionary swimmer defense technology evaluation. The technologies that emerged were the result of a broad agency announcement.

Photo courtesy of Christian Schumacher

One of the unmanned surface vehicles used in the test included the British 9-meter Maritime Autonomy Surface Testbed vessel. Photo courtesy of Christian Schumacher

The ONR sponsors also were members of Technical Panel 9 of the Technical Cooperation Program (TTCP), which included members from Australia, Canada, New Zealand, the United Kingdom, and the United States. With the focus of the panel on port and harbor surface and subsurface defense, ONR also invited members of TTCP to participate in the event. As a result of this panel, NUWC Division Newport personnel had the opportunity to meet with TTCP members and conduct some preliminary discussions about potential collaboration efforts.

At the conclusion of the event, ONR asked a NUWC Division Newport representative to be a member of TTCP's panel, which helped facilitate further discussions. The following year, NUWC Division Newport submitted a Coalition Warfare program proposal for its Waterside Rapid Deployment Security System (WRDSS). All members of the TTCP Panel were invited to participate.

Because of funding concerns and other priorities at the time, only the United States and Australia pursued the WRDSS funding. The proposal was under serious consideration by the Coalition Warfare program, but ultimately it was not selected. The Naval International Projects Office, however, had significant interest in the proposal and soon the WRDSS project was able to proceed.

At the conclusion of the project, the United States and Australia wanted to continue the relationship and submitted a follow-on proposal that would focus on autonomy—this was how the AMAPS program began. Both countries invited the other TTCP panel partners, including the United Kingdom, to join the team. The proposal was approved for a three-country collaboration. Before the project commenced, however, Australia underwent some management changes and backed out of the project. The other two partners proceeded with the effort and they continue their collaboration a decade later.

Today, the AMAPS project remains a collaboration between DSTL and NUWC Division Newport with the goal of combining above-water and underwater sensors and response systems to assess the role of autonomy in harbor or critical infrastructure protection. WRDSS has since evolved into "Argus," NUWC's expeditionary maritime defense system providing underwater harbor defense capabilities.

In their joint exercise, DSTL's Integrated Test Facility provides surface situational awareness and autonomous defense platforms. All sensor and response information is displayed in DSTL's AMAPS command-and-control system. This system has built on the Maritime Autonomous Platform Exploitation program, which provides the information architecture for autonomous systems. The AMAPS and Argus command-and-control systems interface with each other so both teams share asset control and tactical picture.

For a their joint exercise, NUWC achieved its goal of developing system performance requirements, combining the two command-and-control systems' software, conducting an operational demonstration in Portland, UK, and obtaining a military utility assessment.

"AMAPS is a good example of technology evolution, leveraging one exercise to feed and improve the next, thus accelerating and improving the overall capability," said Trevor Kelly-Bissonnette, NUWC's director of international cooperation. "When impacted by COVID, the team adjusted and pushed forward with LVC, de-risking the next in-water experiment. This is in line with the [Chief of Naval Operations] and [First Sea Lord's] Statement of Intent regarding Future Integrated Warfighting 'building on the established cooperation...that delivers genuine warfighting capabilities with incorporated interoperability' with the forward vision of interchangeability."

"Moving forward, the UK aim to transition some of the software and systems into the hands of the warfighter as this will form the true test of what has been developed," said McIntyre. "The Royal Navy's NavyX autonomy accelerator can take the system on the next stage of development with operator-led experiments."

About the author:

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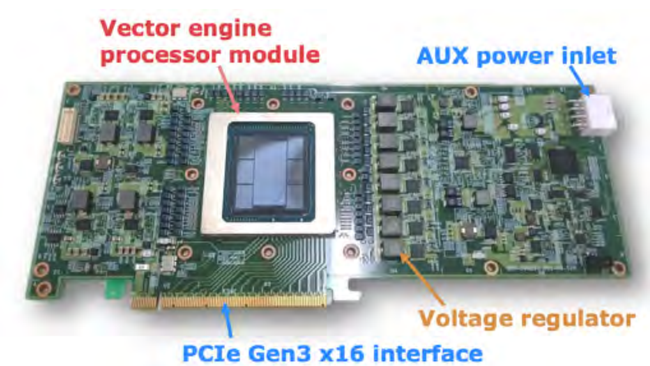
Shutterstock photo by mikha AF

NEC VECTOR ENGINE IS PROMISING FOR LEGACY CFD APPLICATIONS

By Yu Yu Khine, Keith Obenschain, Gopal Patnaik, and Robert Rosenberg

COMPUTATIONAL FLUID DYNAMICS (CFD) SIMULATIONS CAN MODEL EVERYTHING FROM AIR FLOW OVER AN AIRCRAFT WING TO YOUR LOCAL WEATHER FORECAST. RESEARCHERS AT THE US NAVAL RESEARCH LABORATORY EXAMINED HOW HARDWARE FROM JAPANESE COMPANY NEC MAKES CFD APPLICATIONS EVEN FASTER.

High-performance computing (HPC) offers insight and analysis into some of the toughest problems and can take us to frontiers of knowledge and groundbreaking innovations. HPC affects everything from food manufacturing to medical research to aerospace to enrich our daily lives. The Department of Defense (DoD) has made significant investments in HPC throughout the years, with a number of codes developed during the vector supercomputing era from 1970s to 1990s. Many of these codes are still in use with their vector-friendly constructs still embedded in their codebase. NEC has released a version of their vector architecture as an accelerator, an air-cooled card attached with a standard interconnect that can potentially allow these legacy codes to run faster than on conventional HPC systems.



A sample NEC Vector Engine. Illustration courtesy of authors.

A group at the Laboratories for Computational Physics and Fluid Dynamics at the US Naval Research Laboratory (NRL) in Washington, DC, has special interests in exploring and evaluating emerging architectures for HPC applications. A wide range of cutting-edge architectures has been studied at NRL over the years, including Intel, AMD, NVIDIA, and ARM systems.

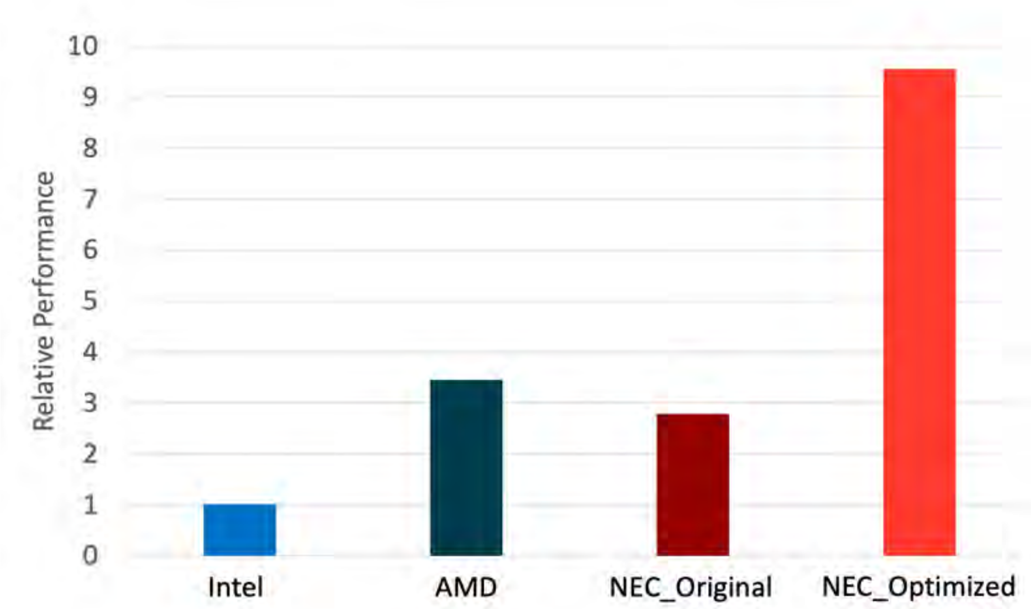
Recently, NRL has been investigating the use of the NEC Vector Engine (VE), manufactured by the NEC Corporation in Japan. The Office of the Secretary of Defense's Foreign Comparative Testing program co-sponsors the project. The objective of the program is to test items and technologies of foreign allies that have a high technology readiness level that may satisfy valid defense requirements quickly and economically. This program has helped to foster the two-way street in defense spending between the United States and its allies through the procurement of more than $5 billion in foreign items since 1980. The program helps avoid research and development costs, lower procurement costs, reduce risk for major acquisition programs, and accelerate the fielding of equipment critical to the readiness and safety of US operating forces.

In general, the computational fluid dynamics (CFD) simulations of various applications involve intensive computations that require large amounts of memory and processing time to achieve accurate results in a desired time frame. The CFD simulations range from aerospace applications, weather prediction simulations, to biomedical treatments that are part of our daily lives. Recently, NEC Corporation has manufactured a state-of-the-art vector architecture with a high technology readiness level that can potentially run codes previously developed for vector processors. Since most of the legacy CFD vector-friendly codes or their descendants are still in use by DoD today, we expect that these codes can achieve improved performance without the time-consuming and labor-intensive refactoring/rewriting often required to run on a new architecture.

NEC has been a major provider in the supercomputing domain for more than 37 years, and, since the early 1980s, it has developed a product line of vector computers. These vector computers have special hardware, including vector registers and arithmetic units, to efficiently handle loops that update array contents, that is much faster than conventional computers. When a loop is able to be optimized in this way, it is called 'vectorized' and the compiler listing will indicate all such loops that have been vectorized.

The prominent machine, SX-2, was developed in 1983, and the SX-6 (better known as "The Earth Simulator") secured the top position on the Top500 list of supercomputers from the year 2002 to 2004. Over advancing computing trends, from specialized to commodity hardware, NEC has evolved to implement the same vector processors on an interface standard for connecting high-speed components (PCIe card) known as the NEC Vector Engine. The figure at left displays a sample NEC Vector Engine. Codes written in C/C++ and Fortran can be built and run on the VE. The VE offers a high-memory bandwidth that it is expected to benefit most CFD applications. The NEC Vector Engine runs at peak efficiency when the VE is able to schedule the processing of many elements in one instruction (i.e., long vector length).

The goal of this project is to assess the ease of use of the VE qualitatively and to quantify the performance speedup over conventional systems that use Intel or AMD processors. The preliminary studies on VE include standard benchmark



Performance comparison of FDL3DI on Intel, AMD, and NEC systems. Illustration courtesy of authors.

codes available publicly as well as CFD codes developed at NRL. The main focus of this project is the legacy CFD solver FDL3DI originally developed at the US Air Force Research Laboratory in the 1990s and which retains its vector-friendly code structure. The solver has been extensively validated and highly utilized by the Air Force over the years. Some applications of FDL3DI include wing-vortex aerodynamics, flow control for laminar flow airfoils, and shock/boundary layer interaction in front of canonical shapes.

The original version of FDL3DI solver can be built and run on the VE without any modification. Modifications of the code were required, however, to take full advantage of the VE architecture to achieve significant speedup of the solver. During the optimization process, the NEC profiling tool was used to study the bottlenecks in the solver. The most time-consuming routines were optimized by vectoring the loops that were not originally vectorized, making a longer vector length by combining the nested loops wherever possible, and using VE's vector register to use memory bandwidth efficiently. In the last process, the participating arrays are manually assigned to vector registers, minimizing time-consuming copies from main memory.

After optimizing the bottleneck routines in the FDL3DI solver, the comparison of performance among the Intel, AMD, and VE can be seen in the figure above. For a test case of interest, the performance of the optimized version of FDL3DI solver outperforms the conventional Intel and AMD processors and demonstrates over three times speedup from the original version of the FDL3DI.

A complete rewrite of the code was not necessary in this case, but significant optimizations of the code were needed to achieve the speedup. The modifications to the solver have no impact on the performance on other platforms such as Intel and AMD. In conclusion, the NEC VE can be beneficial for CFD applications that require high memory bandwidth and that can take advantage of long vector length. It can save time and costs associated with refactoring legacy CFD codes from vector supercomputing era to achieve a useful performance boost.

This work also benefits the DoD High-Performance Computing Modernization program whose mission is to accelerate technology development and transition into superior defense capabilities through the strategic application of high performance computing, networking, and computational expertise. This study of the NEC Vector Engine's performance is useful in future acquisitions of high-performance computing systems for DoD.

The details of the project can be viewed at: https://www.nec.com/en/global/solutions/hpc/event/sc20/index.html

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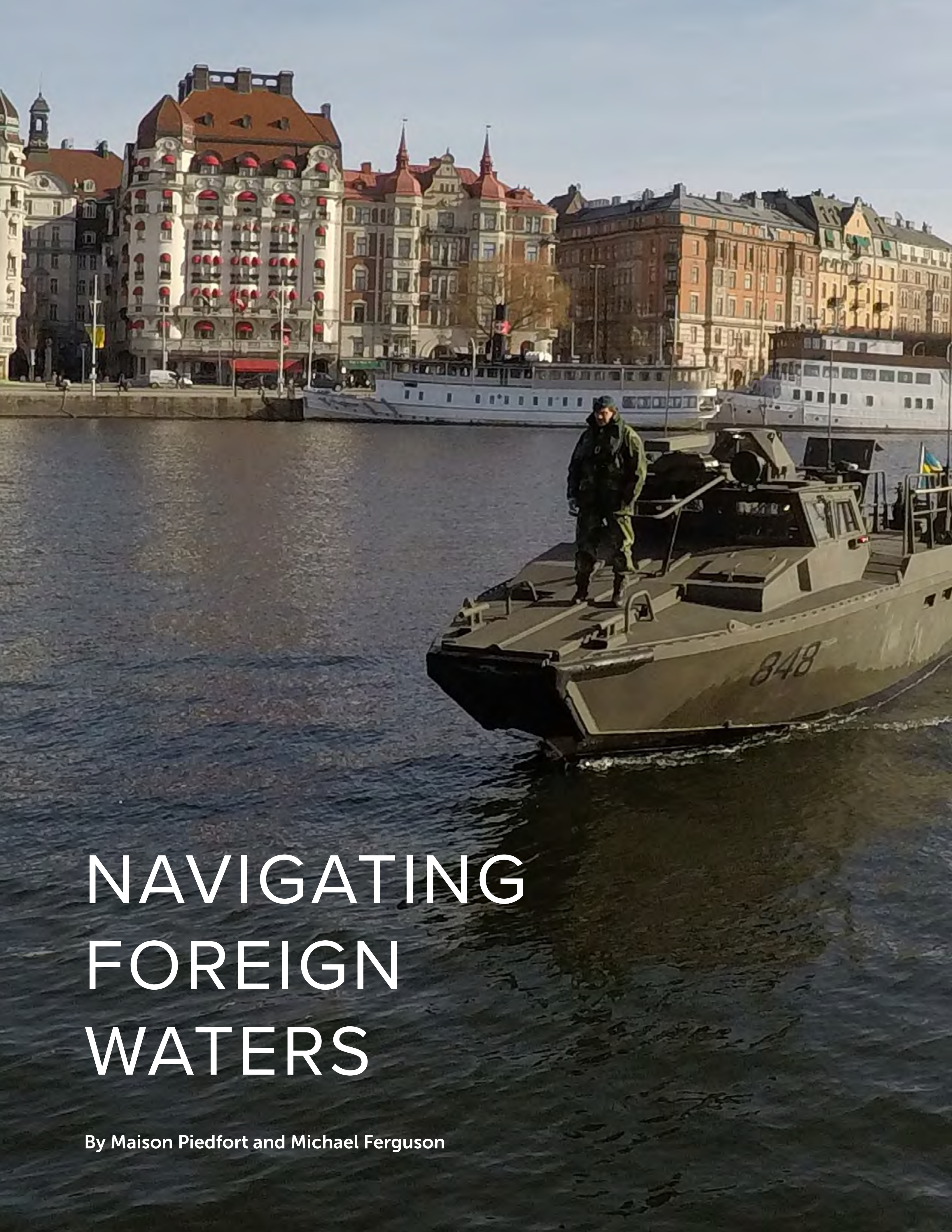

NAVIGATING FOREIGN WATERS

By Maison Piedfort and Michael Ferguson

PARTNERING WITH THE SWEDISH GOVERNMENT, ENGINEERS AT THE NAVAL INFORMATION WARFARE CENTER PACIFIC ARE WORKING ON NEW SYSTEMS THAT CAN PROVIDE NAVIGATIONAL INFORMATION WHEN SIZE—AND GPS—IS AT A PREMIUM.

Imagine you're driving a car. You're relying on GPS to traverse an unfamiliar environment. You lose the satellite signal when you drive through a tunnel, but the car's inertial navigation system tracks your movement in space so it can maintain your position relative to the road. It's a temporary solution, but without GPS—without the ability to reorient yourself in time and space—you've lost yourself in the bigger picture. You don't know your next turn. Without GPS or a backup system, you're in the dark.

Naval Information Warfare Center (NIWC) Pacific solves this problem for the fleet through technology that provides resilient and assured positioning, navigation, and timing (PNT) data with holdover capability in a GPS-challenged environment.

When it comes to allocating GPS solutions, the US Navy's surface combatants with high-value platforms take priority over platforms on other vessels that cannot support the cost of current solutions and do not have room for the large racks of equipment typical on a combatant ship. This creates a capability gap for resource- and space-constrained platforms on smaller vessels.

Integrated Solutions

Before GPS, there was the inertial navigation system (INS). Modern high-end INS uses lasers and fiber optics to compute a platform's dead-reckoning position. INS sensors that can maintain positioning without GPS are expensive and proprietary, which makes their integration and lifecycle support costs unaffordable for most platforms.

Enter the NIWC Pacific PNT Systems Integration Branch and its mission: create a low-size, -weight, -power, and -cost (or SWaP–C) PNT data solution that can meet the requirements of resource-constrained platforms. The team's Advanced Scalable Assured PNT (ASAP) system integrates other sensors in addition to GPS and INS to fill the gap and keep vessels with low operating costs out of the dark.

"That's the big win here—we're able to perform that internal navigation that's been used even before GPS, but now we can do it at a much lower SWaP–C," said Ken Simonsen, division head for NIWC Pacific's PNT Division. "The ASAP project is an investment in equipping our warfighters with robust, assured PNT capability under any and all operational conditions and physical environments."

The NIWC Pacific team developed the ASAP real-time software framework with the goal of demonstrating the system in an operational environment, achieved in less than two years when the team tested the prototype aboard military sealift command ship USNS *Spearhead* (T-EPF 1) during an Office of Naval Research fleet experiment.

Regardless of vessel size, ASAP is insurance for a fleet that relies on the ubiquitous use of GPS. Along with the introduction of the improved military code known as M-Code and jam-resistant antennas, it is one more way the Navy is innovating to protect fleet assets so operations can continue in GPS-contested environments.

"ASAP focuses on integrating existing GPS-dependent capabilities, GPS-independent solutions, and miniaturized, scalable PNT solutions," said Simonsen. "The ASAP team's focus and excitement on executing the 'art-of-possible' captures the entrepreneurial spirit of this team."

Open Architecture Production

The Defense Advanced Research Projects Agency sponsored development of an algorithm for the all-source positioning and navigation particle filter ASAP uses to perform INS functionality. The version used by ASAP, called Assured Data Engine for Positioning and Timing (ADEPT), implements a dynamically reconfigurable particle filter for sensor data fusion and navigation equations. The ASAP team integrated the ADEPT source code, provided to the government with unlimited rights, to its real-time software framework to ensure the particle filter would run in deterministic real-time.

The flexible framework built by the ASAP team—using a government-owned solution not contingent on integration with proprietary technology—means lower costs and greater compatibility with existing fleet hardware, such as sensors from various vendors.

While a commercial system requires only one filter solution designed to meet its particular platform requirements, the ASAP system can run four parallel particle filters at once, useful for further research and development. Running multiple filters concurrently enables accurate comparison of test results under one set of scenario-dynamic motions.

The second version of the Advanced Scalable Assured Positioning, Navigation and Timing (ASAP) system prototype, which is roughly half the size of a shoe box. Photo by Michael Ferguson

Foreign Partnership

Before testing on *Spearhead*, the NIWC Pacific ASAP team was invited to join an ongoing collaboration effort with Sweden as part of an undersea surveillance and communications project agreement. Sweden's location in the Baltic Sea, an area prone to GPS disruption, makes it an ideal partner for the US military, but this foreign collaboration came with challenges.

The ASAP team had to work within limitations set by US regulatory oversight, which restricts exports of Department of Defense-related technologies. To comply with American and Swedish data-exchange agreements, the NIWC Pacific team sent the ASAP system to Sweden without its typical antenna and GPS receiver. But the ASAP system was built with flexibility in mind, so its modular open systems architecture configuration allowed for easy integration with Swedish antennas and receivers. The system proved easy to transport without complicated logistical planning or high shipping costs by fitting into a carry-on suitcase.

The teams pretested the ASAP prototype at the Swedish Defence Research Agency laboratory in Linköping, Sweden, then continued testing aboard a Swedish combat vessel (a CB90-class fast assault craft) during sea trials in November 2019. Results aboard the CB90 were promising, as was the Swedish team's commitment to collaboration—in the words of Carl Ahlden of Sweden's 1st Marine Regiment, who made it clear the purpose of the platform was to serve testing: "If you need to drill a hole, I'll drill a hole."

Subsequent technical exchange meetings and water cooler chats pushed the partnering teams to innovate further: Could the system run on a low-resource computer using system-on-a-chip technology? Could one of the Swedish engineers install ASAP on a jet ski?

Thanks to ASAP's adherence to open programming standards, porting the system to run on the operating system was straightforward, though it did require validation. Once validated, a new micro ASAP system with dramatically reduced size was baselined, a major achievement that could invite even smaller platforms, such as unmanned underwater vehicles, into the fold after more testing.

Long-Distance Collaboration

Then came the coronavirus, a global pandemic that threw a wrench in collaboration for teams such as NIWC Pacific and their Swedish partners. Before COVID-19, the teams managed to overcome barriers to collaboration, such as differences in time zone and language. When, in March 2020, the Swedish government banned all in-bound travel from most countries, it was just one more opportunity to adapt.

A crane lifts the first Advanced Scalable Assured Positioning, Navigation and Timing (ASAP) system prototype onto USNS *Spearhead* (T-EPF 1) during an Office of Naval Research fleet experiment. Photo by Michael Ferguson

The ASAP system was shipped to Sweden on loan for continued testing. The ASAP team in San Diego continues to provide remote technical support, which compounds language and cultural challenges more easily handled in person. Data exchange in the form of large log files proved to be a challenge. Still, recent results from testing on the CB90 continue to show promise. These latest performance improvements were thanks to use of a higher-performance fiber optic gyro inertial measurement unit sensor.

Now the teams are preparing for upcoming sea trials on the CB90, during which the boat's speed log will be integrated into the ASAP system, along with an additional midrange attitude and heading reference system. Another contender for this system's integration is a lower-cost version based on micro-electromechanical systems technology, which is performing well in current vehicle testing at NIWC Pacific.

That is the draw of the all-source positioning and navigation particle filter's flexibility: its ability to integrate with the right mix of sensors for any given platform means the ASAP system can be fine-tuned to a vessel's existing hardware and meet requirements.

Continued Innovation

A two-year extension to the project agreement allows for continued collaboration, including work on characterizing sensors for dynamic operational performance. Also of interest is the expansion of 3D-sensor processing that does not use GPS, which will expand the range of applications ASAP can support. Recent test results that involved using a new inertial measurement unit sensor borrowed from Sweden for the micro ASAP system show even more promise for lowering size and cost.

As the NIWC Pacific ASAP team's innovations continue, it is possible their Swedish partner could run ASAP on a jet ski after all. That would mean having the capability to navigate without GPS—even on a jet ski. It would be like driving through a tunnel and losing GPS but knowing that even then, you're never really in the dark. You're grounded, no matter what. With the ASAP system, that translates into better and cheaper positioning capability for vessels of all sizes, GPS or not. It means navigating foreign waters with confidence. For the fleet at large, it means increased readiness no matter the mission.

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Marines with Marine Fighter Attack Squadron 211 conduct preflight checks on an F-35B Lightning II aboard the Royal Navy aircraft carrier HMS *Queen Elizabeth* (R 08) in the North Sea during Joint Warrior Exercise 2020.
Photo by 1st Lt. Zachary Bodner

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