The Coast Guard Journal of Safety & Security at Sea

PROCEEDINGS

Spring 2025 of the Marine Safety & Security Council

The U.S. Coast Guard Research and

The Evolution of the Research and Development Center's Focus on Coast Guard Missions

Argo Merchant

Aids to Navigation Becomes a Focus

Exxon Valdez

AIS is Developed

9/11 Attacks

Hurricane Katrina; RDC moves to CG-9

- Search and Rescue
- Aids to Navigation
- Spill Response
- Shipboard Fire Safety Standard
- Acquisition Support Systems
- Port Security
- Cyber Security
- Operation Improvements
- Space-Based

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CG RDC

SERVING THE COAST GUARD FROM 1972 TO 2022 • CELEBRATING FIFTY YEARS OF LEADING & RESEARCH & DEVELOPMENT CENTER • UNITED STATES COAST GUARD • FROM HERE...YOU CAN SEE TOMORROW

- Test Recreation Vehicle Foam Flotation
- Safer and More Stable Jon Boats
- Fire Testing
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- 47-MLB
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- Visual Search Performance
- NVG Sweep Widths
- SAROPS
- Self-Locating Datum Marker Buoy

1972
The Coast Guard Research and Development Center (RDC) opens at Avery Point

1980
The Coast Guard plays a crucial role during the Mariel Boatlift when thousands of Cubans migrate to the United States

1990
In response to the Oil Pollution Act of 1990, the Coast Guard develops a new prevention and response technology portfolio

2000
New York Coast Guard units are first military responders in the aftermath of 9/11

Development Center: 1972-Present

Deepwater Horizon

Cyber Strategy

Adverse Weather Events

UxS, c-UAS, and Counterintellgence

Space Technology

- CG CubeSat Technology
- High-Latitude Communications
- AI/ML
- Extended Reality
- Enhanced SAROPS
- Cyber Security for Maritime Transport
- Cyber Risk Mitigation
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- Enhanced PIW
- RADAR Performance
- Targets on Ice
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- Cellphone Use for SAR
- Remotely Operated Lifesaving Devices

2005

The Coast Guard responds to Hurricane Katrina, saving more than 30,000 lives

2010

The RDC tests Predator uncrewed aerial vehicle for law enforcement use in 2008; the RDC opens its doors in New London, Connecticut, in 2009

2015

In 2014, the RDC opens the Modeling and Simulation Center of Expertise; in 2015, it approves first FAA Unmanned Aerial System Certificate of Authorization

2020

Cyber interference becomes global issue, and the RDC participates in National Lab and Evergreen Strategies; in 2022, the RDC celebrates 50th anniversary

2025

The RDC continues to execute more than 40 projects each year

PROCEEDINGS

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Coast Guard Research and Development

Partnership's Role in Research

Current Research Supporting Coast Guard Missions

Strategic Research and Development

Focused on the Future

On Deck

On the Cover: Since its commissioning more than 50 years ago, the U.S. Coast Guard Research and Development Center has embodied transformation, harnessing the full spectrum of scientific discovery to create research that drives impactful advancements and shapes tomorrow's breakthroughs. This research has shifted the tide from 1900s technology to cutting-edge autonomous craft and ISR buoys that provide enhanced maritime domain awareness.

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Correction

In the Fall 2024 issue of Proceedings, LCDR Mike Moyseowicz's byline was inadvertently left off of the Olmsted Scholar Program article he helped author. He is the operations officer on the CGC *James*.

Champion's Note

The Champion would like to thank Elizabeth Webber and Kellie August for their assistance in the successful completion of this issue highlighting Coast Guard research and development.

Deputy Assistant Commandant's Perspective

by Lisa Schleder-Kirkpatrick
Deputy Assistant Commandant for Capability
U.S. Coast Guard

It is my honor to introduce to you the spring 2025 edition of Proceedings dedicated to Coast Guard research. My first introduction to the Coast Guard Research and Development Center (RDC) was while participating in an annual assessment of prospective portfolio review. I had the opportunity to jury proposed projects with an esteemed panel of senior leaders and colleagues from across the Coast Guard, Department of Homeland Security, and Department of Defense partner labs. The individual researchers presented exceptional project briefs. However, I noticed a need for executive leadership to champion these initiatives and provide active sponsorship to ensure that

Champion's Point of View

by Vice Admiral Nathan A. Moore
Commander
Atlantic Area
U.S. Coast Guard

The Coast Guard Research and Development Center's (RDC) importance to the successful execution of all 11 Coast Guard missions cannot be understated. When I drafted my Commander's Intent, I had three primary focuses, one of which was, "Mission: We will strengthen operational readiness while delivering mission excellence." Within this guiding principle, I reflected on the RDC, which I consider a center of gravity for the strategic, operational, and tactical levels of research for the service. As that center of gravity, we will innovate in concepts and approaches to operations and leverage advancement in technology and research for greater operational effect.

It is through dedicated, academically rich and rigorous research that the RDC impacts a wide range of missions the Atlantic Area, the subordinate districts

the results—whether they pertain to products, policies, or process improvements—are effectively transitioned and implemented. Bringing transformative technologies and capabilities into operations are a whole-of-service responsibility.

In 2024, a decision was made to move the RDC under the Assistant Commandant for Capability (CG-7), fostering prioritized alignment of research projects against the most critical and imminent capability gaps. In parallel, the Research, Development and Innovation Governance Council has already started meeting with key sponsors and stakeholders to ensure alignment for the transition of the most promising technologies, focusing on those that offer significant capability, efficacy, and efficiency.

In my role as CG-7D, my responsibility is to ensure we identify capability gaps across the Coast Guard enterprise, seek opportunities to expand or improve capabilities, competencies, and capacity, and then deploy modernized or new technologies, keeping our workforce ready and relevant. These efforts are codified by developing standards for staffing, training, equipping, sustaining, and employing Coast Guard forces to meet mission requirements. The RDC will continue to be a strategic resource for the enterprise just as it has been since its establishment in September 1972.

CG-7 looks forward to the opportunity to highlight its ongoing successes and pursue, promote, and deliver new and emerging capabilities that address the complex and ever-changing environment that our men and women of the Coast Guard operate in every single day.

Please enjoy this edition of Proceedings that showcases some of the work being done by the talented Coast Guard research community, reminds us why research is important to the service, and highlights the power of partnerships across the nation's research enterprise.

and sectors, as well as their associated commands, are involved in. From illegal, unreported, and unregulated fishing, human and narcotics smuggling, and search and rescue to polar operations, environmental response, and all facets of the Marine Transportation System, the need for the RDC's research discipline has never been greater. I am amazed that this small command does so much that impacts those of us in the field.

Our adversaries are constantly changing tactics and the need for durable maritime domain awareness and the application of autonomous capabilities have never been more important, especially when it allows decision-makers to carefully select assets. The RDC's work in ArcGIS, their autonomy sprints, their work with communications advances, such as Starlink, and search and rescue tools like i911 make a difference.

The RDC must continue to work with the operators and Coast Guard Headquarters programs to apply science and research to address these issues. I have been impressed with the number of partners, inside the government and out, including academia and industry. The Evergreen events the RDC has sponsored with the Coast Guard's Office of Emerging Policy have benefitted my command, and the knowledge products generated are useful in developing operational orders and future strategies. Having RDC talent participate in our chartered work groups adds to the perspective and the courses of action considered.

The operational commanders need to engage in a continuous manner with the RDC to ensure two-way communication, which is why I assigned liaisons to work directly with their staffs. If the RDC wants to conduct experimentation in my area of responsibility, my staff will support them, and we will work to ensure the district, sector, cutter, or aircraft are true partners. I know my counterpart on the West Coast, VADM Andrew Tiongson, feels equally strongly about the RDC's value.

We live in a constantly changing world. Having the RDC and Coast Guard research partners look to the future, conduct priority research, and test technology that supports my command and the service is a strategic imperative. As you read this edition, I hope you gain insight into the various areas the RDC is involved in and the impact it makes.

Welcome to the Coast Guard Research and Development Center

by CAPT Michael P. Chien
Commanding Officer
Research and Development Center
U.S. Coast Guard

It is my distinct pleasure and honor to provide our readers with a glimpse into who we are at the Coast Guard Research and Development Center (RDC). The RDC comprises a strong, diverse group of personnel ranging primarily from a civilian workforce to a core set of military personnel.

Since being established in 1972, our staffing levels have fluctuated. We saw our highest staffing levels in 1976 with 133 personnel to a low of 83 in 2024. Supporting the RDC is a 33-person virtual Auxiliary unit with an impressive set of skills that we employ in our portfolio execution. Combined, we have more than 872 years of federal service; 167 years in active-duty service; and 691 total years of service at the RDC. This workforce also boasts a combined 42 master's degrees, four doctoral degrees, and numerous certifications ranging from Certified Information Systems Security Professional to project management professionals.

Our researchers support research across all Coast Guard missions, including many you will read about in this issue. Additionally, our civilian workforce provides important subject matter expertise and continuity across research areas and projects. Our military work provides critical connectivity with Coast Guard operators and missions and lends its unique experiences to the RDC to help provide that extra visibility and connection to our missions and operational community. When active-duty members return to the operational Coast Guard, they bring a rare perspective on the disciplines of research and its impact on mission success.

Interspersed throughout the research we conduct is the great support staff, who ensure we are fiscally responsible in executing our budget and have the equipment our staff needs to conduct research in-house or in the field. These staff members also provide a secure facility and ensure we follow enterprise IT requirements for the unique things we do. When resources are tight, our support staff steps in to assist in field test and evaluation events. Their dedication is one of the foundations of our success.

Additionally, we are the only Coast Guard facility that receives a research and development appropriation and have delivered more than 2,000 research products to our customers in the center's 52 years. We have successfully accomplished this with widely varying budgets. For example, in 1992, we received our highest appropriation of $29.2 million. The lowest was $5 million in 2020, and FY 24 came in at $6.5 million.

In conclusion, I want to thank the Proceedings team for providing the RDC with the opportunity for its team members and Coast Guard research partners to highlight just a sampling of our work benefitting Coast Guard operators. We remain committed to working with everyone to help improve mission execution and staying relevant going through the 21st century.

About the author:

CAPT Michael P. Chien is a 2001 graduate of the U.S. Coast Guard Academy and, as a lieutenant, had the privilege of being stationed at the Coast Guard Research and Development Center from 2005 to 2008, when it was located on the University of Connecticut Avery Point campus.

Please feel free to contact the RDC at **rdc.technical-support@uscg.mil**

From Here, You Can See Tomorrow

The first 50 years of the U.S. Coast Guard Research and Development Center

by Patrick Alarcon
Research and Development Center
U.S. Coast Guard Auxiliary

Leslie Schwartz
Research and Development Center
U.S. Coast Guard Auxiliary

The scientific method is driven by questions that trigger a problem-solving process. ADM Chester Bender, former Commandant of the U.S. Coast Guard understood this and, owing to his leadership and vision, Congress created the Coast Guard Research and Development Center in 1972.

Since the inception of the Research and Development Center (RDC) at the University of Connecticut's Avery Point in Groton, scientists and engineers have formulated questions in response to the Coast Guard's operational needs and challenges. Early accomplishments such as oil fingerprinting, mobile response to chemical spills, safer and steadier jon boats, and foam flotation testing provided answers to these needs. To date, researchers have collectively designed and developed more than 2,000 products to help the Coast Guard undertake and maximize its many vital endeavors. The RDC's mission statement to "provide innovative technologies, premier analysis, and decision support to enhance operational performance and reduce acquisition risk across all U.S. Coast Guard missions" reflects this purpose and dedication.

The RDC's mission statement is to "provide innovative technologies, premier analysis, and decision support to enhance operational performance and reduce acquisition risk across all U.S. Coast Guard missions."

In the beginning, researchers at Avery Point focused on testing and evaluating recreational boats for safety and continued making advancements for mission-specific needs that allowed for more effective operations, including:

- Solar power
- Digitizing navigational charts
- Search and rescue patterns
- Gas chromatography for oil spill-to-source matching
- Buoy corrosion analysis
- Active electro-optical camera systems
- Wave-activated turbine generators

Necessity Prompts Invention

Events in our hemisphere brought exceptional pressures to bear on the Coast Guard during these early years. Resulting in what the National Oceanic and Atmospheric Administration calls the birth of modern oil spill response,[1] the *Argo Merchant* incident on December 15, 1976, presented researchers with many new questions about the effects of oil on water and the environment.

The Mariel Boatlift of 1980, with 125,000 Cuban refugees aided by around-the-clock Coast Guard search and rescue (SAR) missions, called for enhancements to night vision goggles (NVG) on the part of the RDC. The *Exxon Valdez* disaster of March 24, 1989, prompted fresh questions on how to improve the Coast Guard's response to oil spills in conjunction with a growing emphasis on marine safety and environmental protection. Investigating new technologies to support the Coast Guard in disaster response and other large-scale encounters occupied countless hours, giving researchers much-needed experience and knowledge that the future would require of them.

Advancements in global positioning systems characterized the 1990s at the RDC, with the establishment of visual aid system design standards. Differential long-range navigation and automatic identification system (AIS) development further advanced Coast Guard capabilities.

At the RDC, the turn of the 21st century brought refined nationwide AIS, and new advancements in oil spill response such as dispersant protocols and managing submerged oil. A new area of focus for researchers—acquisition support—brought Juniper-class buoy tenders and 47-foot motor lifeboats to the service.

Center innovations also directly supported armed forces and disaster response efforts with the Coast Guard rendering security and aid in its first direct military response to the 9/11 terrorist attacks and after Hurricane Katrina in 2005. Of the estimated 60,000 people in need of rescue from rooftops and flooded homes after Katrina, Coast Guardsmen saved more than 33,500, including the evacuation of 9,409 medical patients.[2] These rescue and response efforts were some of the largest in Coast Guard history, involving units from every district.

Questions about solutions for mission aid remained at the forefront of the RDC's purpose when it was rehomed in New London, Connecticut, in 2009. SAR-based research steadily drove new advancements to the service as it had since the center's creation in 1972. These efforts now resulted in lateral range curves—a method for estimating effective sweep width during searches—and NVG sweep widths, along with self-locating datum marker buoys, upgraded radar performance, and a SAR victim empirical survival model, to name only a few. Researchers also continued advancing oil spill response with oil-in-ice studies and the development of a strategic plan for oil/hazardous materials accounting for much of the inquiry through 2010. As port security came under Coast Guard auspices, surveillance systems, nonlethal vessel stopping, risk-based decision-making, and WMD response augmented mission performance. The largest accidental offshore oil spill in the history of the petroleum industry—the *Deepwater Horizon* disaster of 2010—catalyzed new research investments in oil spill response including full-scale, in-situ burning of oil in both seawater and freshwater.

Between 2010 and 2015, research in high-latitude capabilities, uncrewed aerial systems (UAS), and polar icebreakers (PIB) further aided the Coast Guard. Other new technologies and creative solutions resulted in the development of biometric identification technologies—the forerunner of today's DHS Office of Biometric Identity Management—and annual Arctic technology evaluations of many new capabilities such as PIB ice radars. SAR benefited from research associated with electro-optical sensor system performance and mass rescues. Continuing research in spill response generated scientific understanding of oil sands products, while aids to navigation research progressed. Additionally, various important aviation and surface fleet organizational decisions benefited when the RDC opened its Modeling and Simulation Center of Expertise in 2014.

Response to natural disasters, including hurricanes, directed much research from 2015 to 2020. At the beginning of 2015, Coast Guard forces assisted with hurricane response, leading to a number of developments in the field of SAR, including multiple person vertical lifts, cellphone location, and enhanced detection of person-in-the-water technology. Additionally, aids to navigation research produced virtual aids based on AIS technology

Coast Guard illustration | iStock/Getty Images

to assist in temporary port reopenings for safe navigation after a hurricane.

In the spill-response arena, research afforded advancements in the detection of oil-in-water columns and sunken oil, while sophisticated developments in object-tracking technologies, nonlethal deterrents, and communication systems assisted the Coast Guard in law enforcement operations. Ongoing requirements and acquisition support research provided beyond visual line-of-sight-capable small UAS, while cybersecurity research exploded with new products for maritime support, along with building a cyber workforce strategy and cyber risk mitigation.

Exploring the Future

Space, counterintelligence, and counter-uncrewed aircraft systems are among the more recent areas of inquiry. In 2020, cyber interference in the United States and around the world heightened as an area of focus, with the RDC subsequently participating in National Laboratories and other efforts to sustain strategic currency. Space-based research brought nanosatellite technology and high-latitude communications, and operational performance improvements delivered extended reality and use cases for artificial intelligence/machine learning, propelling the RDC to its full potential. Current research is bringing human-machine teaming of crewed and uncrewed assets, while multiple missions are benefiting from goals established in 2023.

The women and men of this noble institution should stand proud, knowing that they continue to serve with honor, respect, and devotion to duty. Given the wealth of human resources and energy dedicated to creating a multitude of products that have enhanced Coast Guard missions over the past 50-plus years, RDC personnel anxiously await questions in the coming decades. As the motto of the Coast Guard Research and Development Center reminds us, "From Here … You Can See Tomorrow."

About the authors:

Patrick Alarcon is a U.S. Coast Guard Auxiliary member assigned to the U.S. Coast Guard Research and Development Center's Auxiliary Unit. Mr. Alarcon teaches at Sacred Heart University in Fairfield, Connecticut.

Leslie Schwartz is a U.S. Coast Guard Auxiliary member assigned to the U.S. Coast Guard Research and Development Center's Auxiliary Unit. She also serves as branch chief—special projects editor with the Auxiliary's national prevention directorate, and as communications aide to the commodore of the Auxiliary's First District Northern Region.

Endnotes:

1. https://response.restoration.noaa.gov/oil-and-chemical-spills/significant-incidents/argo-merchant-oil-spill/argo-merchant-birth-modern-oil
2. USCG (2005) Historical Index: The U.S. Coast Guard & Hurricane Katrina. Retrieved from https://media.defense.gov/2017/Oct/31/2001835784/-1/-1/0/KATRINA%20INDEX.PDF

Editor's note

A full-length book detailing the first 50 years of the U.S. Coast Guard Research and Development Center will be available in 2025.

Why Research and Development is Important

by Retired Coast Guard CAPT Al Arsenault
Technical Director
Research and Development Center
U.S. Coast Guard

The Coast Guard values innovative thought, but innovation and research and development (R&D) are different in terms of scope, focus, outcomes, timeline, culture, and mindset.

R&D refers to the systematic and creative work undertaken to increase knowledge in a particular field or to solve specific problems. It involves the generation and application of new ideas, theories, and technologies, typically within a scientific or engineering context. Innovation, on the other hand, is a broader concept that refers to the implementation and commercialization of new ideas, processes, or products, often with the goal of creating value or improving existing practices.

But what is it that makes R&D important to the Coast Guard? In short, the answer is its ability to help the service meet its mission of ensuring maritime safety, security, and stewardship. This includes R&D in several areas.

Advanced Technology

R&D can lead to the development of new and improved technology, such as advanced sensors, communication systems, and uncrewed vehicles, which can enhance the Coast Guard's capabilities for surveillance, search and rescue, and law enforcement operations.

Environmental Protection

The Coast Guard plays a critical role in protecting the marine environment, and R&D can help develop new technologies and techniques for responding to oil spills, mitigating pollution, and preserving marine ecosystems.

Navigation and Transportation

R&D can also support the Coast Guard's mission to ensure safe and efficient navigation and transportation in U.S. waters. For example, R&D can help develop new aids to navigation, improve vessel traffic management systems, and enhance port security.

Improved Operational Efficiency

R&D can lead to more efficient and effective Coast Guard operations, such as developing better decision-support tools for command and control, improving the design and performance of cutters and other vessels, and optimizing logistics and supply chain management.

Discipline Emphases

In addition to its innovative spirit, the Research and Development Center (RDC) lives and breathes research. That is its dedicated function in support of the 11 statutory missions of the Coast Guard. The RDC has the tools, disciplines, authorities, partnerships, and processes to help make sound conclusions based on true research findings. The RDC's discipline emphasis includes:

Scientific Integrity

This refers to the principles and practices that uphold

Coast Guard illustration | iStock/Getty Images

honesty, objectivity, and reliability in scientific research and communication. The term is often used to describe a commitment to ethical conduct, accountability, and responsible stewardship of the scientific enterprise. The RDC ensures the integrity of our research by having a well-defined team review all research outcomes from every angle—scientific and technical information, operations security, legal, counterintelligence, human subjects research, and peer review.

Experimental Design

Sound experimental design helps ensure that the results obtained from a study are valid, reliable and can be generalized to other contexts. A significant part of the RDC's project planning is centered around field experiments and data collection. The experimental design must include well-defined research questions, a proper control group, randomization, replication under different conditions, use of the proper sample size, and data analysis. Sound conclusions cannot be made without a well-designed experiment or test.

Human Subjects Research

Human subjects research involves gathering and analyzing data through interaction or intervention with people. To protect the rights, welfare, and privacy of individuals participating in research, institutional review boards (IRB) review, approve, modify, or disapprove research studies involving human subjects. The RDC has one of three IRBs in the Coast Guard.[1] Research with human subjects can involve various methods, like surveys and questionnaires, interviews and focus groups, observational studies, clinical trials, experimental research, and analysis of biological samples and/or health records. Potential participants must voluntarily agree to participate in the research after fully understanding its nature and consequences.

Prototype Installations/Testing

The vast majority of RDC knowledge products are based on field experimentation. RDC test planning includes processes to ensure a multitude of required approvals are obtained before moving forward. Some of those approvals and/or processes include:

- Request for forces
- Spectrum authorization—communications/data link/command and control/radar
- Aviation Configuration Control Board approval
- Time compliance technical order/prototype authorization
- Electromagnetic compatibility/electromagnetic interference test
- Safety of flight test/check
- Platform IT assessment, authority to operate, interim authority to test
- Universal flight clearance—airworthiness, operator qualifications, and test plan
- Department of Homeland Security privacy threshold assessment/privacy impact assessment
- Airspace authorization, certificate of authorization update and/or activation
- Notice to airmen
- Broadcast notice to mariners
- Environmental assessment, National Environmental Policy Act compliance
- IRB approval for human subjects research

Industry Partnerships

The RDC leverages the Coast Guard's authority to enter into Cooperative Research and Development Agreements (CRADA) with its industry partners. These agreements are created to facilitate collaboration and information sharing on research and development projects, with the aim of advancing scientific knowledge and promoting technology transfer. The RDC uses these no-cost agreements as a force multiplier to get capabilities into the hands of Coast Guard operators. At any given time, the RDC has five to 10 CRADAs in place.

Conclusion

While R&D is important to the organization, a professional R&D organization is also important. The RDC has filled that role since 1972 and plans to be around to support Coast Guard missions in the future.

The RDC is characterized by well-established processes, strong leadership, and a commitment to excellence. It provides innovative technologies, premier analysis, and decision support to increase readiness, improve mission effectiveness, and reduce risk across all Coast Guard missions. Our disciplined organization is centered on clear research goals and objectives, structured R&D processes, strong governance, diversity of expertise, collaboration and partnerships, investment in capabilities, and commitment to continuous improvement.

About the author:

Retired Coast Guard CAPT Al Arsenault served on active duty for 27 years, last serving as the commanding officer of the Coast Guard Research and Development Center (RDC). He has served in many capacities including various engineering and major acquisition project management roles. He has been a civilian at the RDC for 10 years.

Endnotes:

1. Coast Guard Research and Development Center Instruction 5430: Research and Development Center Institutional Review Board Standard Operating Procedure.

The Power of Partnerships

by Joe DiRenzo, Ph.D.
Partnership Director
Research and Development Center
U.S. Coast Guard

In the dynamic world of research and development, partnerships play a pivotal role in amplifying the impact and importance of an organization's work. To understand the significance of these collaborations for the Coast Guard Research and Development Center (RDC) consider its staff, just over 80 people comprising leadership, scientists, engineers, and support staff, is a component of the National Security Research Enterprise (NSRE). The RDC may seem like a small fish in a big pond when compared to other NSRE members like the Air Force Research Lab, which boasts 11,500 military, civilian, and contract personnel across 10 states with a budget of $7 billion. However, this size comparison does not fully capture the RDC's impact over 52 years of service as the science advisor to the Coast Guard.

The RDC has had a well-earned reputation of doing more with less. A testament to its ability to exceed expectations, Commandant of the Coast Guard ADM Linda L. Fagan acknowledged during her remarks during the 50th anniversary celebration in February 2023 that the RDC has been "punching above our weight class." This is facilitated, in part, by leveraging the ultimate force multiplier—partnerships. Currently, more than 80% of the FY 2025-approved portfolio leverages at least one partner, and occasionally more.

These alliances amplify the RDC's effectiveness, enabling it to make a disproportionately large impact relative to its size, underscoring the potential of partnerships to drive exceptional results and uplift even relatively smaller organizations to outperform their contemporaries. The RDC's success story thus serves as a powerful reminder of the transformative potential of strategic collaborations.

Before delving into the intricacies of leveraging partnerships, it is essential to understand what the term "partnerships" entails within the context of the RDC. In this context, partnerships refer to a range of activities and agreements that the RDC's researchers can employ to foster collaborative efforts, including memorandums of understanding (MOUs) and cooperative research and development agreements (CRADA), as well as engagement with:

- Department of Defense (DoD)
- Department of Energy commands and labs
- The Federal Lab Consortium (FLC)
- Federally funded research and development centers
- Academia
- The Commandant's Emerging Policy staff for Evergreen events and War Games
- Engagement with the U.S. Coast Guard Academy (CGA) and national symposiums
- Private industry
- Other state and federal agencies

Each partnership activity offers unique benefits and advantages, contributing to the RDC's overall success. These relationships not only enhance the center's capabilities, but also strengthen the NSRE as a whole. Therefore, it is essential for the RDC to strategically engage in these partnership activities to maximize their potential impact and value. In the following sections, each partnership activity will be explored in detail, providing insights and best practices for leveraging these collaborative opportunities.

Memorandums of Understanding and DoD Lab Commanders

The RDC employs MOUs as a formal method to establish connections between entities engaged in collaborative research. MOUs serve to clarify individual responsibilities, mutual focus, and objectives, ensuring that all parties involved have a clear understanding of the relationship. These documents establish expectations, identify points of contact, and define a specific duration for the partnership.

One of the most impactful partnerships is with the DoD laboratory commanders. Signed on October 28, 2019, this MOU includes the Army, Navy, Air Force, and Coast Guard, and is intended to facilitate cooperation on a diverse array of programs, enhancing the overall collaborative efforts of the armed forces. The MOU has a seven-year term, providing a stable foundation for long-term partnerships.

This DoD Laboratory Commander Sync MOU enables all signatories to share science and technology (S&T) and research and development (R&D) data, including

Shalane Regan, the Coast Guard Research and Development Center's (RDC) lead polar scientist, operates the Strategic Quad for Reconnaissance & Logistics, or SQRL, uncrewed ground vehicle at the Army Research Laboratory's Robotics Research Collaboration Campus (R2C2) in Middle River, Maryland, on June 2, 2024. RDC members, along with members of R2C2, collaborated on how to operate and maintain the SQRL vehicle while also brainstorming what polar excursions could look like in the future. Coast Guard photo by Petty Officer 3rd Class Carmen Caver

contracts and other methods of approved money/service exchanges. This facilitates increased collaboration, reduces redundancy, and improves the overall strength and efficiency of the Armed Forces' S&T and R&D portfolios. The RDC has greatly benefited from this relationship, gaining access to ongoing DoD experimentation, subject matter experts, databases, and collaboration opportunities. For instance, the Coast Guard's counter-uncrewed aerial system (c-UAS) was developed through cooperation with DoD Lab Sync members.

While MOUs like the DoD Lab Sync are basically pieces of paper that outline a framework for collaboration, it is the driven individuals involved who have gotten to know and trust each other over the years that make it work. The nonstop engagement of each agency's lab leadership makes DoD Lab Sync the single best example of collaboration. Apart from the DoD Lab Sync, the RDC has 17 active MOUs, highlighting the importance of these partnerships in driving research innovation.

In a cyberattack exercise, red teams take on the role of an attacker.

One of the most significant partnerships is with the Connecticut National Guard, signed by state Adjutant General Francis Evon. This relationship has provided mutual benefits, with National Guard members invited to participate in Coast Guard Strategic Evergreen events. Additionally, the Coast Guard has used National Guard facilities for kinetic c-UAS testing and housing for RDC summer interns, as well as collaborating on community science, technology, engineering, and mathematics events. The value of this partnership with the Coast Guard resulted in Evon assigning a major as a liaison to the RDC. The RDC has since been invited to the National Guard's regional cyber warfare event, Cyber Yankee. This is a regional New England cybersecurity exercise in which National Guard and industry representatives work against a simulated red team. The benefit to the RDC is exposure to some of the region's finest cyber experts and the latest thinking on cyber issues and research.

The Naval Postgraduate School (NPS) MOU, signed by NPS President and retired Navy Vice Adm. Anne Rondeau, provides another pathway for collaborative

research. This partnership includes proposing thesis questions for students and faculty to consider, seven of which are already complete. The partnership benefits NPS by offering students access to RDC researchers and Coast Guard research topics, while the RDC gains academic work products that can delve deeper into areas of interest from the portfolio. Moreover, NPS has engaged with RDC researchers on satellite research, additive manufacturing, and even placed an NPS faculty researcher onboard the CGC *Healy* for the RDC's Polar Research Technology Evaluation, an RDC-sponsored research effort. Annually, this partnership allows NPS faculty and administrators to be introduced to Coast Guard commands, leading to further research opportunities for the service.

The MOU with the U.S. Space Force, signed by Dr. Joel Mozer, the director of science, technology, and research, is another notable partnership. This partnership has offered insights and lessons from the nation's newest service, as Space Force senior scientists have participated in the RDC's Annual Assessment of Prospective Portfolio, providing valuable feedback on new research projects. The RDC sent an active-duty researcher to the Space Force to learn about the host agency's priorities and focus with plans on an exchange the other way.

The RDC is home to the service's three autonomous vessels. An MOU was developed with three Navy commands to support maintenance and logistics. Naval Submarine Base New London (SUBASE), Navy Reserve Center New London, and Maritime Expeditionary Security Squadron (MSRON) 8 Detachment Groton, Navy Region Mid-Atlantic, and Navy Reserve Expeditionary Maintenance Detachment New London are also parties to the MOU.

The MOU solidifies the cooperation between the commands to provide for the temporary storage and maintenance of the RDC's three optionally crewed/uncrewed surface vessels (USVs) at the SUBASE. The USVs are the leading edge of the RDC's autonomy research and encompass experimentation in areas from vessel control systems to new sensors, navigation systems, and state-of-the-art communications capabilities.

For the sailors from SUBASE Port Operations, the MSRON, and the Reserve Expeditionary Maintenance Detachment, the opportunity has multiple benefits.

"This cooperative effort not only provides our Navy Sailors with valuable training opportunities to sharpen their skills and maintain mission readiness across several platforms, but also to work with fellow sea service professionals in the Coast Guard," said Cmdr. Drew Nilsson, commanding officer of Navy Reserve Center New London. "Additionally, it exposes them to experimental, cutting-edge systems and technologies that may be the standard in the future," noted Cmdr. David Sigler, officer in charge of MSRON 8 Detachment Groton.

Extragovernmental MOUs

Lastly, the RDC employs MOUs with organizations outside of government like university-affiliated research centers, or UARCs. One of these, which has led to a variety of efforts including cyber-focused research, is with Johns Hopkins Applied Physics Lab in Laurel, Maryland. This UARC is the largest in the nation with an 8,800-member technical staff.

The MOU between the RDC and the American Bureau of Shipping is facilitating collaborative research on technologies impacting the maritime industry. This partnership covers various research areas, including remote and autonomous systems, advanced data analytics, cybersecurity, changing risks associated with the Marine Transportation System, and impacts of energy transition and alternative fuels. These collaborations, enabled by MOUs and the dedicated people behind them, have significantly expanded the RDC's capabilities and resources, leading to new research opportunities and improved outcomes in critical research areas.

CAPT Michael Chien, left, commanding officer of the Coast Guard Research and Development Center, and Bruce Baffer, senior vice president for global government services for the American Bureau of Shipping, met virtually on July 17, 2024, to review and sign a new memorandum of understanding to collaborate on technologies. Photo courtesy of American Bureau of Shipping

Partnerships with DHS S&T and Polar Research Technology Evaluation

The RDC maintains a robust partnership with the Department of Homeland Security Science and Technology (DHS S&T) Directorate, and its member labs. These collaborations span various projects, including autonomous vessel testing, counter-underwater uncrewed vessels with the Navy and proliferated low-Earth orbit satellite research. DHS S&T also supports the RDC's efforts in recruiting from minority served institutions. For example, DHS S&T supported research from Texas Southern University to assist Coast Guard research on blockchain and its maritime applications. This partnership resulted in a well-documented, academically

rigorous report that has been provided to the Office of Cyberspace Forces and other programs within the Coast Guard Assistant Commandant for Prevention Policy directorate.

The Polar Research Technology Evaluation (PRTE) partnership engages multiple commands, other agencies, and academia to collaborate in high-latitude experimentation. During the 2023 PRTE summer deployment on CGC *Healy*, the RDC supported 18 multidisciplinary projects from 17 partner organizations. The areas of research focused on artificial intelligence and machine learning, machine vision, high-latitude communications and connectivity, maritime domain awareness, operator performance, and ice characterization and observation. Results from projects like measurement of NO2 and ozone in the Arctic from the U.S. Coast Guard Academy's physics department are being used to develop a baseline against which future levels can be compared to determine the impact of increased maritime traffic in that region. This is just one example of many that will impact future Arctic operations and systems.

A polar bear investigates a research partner's communication experimentation during Polar Research Technology Evaluation 2023, where the Research and Development Center was the science lead. Coast Guard photo

Federal Laboratory Consortium

The RDC is a member of the Federal Laboratory Consortium (FLC) for technology transfer, a nationwide network connecting more than 300 federal laboratories and research centers. Through taxpayer-funded R&D, the consortium fosters scientific breakthroughs that contribute to economic growth by creating new industries, businesses, and jobs through technology transfer. As a member of the FLC, the RDC benefits include:

- Access to more than 300 federal labs and all of their subject matter experts
- Ability to leverage research that is already completed or ongoing by other labs
- Access to multiple tools and techniques in technology transfer

In February 2023, the RDC was featured in a lab showcase and the command hosted the Northeast regional event four months later. The RDC was also recognized in a National FLC Technology Transfer Innovation Award and in an individual Researcher Northeast FLC Regional Award.

Internal Coast Guard Partnerships

The RDC routinely partners within the Coast Guard. In addition to our sponsors and stakeholders, we work closely with the Coast Guard Auxiliary, and the CGA. The RDC, working with Coast Guard District 1, established the first-ever virtual Coast Guard Auxiliary Unit. The new unit provides personnel, boats, and specialized technical and communication skills in support of the Coast Guard's research portfolio. The Auxiliary's impact has been significant, as evidenced by the developments like a computer application to record the information required to properly position and verify private aids to navigation. The application had an immediate impact on effectiveness and efficiency.

Separated by less than 2.5 miles, the RDC and the CGA share a 50-year relationship of collaboration and mutual growth. This partnership encompasses both commands' faculty, staff, researchers, and support staff, as well as CGA cadets.

While RDC collaborations with research institutions and academies are not uncommon, the RDC and CGA partnership stands out due to their proximity, size, and potential impact on the service.

CGA faculty and students have worked on projects with the RDC team for decades. The collaboration between the two has significantly enhanced innovation, research, and education within the Coast Guard. Exemplified through cadet capstone projects, this partnership showcases the benefits of strategic alliances and has resulted in recent CGA capstone projects focused on natural language processing for maritime distress signals, the effects of windfarms on SAR, and an electric P6 Portable Fire Pump project.

Cooperative Research and Development Agreements

Under the authority of the U.S. Federal Technology Transfer Act, the RDC has been delegated the authority to enter into CRADAs with the private sector to collaborate when there is mutual interest in technology development. The RDC has used these agreements in support of portfolio execution for many years. Examples include the development of diesel outboard motors, autonomous control systems, and the use of biodiesel fuel. A notable example of the impact of a CRADA partnership was an effort to support search and rescue operations by improving the accuracy and speed at which cellular

The Coast Guard Research and Development Center and U.S. Coast Guard Academy partnership on CubeSat experiments was wide-ranging involving RDC Researchers, CGA faculty and cadets. As part of a collaborative effort, an 18-foot diameter fiberglass geodesic dome, or radome, and satellite ground station were established on the academy grounds in 2018 to support the tracking of two CubeSats after they were launched. Coast Guard photo

phones can be geolocated.

The Callyo 2009 Corporation and the RDC worked together to customize features of Callyo's i911 software to optimize use by watchstanders in Coast Guard command centers and pilot test it within District 1. The tool enables the Coast Guard to send a distressed mariner a request to receive their cellphone's GPS position, providing an immediate geolocation with single-meter accuracy. The incredible work done through this CRADA enabled a fast transition, and i911 went fully operational in all command centers on March 26, 2020. During the peak of the SAR season that summer, i911 was used an average of 22 times a day across the Coast Guard.

Conclusion

With a small staff and a massive mission to support all 11 of the service's statutory missions, our scientists accomplish their work through technical expertise, out-of-the box thinking, and close collaborations with partners.

Sports are a common analogy for all kinds of teamwork. In many ways, the RDC has taken a page from fictional soccer coach Ted Lasso, who underscored, in his three-year tenure at AFC Richmond, the power of collaboration, partnerships, optimism, and shared values. The power of partnerships is a real force multiplier. It can take a good idea and make it a great one. It can inspire collaborators to think about the what-if factor.

As coach Lasso is fond of saying, "You say impossible, but all I hear is 'I'm possible.'"

About the author:

Joe DiRenzo, Ph.D., is the director of research partnerships at the Coast Guard Research and Development Center. He is a career cutterman, has held cutter command, and has been a division chief at Atlantic Area. The five-time winner of the Coast Guard's Chief Journalist Alex Haley Award is a graduate of both the Marine Corps University and Naval War College.

Successful Partnerships Thrive on Effective Communication

by Bruce Buckley
Commander
Research and Development Center Auxiliary Unit
U.S. Coast Guard

For 50 years, the U.S. Coast Guard Research and Development Center (RDC) has developed technology and knowledge products which significantly enhance the Coast Guard's ability to reduce the risk and raise the value of introducing new technologies into the service. This is achieved by evaluating how the RDC can be effectively applied in the execution of the Coast Guard's 11 statutory missions. Continuous improvement and impactful, deliberate peer-reviewed research with the capability to transition have been key to the RDC's ongoing success.

To address an ever-expanding list of research efforts, the RDC knew it had to increase its research capacity. The command was not growing, so the RDC implemented closer collaboration with private and public organizations as "force multipliers." Perhaps one of the most successful collaborations is with the Coast Guard Auxiliary, which has become a trusted partner and is, indeed, a force multiplier.

The 21,000-member Auxiliary is a national, all-volunteer Coast Guard organization. A part of the service since 1939, the Auxiliary's core support mission has not changed significantly over the years, though how it supports the service has evolved to remain productive, relevant, and in alignment with the active component.

Beginning in 2016, local Auxiliary personnel participated in shoreside test observations, with their various vessels serving as test observation platforms on the water. Two years later, Auxiliary members were invited to attend the three-day Annual Assessment of Prospective Portfolio event. This is the primary working meeting where stakeholders and subject matter experts from the Coast Guard and other Department of Homeland Security agencies, the National Oceanic and Atmospheric Agency, and the Department of Defense evaluate the value of proposed projects for the coming fiscal year.

As the RDC-Auxiliary relationship grew, the need for sustainable national support became apparent. In 2019, the Auxiliary's First Southern District Commodore, William Bowen, coordinated with the RDC's commanding officer, then-CAPT Greg Rothrock, and First Coast Guard District Commander then-VADM Thomas G. Allan Jr. to create an Auxiliary Unit Coordinator (AUC) to manage the relationship. The position is defined in the Auxiliary Manual as follows:

> *The primary purpose of an AUC shall be to facilitate the timely provision of high-quality administrative and operational support by the Auxiliary to the associated Coast Guard unit. The AUC shall work closely with the Coast Guard unit to develop and maintain the necessary relationships to deliver such service.*

This RDC Auxiliary Unit was the first virtual unit created. It now serves as a virtual organization that continues to leverage members' special skills and talents nationally, performing at an exceptionally high level supporting eight to 10 portfolio projects a year.

A testament to this very successful collaboration, the Commodore Viggo C. Bertelsen Jr. and Vice Admiral John P. Currier Auxiliary Integration Award presented by the Commandant of the U.S. Coast Guard in 2023, reads:

> *For exceptionally demonstrating applied innovation, creativity and diversity in leveraging U.S. Coast Guard Auxiliary skills, experience and resources that enabled the Research and Development Center to efficiently and effectively perform its mission from January 2022 to December 2022. By collaborating with the Auxiliary support team to employ new ideas to develop and implement practices and tools that enhanced and improved readiness, preparedness, and mission execution. Foster a culture of continuous innovation and learning. Increased the potential for rapidly generating ideas to solve challenges. Discovered new solutions to challenges, through encouraging, recognizing and rewarding innovative ideas. And improved unit/office morale and esprit-de-corps.*

Since then, the RDC Auxiliary Unit has become a valuable resource for the organization, supporting its complex and varied research needs, which range from

The U.S. Coast Guard Auxiliary supports the Coast Guard Research and Development Center's in-situ burn experiments at Little Sand Island in Mobile, Alabama, by using drones to capture emissions data. Coast Guard photo

fixing a computer-based watering system for hydroponic gardening technology aboard the CGC *Polar Star* to providing videography and editing services for a video showcasing oil spill response research at the Joint Maritime Test Facility in Mobile, Alabama. The auxiliarist documented the experimental design and setup process, safety processes, execution, oil residue collection and analysis, and cleanup, interviewing technical experts, senior RDC personnel, and Great Lakes-area stakeholders to create a robust record of the work.

Perhaps the most significant collaboration between the RDC Auxiliary Unit and the RDC was the development of a computer application to streamline the process of verifying and reporting on private aids to navigation (PATON). The Coast Guard administers 41,000 PATON nationwide, and that number is expected to increase as the Marine Transportation System continues to evolve. PATON use has expanded to include restricting space launch zones and marking offshore wind turbines.

Consequently, auxiliarists in South Florida developed and implemented a new PATON inspection and verification application in their district, the Aid Verification Assistant (AVA). AVA is a mobile app created by a District 7 Auxiliary member to streamline the collection of private aid to navigation information. The app simplifies a formerly complex process, previously managed with handwritten notes or Excel spreadsheets, into an intuitive, user-friendly series of tasks. In short, the application automates multiple steps in the reporting process and eliminates paper documentation.

The use of new tools like AVA and a streamlined PATON reporting process will allow Coast Guard and Auxiliary users to more efficiently use limited resources to address current and future waterways demands and challenges. The RDC project report, part of the AVA development program, also summarizes findings on current reporting processes used nationwide and overall improvements the Coast Guard could make to further modernize the PATON mission. This PATON inspection application project marks the first start-to-finish collaboration between the Auxiliary and the RDC to develop and roll out new state of the art technology.

In each of these cases, the Auxiliary has provided specialized skills and experience that have enhanced the RDC's research and mission execution. RDC Commanding Officer CAPT Michael Chien has praised the impact of the Auxiliary on Coast Guard research, noting that "the words 'force multiplier' do not even begin to convey what the Auxiliary has done for the RDC. We're beyond grateful to them and their amazing skill sets which we use in every single one of our branches."

The impact of the Auxiliary on the RDC's work can be measured in many ways. However, the greatest testament to this collaboration's success is the national-level Commodore Viggo C. Bertelsen Jr. and Vice Admiral John P. Currier Auxiliary Integration Award.

The close bond between the RDC and the Auxiliary is a testament to the importance of effective communication in successful partnerships. As Coast Guard Commandant ADM Linda L. Fagan said, "Tomorrow looks different. So will we."

The RDC-Auxiliary partnership is a shining example of the power of collaboration that will ensure the Coast Guard remains ready, relevant, and responsive in a dynamic and ever-changing world.

About the author:

Auxiliarist Bruce Buckley is a 20-year member of the Coast Guard Auxiliary and is currently serving in the role as the RDC Auxiliary unit coordinator. He has held numerous workforce qualifications as well as appointed and elected positions of leadership, including national leadership training instructor, boat crew, vessel examiner, public affairs officer, and aids to navigation verifier.

The Navy-Coast Guard Research Partnership

The Naval Postgraduate School perspective

by Retired Marine Corps Col. Randy Pugh
Vice Provost for Warfare Studies
Naval Postgraduate School

In 1907, President Theodore Roosevelt ordered two squadrons consisting of 16 battleships and numerous smaller vessels on a deployment around the world. This two-year cruise was a deliberate way to demonstrate the U.S. Navy's technical superiority as well as its ability to conduct prolonged blue-water operations. It was a display of power and agility that would serve as deterrence to the potential aspiration of rising powers. Upon the conclusion of the Great White Fleet's circumnavigation of the globe, one obvious lesson learned was that technologically advanced ships and sophisticated combat systems were going to need highly educated officers to effectively employ and maintain them.

In 1909, the Navy established a graduate school of marine engineering at the U.S. Naval Academy with the mission of training officers in the rapidly evolving fields of ordnance and gunnery, electrical engineering, radio telegraphy, and naval construction. These officers, armed with superior knowledge and skills, would prove critical to sustaining maritime dominance in the decades that followed, a time of rapid technological advancements in platforms and weapons systems.[1]

As technology has evolved, the school has changed its name from the School of Marine Engineering to the Naval Postgraduate School (NPS) and has relocated to Monterey, California. However, it still maintains its core mission to meet unique naval needs in graduate education. Considering the current assertions of a revisionist Chinese Communist Party, its illegal, coercive, aggressive, and deceptive activities in the South China Sea, and the People's Liberation Army Navy's rapid development of advanced capabilities and capacity, NPS's contribution to the Navy's mission and the nation has never been more critical.

Since NPS's founding, the world's economies have grown increasingly interconnected and interdependent, and the Navy's role has expanded to providing global maritime security in partnership with allied nations. In response, NPS has found it necessary to constantly evolve. Its partnerships with other federal agencies, the militaries of partner and allied countries, academia, private industry, and think tanks have been large contributors to the school's evolution and its continual effectiveness. One relationship that has proved especially impactful is an ongoing seven-year engagement with the U.S. Coast Guard Research and Development Center (RDC).

The relationship between the Coast Guard and NPS is not new. Coast Guard officers have attended NPS throughout the school's history with more than 75 earning master's degrees in the past decade. The commonality between the Coast Guard's and the Navy's missions, operating environments, platforms, and systems naturally make many of the academic programs NPS executes on behalf of the Navy also highly relevant to Coast Guard students. This general applicability and benefit to individual Coast Guard officers became an increasing priority for NPS following the publication of the Tri-Service Maritime Strategy in 2020.

Accordingly, in 2021, NPS and the RDC renewed and expanded the NPS-Coast Guard RDC Memorandum of Understanding (MOU) originally signed in 2018. The MOU appointed Dr. Joe DiRenzo of the RDC as its liaison officer to NPS and he began an aggressive pursuit of key objectives of the joint cooperation. These initiatives included:

- Jointly submitting research proposals with NPS and RDC co-investigators
- Sharing access to and use of unique laboratories, facilities, and other assets
- Sharing of publications of studies, evaluations, and lessons learned
- Joint participation in conferences, symposia, courses, workshops, exhibitions, and other meetings of mutual benefit, and exchanging technical data and information[2]

"Since an MOU was signed three years ago, the RDC has become a topic sponsor," CAPT Daniel Keane,

then-commander of the RDC, said at the MOU re-signing. "We have proposed questions related to our portfolio that have turned into academic products, NPS researchers have worked with our researchers on summer studies, and we have provided platforms for NPS experimentation. We believe that we have just scratched the surface and the future is incredibly bright."[3]

The Coast Guard and NPS increasingly see each other as critical partners in the development of 21st century warfighter and warfighting capabilities and both organizations are working to cultivate greater synergy through organizational alignment and collaboration. Increased awareness of the Coast Guard's missions, capabilities, limitations, emerging operational concepts, knowledge and skills requirements, and research needs has provided NPS's faculty the ability to tailor its academic courses to account for the new model of "integrated all-domain naval power."[4] It has also provided the students and faculty with the insights they need to conduct highly relevant applied research.

The RDC's awareness of, and input into, NPS's educational and research activities has enabled the RDC to benefit from "dual use" of Navy-centric work that is also aligned with the priorities of the Coast Guard and NPS. Additionally, the Navy has been able to leverage the Coast Guard's extensive knowledge of increasingly complex issues below the threshold of war—illegal, coercive, aggressive, and deceptive maritime operations by the People's Republic of China in the South China Sea, for example. The goal is to continue this work towards enhanced education and research for greater impact and contribution to maritime advantage.

At the deck plate level, collaboration between NPS and the Coast Guard is intentionally aligned with NPS's enduring priorities in education, research, and innovation.

Learning is the center of gravity for the NPS-Coast Guard partnership and that begins with shared awareness. Matching NPS academic offerings, and the skills they develop, to the RDC portfolio was an important first step. This was immediately complemented through NPS leadership visits with the New London, Connecticut-based RDC. As awareness of RDC priorities grew into integration of efforts, NPS was granted voting member status for the Annual Assessment of Prospective Portfolio. This allows senior individuals from other agencies to join with Coast Guard flag and senior executive service members to evaluate the Coast Guard's proposed research for the following year. This event now allows NPS representatives to hear about other agencies' research and identify NPS work that might be natural collaboration connections. NPS leaders also engage with RDC's scientists to develop professional connections in critical shared areas of interest such as space, weather extremes, artificial intelligence, and autonomy.

Three years ago, the RDC initiated a mission familiarization event for NPS with Coast Guard Pacific Area, District 11, Maritime Intelligence Fusion Center Pacific, and Sector San Francisco that provides intense, two-day

Current and retired flag and general officers from the U.S. Coast Guard, Navy, and Marine Corps discuss maritime security issues during a panel at the Maritime Risk Symposium held in June 2024 at the Naval Postgraduate School in Monterey, California. The event was co-sponsored by the U.S. Coast Guard and National Academy of Sciences Transportation Research Board. Navy photo by Petty Officer 2nd Class James Norket

unit visits. All NPS leadership, along with faculty members from several disciplines, have participated in these visits. The benefit to both organizations has been significant. NPS faculty members see operational issues and possible gaps that academia can address, while Coast Guard members can talk with experts on acoustics, oceanography, autonomy, and computer science. These visits have resulted in NPS faculty inviting RDC participation in experimentation and to exercises at NPS' quarterly Joint Interagency Field Experimentation events at Camp Roberts, California. NPS also now ensures the RDC has full visibility of the 60 to 80 studies commissioned each year by the deputy chief of Naval Operations for Warfighter and Warfighting Development via the Naval Research Program.

This spirit of cooperation and inclusiveness has permeated throughout both organizations through engagements like the RDC-led 2023 Polar Research Technology Experimentation. During this engagement, an NPS researcher deployed aboard the CGC *Healy* to conduct crew endurance studies and other applied research projects in the operating environment north of the Arctic Circle. The Coast Guard has co-sponsored seven student thesis topics derived directly from the RDC portfolio. Two of these were applicable to uncrewed aerial vehicles and spill response planning. Others supported an RDC effort called Bear Trap to use research and knowledge products to address illegal smuggling in the southwestern maritime border.

In every case, the RDC has ensured a Navy co-sponsor is willing to support the research. All parties work together to craft a thesis question that will answer individual service questions but will also benefit the maritime services. To seed this effort, each year the RDC's technical director provides NPS's vice provost of research with 10 to 15 questions for student and faculty consideration.

Conclusion

America is at a critical point in its history. The rise of the People's Republic of China, its rapid buildup of offensive naval capabilities and capacity, and its disregard for international law and global norms, especially in the maritime realm, compel a response. Given the size and complexity of this challenge, the Navy, Marine Corps, and Coast Guard must integrate their capabilities in ways not previously imagined and the NPS-RDC partnership is critical to strengthening collaborative efforts across the services. This relationship enables NPS to fulfill its mission and help realize the Tri-Service Maritime Strategy's vision of an all-domain integrated maritime force that can provide the nation with the forward-deployed, fully integrated, all-domain naval power America needs.

About the author:

Retired Marine Corps Col. Randy Pugh is the Naval Postgraduate School's vice provost for warfare studies and the director of the Naval Warfare Studies Institute. He is one of the school's liaisons to the Coast Guard Research and Development Center. He served in the Marine Corps for 34 years, first as an enlisted combat engineer, then as a signals intelligence, electronic warfare, and intelligence officer.

Endnotes:

1. https://library.nps.edu/nps-history
2. NPS (2018) MOU Signing
3. https://nps.edu/-/nps-u.s.-coast-guard-r-d-center-to-jointly-research-maritime-solutions
4. Tri-Service Maritime Strategy

Maritime Risk Symposium

NPS and the RDC achieved a new milestone in coordination in 2024 when they co-hosted the Maritime Risk Symposium. This seminal event, co-sponsored by the Coast Guard and the National Academies of Sciences, Engineering, and Medicine's Transportation Research Board, focused on deterring and defeating adversaries' illegal, coercive, aggressive, and deceptive activities, often called "gray zone" operations. The event drew more than 200 participants, including four active-duty flag officers from the Coast Guard, Navy, and National Oceanic and Atmospheric Administration.

What is the DoD Lab Commander's Sync?

by Joe DiRenzo, Ph.D.
Sync Action Officer
U.S. Coast Guard

Derhun Sanders
Sync Action Officer
U.S. Army

Phyllis Pennington
Sync Action Officer
U.S. Air Force

Retired Marine Corps Maj. Miquel Becerril
Sync Action Officer
U.S. Navy and Marine Corps

Jointness is not automatic, and it is perishable.
It must be advanced through continual joint force development efforts.

—Joint Publication 1, Doctrine for the Armed Forces of the United States

Joint Publication 1 (JP-1) is the capstone document for the armed forces of the United States and provides fundamental principles and overarching guidance for the Army, Navy, Coast Guard, Air Force, Space Force, and Marine Corps. The Department of Defense (DoD) Laboratory Commander Sync exemplifies this joint team. The Lab Sync brings commanders of the Army Development Command, the Office of Naval Research, the Air Force Research Lab, and the Coast Guard Research and Development Center together regularly to address research issues of joint interest.

On November 19, 2019, commanders and senior leaders from the Office of Naval Research (ONR), Air Force Research Laboratory, Army Combat Capabilities Development Command, and the Coast Guard Research and Development Center (RDC) signed a memorandum of understanding (MOU). This memorandum works to enhance collaboration on science and technology (S&T) programs. This was an important step for the Coast Guard as it formalized the service's relationship with the National Security Research Enterprise.

RDML Greg Rothrock, then a captain and the RDC's commanding officer, said, "We get the opportunity to collaborate with a world-class military lab that shares a lot of common interest areas with us, and it helps both of our services explore and adopt technology, hopefully, faster."

The MOU facilitates sharing S&T and research and development (R&D) data, including contracts, to increase collaboration, reduce redundancies, and improve the armed forces' S&T and R&D portfolios. Since the initial sync, the group has benefitted from access to subject matter experts and tackled issues like talent recruitment, management, and retention, as well as data, experimentation, and parts provided by other services. For example, the Coast Guard's counter-uncrewed aerial vehicle system was developed through cooperation with other DoD Lab Sync members.

Dr. Eric Moore, deputy to the commanding general of U.S. Army Combat Capabilities Development Command (DEVCOM) added:

> *The U.S. Army and DEVCOM values its collaboration with the Coast Guard because it brings together our unique capabilities and perspectives to solve complex challenges. Working with the Coast Guard allows us to leverage their expertise in maritime operations while they benefit from our advancements in land and aerial technologies. This partnership not only strengthens our respective missions but also enhances the overall readiness and effectiveness of the joint force. By combining our efforts, we ensure that both services remain at the cutting edge of technological innovation, which is essential for maintaining national security.*

Technological advancements are crucial for maintaining a competitive edge in modern warfare. Collaboration allows each lab to leverage the strengths of their counterparts, ensuring rapid progress and innovation.

"This is a great example of how ONR partners with our fellow services to ensure we develop capabilities to support the joint fight," said Navy RADM Kurt Rothenhaus, the chief of naval research.

The sync has underscored that technological advancements are crucial in maintaining a competitive edge in modern warfare. Therefore, the ability to quickly progress and innovate in this area is vital for the success of each military service. Collaboration allows each lab to leverage the strengths of their counterparts and build upon existing innovations, rather than starting from scratch, accelerating progress and ensuring they remain at the forefront of technological advancements. The RDC has been able to link elements of its approved national portfolio with work that is ongoing at the Navy, Army, Space Force, and Air Force laboratories.

Quarterly Lab Sync meetings bring commanders of the Army Development Command, the Office of Naval Research, the Air Force Research Lab, and the Coast Guard Research and Development Center together to collaborate on opportunities that benefit the National Security Enterprise. Coast Guard photo

Secondly, personnel retention is a critical issue in the military, and the ability to attract and retain top talent is essential for success. Collaboration and a supportive working environment can greatly improve staff morale, job satisfaction, and retention. By working together and leveraging each other's strengths, labs can create a more productive and fulfilling work environment, leading to a more stable and effective workforce.

Lastly, collaboration fosters a more connected and unified military community. By actively working together and sharing resources, each individual lab is strengthened along with the broader military community. This collaborative approach leads to greater coordination, faster progress, and greater success for all involved. This was demonstrated last September with the RDC's OPS Demo Coqui which flexed elements of autonomy in the Puerto Rico area of responsibility. For example, the Army Research Laboratory provided acoustic sensors for the demo and the Air Force Research Lab offered a command-and-control system.

"The Lab Commanders Sync is a powerful forum where we break down service barriers to accelerate high-impact S&T to the joint force," said Air Force Brig. Gen. Jason Bartolomei, commander of the Air Force Research Laboratory and the newest commander to the sync. "I am looking forward to working with our joint partners to remove blockers and find solutions to our biggest technical challenges."

With any collaboration, the importance of contact cannot be underestimated. So, how often do the commanders and their deputy/executive directors meet? The answer is every three months.

The quarterly formal leader meetings are divided between live and hybrid. The action officers work with their parent commands to tee up agenda items and the meetings support engagement through detailed planning efforts. Actively pursuing collaborative opportunities is essential for both the individual military service senior leaders and the future of the National Security Enterprise. It helps maintain a competitive edge over potential threats, improves personnel retention, creates a more connected and unified military community, and ultimately enhances overall national security in the long term.

Heading into the next year, the DoD Lab Sync will continue to cultivate transparency, collaboration, and opportunities for all the members of the armed services and their research capabilities. The American taxpayer is the big winner here as commands and services can share efforts and enhance effectiveness and efficiency. A model for collaboration, the DoD Lab Sync will get more important over time.

About the authors:

Joe DiRenzo, Ph.D., is the Coast Guard liaison to the DoD Lab Sync. He is a career cutterman, has held cutter command, and has been a division chief at Atlantic Area. The five-time winner of the Coast Guard's Chief Journalist Alex Haley Award is a graduate of both the Marine Corps University and Naval War College.

Phyllis Pennington is the Air Force action officer to the Department of Defense Laboratory Commanders Sync.

Derhun Sanders, a Michigan Technological University (MTU) graduate, is the chief of domestic partnerships for the U.S. Army Combat Capabilities and Development Command. With extensive experience in defense technology, strategic planning, and budget management, he is a key leader in the defense industry. He also serves as a board of trustees member at MTU and is the Army action officer to the Department of Defense Laboratory Commander's Sync.

Miguel Becerril served for 20-plus years in the Navy and Marine Corps. A 1978 graduate of the U.S. Naval Academy, he served in the Puerto Rico Federal Affairs Administration and in the governor of Puerto Rico's Washington, D.C., office, as director of federal programs. He serves as a senior program manager with the Office of Naval Research and is the Navy action officer to the Department of Defense Laboratory Commander's Sync.

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Preparing the Fleet for the Future of Uncrewed Systems

by Derek Meier
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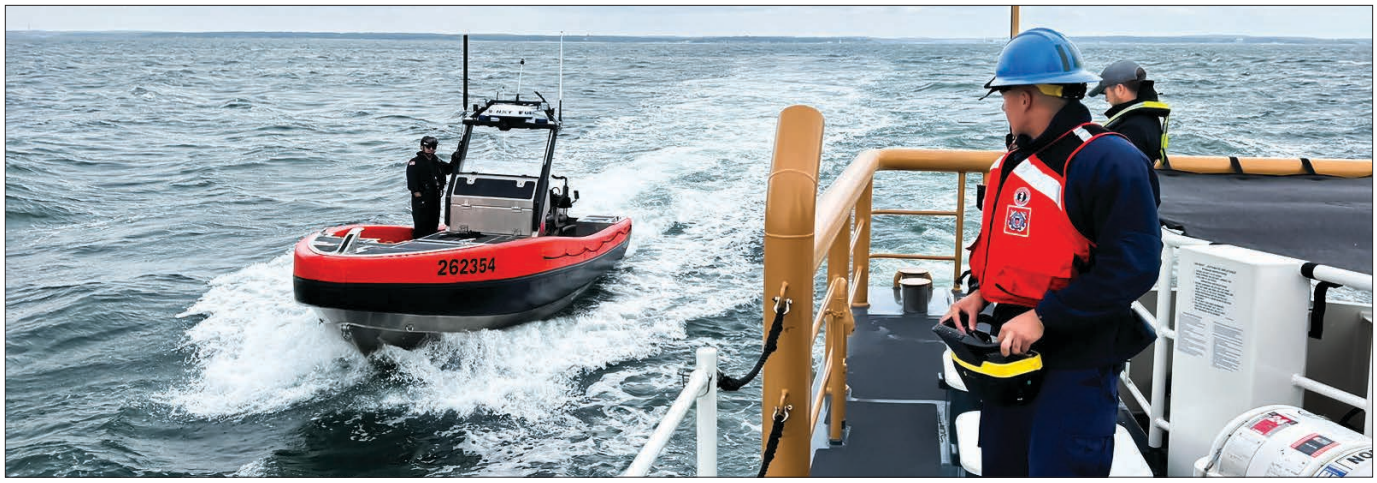
As uncrewed systems (UxS) continue to enhance the efficiency and effectiveness of both commercial and defense operations, the Coast Guard is poised to expand its own capabilities. UxS, which include air, surface, and subsurface vehicles that operate without a human onboard, have demonstrated significant potential in expanding mission reach and improving operational safety. However, current UxS integration within the Coast Guard is limited. Beyond the remotely operated vehicles used for subsurface inspection, the national security cutter (NSC) remains the sole cutter class in the fleet to be situationally equipped with operational UxS systems. Recognizing the necessity of broader UxS deployment, the Coast Guard's 2023 Unmanned Systems Strategic Plan set forth an ambitious goal of exploring the feasibility of deploying UxS on cutters beyond the NSC.[1]

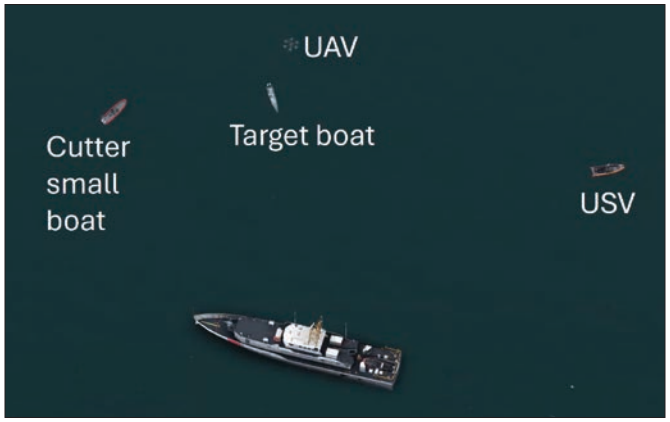
In pursuit of these objectives, the Coast Guard Research and Development Center (RDC) initiated the Cutter-Based Uncrewed Systems Integration Analysis research project. This project focuses on determining whether other cutter classes—particularly buoy tenders and fast response cutters—can support the size, weight, and power requirements necessary for UxS integration. Given that these vessels were not originally designed with UxS in mind, this research is critical to understanding how these systems can be effectively incorporated into the Coast Guard's unique operational environment. By examining the possibilities for UxS deployment on these unconventional platforms, the RDC aims to inform the Coast Guard's strategy and guide the future of UxS integration across the fleet.

Understanding the Autonomy Landscape

The first step in advancing the Coast Guard's capabilities with UxS was to conduct a thorough analysis of the current technological landscape. This involved acquiring and reviewing data from the Association for Uncrewed Vehicle Systems International, which provided comprehensive insights into a wide range of maritime and aerial UxS technologies. The data collected from this resource was then imported into a digital dashboard, allowing for an interactive examination of key characteristics such as size, weight, energy source, endurance, and operational capabilities. This analysis was instrumental in identifying the potential fit of various UxS technologies within the Coast Guard's fleet, particularly for platforms like fast response cutters, coastal buoy tenders, and seagoing buoy tenders. By systematically reviewing the



A crewmember from the CGC *Razorbill* operates the *26RDC* remotely. Coast Guard photo by LT j.g. Jorge Wismar



SCANTS simulations, like the one above, were critical to understanding the possibilities and limitations of UxS. Coast Guard photo by James Hines

operational and logistical constraints of these cutters—supported by ship drawings, information manuals, and site visits—we could establish a clearer understanding of the possibilities and limitations for UxS integration.

To further ground our analysis in practical applications, we coordinated directly with the U.S. Coast Guard Academy's Ship Control and Navigation Training System (SCANTS) team. The SCANTS simulations were developed to model UxS and cutter teaming in operational missions, such as identifying and intercepting targets of interest, conducting aids to navigation (ATON) verification, and responding to environmental incidents. These simulations were vital in translating theoretical concepts into actionable scenarios, providing a foundation for the workshops and discussions that would follow.

Rather than focusing on selecting a single system for acquisition, our goal was to map out the operational constraints and opportunities for UxS integration. By applying rigorous criteria, like minimum endurance thresholds and specific power requirements, we refined our understanding of where current UxS technologies align with the Coast Guard's needs and identified areas where further research or development may be necessary.

Bridging Theory and Practice

Building on the initial analysis of the technological landscape, the project advanced to a more hands-on approach, focusing on validating findings through direct engagement with Coast Guard personnel and testing the practicalities of UxS integration in real-world scenarios.

To achieve this, we conducted a series of workshops with key stakeholders, including crews from fast response cutters in Boston and buoy tenders in Newport, Rhode Island. These workshops were meticulously planned, incorporating insights from the SCANTS simulations developed earlier in the project. The simulations, which modeled potential UxS/cutter teaming scenarios, provided a critical foundation for the discussions, allowing participants to visualize how UxS could be operationalized within their specific mission sets.

During these workshops, we engaged in detailed discussions about the practicalities of UxS integration, including storage, energy requirements, and the physical constraints of the cutters. The scenarios, like using UxS for autonomous passenger transfers to and from cutters, supply transport, and ATON verification, were used to explore the feasibility of various operational concepts. These discussions also highlighted significant challenges, particularly regarding crew training, asset maintenance, and the operational impact of introducing UxS into existing workflows.

The insights gained from these workshops were invaluable in refining our approach to UxS integration. The hands-on demonstrations and scenario-based discussions helped identify key areas where further development is needed, such as the need for specialized training programs and adjustments to current safety procedures. Additionally, these interactions underscored the importance of having UxS-certified personnel available during operations, as well as the logistical considerations of launching and recovering UxS under various environmental conditions.

Field Testing UxS Capabilities

After comprehensive analysis and stakeholder engagement, the next crucial step was to test the feasibility of UxS integration through real-world trials and operational demonstrations. The Coast Guard faced the challenge of selecting suitable uncrewed systems for testing without narrowing the focus to a single asset prematurely. To address this, the project leveraged existing assets, including both uncrewed surface vehicles (USVs) and uncrewed aerial systems (UAS), to conduct a series

Researchers install a custom mast and forward-looking infrared technology on the *26RDC* in March 2024. Coast Guard photo by Evan Gross

of integrated trials.

Previously, the RDC decided to retrofit existing small boats—specifically, the 26-foot over the horizon cutter boat Mark V *(26RDC)* and the 29-foot response boat-small II with Sea Machines autonomy packages. These retrofitted boats provided a versatile platform for testing various UxS capabilities and concepts of operation. Additionally, the RDC's existing UAS program provided key findings with its AeroVironment Puma LE, a lightweight, hand-launched fixed-wing drone, that was leveraged to enhance testing.

These autonomous small boats were designed to be optionally uncrewed, allowing them to operate both as traditional manned vessels and as uncrewed systems. This dual capability was crucial for testing the flexibility and adaptability of UxS in Coast Guard operations. The remote helm, a belt-pack controller that allows for line-of-sight operation, enabled operators to control the small boats without being onboard. Additionally, the Sea Machines interface on a laptop provided more advanced control options, including waypoint navigation and collision avoidance.

Through a series of trials, the project team evaluated key operational scenarios, such as bringing the small boat alongside a cutter underway. Prior experience with driving small boats quickly proved to be a significant factor in mastering the remote helm, with qualified operators able to effectively maneuver the boat after minimal training. These trials also explored practical solutions for line handling and securing the small boat alongside the cutter, ultimately developing techniques like conducting supply transfers by using boat hooks to grab payloads.

The integration of these systems with the cutter's operational workflow was further refined through the use of the Sea Machines interface, which allowed for seamless transitions between autonomous missions and manual control. This setup was critical in testing scenarios such as autonomous refueling, supply transfer, and ATON verification—demonstrating that UxS could significantly enhance operational efficiency while maintaining safety and reliability.

As the testing continued, focus shifted to pushing the limits of the boats' operational capacities. Enhancements including forward-looking infrared technology, networked radars, and advanced domain awareness cameras were integrated to increase maritime domain awareness. By networking all data through wireless mesh network radios and leveraging Starlink, a satellite-based internet service for improved global connectivity, the project aimed to maximize the effectiveness of both surface and aerial uncrewed systems in Coast Guard operations. As part of this networking effort, the AeroVironment Puma LE UAS was able to send cursor-on-target data to the autonomous systems, directing the boats toward a target of interest with precision, demonstrating the potential for coordinated UxS operations in complex mission environments.

Realizing the Vision: UxS in Coast Guard Operations

The exploration of uncrewed systems within the Coast Guard has revealed significant potential for these technologies to enhance mission effectiveness and operational efficiency across the fleet. The successful testing and integration of UxS with smaller cutter classes, like buoy tenders and fast response cutters, underscore the adaptability and versatility of these systems in real-world scenarios.

However, realizing the full potential of UxS within the Coast Guard will require continued effort and investment. The findings of this project highlight not only the operational benefits of UxS, but also the challenges that must be addressed to fully integrate these systems into the fleet. Issues such as crew training, maintenance, and the physical and logistical constraints of smaller vessels remain critical considerations.

Moreover, the Coast Guard must continue to refine its strategy, ensuring that future UxS technologies align with the unique demands of its missions. The research conducted up to this point offers foundational understanding of these requirements, but the journey toward widespread UxS adoption is far from complete. Continued innovation, rigorous testing, and strategic planning will be essential to achieving the vision of a fleet where UxS are an integral part of operations.

Looking forward, it is clear uncrewed systems have the potential to transform the way the Coast Guard conducts its missions. By building on the insights gained from this project and addressing the identified challenges, the Coast Guard can chart a course toward a future where UxS not only augment but also redefine its capabilities.

About the authors:

Derek Meier is a project manager within the Surface Branch of the Coast Guard Research and Development Center, primarily working on autonomous surface vessel technologies. He holds a degree in mechanical engineering from the University of Connecticut. After starting his career in submarine construction, he later transitioned to the Research and Development Center, where he has served for more than five years.

LT j.g. Jorge Wismar, a 2021 graduate of the U.S. Coast Guard Academy, earned a bachelor's degree in operations research and computer analysis and serves as a project manager and military advisor in the Surface Branch of the Coast Guard Research and Development Center, specializing in the integration and operational testing of uncrewed systems.

Endnotes:

1. United States Coast Guard, Unmanned Systems Strategic Plan March 2023, https://www.dco.uscg.mil/Portals/9/DCO%20Documents/2023%20Unmanned%20Systems%20Strategic%20Plan.pdf

Unlocking Technology Potential

Uncrewed aircraft systems beyond visual line of sight

by Stephen C. Dunn
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Imagine you are the commanding officer of a Coast Guard patrol vessel operating somewhere at sea, there is no land in sight, and you are reliant on the limited information you have regarding the whereabouts of "targets of interest." You have an excellent crew, a radar, and binoculars. Beyond those tools, you might rely on a patrol aircraft in the area. What if you had a tool that could expand your ability to see beyond the reach of these onboard tools?

Therein lies the promise of uncrewed systems. Whether airborne, surface, or underwater, these systems give crews the ability to see beyond the horizon and potentially provide a substantial increase in maritime domain awareness.

Why the Need to Fly Beyond Visual Line of Sight?

One of the keys for unlocking the full potential of uncrewed aircraft systems (UAS) to support Coast Guard mission sets is the ability to operate beyond visual line of sight (BVLOS). If the UAS flies within line of site, there is not much improvement over using current tools. By using the UAS, the cutter's commanding officer can operate more efficiently, whether by visually confirming a contact or determining if the cutter should proceed to that location.

Additionally, the UAS serves as a tool for Coast Guard cutter decision-makers, helping expedite assessments such as issuing statements of no objection, estimating the number of people or amount of contraband on deck, and determining if crewmembers are armed, all of which contribute to safer boardings.

This new capability also requires UAS to operate continuously for more than three hours, which may create challenges. To enable extended reach beyond line of sight, a directional tracking antenna is required to support longer ranges, as well as onboard detect-and-avoid (DAA) technology that allows operators to segregate airspace to provide persistent surveillance and improved maritime domain awareness.

The DAA Problem Defined

A Coast Guard aviation patrol craft, such as a helicopter, normally has two pilots and an additional crewmember who can make quick decisions when encountering conflicting aircraft in the vicinity. They can judge distance and speed and take corrective actions quickly. A UAS cannot do the same without an added tool. This is where DAA comes into play. It is paramount to incorporate technology that cannot only sense other aircraft, but also provide either an unambiguous warning or take autonomous avoidance maneuvers to replicate human capabilities.

The Federal Aviation Administration (FAA) provides examples, but not the specific parameters defining how the UAS can be trusted to make these important safety decisions regarding other aircraft. Individual UAS operators must apply to the FAA and submit comprehensive data on how the DAA technology they plan to implement is incorporated into their operations. Operators may apply for an FAA certificate of waiver or authorization

What is a Statement of No Objection?

Before a boarding can be initiated, a statement from the vessel's country of origin must be obtained declaring it has no objection.

to obtain permission to operate within a strictly defined airspace.

Many operators rely on the ASTM International Standard known as ASTM F3442M/F3442- 231 for safety determinations. Formally known as American Society for Testing and Materials, this standard defines the volume of airspace for remaining "well clear" of other aircraft and further defines what constitutes a near midair collision (NMAC).

Well clear is defined by ASTM as being more than 2,000 feet from an object laterally and more than 250 feet vertically. The NMAC boundary is 500 feet laterally and 100 feet vertically. The standard also includes the mathematical formulae for determining risk ratios for loss of well clear and near midair collisions.

BVLOS and DAA background for the Coast Guard

Currently, the only Coast Guard program of record for UAS to operate BVLOS is onboard the national security cutters (NSC) using the Boeing Insitu ScanEagle UAS. The ScanEagle has proven successful for the Coast Guard for several years. However, the system currently relies on an air search radar (ASR) and a qualified radar operator onboard to meet Department of Defense requirements to segregate airspace. When operating outside of 12 nautical miles (nm), the Coast Guard can operate in international airspace under the regulations referred to as "Due Regard."[2] NSC ScanEagle operations within 12 nm of U.S. shores are conducted with approval from the FAA.

The FAA has yet to establish firm rules facilitating full integration of UAS into the National Airspace System. For UAS to support cutter classes without ASR capabilities, such as Coast Guard fast response cutters, and still meet Due Regard requirements, an approved DAA technology is required onboard the UAS.

DAA Technology Types Currently Available

The main challenge with integrating DAA technologies onboard small uncrewed aircraft systems (sUAS) is the size, weight, and power (SWAP) requirements. These aircraft are small with limited power, minimal weight, and less space available for managing the center of gravity for flight operations. There are generally three types of DAA technologies available:

- **Radar:** Typically bulky and heavy for sUAS, it has a limited field of view—120 degrees per array—and a transmitter with a large power draw that creates challenges with command-and-control links, but works well in restricted-visibility conditions like clouds or fog.
- **Visual/Camera-Based:** Current technology only has a daytime camera solution, restricting operational periods, and requires multiple cameras for obtaining a 360-degree field of view. It has a passive, low power draw, but it is challenged in restricted-visibility conditions.
- **Acoustic:** This type has a low power draw, 360-degree field of regard, day or night operation, and works well in restricted-visibility conditions.

After in-depth market research, the RDC program managers selected an acoustic system as the best option to meet DAA standards in 2020 and proceeded with further investigation.

What is Required to Fly BVLOS?

UAS platforms must be selected based on missions. There are many options to choose from, ranging from low-cost quadcopters with relatively short ranges that operate on Li-ion batteries, to long-range platforms with commensurately high purchase and operating costs, such as an MQ-9 Reaper or the MQ-4C Triton.

For an sUAS, the RDC chose AeroVironment Puma platforms which are small, fixed-wing aircraft that can land in water. For flight deck-equipped cutters, a medium UAS, like the L3 Harris FVR-90, would be appropriate. These types typically fly faster and longer than an sUAS but require a larger area to operate from. The RDC chose

An FVR-90, a medium UAS with Passive Acoustic Non-Cooperative Aircraft System acoustic probes installed, is in flight. Coast Guard photo

An AeroVironment Puma LE with a Passive Acoustic Non-Cooperative Aircraft System installed is launched from the CGC *Robert Yered*. Coast Guard photo

this hybrid quad-rotor technology that uses a vertical takeoff and landing capability powered by batteries that transitions to a fuel-powered, fixed-wing design during forward propulsion and delivers excellent endurance. The RDC continues to investigate using both platforms.

When operating a UAS, there is a ground control station that requires a radio frequency (RF) link for command and control (C2). There are numerous RF technologies available that use multiple-input, multiple-output technologies which rely on multiple antennas to transmit data at the same time to improve communication performance.

For land-based operations, a fixed, directional antenna can deliver good range. However, a ship platform at sea will change course many times, often very subtly, with no land masses for the UAS operator to refer to. Therefore, a directional tracking antenna which automatically follows the asset is a must to maintain C2 and not "lose link."

The RDC chose SARA Inc.'s Passive Acoustic Non-Cooperative Aircraft System as the DAA technology to provide situational information about conflicting aircraft. A graphical user interface is necessary to enable the operator to quickly digest this information for an appropriate and rapid response.

According to Technology Service Corporation, its Mobile Tracking System 2.0, an L-band antenna, has the capability to be used in maritime and vehicular environments without RF degradation or attenuation during pitch and rolls. Coast Guard photo

UAS Challenges

Several issues still need to be resolved before DAA and BVLOS technologies are operationalized, including:

The Passive Acoustic Non-Cooperative Aircraft System graphical user interface is displayed during a demonstration. Photo courtesy of SARA. Inc.

- **Integration on the UAS:** The DAA technology requires development on each individual platform. Transitioning from prototype systems that are temporary installations to operationally ready requires significant testing and evaluation before being sent into the field.
- **SWAP penalties:** Small UAS are particularly sensitive to added weight. Just a few ounces can cause a loss in endurance and higher power usage. Even if the additional weight can meet the required weight and balance parameters for the sUAS, any added power burden can drastically restrict its ability to achieve mission requirements.
- **Avoidance:** Another aspect of DAA that the Coast Guard Research and Development Center is investigating is automated avoidance maneuvers. SARA Inc. has developed algorithms within its DAA technology that will automatically sense and avoid aircraft independently, eliminating the need for human intervention, and potentially reducing errors and improving the timely avoidance of conflicting aircraft.

The Future of DAA and BVLOS

While there have been significant advances in technology for UAS and DAA, the regulatory landscape continues to evolve as more use cases are presented and more manufacturers and operators look to employ UAS. The FAA has the task of keeping the skies safe for commercial and civil aircraft while allowing the UAS industry to grow and adapt. It is not an easy balance to strike.

The task for the Coast Guard is somewhat less difficult because of lower air traffic density. However, the service is still required to fully comply with FAA and Due Regard regulations to be stewards of safety in all situations.

As technologies and system capabilities advance, the Coast Guard can look forward to improving its maritime domain awareness by using technology that allows it to operate far beyond its current capabilities.

About the authors:

Stephen Dunn served on active duty in the Coast Guard for more than 30 years with tours of duty at Air Stations Miami and Clearwater, Florida; Aviation Repair Supply Center, Aviation Logistics Center, and Aviation Technical Training Center—all in Elizabeth City, North Carolina—and the Coast Guard Research and Development Center in New London, Connecticut. He has served as a civilian for 10 years with the RDC.

Jay Carey served on active duty in the Coast Guard for 25 years with tours of duty in aeronautical engineering, navigation engineering, and research and development. He has served as a Coast Guard civilian for more than 15 years, all with the Coast Guard Research and Development Center.

Shelly Wyman is a U.S. Coast Guard Academy graduate who served on active duty for nine years. Her tours include incident management and program management, five years as an engineering lecturer at her alma mater, and two years with the Coast Guard Research and Development Center. She holds degrees in civil engineering and is a licensed professional engineer.

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Maritime Domain Awareness On Demand

Sensor-deployment research at the edge

by Evan Gross
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Coast Guard operating environments are marked by vastness, complexity, and ever-changing conditions, presenting unique challenges to operational decision-making. At present, the power of situational awareness data— information that helps people understand and respond to their environment—on operational effectiveness cannot be overstated. The Coast Guard Research and Development Center (RDC) fields a steady demand for technologies that provide a tactical advantage in these dynamic settings.

Research into emerging sensor technologies, deployment strategies, and tactical networking is critical to fully realizing the benefits of actionable maritime domain awareness. Fueled by increasingly low-cost sensing and networking technologies, sensor deployment experimentation is being executed in close proximity to real-world operations. This research activity promises to deliver cost-effective, high-resolution situational awareness tools, enhancing operations across the service's mission set.

The Ubiquity of Low-Cost Sensor Capabilities

Today, multiple Coast Guard research initiatives leverage the widespread availability of low-cost, off-the-shelf sensor technologies, creating an array of deployable data sources. Teamed with tactical networking solutions and edge-processing capabilities, this design concept offers rapid emplacement, limitless customization, and acceptable attrition thresholds. Intelligently linking these sources increases their value further, creating mobile and adaptive sensor networks which can adjust rapidly to the changing needs of the mission. Taking full advantage of edge-computing techniques—the practice of processing data closer to its source, rather than at a central data center—by integrating ruggedized and weatherproof processing units, analysis and interpretation functions can be enabled close to the sensors themselves, reducing latency and optimizing data use.

"Low-cost sensing solutions have significantly lowered the barriers to operational data access," said Derek Meier, a senior engineer at the RDC. "As researchers, we are exploring the impacts of current technology on mission performance, while also attempting to predict how technology deployment by our service and adversaries will shape the future operational landscape."

Novel Approaches to Maritime Sensor Deployment

Along with studying the rapid advancement of technology itself, research teams are also exploring innovative methods for deployment within the maritime environment to address the limitations associated with traditional fixed sensors. From uncrewed aircraft and surface vessels, to buoys which incorporate solar and wind power, a growing number of platforms act as reliable sensor hosts, even in harsh conditions. Despite the rapid advancement of technology in this market, strategic and often layered sensor deployment schemes must be shaped by trials in the field.

"Development of dynamic and adaptive sensor deployment strategies [is] needed to enable rapid response and flexible reconfiguration that keeps pace with evolving needs or threats," said Sean Lester, a technical division branch chief at the RDC. "Uncrewed systems represent a prime vector for flexible sensor deployment, especially when teamed with improved integration of sensors on legacy assets and infrastructure."

Strategic Use of Tactical Networking Technologies

As experimentation evolves into proved concepts and transferable capabilities, additional elements often appear to challenge the full implementation of the research. In the case of next-generation remote sensing, reliable connectivity and ensured data throughput is an ever-present contest. While modern solutions such as Mobile Ad-Hoc Networking, or MANET, Proliferated Low-Earth Orbit, or PLEO, satellite services, and AI-enabled network management are better than ever, a fair amount of ingenuity is still required to deliver critical data from the

operational edge and back again.

The RDC, supported by a multitude of partners, continues to design, configure, and test hybrid satellite/terrestrial communication solutions to convey situational awareness data products. Research in this field centers on resilience, frequently employing layered solutions to maintain continuity, and agility to enable smooth integration with evolving maritime platforms and devices.

"The tools we now have available, particularly what has emerged in the last few years, have opened the floodgates to high-bandwidth transmission from the most remote regions on Earth," Lester said. "But with these solutions comes the challenge of reliability, affordability, and scaling. The data is of such tremendous value, once provided it's hard to operate without it."

Coast Guard research applies analysis and optimization techniques to this technological puzzle with performance and fiscal trade-offs to ensure the most efficient use of resources and maximize the availability of deployed sensor assets.

Coast Guard research into emerging sensor technologies, nontraditional deployment opportunities, and advanced networking is transforming the way we monitor and protect our maritime domain. With the power of data to enhance operational effectiveness and efficiency not fully realized, the lessons of today's experiments will have a direct impact on tomorrow's mission outcomes. The immense potential of a real-time, scalable, and high-resolution situational awareness toolset is likely to transform the art of operational decision-making well into the future. By harnessing advanced technologies and examining performance at the operational edge, the RDC is delivering new tools to face the dynamic maritime environment, secure the maritime domain, and safeguard life at sea.

RDC uncrewed test assets, used in remote-sensing field experimentation, are displayed in New London, Connecticut, in June 2024. Coast Guard photo by Evan Gross

Terrestrial and satellite networking solutions enable remote operation and data transmission from the *26RDC*, an uncrewed surface vessel testbed, in July 2024. Coast Guard photo by Evan Gross

About the author:

Evan Gross currently serves as the Surface Branch chief at the Coast Guard Research and Development Center in New London, Connecticut. He leads a team tasked with the development and execution of research projects that deliver advanced capabilities for Coast Guard afloat operations. Gross graduated from Lehigh University in Bethlehem, Pennsylvania, with a Bachelor of Science degree in materials science engineering in 2006 and also holds a Master of Engineering degree in integrated product development from the Stevens Institute of Technology in Hoboken, New Jersey.

Developing a Lifesaving Device for Mass Rescue Operations

by Monica Cisternelli
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The International Maritime Organization (IMO) defines a mass rescue operation (MRO) as a situation where a large number of people in distress need immediate help and the usual resources and capabilities available to search and rescue (SAR) authorities are inadequate.

A catastrophic passenger vessel emergency in a remote area that requires personnel to leave the vessel with limited or no access to the vessel's lifesaving apparatus is an example of an MRO. Mass rescue response options in offshore scenarios are generally limited to rescue vessels, which can have a response time of hours to days depending on the location, or fixed-wing aircraft, which have limited capabilities to relieve an offshore MRO event.

MROs are considered low-probability, high-consequence events. They are low probability because passenger vessels and aircraft are equipped with redundant safety features which are designed to prevent MRO scenarios. These events are considered high-consequence incidents because they require significant time and effort in advance planning to prevent loss of life.

A mass rescue operation scoping study[1] conducted by the New London, Connecticut-based Coast Guard Research and Development Center (RDC) in 2007 found several types of mass rescue incidents encountered by the Coast Guard, including:

- Cruise ship, ferry, and other vessel sinkings
- Oil rig disasters—explosions, fires, and sinkings
- Cruise ship fires
- Natural disasters—hurricanes, floods, and earthquakes, among others
- Land and air transport incidents requiring marine rescues
- Refugee rescues and interdictions
- Miscellaneous incidents involving marine rescues and evacuations

Incidents involving refugees or migrants can involve hundreds of people on an overloaded or stricken vessel, putting all on board at risk of ending up in the water.

Occasionally, migrant activity closer to shore can also become a mass rescue operation. For example, in August 2022, a large sailing vessel grounded near Key Largo, Florida, with more than 300 Haitian migrants on board. Over one-third of them entered the water without life jackets as they attempted to swim to shore.

Haitian migrants aboard an overloaded vessel are rescued by Coast Guard personnel off North Key Largo, Florida, in August 2022. Coast Guard photo

Toronto Police Department's 75-person mass rescue life raft is stowed in the patrol boat's discharge tube, pictured below, and inflated when it is released into the water. Coast Guard photos

Raft Technology Enhances Rescues

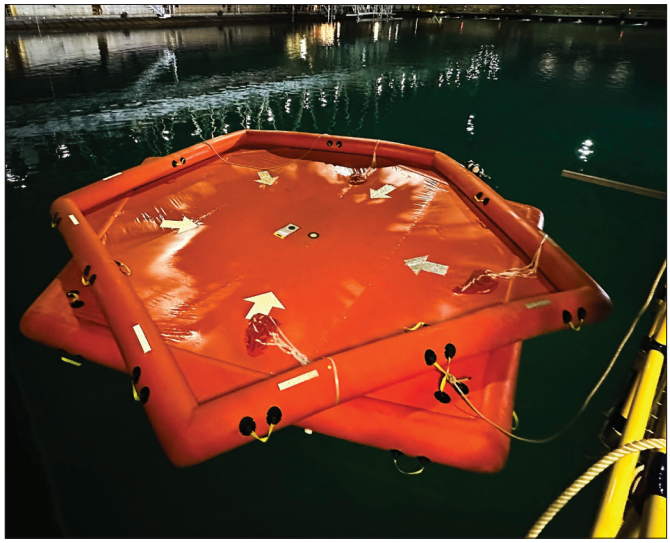
Large-capacity life rafts or inflatable rescue devices have rigid shell containers and can weigh more than 800 pounds, limiting how and where they can be stowed. A market research report developed by the RDC in 2010 looked at different technologies to assist in responding to mass rescue events. For example, the Toronto Police Department took a unique approach by stowing and deploying a 75-person raft from discharge tubes on its 34-foot patrol boat. The mass rescue raft could be used in the event of a passenger aircraft or ferry casualty in Toronto Harbor.[2]

The RDC and DHS Collaborate on a Safety Solution

The RDC has worked with the Coast Guard's Office of Search and Rescue and district passenger vessel safety specialists since 2005. In addition to the previously discussed Mass Rescue Operations Scoping Study, the RDC also explored maritime mass rescue interventions, as well as methods and technologies designed to enhance the safety of mass rescue survivors.

To mitigate loss of life, the RDC researched the feasibility of developing a nonstandard, one-time use, lightweight floating device to augment the Coast Guard's current inventory of life rafts that could be deployed from Coast Guard aircraft or vessels during MROs. The desired device differed from existing off-the-shelf Coast Guard and International Convention for the Safety of Life at Sea-compliant products. It needed to be lighter, more portable, and provide basic functionality.

The RDC worked with the Department of Homeland Security (DHS) Science and Technology Directorate,



On the first day of testing, a life raft prototype is inflated in the Naval Surface Warfare Center's maneuvering and seakeeping basin in Bethesda, Maryland, in April 2024. Coast Guard photo

Proposed Device Characteristics

A Broad Agency Announcement (BAA) is a tool used by government agencies for acquisition of basic and applied research and that is part of development not related to the development of a specific system or hardware procurement. Below are the functional characteristics that the RDC and DHS requested in the BAA for a nonstandard, one-time use, lightweight floating device.

Functional Characteristics for Desired Life-Saving Device	**Threshold** (Minimum Acceptable Value)	**Objective** (Desired Value)
Person capacity (185 pounds per person)	100	150
Total weight of device	150 lbs.	100 lbs.
Functions as a lifesaving device	24 hours	36 hours
Size of packaged system	-	7 cubic feet
Shelf life	5 years	10 years
Maintenance requirements	3 to 5 years	No maintenance

which funded a Broad Agency Announcement (BAA) for design concepts for a lifesaving device. The proposed device should be easily deployable by aircraft or vessels and capable of accommodating at least 100 people for up to 24 hours. The scope of the BAA included a Phase I for design concept, prototype development, and controlled environment testing, and a Phase II option for final design and open-water testing.

Phase I: Prototype Development and Testing

The companies chosen through the BAA were charged with designing and developing a prototype that met the Coast Guard's specific functional requirements. To achieve the goals for size, weight, and capacity, industry innovators proposed alternatives to traditional life rafts. These included floating platforms and mats, the use of lightweight materials like Dyneema, Spectra, and Vectran—which are often used in high-altitude balloons and other lightweight fabric applications—and incorporating compressed air and air aspirators to reduce the overall size and weight of the inflation system. Government-proposed design features also included redundant buoyancy, boarding ramps and ladders, carrying cases for easier portability and stowage, and full reversibility so the device can be used either side up.

Two companies were selected for Phase 1 prototype development and testing at the Naval Surface Warfare Center in Bethesda, Maryland, in April 2024. The purpose of the tests was to observe each device's performance in a controlled environment with and without waves, and to use human subjects to test that the devices' boarding aids operated as intended.

During testing, Coast Guard and DHS observers evaluated each device on its overall packaged size—length, width, height, weight—its ability to hold required weight, and its ability to be boarded and egressed using available boarding aids.

Once inflated, the devices were loaded with about 16,000 pounds to simulate 100 people. Large-volume water bags were used for weights, with each holding between 140 and 200 gallons of water. The government evaluated each device's performance under load, focusing on its ability to maintain shape and pressure. The devices did show some deformation when loaded, including stress on the seams, inflation tubes, and floor.

Human Subject Boarding Exercises

The RDC recruited volunteers to enter the pool and attempt to board the devices, in order to evaluate how easy or difficult it was to board from the water. Twenty-four volunteers from the Coast Guard, DHS, and the Department of Defense participated in boarding exercises, including Coast Guard Auxiliarists, rescue swimmers, and divers. There was a wide range of volunteer ages, fitness levels and experience with life rafts, which resulted in various degrees of boarding success. Volunteers wore clothing ranging from wetsuits and anti-exposure suits to bathing suits and street clothes. They were required to wear life jackets while in the test pool and were not given instructions on how or where to board the vessel and were encouraged to board without assistance from others. Personnel from the project team observed volunteers as they boarded, noting which boarding aids they approached first, if they were successful getting in, how many attempts were made, and if they required assistance from others.

At the end of testing, volunteers were asked a series of questions for feedback on how easy or difficult it was to board and how many attempts boarding took. Most volunteers were able to board on their first attempt, but some reported difficulty and required multiple attempts and assistance from others. Volunteers reported that boarding was easier with waves due to the ramps and grab handles being easier to access, and the ability to time their boarding attempt with the passing crest of a wave. Sixty-eight percent were able to board on the first attempt with no waves and 91% were able to board on the first attempt with waves.

Phase II: Final Design and Open-Water Testing

At the conclusion of testing, Coast Guard and DHS representatives met with the vendors to discuss the results and provide feedback on design changes and improvements. The next phase of this effort will be final design and open water testing with the goal of testing the devices in a simulated open-water search and rescue scenario. This will include observing their performance as people in the water attempt to board under different environmental conditions, as well as during deployment from both a Coast Guard aircraft and vessel.

Conclusion

The results of Phase II will help the Coast Guard determine if these large-capacity, lightweight lifesaving devices are practical and beneficial as another tool Coast Guard responders can use during mass rescue events.

About the author:

Monica Cisternelli has been a Research and Development Center staff member for 15 years and has managed several different projects related to the Coast Guard's search and rescue mission, including human survivability in water, focusing on changes in core and skin temperature in water over 60 degrees Fahrenheit, and the impacts to the Coast Guard's search and rescue mission due to the presence of wind farms.

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Using Research to Challenge Assumptions

Evaluating International Orange alternatives

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As the nation's lead maritime regulatory body, the U.S. Coast Guard is charged with promulgating regulations that support its 11 statutory missions. One of these missions, marine safety, includes the approval of lifesaving equipment intended for use on commercial vessels. Title 46 of the Code of Federal Regulations (CFR) Subchapter Q contains strict prescriptive and performance requirements to which equipment must be manufactured and independently tested prior to receiving Coast Guard approval. One of those requirements is color.

Currently, permitted colors for Coast Guard-approved lifesaving equipment are variations of orange or reddish orange, including Indian Orange, International Orange, Scarlet Munsell 7.5 Red 6/10, and Vivid Reddish Orange—or a fluorescent color of similar hue.[1] The decision to select these colors originated from a 1955 U.S. Navy research project that determined orange and similar hues were the most detectable color in the largest variety of weather and light conditions.[2] Similarly, the International Convention for the Safety of Life at Sea, an international treaty formed to increase ship and mariner safety,[3] requires compliance with the International Life-Saving Equipment Appliance (LSA) Code and specifies International Orange, Vivid Reddish Orange, or a comparably highly visible color.[4]

In 2012, the International Maritime Organization published unified interpretation MSC.1/Circular 1423, titled Unified Interpretation of Paragraph 1.2.2.6 of the LSA Concerning Lifeboat Exterior Colour. This permitted member governments to accept a comparably highly visible color for lifeboat exteriors in lieu of International Orange or Vivid Reddish Orange.[5]

In accordance with the circular, several member governments approved, or requested their maritime administrations approve, alternative colors for lifeboat exteriors, particularly lifeboats carried aboard large passenger vessels and cruise ships. These actions have been a catalyst for increased requests to the Coast Guard for alternative colors for lifeboats, as well as other Coast Guard-approved lifesaving equipment. In response, the Lifesaving and Fire Safety Standards Division (CG-ENG-4) in the Office of Design and Engineering Standards at Coast Guard Headquarters sponsored a Coast Guard Research and Development Center (RDC) project to evaluate the detectability of alternative lifesaving equipment colors in the maritime environment.

The Science of Color

Evaluating a color's influence on the detectability of an object, or target, is a complex problem and requires knowledge of several multidisciplinary topics such as electromagnetic energy, human color perception, and precision color measurement and comparison techniques. Energy emitted by the sun is composed of electromagnetic waves emitted across a broad spectrum of energy, frequencies, and wavelengths called the electromagnetic spectrum.[6] The range of wavelengths that encompass all colors detectable by the human eye is called the visible spectrum and spans from approximately 400 nanometers

Coast Guard recruits conduct survival float training at U.S. Coast Guard Training Center Cape May, New Jersey, on July 13, 2023. Navy photo by Petty Officer 2nd Class Gregory Schell

(nm) to 760 nm, though the actual visible range may vary slightly among individuals.[7]

The ability to sense light and color is dependent on photosensitive rods and cones in the eyes, which become active under specific lighting conditions.[8] Rods are highly sensitive to light and rod activity dominates in low light, or scotopic conditions. Scotopic vision is characterized by achromaticity or, for example, a lack of color, or grayness in color, and low visual acuity, which is why an object's color and physical details may be difficult to identify in low lighting. In brighter light, or photopic conditions, rods deactivate and cone activity dominates. Photopic vision is characterized by full color vision and high visual acuity. The light range where some proportion of both rods and cones are active is called mesopic vision.[9] Since color is most discernable during photopic and mesopic conditions, RDC efforts are focused on color detectability during the full range of daylight hours, including dawn and dusk.

The perception of color can vary by individual, ambient lighting conditions, and a host of environmental factors. For this reason, high-precision color spectrophotometers are used to eliminate variables by quantifying colors mathematically within a color space. A color space maps colors onto a three-dimensional coordinate system, allowing for accurate and repeatable color representation. The International Commission on Illumination (CIE) developed a perceptual color space called CIELAB that closely models human color vision[10] and is preferred in many color perception and vision research applications.

The coordinate system axes in the CIELAB color space are labeled L^*, a^*, and b^*. The term L^* denotes luminance, a measurable quantity most closely associated to the human psychophysical perception of brightness[11] and often referred to as perceptual lightness.[12] The terms a^* and b^* define chromaticity, the color of an object independent of its luminance.[13] The numerical values of L^*, a^*, and b^* are called color coordinates and plot a discrete point within the CIELAB color space.

Detectability and Physical Salience

The detectability of a target is greatly influenced by its physical characteristics and the surrounding environment. The physical characteristics or properties that increase the likelihood that a target will draw the attention of an observer is called conspicuity.[14] Conspicuity is often increased by maximizing the chromaticity and/or luminance of an object.[15] High chromaticity colors appear intense or pure, while low chromaticity colors contain larger amounts of grey and may look muted. High luminance colors contain larger amounts of white and appear brighter while low luminance colors seem darker. Accordingly, high chromaticity, high luminance colors are typically perceived as intense and bright.

The Coast Guard's search and rescue (SAR) environment is maritime and highly dynamic. A SAR crew may encounter any range of lighting, cloud cover, sea state, visibility, and precipitation which may change the apparent color of the water and increase the number of distractors, or irrelevant targets, in the search environment—whitecaps and debris, for instance. Apparent water color also changes with the observer's viewing angle, or the height of their eye,[16] proximity to shore, and the waterbody in which the target is located, such as the Pacific Ocean versus the Gulf of Mexico.

The degree to which the conspicuity of a target draws attention in its environment is called physical salience. Physical salience is how much the basic, low-level visual features of a stimulus—the target's properties—differ from its environment.[17] For this project, the RDC correlates high detection probability to high physical salience of a target. The likelihood of target detection increases as the physical salience of that target increases. Specifically, the RDC is attempting to quantify the extent that various colors affect target salience, while holding all other target features constant, under assorted maritime environmental conditions.

Psychophysical Factors

Another significant aspect of target detectability is the psychophysics of visual search. Psychophysics studies the relationship between the physical characteristics of a stimulus and the human perception of that stimulus.[18] A key challenge in human information processing is the vast amount of sensory information constantly taken in by our sensory organs, like photoreceptors and hair cells, among others. Humans cannot fully process all sensory data received and require selective attention, or guidance, to focus the processing of relevant information while suppressing irrelevant information.[19]

While several forms of guidance exist in visual search, two primary modes are bottom-up attentional guidance and top-down attentional guidance. Bottom-up attentional guidance is driven by external, or stimulus-driven, factors that capture the observer's attention and is typically associated with the salience of an object in the search environment.[20] The salience of a search target is impacted by several factors such as the contrast between the target and distractors, amongst distractors,[21] as well as the target against ambient background color.[22] Additionally, when a single feature is unique compared to its surroundings—a red X among black Xs, for example—it is a feature singleton, which can pop out to an observer.[23] Examples of bottom-up search guidance include a single bright orange lifeboat against a dark blue ocean or the flash of a strobe light in contrast with the dark of night. Although these attributes can greatly assist in target detection, search distractors

RDC field experiments conducted in Long Island Sound on August 21, 2024, demonstrate how the physical salience of a target varies with environmental conditions including sun angle, which affects the apparent color of water. Coast Guard photo by Joshua Pennington

with highly salient properties are also likely to capture attention, reducing search efficiency through momentary distraction.[24] For example, searching for a person in the debris field of a capsized boat where a bright red crab pot buoy may stand out.

Top-down attentional, or goal-directed, guidance is internal to the observer's search intentions.[25] This guidance originates from the observer's knowledge or beliefs about a given task that guides their search and influences what is selected in their visual field. In contrast to stimulus-driven attentional capture, top-down guidance may depend on the attentional set of the searcher, or information provided to the searcher that influences what is selected for attention.[26] Physical salience alone will not involuntarily capture attention, unless it is congruent with the attentional set. A real-world example is if SAR responders are told that crewmembers from a ship in distress have abandoned ship and are now on a green life raft. The SAR responders can establish their attentional set to guide their search for green as opposed to other colors in the environment.

Multiple-color visual search studies suggest that single-color guidance is more efficient than multiple-color guidance.[27] For example, a SAR responder's search can be guided by the color orange, but not simultaneously by both orange and green. Holding a color in working memory while searching for a second color increased error rates among observers, and is theorized to have placed a load on working memory that interfered with prespecified search guidance.[28] A recent study provided evidence that two attentional templates—two colors—can be active simultaneously, though search performance decreases were unclear.[29] A similar study found that two colors could be attended to and improved performance in comparison to no color guidance, but single-color guidance performed best.[30]

Interestingly, two search targets that are close in color, like orange and red, had faster response times than two distinctly different-colored targets, like orange and green.[31] Thus, while multiple-color attentional guidance is possible, it appears to come at a performance cost compared to single-color or similar color attentional guidance.

Previous Color Studies

The original 1955 Navy study found high color saturation and/or high brightness colors performed best among nonfluorescent colors, with the exception of hues of yellow and white which were often misidentified at a distance, or not detected at all.[32] Since SAR operations often occur in rough seas with abundant white caps, yellows and whites were excluded as acceptable lifesaving equipment colors. Hues of orange and red, while not the most detectable colors in all environmental conditions, performed best on average across the broadest range of conditions.[33]

Due to concerns in the mid-1950s with the color permanence of fluorescent dyes and paints, fluorescent colors were not considered for lifesaving equipment. However, the 1955 Navy report concluded the detectability of fluorescent yellow-orange and fluorescent red-orange far exceeded all nonfluorescent colors.[34] Fluorescent colors have been shown to involuntarily attract the attention of observers, both in direct and peripheral vision.[35] They are more conspicuous during daylight hours, including the low-light times of dusk and dawn, than standard colors.[36] Considerable improvements have been made to fluorescent color permanence in the past 70 years, particularly in terms of ultraviolet light degradation. Color permanence concerns continue to appear in literature, and the degree of color permanence appears to vary greatly among fabrics, dye processes, coatings, and base materials.[37]

Color patterns are another means of increasing conspicuity by drawing the attention of observers. Multiple patterns are currently used in highway safety and emergency response. While there has been work on identifying a single most effective pattern, an overarching theme is placing highly contrasting colors in a pattern not occurring in nature. The colors used in these patterns tend to be high chromaticity colors adjacent to high luminance colors, such as the red and yellow chevron recommended for fire apparatus.[38] Importantly, visual search in a maritime domain can be over several nautical miles and the patterns may lose visual effectiveness, or conspicuity.

The Way Forward

The RDC published a comprehensive lifesaving equipment colors literature review in 2023. Four colors—gleaned from the literature review, CG-ENG-4, and maritime industry input—were identified for

detectability testing: fluorescent red, fluorescent orange, fluorescent pink, and fluorescent green.[39] The RDC has developed an experimental plan for upcoming field tests to determine and validate optimally visible color(s) that aid in the detection of search targets across a variety of marine environmental conditions. Experimental colors will be assessed using both subjective and objective measures, using the detectability of current Coast Guard-approved lifesaving equipment colors as the baseline.

As previously discussed, the background color of a maritime environment can change due to a host of factors. The sheer number of variables indicates that no single color is the most detectable in every scenario. However, colors can be evaluated for optimum detectability in specific environmental conditions as well as over the broadest range of conditions. Field testing is ongoing and scheduled to conclude in summer 2025. The data and associated analysis obtained from field tests will be provided to CG-ENG-4 to inform future Coast Guard lifesaving equipment regulation and policy reviews and will be made available to global stakeholders.

About the author:

Joshua Pennington served 22 years in the Coast Guard as a casualty and accident investigator, commercial vessel inspector, and marine safety engineer. He continues maritime safety improvement efforts through lifesaving equipment and fire protection research.

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Combating Adversarial Use of Technology Through Counter-Uncrewed Systems Research and Development

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The widespread proliferation of uncrewed systems (UxS) in recent years has had far-reaching impacts on industries like agriculture, delivery and logistics, film and photography, real estate, public safety, emergency response, and defense, which has altered the battlefield. These systems bring unprecedented capabilities, increasing efficiency while improving safety and reducing costs.

While the increasing accessibility to and capabilities of these systems have transformed commercial industries, malicious use of the same technology has created a security threat in the United States and abroad. The use of UxS by adversarial actors, both state-sponsored and non-state-sponsored—such as terrorist groups and smugglers—has created significant security challenges for governments and organizations around the world. As the primary federal agency for maritime law enforcement, the Coast Guard is tasked with addressing an evolving threat landscape that requires innovative and multipurpose countermeasures to handle both crewed and uncrewed systems in, on, and over the water.

Coast Guard Uncrewed Systems Strategy

"The Coast Guard will … move with purpose to defend against and regulate unmanned systems in the complex maritime environment. We will employ counter-UxS capability appropriate to the Coast Guard's maritime security role across all domains to help assure the security of the Marine Transportation System (MTS) … We will exercise our authority and responsibility to ensure the continued safe and secure operations and movement of goods throughout the MTS upon which our nation depends."

—VADM Peter W. Gautier, Unmanned Systems Strategic Plan

Benefits of UxS

The Coast Guard is fielding uncrewed aerial systems (UAS) in support of multiple missions. Under the Short Range UAS Program, the Office of Aviation Forces UAS Division has fielded small, multirotor UAS for a variety of operational scenarios, including ports, waterways, coastal security, cutter operations, civil engineering inspections, and disaster response. The Coast Guard is also using larger contractor-owned and -operated UAS on national security cutters to provide a cost-effective means of addressing an operational need for a persistent airborne surveillance capability. UAS are used to expand maritime domain awareness and disseminate actionable intelligence on maritime hazards and threats.[1,2] Ongoing research and development efforts at the Coast Guard Research and Development Center (RDC) are investigating the use of UAS for search and rescue (SAR) and ensuring aids to navigation like buoys are in the proper location.

While not yet fielded, the future potential of operating surface vessels in optionally crewed and uncrewed modes would enable uncrewed surface vessels (USV) to be a force multiplier. As undersea exploration markets expand, the Coast Guard has increasingly been tasked with conducting sub-surface SAR missions. Notable examples include its response to the 2024 Key Bridge collapse in Baltimore, Maryland,[3] and the 2023 *Titan* implosion. These missions benefit significantly from the use

of remotely operated or uncrewed underwater vehicles (UUV).

UxS Threats

UAS Threat

The same capabilities of UAS that allow the Coast Guard to more effectively execute its missions also make them excellent for commercial applications such as monitoring agriculture, capturing images for real estate, and infrastructure inspections. As UAS technology has become more widely adopted, costs have decreased and capabilities have expanded, making these systems accessible not only for various industries but also for recreational use by consumers. However, the same systems that are used for spraying fertilizers and pesticides on fields can also be used for nefarious purposes such as chemical, biological, and physical attacks.

On July 30, 2021, the M/T *Mercer Street*, an Israeli-managed, Liberian-flagged oil tanker, was sailing in the Arabian Sea when it was struck by a one-way attack (OWA) UAS, blowing a six-foot hole in the top of the pilothouse and killing the captain and a crewmember. Since the start of the Israel-Hamas war in October 2023, these types of attacks by Iranian-backed, Yemen-based Houthi rebels have increased significantly in the Red Sea and Gulf of Aden as vessels transit through the Bab al-Mandab Strait.

The threats, however, are not limited to larger OWA UAS. These aircraft have been instrumental in the conflict in Ukraine, with commercial drones and first-person view drones being used for reconnaissance, grenade delivery, and command and control (C2). First-person view drones—those controlled by a pilot wearing goggles that provide a virtual perspective of what the drone sees—can be used to guide vehicle-mounted weapons to their targets, enabling precise attacks on enemy personnel and vehicles. Group 1 and 2 UAS under 55 pounds can carry payloads to conduct direct attacks, such as the 2018 drone attack on President Nicolás Maduro of Venezuela.[4] The threats are not limited to overseas locations. There are examples of UAS causing issues in the United States, including accounts of them being used to conduct surveillance of critical infrastructure, like ports and oil and gas facilities, in the maritime environment. In December 2023, there were numerous reported UAS incursions over Langley Air Force Base in Hampton, Virginia. Even seemingly innocuous use of UAS to capture imagery at major sporting events poses a danger of injury to those working and attending the events and increases the risk of collision with manned aircraft overflights.

UUV Threats

While the Navy has been at the forefront of countering submarines and other underwater vehicles in deep water, the advent, current availability, and future proliferation of UUVs has prompted the size of these underwater vehicles. Thus, they are more capable of operating in the shallow coastal waters and ports the Coast Guard is charged with protecting.

There have been several incidents of the Coast Guard intercepting submersible and semisubmersible vessels used in drug smuggling. Similar vessels could be used for conducting surveillance, attacking ships, boats, or ports, disrupting the Marine Transportation System and posing environmental threats. These types of vehicles are difficult to find with traditional surface vessel detection techniques.

USV Threats

Surface targets, while easier to detect, still pose the same risks to assets and ports as their subsurface counterparts. They are as challenging to stop as noncompliant crewed vessels. Historical examples of surface attack vectors, such as the 2000 suicide bombing of the USS *Cole* in Yemen using a small, fast craft, can now be replicated with ease by using USVs. In another example, a bomb-laden USV that the Navy attributed to Iran was used to attack a Saudi frigate[5] in January 2017, and similar attacks remain a real threat to the Coast Guard and the ports it protects.

The conflict in Ukraine has led to the development of USVs equipped with anti-aircraft missiles, which are used to patrol the Black Sea. Despite having a small Navy, Ukraine has been able to dominate the maritime domain in the conflict by using UUVs and USVs as force multipliers.

Legal Authorities

Legal Authorities for Counter-UAS

The Protecting Emerging Threats Act of 2018 granted the Department of Homeland Security (DHS) and Department of Justice (DOJ) statutory authority to counter credible threats from UAS for the safety or security of people, facilities, and assets. These authorities are codified in Title 6 U.S.C. § 124n and allow DHS to detect, identify, monitor, and track UAS, as well as mitigate credible threats by disrupting control and, if necessary, use reasonable force to disable, damage, or destroy them.

This legislation grants DHS and DOJ the authority to conduct counter-UAS (c-UAS) operations in support of National Special Security Events (NSSE), Special Event Assessment Rating (SEAR) events, mass gatherings, and protection of federal law enforcement investigations, emergency response, or security function for specified duration and location. Additionally, the Coast Guard is authorized to conduct c-UAS operations when conducting Coast Guard-authorized missions under Title

A counter uncrewed aerial system vehicle is secured to the deck of a Navy ship in January 2023. Marine Corps photo by Cpl. Matthew Romonoyske-Bean

14, which is the United States Code that established the Coast Guard and its duties, powers, administration, and personnel. Similar authorities exist for the Department of Defense (DoD) and are codified under Title 10 U.S.C. § 130i. While currently under DHS, the Coast Guard is one of six armed services of the United States and can operate under Title 10 authorities, which is the United States Code that established the roles, missions, and organization of the armed forces and DoD.

Legal Authorities for Counter-USV and UUV

The Coast Guard can draw from a variety of authorities to support counter-USV (c-USV) and counter-UUV (c-UUV) operations. Under the Coast Guard's ports, waterways, and coastal security mission there are two statutes that provide the authority to protect and secure vessels, harbors and waterfront facilities from a variety of threats:

- 46 U.S.C. § 70051, or the Magnuson Act
- 46 U.S.C. § 70001, or the Ports and Waterways Safety Act

These statutes permit the Coast Guard to establish security zones that prohibit surface and subsurface navigation to protect vessels or maritime facilities from acts of terrorism, warfare, or other declared national emergencies, and include the authority to enforce these zones. Additionally, the Coast Guard's general law enforcement authority under 14 U.S.C. § 522(a) provides the Coast Guard with broad authority to enforce applicable U.S. laws on a vessel subject to U.S. jurisdiction. Under this authority, the Coast Guard may exercise law enforcement jurisdiction onboard any U.S.-flagged vessel, regardless of its location, as well as vessels within U.S. territorial seas if there is a basis to suspect that vessel of violating a U.S. law.

Counter UxS Research and Development

Counter UAS Research and Development

The RDC has a long history of research and development in countering UAS. This work goes back to a maritime c-UAS project which began in fall 2016. This work began with conducting market research to identify government off-the-shelf and commercial off-the-shelf (COTS) systems that could satisfy Coast Guard requirements. Nearly all these systems were designed for land-based applications and not for the harsh maritime environment with a requirement to work on the move (OTM).

Therefore, the next step was to evaluate these systems in an operational maritime environment. In fall 2017, the RDC's commanding officer and c-UAS project officer traveled to the Air Force Research Lab Information Directorate in Rome, New York, to meet with the lab's director and the c-UAS technical director to discuss areas of mutual interest and collaboration opportunities. The meeting resulted in a January 2018 site survey and installation design event on the CGC *Sanibel* for a prototype radio frequency (RF) system developed by the Air Force Research Lab. This prototype was tested three

months later in an operational environment aboard a Coast Guard asset in the field.

At that time, the system was tested for operational suitability and demonstrated for the chief of naval research, who was impressed by the speed at which the team was moving to tackle this difficult problem. Further discussions between the RDC and the Office of Naval Research (ONR) led to the involvement of Naval Surface Warfare Center Dahlgren Division in Virginia. The division was already working on the evaluation and OTM capability of a c-UAS air search radar for an effort funded by ONR. The Dahlgren team conducted a site survey in May 2018 to assess temporary installation options. The radar system's capability was demonstrated on the move and afloat from aboard a Coast Guard patrol boat for the first time a month later.

C-UAS Systems Integration

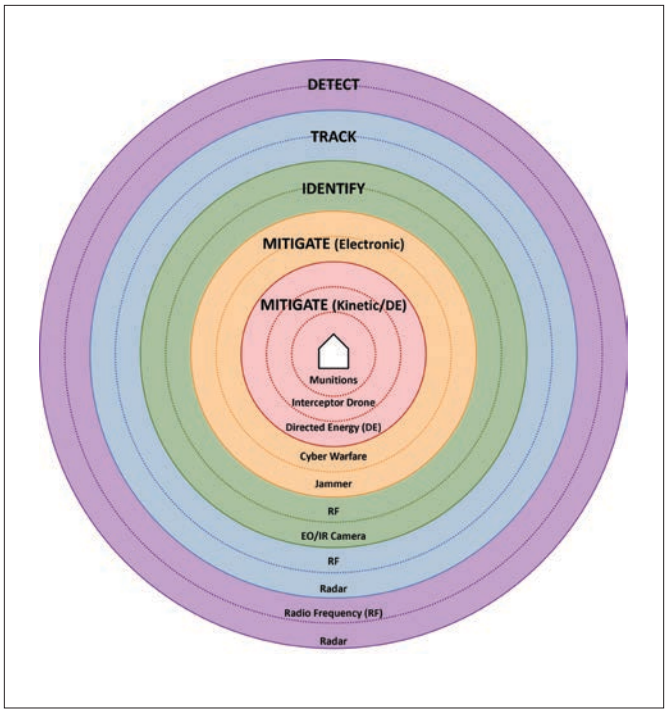
To address the variety of threats in different areas of responsibility, a layered approach with various sensor modalities such as RF, radar, and electro-optical/infrared (EO/IR) cameras is required. With multiple sensors, each having their own user interface, it was evident that a single C2 system would be required. In short order, these systems were then integrated into a layered defensive system prototype capable of executing the entire detect, identify, monitor, track, and mitigate process. In September 2018, the RDC and Dahlgren teams successfully demonstrated the capability to place collocated radars on either side of the pilothouse using a temporary mounting solution. This setup provided comprehensive air domain coverage and was the first instance of such technology being implemented on a maritime vessel without impacting the space, weight, or power needed for its other missions. Over the course of one year, both systems, plus an additional RF system provided by the Navy and the cutter's EO/IR system, were all integrated into a C2 application where the operator could control all subsystems in one user interface.

The success and importance of this work led to follow-on work under the Advanced Maritime c-UAS Technologies project. Ongoing work at the RDC includes automating the object detection and classification of targets using EO/IR cameras to reduce false alarms of air search radars caused by significant clutter, such as birds, in coastal regions. Other ongoing efforts focus on exploring the applicability of data-fusion algorithms and machine learning to combine multiple data types into a single threat track to reduce operator workloads, uncertainty, and response times.

Yet another line of effort follows new development and maturation of kinetic defeat solutions—systems that physically harm the UAS to remove it from the airspace—that are commercially available or being developed by other government agencies. The Army Combat Capabilities Development Command Armaments Center, with a focus on low collateral damage solutions for use domestically and abroad, is just one example. All of these research areas allow the RDC, as subject matter experts, to provide technical guidance on system employment for various mission sets based on legal authorities and tactics, techniques, and procedures (TTPs).

Counter-UUV Research and Development

In late 2018, the RDC began a c-UUV project aimed at delivering decision-support information regarding improved c-UUV capabilities for detecting, tracking, classifying, and deterring underwater threats building on the RDC's past work on anti-swimmer technology.[6] Anti-swimmer technologies are systems that detect swimmers in protected waters and alert security forces so they can intercept the individuals and remove them from the security zone. The RDC partnered with the Naval Undersea Warfare Center (NUWC) Division Newport in Rhode Island to evaluate the capabilities of their Argus Expeditionary Maritime Defense System.[7] This project culminated with a limited user evaluation of the system with the RDC, NUWC Newport, and the Coast Guard Maritime Safety and Security Team Cape Cod. During this event, Coast Guard personnel evaluated the system's applicability for Coast Guard missions,



This diagram shows the layered defensive system concept using radar, RF, EO/IR to Detect, Track, Identify, and Monitor UAS. Coast Guard graphic by Chris Davidson

assessed interoperability with its response teams, and provided feedback on how the system could be integrated with Coast Guard TTPs. The RDC's efforts to address this threat will be continued in new research focused on capabilities and technologies to defeat UUVs in FY 25.

The Future of USCG C-UxS

Transitioning Capability

The Coast Guard has transitioned capabilities from research and development to operational units, routinely deploying these resources to support NSSE and SEAR events, such as the United Nations General Assembly and New York City Marathon.[8]

During the 2023 Seafair Weekend Festival Airshow, the Coast Guard collaborated with the Federal Aviation Administration (FAA), Seattle Police Department, and Mercer Island Police Department to employ c-UAS capabilities to enforce the FAA-issued temporary flight restrictions (TFR) on Lake Washington. During this event, the Coast Guard detected 16 UAS pilots violating the TFR and assisted the Seattle and Mercer Island police departments in locating the pilots to provide education on airspace restrictions and safe UAS operations. The Seattle police cited one pilot for reckless endangerment.[9] The Coast Guard will continue to conduct these missions to support pilot education and provide safety and security at NSSE and SEAR events.

The Coast Guard's missions at home and abroad are vast, but the RDC has transitioned c-UAS capability to the operational fleet and will continue to support transitioning new capabilities to address emerging threats.

Defense and Safety Systems Research Program

Even with all the work that has been completed, more research and development is required to address current and future UxS threats. New projects are starting to analyze the applicability of directed energy (DE) technology to stop both crewed vessels that are not obeying orders and uncrewed systems. The RDC will assess how DE

Argus is a multidomain system that uses government-developed command and control and integrates commercially available active sonars to detect, track, and classify underwater targets. It also incorporates radar and electro-optical/infrared cameras to track surface and airborne targets.

In partnership with the Office of Naval Research and the Naval Surface Warfare Center Dahlgren Division, the Coast Guard Research and Development Center undertakes initial maritime testing of an on-the-move air search radar system. Coast Guard photo by Amy Cutting

CGC *Sanibel* participates in a National Special Security Event in New York City during the 2021 United Nations General Assembly. Coast Guard photo by Amy Cutting

technologies could be integrated into Coast Guard operations. The RDC will leverage the significant resources that the DoD and DHS have invested in directed energy technologies such as high-power microwave and laser weapons systems to assess the technical readiness of existing and emerging solutions.

Non-RF-emitting UAS are known as dark UAS and groups of UxS are known as swarms.

Ongoing research will focus on countering emerging threats such as Non-RF-emitting UAS and multiple simultaneous UxS that overwhelm operators and defensive systems. Future efforts will leverage the power of software-defined systems to use existing c-UAS sensors for c-USV and address countering multiUxS threats—systems capable of changing from air to surface to subsurface and back. Software-defined refers to a system where the functionalities of a hardware device are controlled and managed by software. The Coast Guard will integrate c-UAS, c-USV, and c-UUV systems into a single C2 system to provide a source for operators conducting security missions.

Conclusion

The RDC will continue transitioning technology from research and development to operational capability for the fleet to enhance mission performance, improve safety and security, and increase efficiency and effectiveness in meeting the Coast Guard's missions and responsibilities. Under the new RDC structure, these projects will be brought into a single Defense and Safety Systems Research Program to increase collaboration and deliver capability to the fleet. We will prepare the service to defend against the autonomous threats of the future.

About the authors:

Christopher Davidson is a mechanical engineer who has been developing and fielding c-UxS systems for 10 years at the Naval Surface Warfare Center Dahlgren Division and for the RDC since 2023.

Amy Cutting has 15 years of civil service experience supporting defensive system research, development, test, evaluation, and simulation for the Coast Guard and Navy.

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Protecting the Fleet's Operational Technology

Platform cybersecurity research

by Robert Coburn
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Onboard cutter control systems represent a unique risk for cyberattacks in that they directly affect physical processes, meaning that anything that impacts the system can also impact real-world activity. The term "operational technology" (OT) has been used to identify these systems as separate from information technology (IT), and in fact OT systems have often been physically separated from IT. With local networks of purpose-built devices communicating via protocols customized to fit specific applications, OT has long existed entirely apart from traditional IT infrastructure. Research and development of the cybersecurity aspects of OT systems is squarely in the Coast Guard Research and Development Center's (RDC) wheelhouse, as the command works with entities within the service to protect the fleet.

This physical separation limits exposure to local connections only, shifting the focus of security towards physical access, for example, those who can put their hands on the system. Any cyberattack on isolated OT would be expected to take a back seat, in terms of impact, to the physical attack required to gain access to the system in the first place. There are much simpler ways for attackers to significantly affect operations if they can take control of real space.

This makes defense against insider threats a top priority for isolated OT, as the credentials needed for system access may not extend beyond those required to physically reach the system if cybersecurity posture has not been specifically considered. Insider threat damage does not even have to be intentional—poor cyber hygiene can be equally devastating. This holds especially true for maintenance vendors and suppliers, who are specifically expected to interact with the system.

As an example, consider the Pro Network Entities operation which ran for more than nine years between 2013 and 2022. Tens of thousands of what appeared to be "new, genuine, and high-quality devices manufactured and authorized by Cisco"[1] were in fact "low quality, modified computer networking devices with counterfeit Cisco labels, stickers, boxes, documentation, and packaging."[2] Per a press release from the court case, these devices ended up in hospitals, schools, government agencies, and the military,[3] emphasizing the critical importance of thorough configuration management, as even isolated systems can still be reached through the supply chain.

Traditionally, OT systems on maritime vessels have been air-gapped, existing independently with no methods of connection to any external networks. Underway connectivity has historically been less than guaranteed, and the costs of remote access to control systems at sea have tended to outweigh the benefits. This is not necessarily true in today's landscape. The increased availability of satellite services and a focus on data-driven decision-making is driving the integration of OT access through remote IT systems, commonly referred to as IT/OT convergence, beyond land-based infrastructure to a truly global scale.

With increased use of autonomous shipping, offshore platforms, and cargo facilities,[4] as mentioned in the 2021 Coast Guard Cyber Strategic Outlook, the Marine Transportation System (MTS) is a prime example of IT/OT convergence. The additional connectivity required to support this evolution also represents new potential attack pathways, which can be seen in many publicly reported incidents.[5]

"Without a question, protecting the Marine Transportation System from cyber threats is a shared responsibility requiring both government and industry participation," said Coast Guard CAPT Andy Meyers, chief of the Office of Port and Facility Compliance.

The MTS is made up of 25,000 miles of coastal and inland waterways serving 261 ports, over 124 shipyards, over 3,500 maritime facilities, 20,000 bridges, 50,000 federal aids to navigation, and 95,000 miles of shoreline.[6] The Coast Guard has a duty to protect the MTS as part of its ports, waterways, and coastal security mission,

which requires cybersecurity not just for its own assets, but also for the MTS. The second line of effort in the Coast Guard's current Cyber Strategic Outlook explicitly directs the protection of the MTS.[7] This requirement was also reinforced in 2013 via Executive Order 13636—Improving Critical Infrastructure Cybersecurity. The RDC developed an assessment framework for the Coast Guard's Office of Port and Facility Activities to apply to MTS facilities in response. Later, the RDC partially adapted this framework to evaluate Coast Guard afloat assets as part of a separate cybersecurity research effort focused on the OT component of the current first Coast Guard cyber strategic line of effort: Defend and Operate the Enterprise Mission Platform.[8]

Layering Protection

The Cybersecurity and Infrastructure Security Agency (CISA) has published several recommended practices for OT cybersecurity,[9] and they hold true for shipboard systems as well as shore-based infrastructure. While not step-by-step instructions, the RDC finds these recommended practices taken together represent an effective cybersecurity policy for asset protection. The recommendations fall generally into four categories including monitoring and awareness, configuration and authentication management, boundary defense, and incident response.

Awareness is the first step in cyber readiness. As quoted by the Instrumentation, Systems, and Automation Society,[10] "Prevention is ideal, but detection is essential."[11] The most direct application of this is monitoring all OT network activity, which can often be more achievable for OT than IT given its more stable configuration. OT devices and associated communications are very predictable, meaning that alerting on any unrecognized activity can be an effective strategy, although the effort scales based on the complexity of the system due to the need to determine what defines a state of normal communications.

Configuration and authentication management go hand-in-hand with awareness, as maintaining a known correct configuration and connections is what allows for easy identification of anomalies. CISA recommends careful validation of system patches to include verification of vendors and their equipment, as well as implementation of credential management to ensure connections hold only the minimum privileges needed to accomplish their specific objectives, also known as a zero-trust approach.

Boundary defense ties into this as well, as devices can be grouped into separate zones and separated by firewalls to limit potential impacts of a cyber breach. Connections to each of these enclaves should be limited to the bare minimum, even configured as unidirectional gateways if the specific application can be achieved with a one-way connection. Any unused ports or paths should be disabled or restricted. Whitelisting can even be used with a well-understood system—like the awareness

Coast Guard and Navy personnel begin joint testing of operational technology aboard a cutter. Coast Guard photo

approach above—to only allow known and expected communications.

The last group of recommendations falls under incident response, or how to limit the impact of intrusions and recover affected systems. This can involve redundant controls on a separate network, forced disconnection or isolation in response to identified threats, or even just training for system owners and operators on effective response measures.

Leveraging a Joint Capability

There are multiple approaches toward implementation of cybersecurity strategies, and the RDC is currently exploring one such path in partnership with the Naval Sea Systems Command (NAVSEA). The Situational Awareness, Boundary Enforcement, and Response (SABER) program is a Navy cyber resiliency program of record focusing on afloat platforms. As such, the partnership offers an opportunity for the Coast Guard to synchronize elements of fleet cyber defense with its routine Defense partner.

Understandably, Coast Guard and Navy requirements do not always align. The RDC is focused on identifying SABER elements that appropriately support the Coast Guard mission set and assets as defined under the Department of Homeland Security, while also exploring opportunities to adapt, improve, and further develop existing Coast Guard requirements. Building cyber resiliency into platforms at the design stage is understandably more efficient than retrofitting solutions to existing systems.

The age of the Coast Guard fleet is well-documented, however, and it is imperative to ensure that both new software and new hardware are fully interoperable with existing control systems. Availability and reliability are the top priorities for OT, so potential security benefits must be weighed against potential performance impacts. The RDC has been able to mitigate this risk in part by testing initial SABER capabilities on a simulator typically used for maintenance training. While not all networks are physically represented, enough devices are present on the existing networks to gauge the potential impact of operating the cybersecurity system during normal operations, even if the traffic is not fully equivalent. This conservative approach also provides an opportunity to demonstrate potential solutions to subject matter experts in a controlled and accessible environment, guiding future development.

Testing on operational systems is clearly important, and the RDC leverages its connections with the fleet for proof-of-concept, verification, and validation testing to better account for the wide range of requirements across the afloat community. Testing cyber resiliency on cutters gives the RDC the opportunity to engage with potential end users of the system and incorporate additional design requirements that may not be immediately evident in a lab environment. By including crewmembers in testing, the RDC has been better able to identify which tools are essential for mission cyber defense and understand how they can be implemented in a manner that is effective and unobtrusive. This also applies to the physical elements. Size, weight, and power are more of a concern for mobile platforms than fixed sites and understanding interferences and limits for hardware is essential. This has also provided value for NAVSEA, as the Coast Guard fleet, being designed and operated for a different mission set, operates at a different scale and a different level of flexibility.

The joint cyber resiliency collaboration between the RDC and NAVSEA continues to provide valuable opportunities for both partners, and the center intends to continue leveraging this relationship for the Coast Guard's benefit. OT cybersecurity is becoming increasingly critical to safeguarding an increasingly interconnected nation, and the Coast Guard aims to keep pace with developments in this field for the benefit of all.

About the author:

Robert Coburn has worked at the Coast Guard Research and Development Center for four years with a general focus on improving mobile data-collection capabilities. He also has four years of private-sector experience supporting maintenance analysis.

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For more information

More details on these strategies can be found on CISA's ICS Recommended Practices page at https://bit.ly/ICSPractices.

Critical Connections

LEO research enhances mission execution

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For more than 25 years, Coast Guard cutters have relied on geostationary satellites for network connectivity to the DoD's Non-classified Internet Protocol Router Network and Secret Internet Protocol Router Network while underway. To overcome the force of gravity, a geostationary satellite needs to orbit the Earth at precisely 35,786 kilometers above the equator. Anything other than that altitude will cause the satellite to desynchronize from the Earth's rotation.

Using geostationary satellite systems requires cutters to operate and maintain satellite terminals with large parabolic antennas and motors to keep a satellite within the antenna's line of sight. As a ship sails north or south to more extreme latitudes, more than 74 degrees, the satellite drops below the horizon and the ship's antenna can no longer communicate with it. This creates network connectivity issues and interruptions for vessels operating in the polar regions.

The advent of low-Earth orbit (LEO) satellites has changed the landscape of satellite communications in reliability, speed, and cost. LEO satellites operate at altitudes between 400 and 2,000 kilometers above the Earth's surface, however, unlike geostationary satellites, LEO satellites do not follow a fixed orbit. These satellites orbit at higher speeds and are not limited to the equatorial plane. With enough of them, whole-Earth coverage can be obtained, providing a distinct advantage over the legacy geostationary satellite constellation. Understanding the implications of this advantage, the Coast Guard Research and Development Center (RDC) set out to research, test, and evaluate the uses of LEO satellite technology aboard Coast Guard cutters.

From left to right, Coast Guard Petty Officer 1st Class Brandon Diko, Coast Guard LT Ian Wood, and the Coast Guard Research and Development Center's Paul Harvey install a prototype Starlink terminal on CGC *Healy*. Coast Guard photo by Jon Turban

Capitalizing on a robust relationship within the Department of Defense's Laboratory Commander Sync, the RDC research team connected with the Air Force Research Laboratory (AFRL), which conducted its own research of the up-and-coming technology on its Global Lightning Project. Global Lightning is a prototyping and experimentation project to provide reliable and secure commercial satellite communications to military aircraft, ships, vehicles, and fixed sites. Starlink was one of the commercial satellite systems Global Lightning was experimenting with. It provides high-speed internet connectivity using thousands of LEO satellites.

The AFRL team provided a prototype Starlink terminal, satellite airtime, and SpaceX engineering expertise to assist with Coast Guard's at-sea testing of the Starlink satellite system. In summer 2021, the RDC team and the CGC *Healy*'s crew installed the first Coast Guard Starlink terminal aboard the polar ice-breaker homeported out of Seattle. During this period, the Starlink system was still being built and was only partially operational. The *Healy* was scheduled for a routine Arctic cruise during the summer months to circumnavigate North America, providing the research team with a first glimpse of Starlink's performance on a ship at sea.

The Starlink terminal provided by AFRL in 2021 included prototype beam stabilization software that compensated for the ship's forward motion, as well as yaw, pitch, and roll of the ship. This software enabled the terminal to electronically steer its flat-panel antenna and track satellites while the ship was

in motion, allowing the *Healy* to maintain high speed internet during six sets of tests. This success demonstrated the technology could maintain connectivity on a moving ship.

However, since the system was still being built and only partially operational, a challenge arose during the Starlink's first deployment aboard *Healy*. Starlink divided the Earth into 22-kilometer-wide cells and a terminal could only be assigned to one cell at a time. The ship would lose Starlink connectivity as it moved from one cell to another.

To solve this, the RDC team and Starlink engineers used *Healy*'s trackline to map its voyage from Boston the ship's *Healy*'s route. It took *Healy* three hours to travel through each test area. During the tests, an RDC researcher aboard the ship had to contact Starlink engineers to manually assign the ship's onboard terminal to the next cell when moving from one cell to the next. This happened about once every 40 minutes.

Despite these challenges, the Starlink system demonstrated great promise as a solution for improved underway network connectivity in the polar regions and around the globe. Throughout initial testing, *Healy* consistently experienced download speeds of up to 150 megabits per second. To test the Starlink system in the six test areas, the crewmembers used Wi-Fi throughout the ship to connect with family and friends at home through emails and video calls, placing a significant load on the system. Not only was this a massive morale boost, the researcher on board was able to take measurements.

Over the next few years, as the satellite system implemented new features, launched more satellites, and developed new versions of satellite terminals, the RDC team tested new capabilities during each deployment. From summer 2022 through winter 2023, the RDC team tested several features aboard both *Healy* and CGC *Polar Star*. During *Healy*'s 2022 summer cruise, Starlink implemented a mobility feature which automatically switched the terminal's assigned cell, allowing the ship to maintain connectivity regardless of the ship's location. *Healy* successfully transited from Juneau, Alaska, to Seattle over several days without a loss of connection or

The prototype Starlink terminal is shown aboard CGC *Healy* while underway in the Arctic. Coast Guard photo by Petty Officer 1st Class Brandon Diko

A Starlink terminal waits to be installed aboard CGC *Eagle* in April 2023. *Eagle* is a 295-foot ship that serves as a training vessel for the U.S. Coast Guard Academy. Coast Guard photo

the need to contact Starlink to change the operating cell. In March 2023, *Polar Star* completed its cruise between Antarctica's McMurdo Station and Seattle with uninterrupted connectivity.

After four deployments over an 18-month span, Starlink became fully operational in March 2023. *Healy* and *Polar Star* successfully maintained high-speed commercial internet and connectivity to CGOne, the Coast Guard's internal network, proving that LEO broadband internet can now operate effectively in extreme latitudes. Based on data collected and positive testimonials from the ships' crews and commands, Starlink was installed on CGC *Eagle*. The crew put the system through its paces crossing the North Atlantic to the Azores.

"Starlink seamlessly transitions from satellite to satellite, unlike the legacy system, which drops service while it looks for and tracks a new satellite," said CAPT Jessica Rozzi-Ochs, captain of the *Eagle*. "This was particularly impressive when we experienced heavy weather 20-foot-plus seas, hard rain, 40 to 50 knots of wind and Starlink didn't go down once."[1]

The Coast Guard continues to install Starlink on all cutters across the fleet, with the goal of every cutter being outfitted.

Conclusion

In 2024, the RDC research team received the DHS Secretary's Award for Innovation. The award celebrated the team's efforts to rapidly leverage a new technology as a solution for vessels operating north or south of 74 degrees latitude and completing the foundational work to position the Coast Guard to quickly deploy Starlink to the operational cutter fleet.

Although it has been a game-changer for Coast Guard cutters, the RDC research team continues to explore alternative solutions to provide enhanced connectivity to cutters operating all over the world. In summer 2024, the RDC entered into a cooperative research and development agreement with Hughes Network Systems to evaluate the coverage and speed of the OneWeb LEO satellite system. The team sought to explore other potential capabilities that may exist, including alternative methods for position, navigation, and timing, as well as the ability to seamlessly switch between multi-orbit satellite systems. That fall, the research team installed a OneWeb terminal on *Polar Star* for testing during its 2024-2025 Operation Deep Freeze deployment to Antarctica.

While the Coast Guard continues to expand its arsenal of space-based communication and connectivity capabilities, the public and commercial sectors also continue to innovate and push the bounds of what is possible. Though Starlink is a leader in LEO connectivity, several others are exploring similar technologies, incorporating differentiated features like seamless transition of service through alternative satellite constellations. To ensure the Coast Guard and its operators have the tools to advance Commandant of the Coast Guard ADM Linda L. Fagan's strategic vision to sharpen our competitive edge, the RDC and its partners will continue to pursue promising technology that enhances mission execution.

About the authors:

Jon Turban is a 1983 graduate of the U.S. Coast Guard Academy. He is a licensed professional engineer with a master's degree in electrical engineering from Yale University. He is a retired Coast Guard officer with a combination of active and reserve service and first came to the Coast Guard Research and Development Center in 1985 while on active duty. Turban has been part of the civilian staff since 1991 and is the project manager for the Research and Development Center's High Latitude Underway Connectivity effort.

LCDR Ryan Cassidy is a 2010 graduate of the U.S. Coast Guard Academy. A career MH-65 pilot, he served as an aircraft commander and instructor pilot in both the search and rescue and rotary wing air intercept missions. He holds master's degrees in information systems and business administration from the University of Maine and is a branch chief at the Coast Guard's Research and Development Center.

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Supercharging Business Intelligence Tools

Using enterprise tools for research

by Jack Cline
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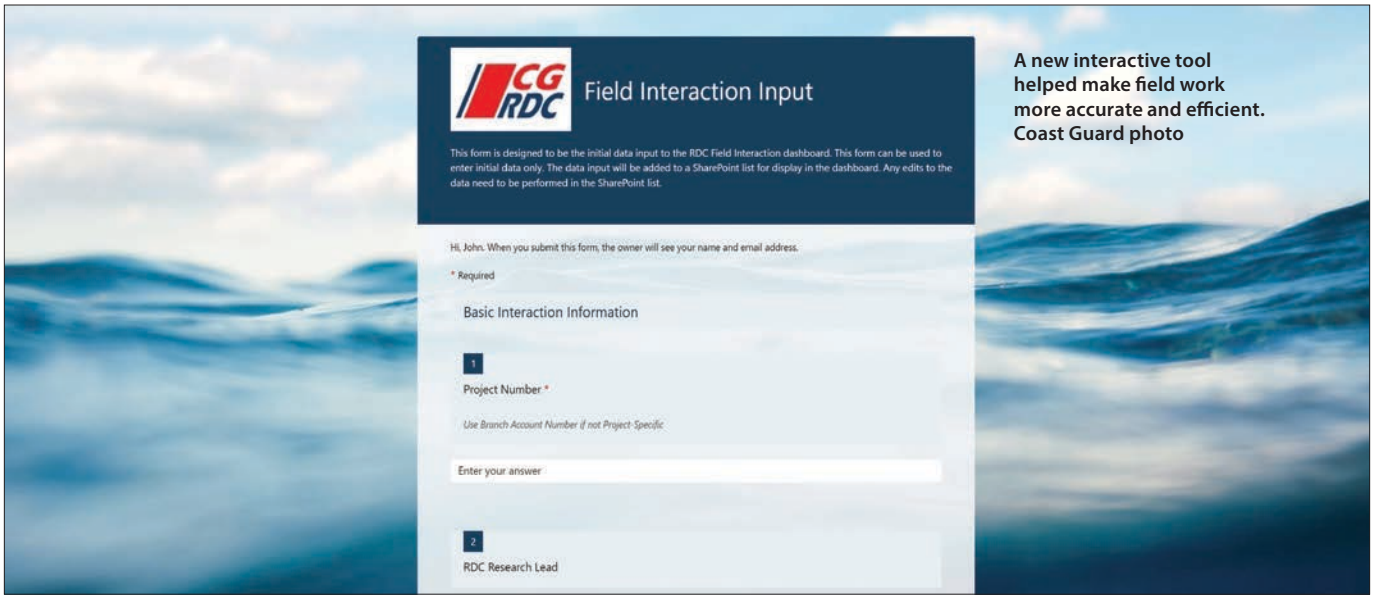
What are business intelligence tools? Simply put, business intelligence (BI) tools help users leverage data to make decisions. Data are typically found in different locations, in different formats, and can be large in size or quantity. BI tools can help overcome these challenges by accessing many different data sources, transforming the data into common formats, and performing tasks across large datasets. BI tools also have the advantage of applying the same processes to additional data to update or refresh a dataset.

Beyond data ingestion and transformation, BI tools can analyze and visualize data in useful ways that convey meaning to end users. They allow users to interact with data and answer their own questions, as well as provide visual elements including charts and maps that make the data easier to understand.

Using Enterprise Tools for Research

One of the Coast Guard Research and Development Center's (RDC) primary goals is to transition the work it does into the service, so it was imperative to use tools the Coast Guard already employs. Two of the most significant tools the service has brought into the enterprise are the Department of Defense's (DoD) version of Microsoft Office 365, known as DoD 365, and Environmental Systems Research Institute's (Esri) Geographic Information Systems (GIS) technology called ArcGIS.

To demonstrate the applicability of the available BI tools, the RDC research team focused on two use cases. The initial case focused on creating a data management and visualization system with DoD 365. This system was designed for RDC staff members to input data about their interactions with the field into a form. The data would then be showcased on a Power BI dashboard, featuring a geographic display to show the locations of field events. The second case involved using ArcGIS technology to display relevant information related to the Coast Guard's effort to combat illegal, unregulated, and unreported



A new interactive tool helped make field work more accurate and efficient. Coast Guard photo

(IUU) fishing activities.

Use Case: Field Interaction Tool

There were several concepts that came together to launch this effort. The first was a desire to explore the capabilities of the DoD 365 suite of software to develop a custom application using the no-code/low-code framework of DoD 365. The second was the desire to show our customers where and how we interacted with them when testing our technology in the field. The third was the desire to show these engagements in an interactive manner on a map.

A thorough review of the DoD 365 tools revealed the following workflow. Data was captured using a Microsoft form. This application allows the user to build an interactive functional object to both capture data and explain the type of information the user is being asked for with no user training required. The technology simplifies the collection of high-quality data by offering single- and multiple-choice options and enabling dynamic form navigation based on responses to specific questions. This design enhances the user's experience while ensuring the collection of accurate and valuable data for subsequent workflow stages.

A storage and editing mechanism for the data was readily available in the Microsoft List application, which stores the data and allows users to edit it as required. The list can be formatted to provide multiple views of the data as needed. Lists also provide additional capability to create calculated fields to include a website link for the specific list entry, making it easy to link an item in the dashboard report to the item in the SharePoint list.

DoD 365 contains a powerful visualization component in Microsoft Power BI. This business intelligence tool provides the ability to access and process data, and then display the data in a variety of interactive formats for users. It is specifically designed to interact with other Microsoft products, especially SharePoint data sources.

For this specific use case, we used a two-page design. Page 1 has a simple summary table, multiple data filters, and a map showing the location of the interaction events shown on the page. Page 2 has a more detailed data table along with the data filters shown on Page 1.

The final component uses Microsoft Power Automate to move data from the form to the SharePoint list and update the report when new data is added, or existing data is modified. This critical component allows the workflow to operate with minimal user intervention.

Use Case: IUU Fishing Activities

The Coast Guard plays a vital role in combating IUU fishing activities. IUU fishing refers to fishing activities that are conducted in violation of national or international laws and regulations, often involving practices such as fishing without proper authorization, exceeding fishing quotas, using prohibited gear, or fishing in protected areas.

The Coast Guard works toward developing maritime domain awareness, which involves gathering and analyzing information about maritime activities, including fishing vessels, their movements, and their interactions with other vessels. This information helps in identifying potential IUU fishing activities and targeting enforcement efforts.

For this use case, we decided to use ArcGIS technologies available in our enterprise to help understand the geospatial aspects of IUU fishing activities. These aspects included analysis of historic Automatic Identification System (AIS) data for Coast Guard vessels, mining open-source vessel information, and improving fish species habitat location technology.

ArcGIS Platforms

The Coast Guard has worked with Esri ArcGIS products for many years. These tools can be categorized into three primary platforms. The first platform is loaded on individual computers and is referred to as ArcGIS Pro. The second, ArcGIS Online, is software as a service hosted on Esri hardware in a cloud environment. The third is ArcGIS Enterprise, which is hosted on an organization's hardware and network. Each of these platforms has advantages and constraints.

ArcGIS Pro allows individuals to conduct geospatial analysis providing access to powerful geoprocessing tools and easily connecting to online data sources. This platform facilitates development and experimentation of workflows that provide relevant information to Coast Guard operations. The primary constraint of this platform is that geoprocessing operations require significant computational power, memory, and storage. Scaling a workflow from a single analysis to an enterprise operation is typically beyond the hardware capabilities of standard, off-the-shelf desktop and laptop computers.

The ArcGIS Online platform provides access to many of the capabilities of the desktop platform, as well as many additional tools that significantly enhance functionality. Content developed on the ArcGIS Pro platform can be uploaded to ArcGIS Online and shared with other users. The most significant capability of this platform is the ability to share information, web maps, and dashboards. The main constraints for this platform are the expense associated with large-scale computational processing and the restriction to hosting only nonsensitive information outside the Coast Guard's firewall.

The ArcGIS Enterprise platform provides functional capabilities similar to ArcGIS Online, but it is hosted on Coast Guard hardware and networks. The platform is owned and operated by the Coast Guard, so it can scale

hardware and software components as necessary to meet performance requirements. The primary disadvantage of this platform is that the Coast Guard must manage the hardware and software.

Key Technologies

Both ArcGIS Online and ArcGIS Enterprise have strong user management and information-sharing capabilities. Information analysis components and products can be easily shared with anyone who has the proper permissions. These large-scale portals make it simple to find and share relevant information.

An ArcGIS web map is an interactive display of geographic information that can be used to tell stories

The IUU Fishing Activity Dashboard

The IUU Fishing Activity Dashboard uses a custom script to draw publicly available data from the Global Fishing Watch (GFW) application programming interface portal (API). The general layout includes a web map in the center and other elements arranged around the map. The dashboard developer has control over the elements chosen, as well as their size, appearance, and placement on the dashboard.

Item 1 in the image shows a stack of list elements. At the bottom of the list elements are controls for the user to navigate through the stack of lists supported by the GFW data. Item 2 shows the filters available in the dashboard. The filters apply to all the list elements and items in the web map layers. This important capability allows each individual user to tailor the information that they see.

The image also illustrates the ability to include chart elements in the dashboard that provide a graphical representation of the data contained in the web map. The graphs can make meaningful pictures of complex data. Other types of charting elements are also available.

A single source of data is rarely useful on its own. Additional data layers in the web map provide context for the dashboard. For instance, in another view showing an expanded view of the list of layers contained in the web map, all the layers from GFW are included under the "Global Fishing Watch Events and Vessels" group and can be individually turned on or off.

Additional layers are included to provide geographic context including the U.S. exclusive economic zone and those EEZs of other nations, and the World Database on Protected Areas. More reference layers can be added to the web map.

and answer questions.[1] A web map is the feature that provides the foundation and contains the data layers needed to investigate specific problems. Web maps can be accessed and investigated using a standard web browser and do not require any additional software on a user's computer.

A dashboard is a presentation of geographic information and data that allows users to monitor events, make decisions, inform others, and see trends. Dashboards are designed to display multiple visualizations that work together on a single screen. They offer a comprehensive view of data and provide insights for at-a-glance decision-making.[2]

Dashboards are based on a web map and allow users to interact with the map data. Users select specific information layers, filter data within the map, and view graphs linked to the displayed data. Together, these features create a user-friendly and intuitive navigation interface.

IUU Fishing Activity Dashboard

The RDC began its exploration of BI tools through the development of the IUU Fishing Activity Dashboard, using publicly available data and hosting curated information on the Coast Guard's instance of ArcGIS Online. ArcGIS platforms can ingest data from many sources using industry standard data formats. For example, Global Fishing Watch (GFW), a nonprofit organization that uses satellite technology to promote transparency in global fishing activities, provides IUU fishing data through an application programming interface portal, which allows other software applications, such as ArcGIS to ingest GFW data.

For this use case, the RDC research team focused on ingesting vessel information and what are known as "encounter events" from the GFW portal. There were four types of events in this dataset: apparent fishing, encounters, loitering, and port visits, each of which is briefly defined below.

Apparent fishing events: GFW analyzes AIS data collected from vessels identified as known or possible commercial fishing vessels and applies a fishing detection algorithm to determine apparent fishing activity based on changes in vessel speed and direction. The algorithm classifies each AIS broadcast data point for these vessels as either apparently fishing or not fishing and shows the apparent fishing effort on the Global Fishing Watch map.[3]

Encounter events: Encounters may indicate potential transshipment or transfer activities between two vessels. Encounters can occur in GFW's vessel viewer between a carrier and fishing vessel or a fishing-support vessel and a fishing vessel. AIS data is used to calculate encounters based on the distance between the two vessels, the vessel speeds, and the duration in a given area. When two vessels are detected within 500 meters of each other for at least two hours and traveling at a median speed of less than 2 knots at least 10 kilometers from a coastal anchorage, an encounter event is logged.[4]

Loitering events: Loitering is when a single vessel exhibits behavior indicative of a potential encounter event. It is possible that loitering events do not indicate a potential transshipment. For example, a vessel may remain relatively stationary during events such as maintenance or while waiting outside the port for docking permission. AIS data is used to calculate loitering events based on a vessel's speed and its distance from shore. Loitering occurs when a carrier vessel travels at an average speed of less than 2 knots, while at least an average of 20 nautical miles from shore. Loitering events are not displayed for fishing vessels due to the challenge in distinguishing loitering from other low-speed operations related to fishing activity.[5]

Port visits: Movements in and out of a port are automatically detected by GFW and categorized according to four distinct types of events: port entry, port stop, port gap—a gap in AIS transmission while in port—and port exit. When at least two of these events occur, then a port visit is detected.[6]

Fish Habitat Explorer Dashboard

The second prototype dashboard was designed on the principle that if you can identify the preferred habitat of fish, fishing vessels are likely to be found in those areas as well. Extensive academic research has identified key parameters that define the ideal habitat for different fish species. These five essential parameters are water temperature, distance to land, chlorophyll production, and salinity. All of this data is publicly accessible in electronic format on the internet.

Previously, Coast Guard subject matter experts had developed workflows in ArcGIS Pro for about a dozen species in the three regions most relevant to the Coast Guard Atlantic area of operations. This work was transitioned to the ArcGIS Online platform with a relatively small amount of effort. The work was then expanded to a significantly larger scope by increasing the accuracy of the analysis, including additional analysis parameters, increasing the number of fish species to over 300, and increasing the geographic scope from three regions to the entire world.

The dashboard development work has provided the Coast Guard with several ways to integrate this important technology into its operations. The final transfer

from the RDC to the operators will complete the concept's journey from each of the three ArcGIS platforms that the Coast Guard supports and uses. The product was developed incrementally starting on the desktop/laptop platform by subject matter experts who developed the initial workflow. It was transitioned to the ArcGIS Online platform where the power of cloud computing was used to greatly expand the scope and depth of the data and make the results easily available to more users. It will be transferred to the ArcGIS Enterprise platform, where it will be used with additional information to assist the Coast Guard in its efforts to combat IUU fishing.

Powerful enterprise tools can be effectively leveraged to solve real-world problems large and small, both in the worlds of research and Coast Guard operations. The use cases discussed here show a repeatable process for the successful development of additional use cases.

About the author:
Jack Cline has worked for the Coast Guard for more than 40 years. He has served in many capacities including 21 years as a commissioned Coast Guard officer, 12 years as a civilian contractor, and 12 years as a researcher at the Coast Guard Research and Development Center specializing in data analysis.

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4. Ibid
5. Ibid
6. Ibid

Evolution of the Fish Habitat Forecast Explorer

Figure 1 is an image of the first version of the Fish Habitat Explorer. At this point, only a dozen species were available for selection in the search pane. Note that the green, yellow, red, and orange coloring have horizontal and vertical boundaries in some locations due to the incorporation of data from only three regions.

Figure 2 is an image of the second version of the Fish Habitat Explorer. The left pane of the dashboard contains filters for protected status, category, species grouping, minimum and maximum temperature, minimum, and maximum salinity. The filters allow the user to find the species of interest or analysis conditions more quickly.

The second panel from the left allows the selection of the individual species of interest. The top part of this panel searches only the species passing through the filters selected in the left pane. This flexible search capability facilitates quickly finding the information of interest to a broad user community.

The web map and dashboard will be transferred from the ArcGIS Online platform onto an ArcGIS Enterprise platform on the Coast Guard network for additional enhancement. Ultimately, the Fish Habitat Explorer technology will be used to assist Coast Guard units in the planning and execution of their IUU fishing mission.

Figure 1

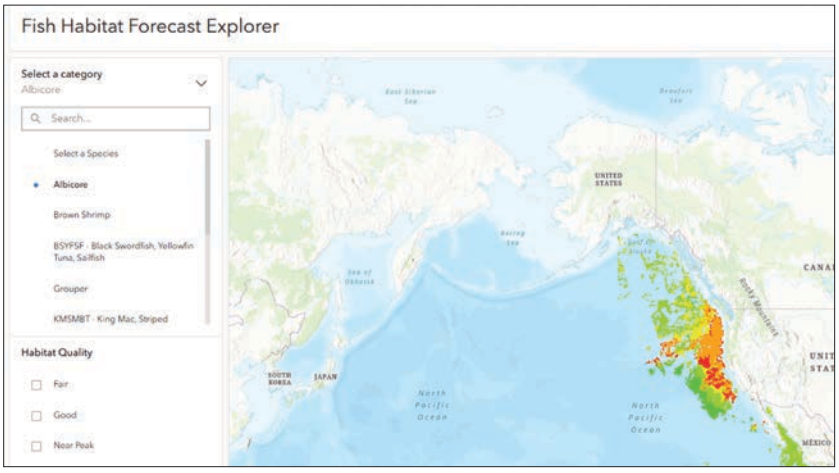
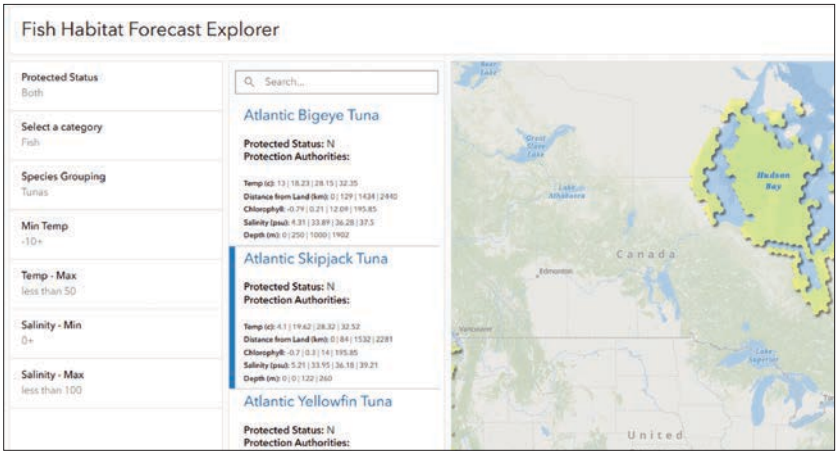


Figure 2



The Evolution of the Nationwide Automatic Identification System

Advancing maritime safety and domain awareness

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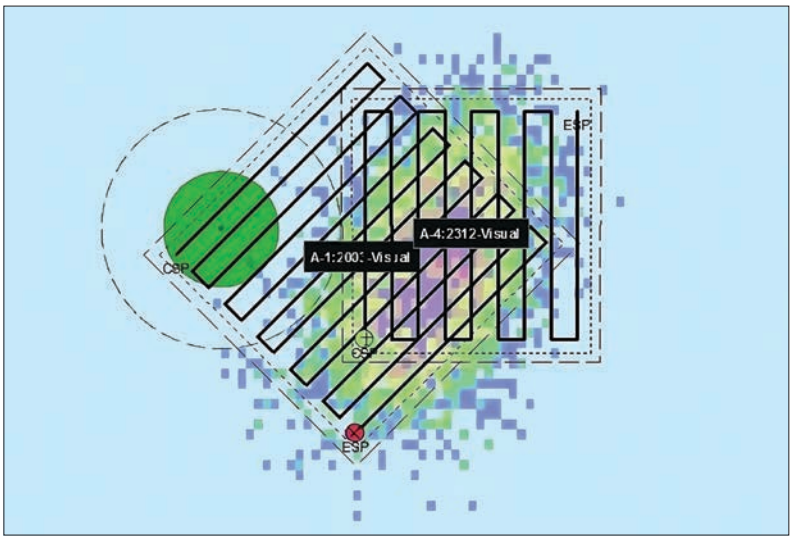
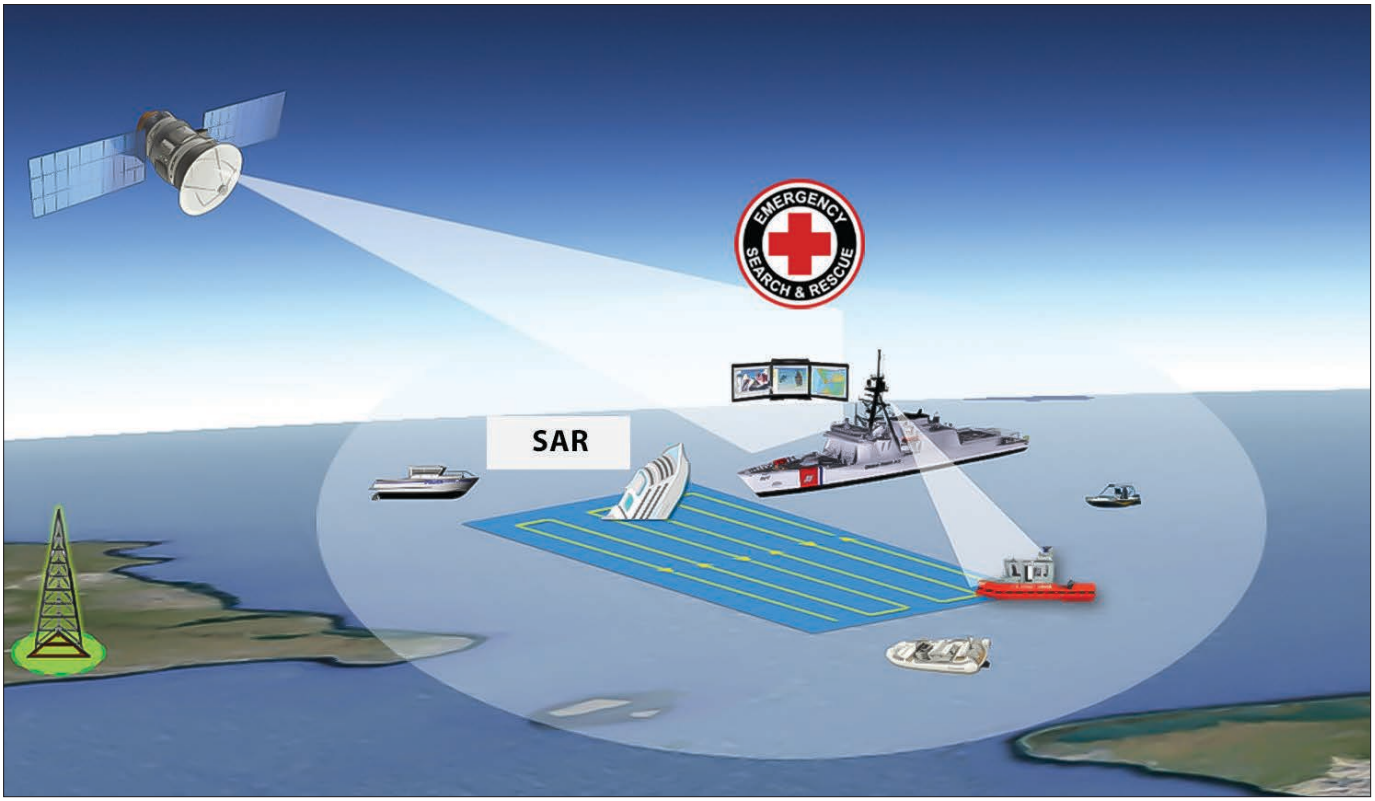
In the vast, ever-evolving world of maritime navigation, safety, and communication, the Coast Guard plays a pivotal role in ensuring the security and well-being of the maritime domain. Over the years, the Automatic Identification System (AIS) has emerged globally as a critical ship-to-ship collision avoidance and communication tool, enabling the sharing of position, speed, and other ship data through a very high frequency (VHF) data link network to maximize situational awareness and intentions of other mariners operating on waterways. The establishment of the Coast Guard's Nationwide Automatic Identification System has further strengthened maritime domain awareness (MDA) by consolidating and disseminating maritime AIS activity to support safety and security in U.S. coastal waters.

In an effort to maximize the utility of AIS beyond collision avoidance, the Coast Guard Research and Development Center (RDC) historically has evaluated and developed different methods of transmitting safety-at-sea messages on the AIS network. The Coast Guard's Office of Navigation Systems swiftly recognized the potential and created use cases for electronic or virtual aids to navigation and geographic notices. This initiative aimed to enhance communication with mariners via AIS and modernize how the Coast Guard conveys information about waterways. Western Rivers tugboat captains were prime customers of these two messages, as vessels with updated navigation software were able to receive AIS messages that contained information such as the approximate wait time to pass through a lock based on current vessel traffic. Knowing where their tugs were in the lock order, captains could adjust their speed to avoid lengthy hold times at the locks simply by viewing the AIS message. Other early uses of these messages were virtual aids to navigation on waterways like the Western Rivers where the channel can change daily. Virtual aids to navigation can be transmitted and their locations updated as shoals shift, eliminating the need to physically move traditional navigational aids like buoys and beacons.

As AIS has become more widely used and better understood, Coast Guard stakeholders have recognized



This graphic shows the search and rescue patterns conducted by Coast Guard assets 529 miles east of Virginia Beach, Virginia, in November 2019 to search for a mariner who entered the water but did not resurface. Two people who entered the water with the missing mariner were recovered by a Good Samaritan vessel that responded to the initial mayday call. Coast Guard graphic



Coast Guard search and rescue (SAR) response involves multimission stations, cutters, aircraft, and boats linked by communications networks. The VHF Data Exchange System may enhance the Coast Guard's ability to quickly exchange SAR data between assets involved in a search, including distress reports, information about the distress, assigned search patterns, and results of searches. Coast Guard graphic

its utility as a tool for supporting other missions. One example is the Coast Guard's interest in using AIS to transmit search and rescue (SAR) patterns directly to a vessel's navigation system. When the Coast Guard receives a SAR case, a Coast Guard watchstander develops a gridded search and rescue pattern that is optimized to reflect the last known position of the distressed mariner, environmental conditions such as wind and current, and available Coast Guard assets, like boats, cutters, rotary, and fixed-wing aircraft. This direct transfer of SAR pattern data via AIS greatly reduces the amount of time crewmembers spend manually entering coordinates and reduces the risk of data entry errors. Other examples of Coast Guard and port partner use cases include encrypted chat, Coast Guard and partner agency asset tracking, and target of interest messages used for law enforcement activities.

However, with the increasing volume of marine vessels using AIS for collision avoidance and other novel uses, growing demand has led to an overload of the two AIS channels currently used for communication, which challenges the system. To address this issue, international organizations including the International Telecommunication Union, the International Maritime Organization (IMO), and the International Association of Marine Aids to Navigation and Lighthouse Authorities, have been developing standards for the next generation of AIS.

Known as the VHF Data Exchange System, or VDES, this advanced maritime communication technology is designed to support the IMO's electronic navigation goals. Using terrestrial and satellite radio communication links in the VHF maritime mobile band, VDES enables global interoperable digital data exchange between ships, between ships and shore, and between ships and satellite. VDES builds upon the original capabilities of AIS, addressing the increasing requirements for data exchange between ships and shore and using the VHF radio spectrum more effectively and efficiently.

Since 2020, the RDC has evaluated VDES through the center's Project 8703 titled, Evaluation and Testing of VDES Impacts on the AIS. The project builds on the RDC's foundational knowledge and years of prior AIS research, helping to inform Coast Guard stakeholders on the potential benefits of adopting VDES in the future for use within the Marine Transportation System.

The RDC team identified several notable benefits of transitioning from AIS to VDES, including:

- VDES (VDE-TER) offers increased capacity for

data communications, up to 32 times the capacity of AIS, making it more suited for handling the ever-growing volume of marine vessel data and communications.
- VDES (VDE-SAT) provides extended coverage, including the Arctic, ensuring seamless communication in remote, hard-to-reach regions.
- VDES allows for the integration of cybersecurity measures, safeguarding maritime communications and data exchange from malicious activities.
- VDES can provide backup positioning navigation and timing for Global Navigation Satellite System-denied environments by de-spoofing AIS through its ranging mode (R-Mode).
- Forward and backward compatibility with legacy AIS.

The Four Major Components of VDES

To accomplish these additional benefits without consuming valuable bandwidth on AIS channels, VDES consists of four individual components/subsystems, each operating in a different frequency range within the VHF maritime mobile band. These components are:

1. VDES retains original AIS channels primarily for collision avoidance and remains compatible with existing AIS systems.
2. VDES adds two new channels for application-specific messages (ASM), providing additional bandwidth for data exchange between ships, and between ships and shore.
3. VDES introduces a high-speed terrestrial data exchange channel using VDE-TER, which provides faster and more efficient data communications between ships and shore stations.
4. VDES also includes a satellite data exchange component, using VDE-SAT channels for global interoperable two-way communication between ships and satellites and satellites and shore stations. This allows for increased range and coverage, including in remote regions away from land-based coverage such as the Arctic region.

The VDES uses a combination of these four components to provide a robust, high-capacity communication network for maritime communication needs. The frequency distribution ensures compatibility with existing AIS systems while providing additional capacity, faster data rates, and extended range for various maritime applications.

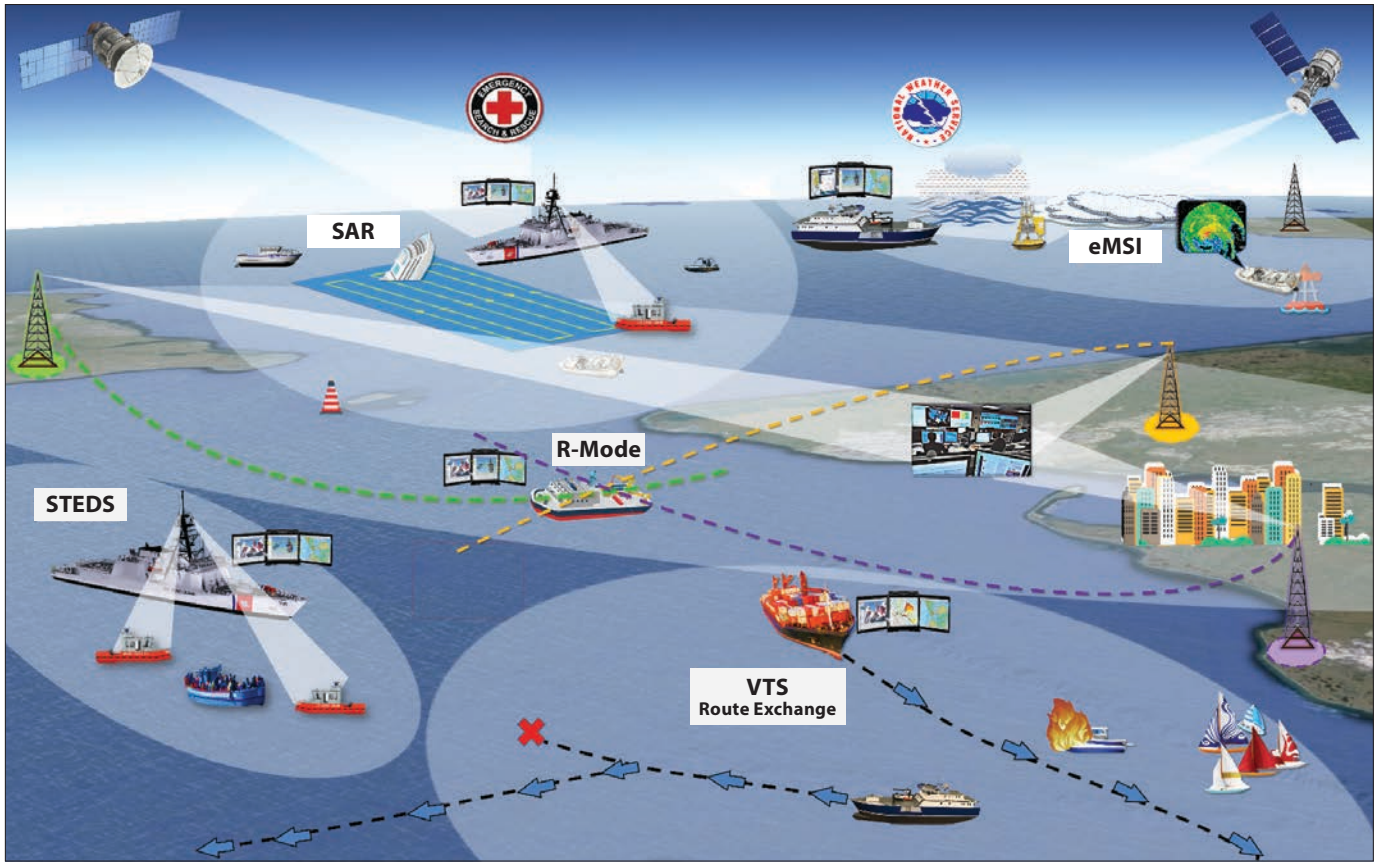
Coast Guard VDES Use Cases

Building on the RDC's previous investigations on the utility of AIS for other applications, the RDC team identified multiple operational use cases that may significantly enhance maritime safety and domain awareness for Coast Guard and mariners.

1. VDES can facilitate ship routing and route exchange services, through the ASM channels, allowing for efficient and accurate communication of routes between vessels and shore stations. This can help optimize vessel traffic flow, reduce collision risk, and minimize environmental impacts.
2. VDES can enable the sharing of enhanced Marine Safety Information (MSI) and meteorological information between ships and shore stations. This can improve situational awareness, enabling mariners to make informed decisions based on the most up-to-date information available.
3. VDES can support SAR operations by providing accurate position, navigation, and communication capabilities. This can help rescue teams locate and extract mariners in distress more efficiently, saving valuable time and increasing the likelihood of successful rescue operations.
4. Using the Sensitive but Unclassified Tactical Exchange Display System (STEDS), VDES can enable the exchange of sensitive but unclassified tactical information between ships and shore stations which can help improve coordination and support maritime security operations.
5. VDES can enable advanced maritime cybersecurity measures, helping protect maritime communications from malicious activities such as hacking, spoofing, and jamming. This can help ensure the integrity, confidentiality, and availability of maritime communications, which is essential for maintaining maritime safety and security.

What is R-Mode?

R-Mode is the term used for ranging using signals of opportunity. The receiver measures the time of arrival of a signal, compares it to the time of transmission to get a travel time, and converts this to the range to the transmitter. If signals from multiple transmitters can be received, then a position can be estimated. R-Mode ensures that positioning, navigation, and timing are maintained, even when Global Navigation Satellite System is denied due to intentional or unintentional causes.



The Coast Guard Research and Development Center team highlighted five VDES use cases that may enhance how the Coast Guard executes its missions and delivers information to mariners, including: improved vessel traffic services (VTS) and route exchange between ships; enhanced delivery of marine safety information (eMSI); the use of VDES ranging mode (R-Mode); SAR information; and the use of Sensitive but Unclassified Tactical Exchange Display System (STEDS) to help improve coordination and support maritime security operations. Coast Guard graphic

These operational use cases highlight a few potential ways VDES could significantly build upon AIS to improve maritime safety and domain awareness.

Evaluation of VDES

Since the RDC first began the VDES project in 2020, the team has closely monitored the development of international VDES standards and subsequent industrial implementation of those standards in new VDES equipment. As VDES transceiver equipment first became available in the market, the RDC initiated its first field test in the New London, Connecticut, area in 2020 and 2021. The first test focused on assessing the use and performance of ASM channels for sending sensitive but unclassified messages instead of using the two AIS channels. The RDC prototyped an ASM channel implementation that allowed Coast Guard boats and cutters to send secure messages over the ASM channel to the AIS channel.

The RDC installed VDES base station sites at Fishers Island, New York, and in New London to support testing and data collection. The RDC also installed VDES equipment on several local Coast Guard assets, including the U.S. Coast Guard Academy's training vessel *Shuman*, two operational Coast Guard units, and two small boats owned by the RDC. The test successfully captured target-of-interest messages and vessel position reports using both AIS and ASM channels.

The RDC's second VDES field test from 2021 to 2022 and had four primary goals:

1. Assessing the ability of VDES, specifically the VDE-TER channels, to meet the Coast Guard's internal and external communication needs.
2. Collecting data to quantify transmission range and message reception rates.
3. Identifying any operational issues that need to be resolved before Coast Guard-wide implementation.
4. Evaluating the state of the market and interoperability of equipment from multiple vendors.

Both field tests were successful in demonstrating the functionality, benefits, and limitations of the ASM and VDE-TER components of the system given the current implementation of international standards. The team

produced three technical reports, including a technology roadmap and two summary reports on each field test respectively. The reports provided Coast Guard stakeholders with early insights on the potential adoption of VDES in the future.

Current Testing and Future Outlook of VDES

Ranging Mode Field Evaluation

The RDC team is currently evaluating another significant feature of interest to the Coast Guard called R-Mode. In support of this testing, the RDC team established three static base stations in 2024 to form a triangular coverage area within the greater New London area and its surrounding waters to transmit and receive VDES R-Mode data messages. The RDC team also established VDES R-Mode "mobile" stations on local test vessels to facilitate continuous data collection within the overlapping coverage area formed by the three base stations. The RDC team plans to use these mobile sites located within the overlapping coverage area to collect data through the end of 2025 to assess the initial implementation and performance of R-Mode signals in VDES.

VDES Satellite

The RDC team also plans to evaluate one of the last major components of the system in 2025, VDE-SAT, which recently achieved initial operating capability with the launch of several VDES capable "test" satellites. More launches are planned in the future to increase global coverage. The project seeks to evaluate the capabilities and limitations of using VDE-SAT to communicate ASM and MSI with vessels operating in polar regions, offshore, or other inshore regions with limited to no VHF coverage, like the Western Rivers.

VDES represents the next generation of AIS. Besides operating on the four AIS channels, it will provide 12 additional digital communication channels—two for ASM, four for VDE-TER, and six for VDE-SAT—greatly increasing marine VHF-FM data communications. With the recent launch of several VDES satellites, the VDE-SAT component may offer an effective means for the Coast Guard to broaden STEDS communication and extend its range beyond terrestrial coverage, including areas like the polar regions, with limited to no coverage. VDE-SAT may improve the ability of both the Coast Guard and mariners to exchange MSI seamlessly across maritime boundaries to promote safe and efficient navigation and to enhance the Coast Guard's maritime domain awareness in remote areas.

A successful evaluation of VDE-SAT will demonstrate the capabilities and limitations of transmitting MSI on the satellite channels, as compared to the current AIS channels, and other communications alternatives. The evaluation will provide Coast Guard decision-makers with supplementary information on VDE-SAT to help inform a decision on potential implementation of VDES as a whole and future implications for the maritime industry. An evaluation of VDE-SAT will also allow the Coast Guard to continue to strengthen its collaboration with international partners and industry to further develop and understand VDES.

As the maritime domain continues to present navigational challenges, the Coast Guard remains committed to ensuring maritime safety and domain awareness. The RDC's historical and ongoing AIS and VDES research continues to grow the body of knowledge about these technologies and maximize their utility as next-generation MDA tools. These efforts demonstrate a commitment to driving innovation and advancements in maritime communication technology to enhance MDA and meet the evolving needs of maritime stakeholders. By embracing VDES and its associated benefits, the Coast Guard can continue to safeguard the vast maritime expanse and maintain the highest standards of maritime safety and security.

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LCDR Ryan Cassidy is a 2010 graduate of the U.S. Coast Guard Academy. A career MH-65 pilot, he served as an aircraft commander and instructor pilot in both the search and rescue and rotary wing air intercept missions. He holds master's degrees in information systems and business administration from the University of Maine and is the project manager for the Coast Guard Research and Development Center's evaluation of VDES effort.

James Spilsbury has been a project manager and physical scientist at the Coast Guard Research and Development Center for five years. He holds a bachelor's degree in marine science from the University of Maine and master's degrees in oceanography and business administration from the University of Rhode Island. He is also a Coast Guard-licensed boat captain 100 ton, inland.

Sean Lester is a career Coast Guard MH-60 pilot and a 1991 graduate of the U.S. Coast Guard Academy. He served a tour underway on the CGC Gallatin *as the navigation officer. After flight school, Lester flew tours in Clearwater, Florida, and Sitka, Alaska. He began his career in research as an active-duty lieutenant commander assigned to the Coast Guard Research and Development Center, where he extended tours and retired from active duty. He now he serves as the aviation branch chief focusing on uncrewed aerial systems and autonomy research.*

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The Role of Research in National Incident Response

by Scott Fields
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Research and Development Center
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Over the past five decades, the Coast Guard Research and Development Center (RDC) has been instrumental in advancing maritime safety and environmental protection. The RDC primarily focuses on applied research with Technology Readiness Level (TRL) 5 and higher. One of the RDC's key strengths is its ability to remain agile and innovative in its research efforts. This flexibility has been critical in responding to incidents of national significance over the past 50 years and adapting to new challenges.

Monumental events like the *Argo Merchant* oil spill, the *Exxon Valdez* disaster, the September 11 attacks, Hurricane Katrina, and the *Deepwater Horizon* spill demonstrate the RDC's adaptability and flexibility to redirect research efforts and harness technology. Each of these incidents resulted in new response strategies, techniques, or equipment.

The Argo Merchant

In December 1976, the *Argo Merchant*, a tanker carrying crude oil, ran aground off the coast of Massachusetts, resulting in a massive spill of more than 7 million gallons of oil into the Atlantic Ocean. This incident marked a pivotal moment for the RDC, catalyzing its focus on oil spill response and cleanup technologies, including the development of several innovative solutions, including:

Oil Identification System:
Developed during the mid-1970s at the RDC, the Oil Identification System (OIS) is based on a multimethod approach to "fingerprinting" oils. OIS is designed to determine the unique, intrinsic chemical properties of oils via analytical techniques and establish whether a common source relationship exists between samples of spilled oil and samples of oil from a suspected source. Using this process, the lab was able to determine that the oil spilled from the rig was from a U.S. source, helping to hold accountable the party responsible for the spill. In 1978, the Central Oil Identification Laboratory (COIL) was established as the operating facility to implement the OIS. In 1988, COIL was renamed the Marine Safety Laboratories.

Oil Booms:
The Oil Boom, a specialized containment boom designed

On December 15, 1976, the Liberian tanker *Argo Merchant* ran aground on Nantucket Shoals, off the Massachusetts coast, in high winds and 10-foot seas. Its destination was Salem, Massachusetts, where the tanker was scheduled to deliver fuel to a local power plant. National Oceanic and Atmospheric Administration photo

to contain and control oil spills, was introduced. This technology remains a fundamental tool in oil spill response.

Exxon Valdez

The March 1989 *Exxon Valdez* spill, which released more than 11 million gallons of oil into Prince William Sound off the coast of Alaska, was one of the largest environmental disasters in U.S. history. The RDC's response to the catastrophe was crucial in mitigating its impact and advancing spill response technologies.

The RDC made significant progress in addressing the various technological needs to enhance Coast Guard oil spill response capabilities and further the development of systems and equipment that can be used by the Coast Guard, other oil spill response agencies, and private industry. The concerted RDC effort was undertaken following the *Exxon Valdez* oil spill and in response to the research and development provisions in the Oil Pollution Act of 1990. Accomplishments were made in four key technology focus areas, including:

Spill Response Planning and Management:
Accomplishments include the development of computer-based decision tools to facilitate contingency planning and response management, and the development of computer-based systems to enhance the Coast Guard's oil spill training and preparedness evaluation program.

Oil Spill Detection and Surveillance:
Oil spill remote sensing systems like synthetic aperture radar, infrared sensors, a laser fluorosensor, and a frequency scanning radiometer were developed, evaluated in a laboratory, and tested under field conditions to define performance characteristics.

Vessel Salvage and Onboard Containment:
Technology assessment studies were undertaken to assess several considerations including:

- The effectiveness of double-hull tankers and barges in preventing spills
- The capability of remote sensing systems and remotely operated vehicles in determining tanker damage and stability
- The technical feasibility and operational advisability of tanker self-help countermeasures
- The feasibility of upgrading the Coast Guard's tanker offloading capability

Spilled Oil Cleanup and Alternative Countermeasures

The RDC developed an integrated oil spill mechanical recovery system for Coast Guard buoy tenders, completed an assessment of systems and techniques for recovering oil in fast-current environments, and the further development of in-situ burning as a response countermeasure. The latter included both the testing of fire-resistant booms at the RDC Fire Safety Test Detachment on Alabama's Little Sand Island and the development of tactics and decision tools to support the implementation of in-situ burning in the field.

Flexibility is Critical to the Coast Guard's Success

Remaining adaptable is necessary for several reasons.

Addressing Emerging Challenges:
Changing times and notable national events can create new challenges and opportunities that require the development of new technologies and solutions. By redirecting research efforts, researchers can focus on addressing these emerging challenges and opportunities, driving innovation and societal progress.

Responding to National Needs:
In times of national crisis or emergency, redirecting research efforts can be critical for addressing national needs. The RDC has always been a flexible organization adapting to the Coast Guard's strategic needs.

Maximizing Resources:
Redirecting research efforts can also help maximize resources by focusing them on the most pressing challenges and opportunities. By prioritizing research efforts based on current needs and conditions, researchers can ensure that resources are being used effectively and efficiently.

Staying Relevant:
Finally, the ability to redirect research efforts in response to changing times and national events can help organizations stay relevant. By quickly pivoting to address emerging challenges and opportunities, the RDC can maintain its relevance and continue to drive progress. This is especially true, as evidenced during the *Deepwater Horizon* event when industry and inventors shared capabilities that they believed would support the national response. The RDC engaged with each and reviewed capabilities allowing the response teams to concentrate on addressing this national event.

September 11 Attacks

The October 20, 2000, attack on USS *Cole* while refueling in Yemen's Aden Harbor, which resulted in the deaths of 17 sailors, demonstrated the United States' vulnerability to different threat vectors, including maritime attacks. The 9/11 terrorist attacks brought new challenges to maritime security and underscored the need for improved maritime domain awareness (MDA). In response to 9/11, the RDC refocused its research portfolio on enhancing its capabilities to address these emerging threats including:

Maritime Domain Awareness:
The RDC exploited the Automatic Identification System (AIS) deigned for ship-to-ship collision avoidance and developed a national real-time ship tracking and maritime monitoring system known as Nationwide Automated Identification System (NAIS).

Port Security Surveillance Systems:
After the attacks, Coast Guard operations underwent significant changes, with a focus on port security. Persistent patrols were needed to ensure security and protection of critical maritime infrastructure. To improve maritime domain awareness and reduce the impact on the number of hours boats are on the water and operational, the RDC tested the Port Surveillance System (PSS), which included commercial-off-the-shelf sensor systems and a Navy-developed waterside surveillance system. The PSS sensors included a commercial small boat radar, a long-range cooled IR camera, a short-range uncooled IR camera, and a daylight TV camera. The system was able to further evaluate and classify a detected contact up to one nautical mile in clear day and night environments. The analysis of this system highlighted a significant improvement in coverage, which is critical to domain awareness.

Hurricane Katrina

Hurricane Katrina, which struck the Gulf Coast in August 2005, revealed significant gaps in disaster response and environmental protection technologies. The RDC's response included:

Enhanced Search and Rescue Technologies:
Uncrewed aerial vehicles and autonomous underwater vehicles were integrated for search and rescue operations and damage assessments. These technologies provide real-time data and support efficient disaster response.

Support to the Unified Command:
The RDC's efforts directly supported the operational Coast Guard commander (Atlantic Area) and the Coast Guard District 8's primary tactical commander.

Deepwater Horizon

The April 2010 *Deepwater Horizon* oil spill was one of the largest environmental disasters in history, requiring a rapid and effective response. The RDC played a key role in evaluating thousands of public-proposed potential cleanup technologies to support the oil spill response.

Interagency Alternative Technology Assessment Program:
The scope, magnitude, and duration of the *Deepwater Horizon* spill led to the submission of tens of thousands of ideas for new or improved oil spill control and response technologies by the public, industry, universities, and nongovernmental organizations. Leadership in the various parts of the response organization recognized the need for rapid assessment of these ideas early in the response as well as a related need to keep the submitters from interfering with response organizations. In an emergency, people want to help, and the *Deepwater Horizon* incident drew a significant response, however many of the ideas were not well-suited to the needs of the response.

The Interagency Alternative Technology Assessment Program (IATAP) formed two groups to meet these

A crane barge serves as an anchor for a boom which was set up to prevent oil from making its way to Perdido Beach, Alabama, in Alabama, in June 2010 following the *Deepwater Horizon* oil spill in the Gulf of Mexico in April 2010. Coast Guard photo by Petty Officer 1st Class Rachel Polish

needs. The federal on-scene coordinator at the Unified Area Command formed the Alternative Response Technologies (ART). The ART collected approximately 400,000 submitted technical ideas, suggestions, and proposals. Approximately 100 suggestions were formally evaluated and/or field tested and approximately 25 of those saw significant use during response operations, including the Ocean Therapy oil/water separator, a heavy oil skimming system, and a fast water oil boom deployment system.

The *Deepwater Horizon* incident saw the first-ever designation of a national incident commander (NIC). The National Contingency Plan specified the role to communicate with affected parties and the public and to coordinate federal, state, local, and international resources at the national level. One element of this staff was the Interagency Solutions Group (IASG), which met the president's mandate for the NIC to oversee the entire incident, including coordination of federal agencies participating in the response.

As issues arose, the IASG established interagency subgroups to address them, including the IATAP to collect and analyze thousands of response recommendations from all sources. The formation of the IATAP was necessary to address the ART, which was overwhelmed with a large number of ideas from the public, industries, and universities. The process created in the IATAP addressed the feedback mechanism to innovators from a perceived nonbiased identity and improved public affairs communications.

The NIC formed the assessment group within the solutions group at the RDC in May 2010 to ensure a fair and systematic government-managed process to solicit, screen, and evaluate technologies suggested in support of *Deepwater Horizon* spill response activities by the public, government agencies, and academia. The RDC quickly stood up and supported the IATAP by establishing an incident command structure including sections for operations, planning, contracting, and logistics. The IATAP consisted of representatives and assessment teams from several federal agencies.

Hurricane Isaac

In anticipation of Hurricane Isaac making landfall in Louisiana and Mississippi in 2012, the RDC provided several portable AIS Go-Kits to the Coast Guard Office of Navigation, which had the ability to transmit virtual channel lines and aids to navigation while Coast Guard assets reconstituted the channels. One of the Go-Kits was deployed to a buoy tender, which allowed maximum coverage of the transmissions to ships in the area.

The AIS Go-Kits allowed for real-world tracking of Coast Guard assets in a simple, inexpensive manner using off-the-shelf technology.

Francis Scott Key Bridge Collapse

On March 26, 2024, the main spans and three approach spans of the Francis Scott Key Bridge collapsed into the Patapsco River in Maryland after the Panama-flagged container ship M/V *Dali* struck one of its piers. In response, the RDC quickly readied to support the unified command and provide a portable Vessel Traffic System consisting of fused data, including AIS, radar, and an automated camera tracking system. This provided the ability to monitor the port and safely move large cargo vessels ensuring the flow of commerce in and out of the port. The RDC further supported the board of inquiry for the Key Bridge collapse with risk analysis expertise.

Conclusion

The RDC has made significant contributions to maritime safety and environmental protection over the past 50 years. From early innovations in oil spill response following the *Argo Merchant* incident to cutting-edge technologies developed in response to the *Deepwater Horizon* disaster, the RDC's commitment to agility and technological advancement has been unwavering.

The RDC's ability to quickly adapt and respond to new challenges—whether environmental, security-related, or disaster-driven—underscores its vital role in safeguarding our nation's coasts and waterways. As we look to the future, the RDC's ongoing dedication to research and development will continue to play a crucial role in addressing emerging threats and ensuring the safety and security of our maritime regions.

About the authors:

Retired Coast Guard CDRs Scott Fields and Sean Lester are both branch chiefs at the Coast Guard Research and Development Center. Fields leads the rapid reaction technology branch and Lester leads the aviation branch.

SAR Research

How lateral range curves improve rescues

by Grace Python
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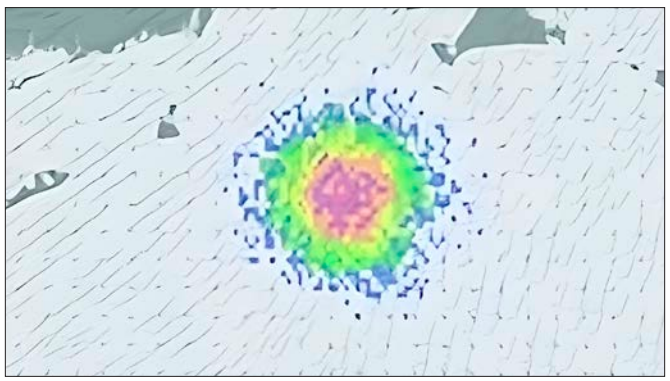
U.S. Code states that the Coast Guard "shall develop, establish, maintain and operate SAR facilities and may render aid to distressed persons and protect and save property on and under the high seas and waters subject to the jurisdiction of the United States."

The Coast Guard's jurisdiction encompasses more than 3.4 million nautical square miles in which the service may conduct search and rescue (SAR) operations for persons in distress. On an average day, the Coast Guard responds to 45 SAR cases. Some of these cases require assistance, but there is no search involved—an individual requires a medical evacuation, or a vessel is disabled and needs help.

For some cases, there is uncertainty about the exact location or condition of the people in distress, which could require a search across an expansive area. For example, a vessel taking on water is able to send a mayday call with an approximate location before communications are lost. Even as the Coast Guard immediately initiates a response, there is uncertainty regarding the vessel's exact position when it went into distress and the object the response team is searching for. Are there individuals still on the vessel or did they abandon ship to a life raft? Perhaps they are in the water, and if they are in the water, are they wearing personal floatation devices? Each of these potential search objects will drift in unique ways based on their geometry and the winds and currents in their area.



This image shows an example of the probability distribution of where an object is likely to be at a specific time given all the uncertainty associated with a case, where the purple sections in the center are more likely, and blue sections are less likely. Coast Guard graphic

To deal with all these aspects of uncertainty, identify the likely location or locations of objects, and plan effective searches, the Coast Guard uses the Search and Rescue Optimal Planning System (SAROPS). Developed by the Coast Guard, SAROPS is a tool that simulates thousands of possible particles, each representing an individual search object, to account for position and time uncertainty associated with the distress and the winds and currents in an area. This information is used to determine the probability that an object will be in a given location at a given time.

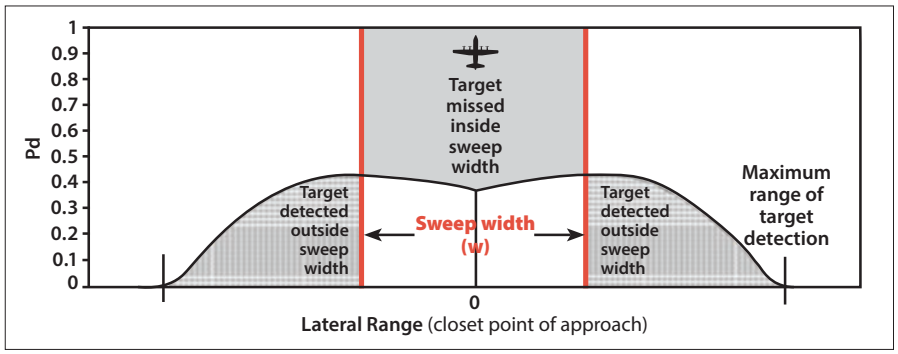
Once probable locations are identified, SAROPS is used to determine an effective pattern for searching the area of interest with the available search assets including those from Coast Guard, other government agencies, and other boaters. Developing a search pattern requires an understanding of how effective any search is at finding the objects of interest.

As a simplified example, consider mowing your lawn. Lawns are often mowed in long, parallel lines because the mower is 100% effective along the path it travels. To achieve efficient coverage of the entire lawn, the distance between these parallel lines should match the length of the mower's blade. This is a well-defined example; the mower is 100% effective where it is used and 0% effective everywhere else.

However, sensors used while searching during a SAR case are rarely 100% effective out to a given range. Sensor effectiveness generally decreases as the distance between the sensor and the search object increases, but that rate of decrease is dependent on numerous factors including:

- The type and size of search object(s)
- Environmental conditions on the scene
- The type of search asset employed—helicopter, fixed-wing aircraft, small boat, or cutter

All these factors are accounted for through a lateral



Since the late 1970s, the Coast Guard Research and Development Center has developed lateral range curves, like those shown here, and their corresponding sweep widths. Coast Guard graphic

range curve (LRC). The lateral range curve quantifies the probability of detecting the search object as a function of the range between the search asset and the object. All variables that impact probability of detection other than range are accounted for within the shape of the LRC. Therefore, a change to any variable will result in a different LRC.

The Coast Guard Research and Development Center (RDC) has developed LRCs and associated sweep widths that have been used by the service and international maritime SAR community since the late 1970s. Historically, the development of LRCs has largely been based on extensive field experiments. Throughout these experiments, search objects of interest—simulated people in the water, life rafts, and small boats—were anchored in an area and search assets would proceed through the area along a specified path. Data were collected regarding several factors, including:

- The search asset and sensor—was it conducted with naked eye or night vision goggles?
- Search parameters like speed and altitude of the search asset
- The search object, including its size
- Environmental conditions like wind speed and meteorological visibility
- When the search assets detected objects throughout the search pattern

All collected data were then analyzed to calculate the necessary LRCs.

There are more than a dozen variables which can impact an LRC, many of which, like environmental conditions, cannot be fully controlled while conducting field experiments. Therefore, collecting sufficient data in each of the possible combinations of variables is not feasible. Early approaches to compute LRCs defined methods of interpolating and extrapolating the data collected in the field to the broader expanse of variables. While effective, this approach still requires thousands of data points across varied environmental conditions per sensor, search asset, and object combination. Collecting this amount of data is made even more challenging by the rate at which new sensors are available and integrated with Coast Guard assets.

Modernizing Lateral Range Curve Development

In recent years, the RDC has examined means of reducing the demand for empirical data when computing LRCs. Nearly 20 commercial and government off-the-shelf, physics-based models were evaluated. These tools, for either radar or electro-optic/infrared (EOIR) sensors, were capable of computing either instantaneous probability of detection as a function of range or information about how the search object appears in the environment. For example, to predict effectiveness of an infrared sensor it is necessary to know the amount of heat emitted by an object within the environment.

Given that no model inherently computes LRCs, the RDC has established methods for translating the aspect-dependent—detectability of a vessel viewed head-on compared to viewed from the side is very different—instantaneous probability of detection as a function of range into an LRC. These previous efforts have defined a new process that uses physics-based models to predict the lateral range curves of human-in-the-loop sensors, and leverages small, targeted field experiments to validate the predictions. The RDC's Data, Modeling, & Decision Support Research Program is continuing to evaluate this new approach to calculating LRCs, with plans to validate the physics-based models against empirical data collected in accordance with the historical approach.

Accurate LRCs are a crucial SAROPS input, enabling the Coast Guard to maximize its probability of finding mariners in distress as effectively as possible.

About the authors:

Grace Python serves as an operations research analyst in the Coast Guard Office of Search and Rescue (Coast Guard-SAR) Policy Division. Prior to joining Coast Guard-SAR, she spent seven years at the Coast Guard Research and Development Center as an operations research analyst, predominantly conducting SAR-related research.

LT Ardy Effendi graduated from the U.S. Coast Guard Academy in 2016 and served aboard multiple Coast Guard cutters and as commanding officer of the Coast Guard Patrol Forces Southwest Asia cutter relief crew. After completing his master's degree in operations research at North Carolina State University in 2020, he reported to the Coast Guard Research and Development Center.

The International Implications of Research

Employing simulation to determine the duration of an Arctic rescue

by Christine Mahoney
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Maritime emergencies in the Arctic present unique challenges to mariners and search and rescue (SAR) response agencies. Ships that navigate Arctic waters transit sparsely populated routes with severe weather conditions, numerous hazards to navigation—primarily ice—and limited means for communication. Agencies responding to Arctic maritime disasters often have limited or seasonal resources, less permanent infrastructure, and cover vast areas of responsibility (AOR). Due to these realities, the time distressed mariners in the Arctic wait for assistance is often longer than a comparable emergency taking place at a lower latitude.

The International Maritime Organization (IMO) Polar Code regulates ships subject to the International Conventions of Safety of Life at Sea and Prevention of Pollution from Ships operating in Arctic and Antarctic waters. The Polar Code requires that equipment and supplies required to sustain life in a maritime emergency must be functional in the polar environment for the maximum expected time of rescue (METR), which the code mandates "shall never be less than five days."[1]

The Polar Code also requires ship owners to establish the METR through an operational assessment. The development of the five-day baseline requirement is not well documented and there is sparse guidance and no enforceable standard for determining METR.[2] It is likely that many Arctic routes will face an event that exceeds five days, but there is little preventing companies from assessing a five-day expected response time due to the lack of a standardized, accepted, and repeatable process to calculate METR. A company calculating a time that is insufficient for a given vessel's route would place its crew and passengers at significant risk.

This project focused on the U.S. Arctic AOR and developed a simulation model to study six conceivable Arctic emergency scenarios as determined by a panel of subject matter experts.[3] The simulation evaluated the scenario response time over several iterations to calculate an interval containing the expected time until the last victim is recovered from the SAR event. These six scenarios take place between the months of June and October, range in victim counts from eight to 320, and extend from the Chukchi and Beaufort Seas north of Alaska to the North Pole.

A vessel of opportunity is one that is close enough to an incident to potentially render aid before a SAR response team can arrive.

The Simulation

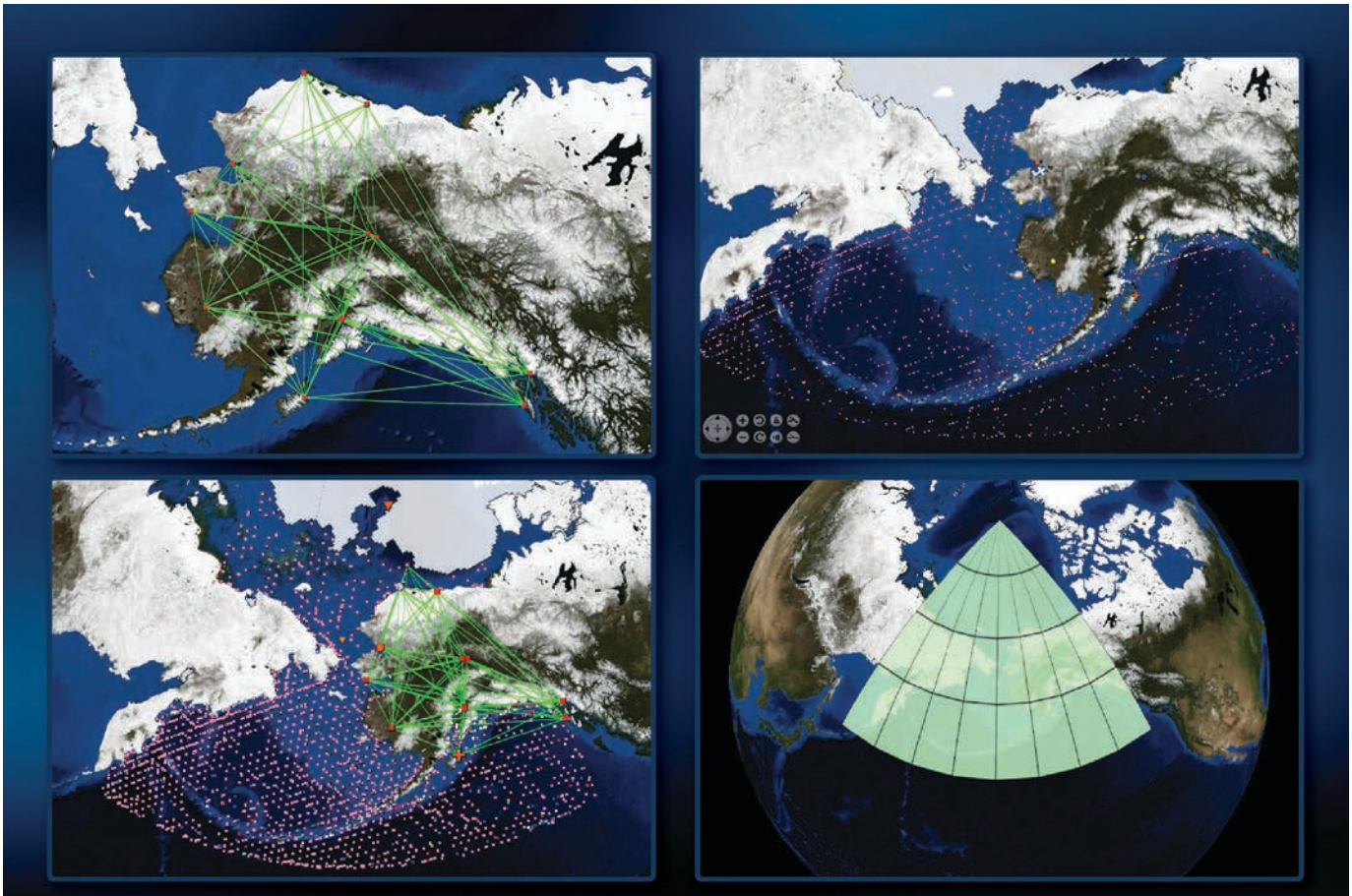
The simulation was created using open-source software, Repast Simphony, and incorporates historical traffic patterns, ice extent, weather data, and the siting of seasonally available assets to run the scenarios.

The project collected more than three years—114,490,900 records—of automatic identification system (AIS) data transiting the area of interest to model the general traffic. The data was analyzed to produce track lines, or vessel routes, that provided insight into where vessels travel throughout the year. From the data, seasonal probability distributions were derived to generate realistic vessel traffic in the appropriate routes throughout the

year in the simulation. These vessels could be included in a SAR response scenario as vessels of opportunity if they were close enough to the incident.

Arctic ice is particularly known for its variability throughout a year, as well as from year to year. To capture this reality as realistically as possible in the simulation, the project relied on the U.S. National Ice Center's repository of Arctic ice extent files. Three years of mean monthly ice extent files were loaded into the simulation. Every time a simulation run is generated, the range of years is randomly selected, and the appropriate month's ice extent shapefile is loaded into the simulation. This simulation used 2019 to 2021. The randomly selected time range allows the simulation to have a realistic and seasonally accurate ice extent with variability between scenario runs. The ice extent limits the routes general vessels and response vessels can travel, with the exception of vessels/response vessels with icebreaking capability.

Weather is one of the largest factors impacting how quickly response assets can arrive on the scene of a SAR event. It is specifically listed as a particular hazard in the IMO Polar Code and affects both surface and air assets.[4] The number of weather factors the project included in the simulation was limited by data availability and time. For this study, sea state, wind, and cloud cover were included. The weather data was pulled from Climate Data Store (CDS) ERA5 Hourly Single Levels dataset,[5] and, to maintain consistency with the AIS data pull, all weather data pulled and analyzed was from 2019 to 2021. The pull allowed users to select the meteorological metric of interest over a period and a particular latitude by longitude section in 10-degree by 10-degree regions. The area of interest extended from 50 to 90 degrees north and 130 degrees west to 140 degrees east to create 32 distinct data pulls used to calculate the weather metrics. These 32 areas were created as "weather zones" in the simulation and have an associated probability distribution for each weather metric by season, for a total of 384 distinct distributions in the simulation. Weather in the simulation is updated every four hours according to the simulation month's seasonal probability distribution for each zone.



Maps used in the simulations show, clockwise from top left, a simulation airport network; ice extent; weather zones; and a simulation case for responding to a search and rescue run. Coast Guard images by Christine Mahoney

The sea state classifies the height of waves into nine different levels ranging from sea state 0, or calm with no swell, to sea state 9, or phenomenal with 46-foot swells.[6] The sea state impacts how fast a surface asset can transit in the simulation.

The wind speed has a direct impact on whether response aircraft can launch on a mission in the simulation. For fixed-wing assets, towing aircraft from the hangar can become hazardous in high winds and rotary assets have wind restrictions for starting and stopping their rotors. In the real world, wind also has an impact on surface assets, as well as victim recovery efforts, but those effects were not included in this simulation.

The cloud ceiling directly impacts whether fixed-wing assets can air drop equipment and supplies to the scene of a SAR event. If the ceiling is too low, the crew cannot visualize the event, which prevents the drop. The CDS ERA5 dataset provided data on the cloud base height, which is the height of the lowest cloud layer, and low cloud cover, or the proportion of the area of interest covered by the lowest cloud levels. When the cloud base height is below the fixed-wing drop limit and the low cloud cover is above 50%, the simulation deems the SAR event obscured to fixed-wing aircraft by cloud cover.

All the environmental data is digested by the simulation to create an accurate representation of the environment that might be presently encountered during an Arctic SAR event. The conditions are continually updated according to the season to impact the behavior of the agents, influencing speed, route taken, and mission success accordingly.

The surface response assets included in the simulation varied by scenario and were selected by a panel of subject matter experts (SME). For nearly every simulation scenario, there are two Coast Guard surface assets included in the response suite—an icebreaking cutter without an onboard helicopter and a non-icebreaking cutter with an onboard helicopter. The simulation includes response delays for planning, recovering victims, and offloading victims. The simulation adapts the respective cutters' speed for transit through open ocean, ice, and varying sea states.

The airborne response assets included fixed-wing and rotary aircraft from the Air Force, Army, Army National Guard, Coast Guard, and the North Slope Borough (NSB) SAR, which serves eight villages in Northern Alaska. The air assets included in the simulation were identified and selected through discussions with SMEs but do not represent every possible air asset available in the region. If a scenario has a manageable victim load and is within range, only Coast Guard and NSB assets are considered. However, if a scenario involves a mass casualty event or takes place in an exceedingly remote location, collaboration with the Department of Defense is required and was simulated. When a Defense Department asset is requested, an additional planning delay is applied to account for the coordination effort required.[7]

The Results

The result of one simulation run reports the first contact of each asset type responding to the SAR event, as well as the total time it took to recover the last victim from the scene. The six scenarios were each run in the simulation 30 times, and those results demonstrated that the five-day minimum requirement is adequate in some of the scenarios but would be insufficient in others. Routes that are beyond the range of response helicopters or rescues involving vessels with significant numbers of people onboard can expect METR to exceed the five-day baseline. Additionally, the starting location of the ice-breaking surface asset had a significant impact on the rescue time of any scenario taking place in the ice extent. If that asset was not already on an Arctic patrol but rather docked in southern Alaska, or worse, in homeport or unavailable, the rescue times would have been radically longer.

Considering the realities this simulation presents, it is recommended that the Polar Code be updated to include specific requirements and/or methods companies may use to repeatably and consistently calculate METR on their operational assessment. This will ensure thorough consideration is applied to polar routes, that every Polar Ship Certificate METR is evaluated from a uniform standard, and that there is sufficient safety apparatus for all persons on board polar voyages in the event of a SAR incident.

About the author:

Christine Mahoney is a 2007 graduate of the U.S. Coast Guard Academy and a 2011 graduate University of Wisconsin-Madison. She served as a marine inspector for the Coast Guard in Seattle before becoming an instructor in the mathematics department at the Coast Guard Academy. After separating from the service, she joined the Coast Guard Research and Development Center as an analyst in the Modeling, Simulation, and Analysis Branch.

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Coast Guard Strategy Research

Simulation tool for Ready Workforce 2030

by Sam Cheung
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LT Ardy Effendi
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The Coast Guard's Ready Workforce 2030 (RW2030) strategy states the need for "creating a system with the ability to generate the force we need, when and where we need it, moving away from our current predictive workforce modeling."

The Coast Guard's Strategic Workforce Planning and Human Resources Analytics Division (DPR-22) currently lacks the capability of fully delivering this demand. To meet RW2030 demands, DPR-22 needs an effective, data-driven modeling tool that is efficient to employ in delivering timely workforce demand forecasts. Further, workforce planning is based on a three-year outlook from resource proposals, reducing the ability to precisely forecast at the strategic level due to limited data. Requests often require custom simulations to be built from scratch, requiring significant time and resources.

Available commercial and government-off-the-shelf products were evaluated with a goal of providing a robust, data-driven, predictive workforce simulation tool capable of modeling and capturing the unique nuances of military workforces. The objectives were to identify a tool with the capability to:

- Address policy/strategy workforce questions—the what-ifs—for decision-makers and programs
- Help analysts efficiently examine human resources data
- Forecast workforce demands at various points in the future—for example, two, five, and 10 years
- Develop a framework for a verification, validation, and accreditation approach

Upon completion of market research on available predictive simulation software suites, a program called Athena was determined to be the best choice to accomplish this project's objectives. One of the main deciding points was that the suite was specifically developed to model military workforces.

Athena is a tested and proven product with an established support infrastructure. The Australian military currently employs the software for forecasting aircraft consolidation impacts, determining submarine requirements and capabilities, and strategizing recruitment and promotion policies. Whereas the Canadian military, which recently acquired Athena, is actively framing similar workforce scenarios. Both countries' militaries currently play major roles within a consortium of users who provide consistent feedback to Athena's Program Office (PO), which headquarters its established support infrastructure. Athena's PO is supported by three main entities:

- The Defense Science Technology Group (DSTG) works closely with research scientists from the University of Melbourne regarding research and development
- Athena's User Group drives software requirements
- Athena's Steering Group ensures clients' needs and concerns are discussed, shared appropriately, and actions are timely

Athena's fully functioning and supported PO, along with its tested and proven history on relevant use cases, further confirms that it is the best investment for the Coast Guard.

To best position Athena for transition, the Coast Guard Research and Development Center (RDC) defined two workforces. The first is a subspecialty within the Coast Guard's prevention workforce; the officer ashore prevention (OAP12) specialty, Marine Investigations. Officers may be promoted in the same fashion of officers in other career paths but go to specific positions and earn proficiencies specific to their career field. Modeling these possibilities requires an accurate depiction of members during each phase of their careers.

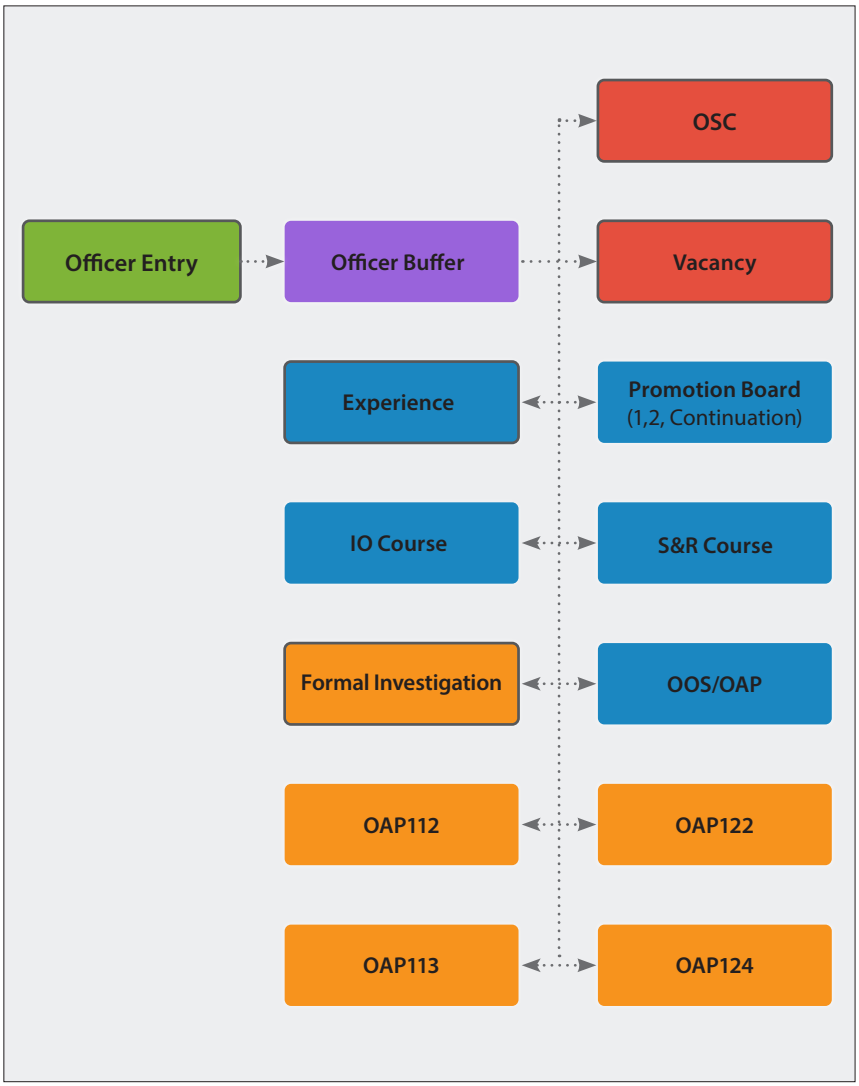
The other workforce is aviation survival specialist (AST). DPR-22 plans to use both OAP12 and AST use cases to serve as models for efficient duplication of future buildouts.

Testing and evaluating use cases required employment of the Research and Development Center Test Environment (RDCTE) cloud, a test environment for research and development purposes only. The purpose of the RDCTE is to provide an innovative space for

research, development, testing, evaluation, and analysis of, historical, and archival Coast Guard data. The RDCTE does not change the operational environment, but provides advanced analytical tools, machine learning, and artificial intelligence techniques, as well as the ability to create high-powered virtual machines to execute the computations required for these analyses.

The project team tested and evaluated both OAP12 and AST use cases in RDCTE with representable data. To operate Athena in this environment, users employed two virtual machines (VM). One VM hosts all Athena images, systems, services, and databases while the other provides users a login page and access to Athena's modeling suite. Both VMs must run for Athena to work properly.

For both real-world and test environments, the standard number of VMs required for employing software is uncertain because it depends on the type of software and the other cloud components needed for the software to run. More research, testing, and evaluation in this area will build expertise and enhance understanding of VMs and how they operate within cloud infrastructures. For this effort, specific cloud systems, services, and databases were required and downloaded from Microsoft Azure Marketplace, a centralized cloud-based platform that offers a wide array of software-as-a-service solution. Descriptions of these required cloud components are summarized below.



The Officer Ashore Prevention, or OAP12, specialty is modeled in Athena. The graphic uses green blocks to illustrate when members enter ranks, blue blocks to highlight when they are eligible for promotion or fulfilling a prerequisite, a purple block to show when transitioning between blocks, and when a vacancy is open for promotion or earning an officer specialty code, red blocks are used. Coast Guard graphic

- Athena Images—Athena software
- Azure Container Registry—A virtual standalone environment to build, store, and manage software applications and images
- Azure Kubernetes Service—A software that manages running the application
- ActiveMQ—A service that provides a communications bridge between components of systems, as well as supports multiple commonly used computer programming languages
- Azure Cache—Stores data temporarily. This helps software performance as data is retrieved from this location rather than databases
- PostgreSQL—A relational database that stores tabular data, useful for storing data that has lots of connections and relationships within it
- Mongo Atlas—Stores documents. This database is useful for storing output and results data

With the help of sponsor involvement, engagement, and briefings, the Deputy Commandant for Mission Support and Assistant Commandant for Human Resources offices are up to date on the status of this project and are aware of the organization's current workforce modeling shortfalls and struggles. The respective offices are strategizing the best approach to bring Athena to the Coast Guard in the future.

Meanwhile, the Talent Management Transformation (TMX) Task Force has successfully routed TMX Initiative Memo: Persistent Workforce Simulation Software and

Coast Guard Petty Officer 3rd Class Wayne Ballard throws a rope to a stranded sailor during a December 2019 rescue in the Gulf of Mexico. Air Force photo by 2nd Lt. Karissa Rodriguez

(TMX) Task Force has successfully routed TMX Initiative Memo: Persistent Workforce Simulation Software and is in the process of routing a Requirements Use Case Catalog for the TMX Initiative Memo. Deemed by the sponsor as the next best step to position the product for higher approval, a use catalog specifies objectives and capability gaps, describes material solutions, and lists assumptions and requirements.

The project team is working closely with DSTG to add a feature to allow for performance of multiple actions concurrently—serving as a unit marine investigator while also attending required search and rescue training, for example. Integrating this new feature will be a focal point for the sponsor because many workforce communities are structured with this fundamental issue—members going on temporary duty to attend prerequisite schools and trainings while in a billeted position.

Additionally, at the request of the project team, Australia's DSTG is in the process of developing an event-based feature to address both current and future modeling challenges. The feature will attempt to handle members' probability of promotion, variable time in position, and whether to hold them in position for a specific duration. For instance, Athena lacks an efficient method to model a member with an 85% chance of promotion after 12, 18, or 24 months in a specific assignment. This is because Coast Guard promotions depend on Signal Number, which indicates the officer's seniority relative to other active-duty officers, and generally on time-in-grade. As a result, capturing early rotations due to promotions is quite challenging.

Conclusion

A major reason for the selection of Athena was its established program office and support infrastructure. Its support team is geared to support users' modeling needs through three main groups: DSTG, Athena User Group, and Athena Steering Group. The constant cycle of collaborative support was evident throughout this effort, as these groups were always willing to help and collaborate in a timely and professional manner with no contract in place or any financial obligation to do so. As DPR-22 and stakeholders continue to pursue a workforce modeling simulation suite, a willing and helpful support team should be important considerations before long-term investments are made.

About the authors:

Sam Cheung served with the Coast Guard for 15 years before coming to the Coast Guard Research and Development Center (RDC) in 2012. While serving, he earned achievement medals from the Coast Guard, Navy, and Marine Corps, as well as the Coast Guard's Commendation Medal. At the RDC, he has led multiple projects in resource optimization and artificial intelligence.

LT Ardy Effendi graduated from the U.S. Coast Guard Academy in 2016 and went on to serve aboard multiple Coast Guard cutters and as commanding officer of the Coast Guard Patrol Forces Southwest Asia cutter relief crew. After completing his master's degree in operations research at North Carolina State University in 2020, he reported to the Coast Guard Research and Development Center.

Alternative Marine Fuels, Safety, and Environmental Hazards

by Alexander Balsley, P.E.
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Every year, the maritime sector's use of conventional bunker fuels such as heavy fuel oil, light fuel oil, and marine diesel contributes approximately 3% of greenhouse gas (GHG) emissions globally.[1]

In its 2023 IMO Strategy on Reduction of GHG Emissions from Ships, the International Maritime Organization (IMO), a specialized agency of the United Nations responsible for regulating maritime transport, established a target of net-zero GHG emissions by or around 2050.[2] It also created a checkpoint to reduce GHG emissions by at least 40% compared to 2008 emission levels before 2030. To reach this goal, IMO recommended that by 2030, alternative fuels that are less carbon intensive or reduce air pollutants should make up 5 to 10% of the total energy used by international shipping.

The Coast Guard is prepared for a significant increase in the use and transport of alternative fuels on U.S. waterways, including the Great Lakes. These alternative fuels include, but are not limited to, liquefied natural gas, liquefied petroleum gas, biofuels, hydrogen, ammonia, low-sulfur fuel oils, methanol, and other alcohols. The maritime industry is also building new vessels or retrofitting existing ones to be powered by alternative fuels, such as methanol and ammonia-based hydrogen

International Maritime Organization workers in hazmat suits stand in surf near the wreck of the M/V *Wakashio* on August 13, 2020. The vessel ran aground on a coral reef in Mauritius on July 25 but did not start leaking very low-sulfur fuel oil right away. It wasn't until August 6 that oil began leaking from the ship, prompting authorities to take action to control the spill and mitigate its impact. International Maritime Organization photo

fuel cells.

While there has been a recent uptick in research interest about the fate and behavior of different alternative fuels in the maritime and port environments, they are still largely unknown. For example, the world's first major—and documented—spillage of very-low sulfur fuel oil (VLSFO) occurred with the grounding of M/V *Wakashio* on a coral reef in Mauritius on July 25, 2020. An estimated 260,000 gallons of VLSFO entered the environment, and responders reported that it was "more fluid and less sticky than traditional fuel oil."[3]

At the International Oil Spill Conference (IOSC) in May 2024, presenters discussed challenges they faced in understanding the wide range of physicochemical properties of different VLSFO blends that exist. They also noted that generally, VLSFO "clustered together into smaller and very sticky lumps,"[4] which can make mechanical recovery much more difficult compared to typical crude or refined oil. This is contradictory to observations made about VLSFO during the M/V *Wakashio* incident, which highlights uncertainty about its fate and behavior in maritime environments. The Arctic Council agreed that if exposed to cold water, VLSFO forms "clumps" whereas heavy fuel oil would remain liquid.[5]

Like VLSFO, biofuels—liquid fuel produced from renewable sources, such as new and used vegetable oils, animal fats, nonfood crops, and algae—come in a wide variety of products that make it difficult for spill responders to apply research findings to specific biofuels. According to the U.S. Energy Information Administration (EIA), there are four major categories of biofuels: ethanol, biodiesel, renewable diesel, and other biofuels.[6] All are being considered as alternative fuels. The many different blends/products in each of the four categories highlights the importance of the Coast Guard maintaining visibility of the type and volume of specific biofuel products potentially at risk for spillage that are or will be transported on U.S. waterways.

Bunkering facilities throughout the United States are preparing to accommodate large volumes of alternative fuels, including ammonia and methanol. With limited knowledge about interactions between alternative fuels and sea/fresh water, and the lack of clear safety protocols for those bunkering facilities in the event of a discharge,

The Coast Guard and the Mississippi Department of Environmental Quality discuss response efforts at Gulfport Harbor in Gulfport, Mississippi, on June 15, 2016. The Coast Guard, state, and local agencies were responding to an estimated 250-gallon diesel spill in Gulfport Harbor. Coast Guard photo by Petty Officer 3rd Class Lora Ratliff

there are significant concerns about safety and health risks for responders. Several Regional Response Team members, especially on the West Coast, cited methanol as an emerging concern due to the ever-increasing volume being transported. Methanol is seen as a benefit for many shippers because of its low production cost, lower risk of flammability compared to gasoline, and can be manufactured from a variety of carbon-based feedstock.[7] Clear guidance is required for responding to a methanol spill incident with emphasis on prioritizing the safety and health of responders.

At IOSC 2024, Jim Elliott, chief operating officer of the Teichman Group of Companies, presented a paper about the current state of alternative fuel response operations.

"Driven by increasingly outdated regulatory standards, the current salvage and oil spill response industries are primarily focused on traditional oil containment, recovery, transfer, and storage operations," Elliott wrote. "To address the risks created by alternative fuels, marine casualty response professionals will need to evolve in planning, preparedness, and response capabilities to manage these unique hazards and risk profiles.[8]

This directly ties to one of the Coast Guard Office of Marine Environmental Response Policy's (CG-MER) top initiatives, which is improving responder safety. This is even more critical with new and emerging alternative fuels on the horizon.

Not only is CG-MER concerned about the most effective approach for mitigating environmental impacts when alternative fuel spills occur, it also seeks guidance about how to prevent risks to responders' health and safety. There is also uncertainty about the effectiveness of oil spill response equipment/strategies typically used for refined products and crude petroleum if they are used with alternative fuels. Anticipating and preparing for alternative fuel spills directly ties to the current Coast

Considerations for Using Liquefied Natural Gas as an Alternative Fuel

Use of liquefied natural gas (LNG) as a fuel has increased significantly over the past decade. Growth in LNG bunkering infrastructure in U.S. ports has grown proportionately with Jacksonville and Port Canaveral, Florida, Houston and Galveston, Texas, Los Angeles/Long Beach, California, and Tacoma, Washington, receiving major investments for LNG bunkering facilities.

The Port of Houston, for example, has approximately 1 million gallons of LNG storage capacity and the Port of Jacksonville has a LNG bunkering terminal, truck-to-ship bunkering, and vessel-to-vessel bunkering capabilities. Container ships, large passenger vessels, roll-on/roll-off carriers, and offshore support vessels are some of the vessel types using and bunkering LNG in the United States.

Numerous resources, like the Coast Guard's Chemical Hazard Response Information System, National Oceanic and Atmospheric Administration's Computer-Aided Management of Emergency Operations chemicals database, and the Department of Transportation's Emergency Response Guidebook 2024 detail LNG's hazards. Additionally, the Liquefied Gas Carrier National Center of Expertise, has played a major role in LNG safety training and fostered the transition to LNG as a maritime fuel, along with the Coast Guard offices of Commercial Vessel Compliance, Operating and Environmental Standards, and Design and Engineering Standards.

As with rapid implementation of any technology, challenges with LNG marine fuel will emerge requiring both comprehensive analysis and technical expertise. The Coast Guard Research and Development Center is uniquely poised to address emerging issues and provide scientifically backed, innovative solutions.

For more information

Visit https://bit.ly/LCGNCOE to learn more about the Liquefied Gas Carrier National Center of Expertise and its extensive compilation of policy letters, guidance, and bulletins.

Guard deputy commandant for Operations' and deputy commandant for Mission Support's strategy of reducing the Coast Guard's vulnerabilities and being resilient to climate-related impacts through research and assessment of technologies.

The Coast Guard Research and Development Center (RDC) is perfectly positioned to address this knowledge gap. The RDC began an effort in October 2024 to develop a response guide for alternative fuel discharges and spills beginning with a literature review of news and journal articles, as well as conference proceedings. It also met and will continue to meet with a variety of stakeholders including:

- District and sector prevention staff
- Captains of the Port
- Members from the National Strike Force Coordination Center
- Marine Safety Center
- National and Regional Response Team members
- Oil spill removal organizations (OSROs)
- Researchers from other federal agencies and academia
- Maritime industry representatives

After conducting preliminary research to identify each alternative fuel's relevant physical and chemical properties—solubility, flash point, specific gravity, and lower explosive limit, for example—and the likely state of matter that it will be in during maritime transport, the RDC and CG-MER will select priority alternative fuels that warrant further research. It will be based on highest probability for spillage in U.S. waterways, highest risk to responders' safety and health, and potential for environmental damage.

Once priority alternative fuels are identified, the RDC will review usage trends and determine volumes expected to be transported on U.S. waterways, including the Great Lakes, and determine each fuel's existing and/or expected storage locations in U.S. ports. It also will conduct more thorough research into each fuel's physical and chemical properties, as well as its health and environmental health hazards, protective measures, and safety precautions for handling, storing, and transporting the fuel. In addition, the RDC will engage fuel suppliers, shippers, and classification societies to fully capture the risks posed to responders' safety and health and review vessel and facility response plans for current approaches to transporting, handling, and responding to potential alternative fuel spills.

OSROs and other spill responders will be consulted to identify existing mechanical response technologies and strategies for each type of alternative fuel and determine what knowledge gaps exist. Based on available information, the RDC and CG-MER will determine the feasibility of testing the effectiveness of existing oil spill response technologies with alternative fuels at a test facility. If carried out, the RDC will summarize test data, findings, and recommendations for each mechanical recovery technology with specific alternative fuels.

This essential information will ensure that the publicly available reference guide, which is targeted to be released by the end of 2026, will be useful and relevant for federal on-scene coordinators and other spill responders across the United States. Stakeholders for national and area contingency plans and geographic response strategies can also benefit from this response guide. By taking a proactive approach with this research effort, the Coast Guard will improve its readiness for this new and emerging challenge of alternative fuel spills.

About the author:

Alexander Balsley has 15 years of experience with pollution response research and is currently managing projects for the Coast Guard Research and Development Center. He received his Bachelor of Science degree in civil and environmental engineering from Northeastern University and his Master of Science degree in environmental engineering from Worcester Polytechnic Institute. He is a registered professional engineer in Massachusetts.

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Modernizing the Aids to Navigation Mission in the Electronic Navigation Age

by James Spilsbury
Project Manager
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The Marine Transportation System (MTS) plays a vital role in the nation's economy with aids to navigation (ATON) being a linchpin of the current system allowing the safe and efficient flow of vessel traffic. According to the U.S. Maritime Administration (MARAD):

> *The MTS includes waterways, ports, and land-side connections. … Waterborne cargo and associated activity transported through the MTS contributes more than $500 billion dollars to the U.S. GDP, generates over $200 billion in annual port sector federal/state/local taxes and sustains over 10 million jobs. Which is why MARAD works constantly to improve the U.S. maritime transportation system, protect all MTS users and support higher levels of maritime traffic in the 21st century.*[1]

Within the MTS, major maritime incidents—collisions, allisions, and groundings—not only have the potential to disrupt commerce on a local waterway, but can also have significant impacts on our global, interconnected supply chain and our nation's economy. One of the Coast Guard's 11 statutory missions, ATON helps reduce overall navigational risk on waterways, minimizing the likelihood of maritime incidents occurring.

The aids to navigation mission dates back to the 1716 construction and illumination of the first American lighthouse on Little Brewster Island in Boston Harbor.

History of ATON

The ATON mission has its roots in the earliest days of the nation's founding, with lighthouses established along our coasts to mark critical waterways and navigational hazards while also serving as an important symbol of a young maritime nation. Today, the Coast Guard maintains more than 48,000 ATON, including numerous lighthouses, beacons, and buoys to aid mariners with safely navigating our waterways. Most modern-day mariners have access to advanced navigation systems that use GPS. However, ATON still serve as a system of checks and balances, providing mariners with reliable references to safely transit busy, dynamic waterways.

The Coast Guard and its predecessor agencies have evolved the ATON mission over the years to adopt new technologies that are proven and more efficient. These technological leaps have been measured, allowing the Coast Guard to provide a high level of service to the mariner while reducing operating costs associated with the system's upkeep and maintenance. Technological advancements in ATON have been methodical, but steady through its history. The evolution of using whale oil in lighthouses in the beginning, to using highly efficient LED lights powered completely by solar panels today is a prime example.

The adoption of these technologies has allowed the Coast Guard to achieve maintenance and cost efficiencies, allowing the service to adapt to an ever-changing MTS as new waterways users and challenges emerge.

The Coast Guard Research and Development Center (RDC) recently completed two ATON modernization projects. The Next Generation Aids to Navigation Buoys & Alternative Moorings and the Private Aids to Navigation (PATON) Verification Improvements projects that informed Coast Guard stakeholders on emerging technologies that may allow the service to make the next

technological leap. The following sections highlight the knowledge gained by these recent efforts and insights as to where the service can go with technology in the electronic navigation age.

Investigation of Next Generation ATON Buoys

Floating navigational aids or buoys are one major element of today's ATON constellation. Since the early 1900s, the Coast Guard has relied on buoys constructed of steel as the core of its short-range ATON program. These steel buoys are durable and have standard service lives of 24 years or more. However, they also come with several key disadvantages like weight, increased acquisition and maintenance costs, and operational challenges—for example, buoys sinking after a hull is breached.

In recent years, maritime organizations around the world have increasingly adopted non-ferrous buoy designs, or those constructed predominantly without steel, which are lighter and require less maintenance. In this project, the RDC first performed an extensive market research effort to evaluate the current state of non-ferrous or next-generation (Next Gen) ATON buoy technology. Next Gen ATON buoys are generally characterized as commercially available buoy designs principally constructed with hard-shelled plastic, foam, or other hybrid designs like plastic and metal.

Through this market research, the RDC identified different Next Gen buoy designs to evaluate during a multiyear field demonstration in open ocean, bay, harbor, and river environments. The Next Gen buoys selected for testing covered the entire range of inventory, from the smallest to largest buoy hull sizes, including several

A Next Gen test buoy is shown alongside an 8X26LR steel buoy on CGC *Elm*. Coast Guard photo by James Spilsbury

Western Rivers buoy prototypes. They were deployed in a range of operational environments in the Northeast, Gulf Coast, and Pacific Northwest regions of the United States. Additionally, the RDC team evaluated alternative mooring technologies, like synthetic rope in lieu of traditional chain mooring systems predominantly used in the ATON system today, to identify benefits and drawbacks of using these systems.

The RDC team worked closely with Coast Guard ATON units to deploy, inspect, and recover Next Gen test buoys from rivers, harbors, bays, and offshore areas in the three test regions. The team completed test deployments of the full range of Coast Guard buoy tender assets from small boats to large seagoing cutters. Objectives of the field demonstration were to evaluate the performance of buoy designs in different environmental conditions, assess operational compatibility, and determine any future fleet impacts. Throughout testing, the team collected invaluable feedback from buoy tender sailors and waterways managers on how the Coast Guard could leverage the technology in the current ATON system. At the conclusion of testing, the project team provided key stakeholders with a summary of the field demonstration and overall recommendations for implementing the technology for maximum operational benefit and return on investment. Further use of this technology may help the Coast Guard yield acquisition, maintenance, and operational cost savings. However, the team also highlighted several risks such as durability, color fade, and recycling that warrant careful consideration to implement the technology.

The Light List is a list of all active ATON and PATON the Coast Guard has authorized and established, their locations, and characteristics.

PATON Verifications with a Mobile App

PATON, or private aids to navigation, is another component of the ATON mission for which the Coast Guard has a key role and regulatory oversight. PATON refers to any ATON such as buoys, fixed structures, or lights used to mark navigational hazards or assist with navigation operations that are established and maintained by private owners or other local, state, or federal entities. Federal law and regulations authorize the Coast Guard to administer PATON located in the United States as mandated in Title 33 Code of Federal Regulations.

In its regulatory authority, the Coast Guard is required to periodically inspect more than 41,000 PATON nationwide to ensure they are charted, functioning properly, and are compliant as permitted. With limited staffing available to complete these inspections, the Coast Guard generally delegates this responsibility to qualified aid verifiers (AV) in the Coast Guard Auxiliary. In a recent project, the RDC partnered with the newly established 33-person Coast Guard Auxiliary Research and Development Unit to investigate ways to modernize and streamline the current PATON verification and reporting process.

In its current state, the process is time consuming and manually intensive for both Coast Guard and Auxiliary personnel. It relies heavily on paper or digital forms and is susceptible to human error. With limited staffing available to handle the regular volume of reports and manually enter report data into the aids to navigation information system (ATONIS) database, the Coast Guard is not able to maximize the value of the data collected in a timely fashion. This data is critical for the Coast Guard to update mariner products like the Light List and provide up-to-date ATON data to the National Oceanic and Atmospheric Administration (NOAA) for nautical chart updates. This project investigated the use of mobile application technology to streamline the PATON reporting process in concert with modern electronic navigation chart (ENC) tools.

To modernize the reporting process, the team surveyed all districts to identify existing tools and processes used to manage and report on PATON. It found and selected the Aid Verification Assistant (AVA), an existing tool, to further develop into an enterprise-capable method to help modernize and improve efficiency in the reporting process. AVA is a mobile app developed by an auxiliarist that leverages mobile phones and devices to automate and simplify the reporting process. It can reduce the time required for a trained AV to generate a report from one to two hours to a few minutes. With the use of the app, AVs no longer must review and print out information from multiple sources. Instead, they can simply open the app and have the latest PATON information at their fingertips. AVA eliminates many sources of manual error and increases confidence in reports through GPS accuracy, data integrity, and annotated photographs.

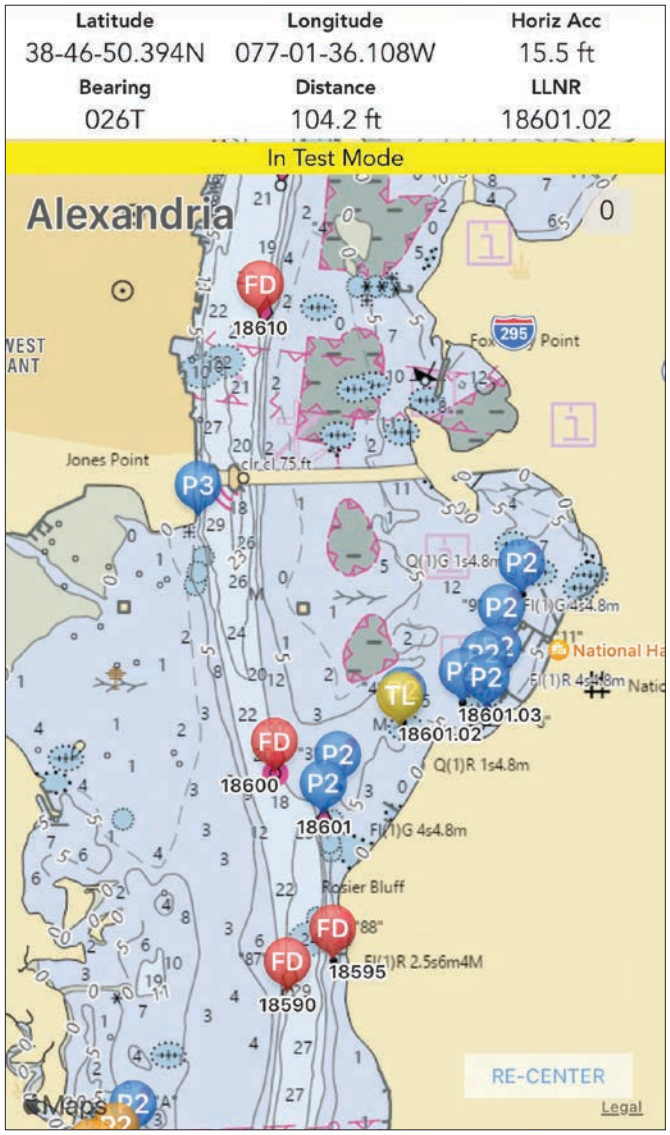
The team integrated several new features in AVA to better meet stakeholder needs, including:

- The latest revised Coast Guard PATON

The CGC Willow crew conducts a buoy evolution during a 32-day patrol in the Caribbean Sea on February 10, 2024, near Puerto Rico. Coast Guard photo by Petty Officer 2nd Class Ryan Schultz

verification report form
- A nautical chart overlay
- A new ATONIS source data file, including Class III PATON previously not available to AVs downloading from the Light List
- Improved app stability and functionality for different user groups

The team then beta-tested the upgraded app in the Northeast, the Mid-Atlantic, and the Southeast to collect feedback and make iterative improvements to the app's stability and performance. Concurrently, the team developed training materials and evaluated potential PATON policy changes, including the use of mobile phones, positioning tolerances, among others, to facilitate use of mobile apps for the PATON mission. Following the RDC's testing, the team released the updated version of the AVA app for AV use. However, AVA requires further development to fully automate the reporting process and eliminate manual data re-entry into ATONIS.



The Aid Verification Assistant, or AVA, is a mobile app that simplifies a formerly complex process by automating multiple steps in the reporting process, eliminating time-consuming paper documentation. Coast Guard photo

The use of AVA will allow the Coast Guard and Auxiliary to leverage technology to perform PATON verification electronically and more efficiently, as both organizations continue to have limited staffing available to conduct the PATON verification mission. With NOAA's transition to ENCs, AVA represents a means by which the Coast Guard can modernize the PATON reporting process to ensure continued accurate and timely chart updates for mariners. The efficient collection and dissemination of data may also advance the Coast Guard's ability to use near real-time data to inform decision-making to optimize ATON operations.

Future Outlook for ATON

It is an exciting time to be a researcher for the aids to navigation mission knowing new technology is on the horizon and within the Coast Guard's reach. These advancements promise to allow our hardworking ATON professionals to be more effective and efficient while continuing to maintain a highly reliable ATON system for mariners that depend on them in the modern electronic navigation age.

It is not beyond our imagination to have a fixed-wing drone flying a waterway after a major hurricane to survey and verify the status of ATON, providing the service advanced awareness to help prioritize repairs needed to reopen a waterway. It is also not beyond our imagination that a navigational buoy could become a multipurpose maritime domain awareness node, using compact and power-efficient instruments and telemetry systems to relay critical maritime safety information about on-water conditions to mariner in real time. The adoption of cutting-edge technologies like composite materials, artificial intelligence, and uncrewed systems will allow the Coast Guard to continue to maintain the ATON system at a high level today while simultaneously adapting to the challenges of tomorrow.

About the author:

James Spilsbury has been a project manager and physical scientist at the Coast Guard's Research and Development Center for five years. He holds a B.S. in marine science from the University of Maine and master's degrees in oceanography and business administration from the University of Rhode Island. He is also a Coast Guard-licensed boat captain 100 ton, inland.

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Emergent Technologies

Accelerating the Coast Guard's adoption of low-investment solutions

by Scott Fields, P.E.
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The Coast Guard Research and Development Center (RDC) has been at the forefront of developing and deploying innovative solutions to address the ever-changing needs of the Coast Guard. While strategic efforts at the RDC are crucial for long-term success, tactical approaches are essential for addressing immediate operational needs. Technology Readiness Levels (TRL) is a framework used to assess the maturity of a technology during its development. It consists of nine levels, ranging from basic research to fully operational systems:

1. **TRL 1—Basic Principles Observed:** Early research and scientific principles are identified.
2. **TRL 2—Technology Concept Formulated:** Practical applications are proposed based on scientific knowledge.
3. **TRL 3—Experimental Proof of Concept:** Initial experimental proof of concept is demonstrated.
4. **TRL 4—Technology Development:** Development of the technology is undertaken in a controlled environment.
5. **TRL 5—Validation in Relevant Environment:** The technology is tested in a relevant environment to validate its performance.
6. **TRL 6—Technology Demonstration:** A prototype or demonstration system is tested in a simulated or operational environment.
7. **TRL 7—System Prototype Demonstration:** The technology is demonstrated in an operational environment with a working prototype.
8. **TRL 8—Actual System Completed:** The technology is fully integrated and proven in its final form.
9. **TRL 9—Actual System Proven:** The technology is fully operational and used in its final form.

This scale helps stakeholders understand the readiness and risk associated with adopting or investing in new technologies. The majority of the RDC portfolio focuses on a strategic approach, with a portfolio focused on research efforts in the transition readiness level of four through seven with an anticipated five-to-10-year implementation. The RDC saw a need to also focus on a tactical approach evaluating and integrating commercially available technologies with high transition readiness levels at level eight or nine. This increased the speed of delivery to the operational and tactical level of the service.

This approach ensures that the Coast Guard can rapidly adopt and deploy technologies that meet urgent requirements, thereby enhancing operational efficiency and effectiveness. A key component of this approach is leveraging emerging technology and other solutions to

The Coast Guard K9 helmet, which integrates ear and eye protection, was acquired by the Research and Development Center to protect military working dogs during helicopter hoisting operations. Coast Guard photo

accelerate the adoption of innovative tools in the field. In 2015, the Department of Homeland Security's (DHS) Science and Technology Directorate (S&T) and the Coast Guard agreed to pilot an innovation center concept and launched the Coast Guard Science & Technology Innovation Center (STIC) as the first of eight component-level innovation centers.

The purpose of the innovation centers was to increase unity of effort and knowledge sharing across DHS components, and to accelerate the identification and fielding of mature solutions. Through the STIC, S&T intended to explore and pilot new concepts, and then incorporate the best practices and lessons learned from the pilot into future STICs. Unfortunately, the other innovation centers were never established.

In FY 2016, the STIC evolved from a concept into an established center housed within the RDC. This shift from theory to practice acknowledged the need for a sustained focus on rapid response to technology challenges, changes, and gaps within the homeland security enterprise. STIC's demonstrations and rapid prototyping have played key roles in the Coast Guard's efforts to develop new technologies, equipment, and corresponding tactics. The STIC received S&T funding and operated from 2018 to 2023. During the STIC pilot period, it field tested and evaluated more than 40 technologies. RDC leadership saw the value of continuing the evaluation of high transition readiness level technologies and continued the STIC mission under a new label, the Rapid Reaction Technology Branch (RRTB).

The RDC's RRTB supports the Coast Guard to address the challenges associated with ever-changing technology capabilities through limited user field demonstrations. The RRTB's investments in technology capability demonstrations help validate the technical feasibility of a capability and explore its operational value. Technologies proven in the lab and ready to begin the transition to a relevant environment are ideal candidates for RRTB's proof of principle demonstrations and prototyping. This type of rapid response effort culminates in a limited end-user evaluation that collects data on key technical knowledge points and allows the operational user to evaluate and offer feedback on a technology or capability from actual field testing. RRTB technology evaluations focus across all 11 mission areas of the Coast Guard.

The Value of the Tactical Approach

The RDC's tactical approach offers several benefits, including rapid technology assessment, compatibility evaluation, benefit analysis, and speed of deployment. By focusing on commercially available technologies with high transition readiness levels, the center can rapidly deploy solutions to address immediate operational demands.

Collaboration with Field Units

Effective technology transition relies on close collaboration with field units. The RDC actively engages with field units to gather insights into their operational requirements and challenges, ensuring that new technologies are relevant and seamlessly integrated into existing workflows. The abandoned vessel marking evaluation, aimed to address the issue of abandoned and derelict vessels that pose a significant hazard to navigation and the environment is an example. The RDC team tested various marking technologies, including GPS-enabled buoys, radio frequency identification, or RFID tags, and satellite-based tracking systems. The evaluations conducted with several units within the District 8 area of responsibility, which includes the Gulf of Mexico, revealed that these technologies could significantly improve the management and disposal of abandoned vessels.

Another example of the importance of collaboration with field units was the evaluation of the recovery ladder on a 29-foot response boat. A member of Coast Guard Station Cleveland Harbor presented an idea to the RDC with a prototype solution of a recovery ladder. The Office of Boat Forces solicited for volunteers during a Boat Advisory Council meeting to evaluate the recovery ladder. Eleven stations in different operating environments across the country were selected to evaluate the ladder. The feedback provided future improvements for the next version.

A Maritime Security Response Team West member reviews wearable sensor data on a mobile device. The RDC worked with field operators to test the sensor, which monitors vital health indicators during strenuous operations. Coast Guard photo

Personnel from Coast Guard Station Juneau in Alaska conduct a field deployment of a recovery ladder. Operators in the field have indicated that a stowable quick-mount ladder, designed for use in small boats, could significantly improve the retrieval of individuals from the water while also enhancing crew safety. Coast Guard photo

Limited End-User Field Testing

Rapid field testing is integral to the tactical approach. The RDC employs agile methodologies in its prototyping and testing processes, conducting field tests and iterative improvements to ensure that the final technology solution is well-suited to the operational environment. The evaluation of heated diving vests for the National Ice Rescue School, which conducts training at Coast Guard Station Saginaw River in Michigan in the winter months, is one example. The training includes demonstrations where the students perform mock ice rescues, which require the students to enter the icy waters. During these trainings, maintaining a comfortable core body temperature can be difficult. The RDC worked with the ice rescue school in testing various off-the-shelf heated diving vests to wear under their dry suits.

The center further conducted an evaluation of the use of wearable devices designed for health monitoring in industrial settings and adapted for maritime operations. These wearables provide real-time health and environmental data, enhancing the safety and well-being of Coast Guard personnel during high-stress missions. Several Coast Guard units operate in high-stress environments and could benefit from real-time monitoring of their personnel

In response to a request from the Maritime Security Response Team (MSRT), the RDC conducted market research and demonstrations to identify wearable sensors for monitoring the health and safety of security teams during training exercises. A system was selected for a yearlong evaluation at MSRT East, which proved effective in monitoring multiple personnel on a single dashboard and providing real-time monitoring of vital characteristics such as heart rate.

Technology Integration and Training

Once a technology is deemed ready for deployment, the center focuses on its effective integration into operational systems and providing training to field units. Seamless integration, training programs, user support, and ongoing evaluation and feedback are critical components of this process. The RDC completed an evaluation of thermal clip-ons and night vision device (NVD) integration aimed to address the issue of limited situational awareness during nighttime operations. The team tested two different thermal clip-on systems in conjunction with Coast Guard-issued NVDs with small boat operators. Both clip-ons were found to be effective in enhancing situational awareness and target detection during nighttime operations.

Conclusion

The tactical approach of the RDC is essential for addressing immediate operational needs and enhancing the Coast Guard's capabilities. By focusing on commercially and/or government available technologies with a transition readiness level of nine and leveraging emergent technologies, the RDC ensures that the Coast Guard can swiftly adopt and deploy solutions that address urgent requirements. This approach not only enhances the service's operational readiness, but also supports the development and implementation of innovative, low-investment solutions that improve efficiency and effectiveness. Balancing tactical efforts with strategic portfolio initiatives enables the RDC to meet both current and future operational demands, ensuring that technological advancements are effectively leveraged to support the mission of safeguarding maritime interests.

About the author:

Scott Fields serves as a branch chief in the technical division of the Coast Guard Research and Development Center (RDC). He is a 1991 graduate of the U.S. Coast Guard Academy and licensed professional engineer. Over his 33-year military and civilian career, he has spent 17 years with the RDC in various roles, including research physical scientist, comptroller, and branch chief.

Positioning to Remain Relevant in a Dynamic Business Environment

by Retired Coast Guard CAPT Al Arsenault
Technical Director
Research and Development Center
U.S. Coast Guard

The Coast Guard is pulled in many directions to support its 11 missions. Financial and personnel resources are always stretched to their limits and the recruitment of new members is ongoing. How does a tactical organization take a step back to think strategically and consider problems five, 10, or 20 years down the road? How does the organization embrace and leverage its small strategic research and development (R&D) program.

Positioning a strategic R&D program to remain relevant in a dynamic business environment requires a focused and deliberate approach. How does the Coast Guard Research and Development Center (RDC) remain relevant?

- We hire the best and brightest talent we can find and maintain a professional staff of research engineers, scientists, analysts, and technicians.
- We stay informed about market trends and continuously monitor these trends, customer preferences, and the activities of its sister laboratories—the Department of Defense (DoD), Department of Homeland Security (DHS), and Customs and Border Protection, among them—to identify emerging opportunities and anticipate future challenges.
- We align R&D with Coast Guard strategy, including Deputy Commandant for Operations and Deputy Commandant for Mission Support research priorities to remain in lockstep with long-term goals and objectives.
- We leverage partnerships and collaborations to access new technologies, ideas, and expertise to help expand the scope of the R&D program and increase its impact.
- We establish a flexible and agile R&D program to ensure both strategic and emergent needs of the service can be met. This includes adopting an iterative R&D process, breaking down projects into smaller components, and regularly reviewing and adjusting priorities.
- We foster a learning culture to remain on top of our game ensuring the program remains relevant and adaptable. This involves promoting knowledge-sharing, providing opportunities for learning and development, and fostering a culture of experimentation.
- We allocate our scarce resources to provide the best opportunity to transition our research to meet the needs of the operational Coast Guard.
- We strive to be an employer of choice, establishing an environment where out-of-the-box thinking is rewarded.

The agility of our R&D program has come to light recently as we transition our portfolio execution, portfolio development processes, and organizational structure to better support strategic research and development. Rather than executing a portfolio consisting of 40 to 60 independent research activities, we are reorganizing those activities under larger enduring research programs including:

Autonomy: The strategic application of automation and autonomous technologies to advance the capabilities of physical, virtual, and other systems.

Integration of autonomy/autonomous systems with legacy assets and infrastructure also comprises a key focus. Unique expertise will also include how autonomy may be used by other maritime stakeholders and/or adversaries, how that use will impact the service, and how the service will need to adapt to maintain a competitive edge. This program's transition goal is to provide clear opportunities for Coast Guard adoption and incorporation of autonomous technology across its operational missions and support functions, as well as how the Coast Guard will interact with autonomous systems used by industry and the public throughout the Marine Transportation System (MTS).

Connectivity: Traditional command, control, communications, computers, cyber, and intelligence focus

extended to include information technology and networking, mobile device solutions, data connectivity from all sensors and platforms, crewed or uncrewed, at any latitude and longitude.

This also includes next-generation remote command and control and bringing data to decision-makers wherever they are, enabling tasking to flow automatically to all assets, and maintaining consistent and reliable communication pathways.

Defense and Safety Systems: Safety of Coast Guard members, the MTS, and the public.

These systems include nonlethal vessel-stopping technologies, counter-uncrewed systems, cybersecurity and redundancy in operational technology and navigation systems, and improvements to mariner safety.

Environmental Evolution and Waterways Resilience: Handling a changing environment and how the Coast Guard and the public interact with our evolving waterways. This includes evolving missions due to sea-level rise, extreme weather events, offshore energy generation and transport, and threats due to a changing maritime domain.

Data, Modeling, and Decision Support: The focus is on enhancing Coast Guard effectiveness through the use of data with research supporting incorporation and development of advanced methodologies, use of emerging data technologies, and complex analytics.

The end goal is to provide decision-support tools to operators, support personnel, and leadership. Research areas include domain awareness and target-of-interest identification, artificial intelligence and natural language processing, modeling and simulation, and data analytics. Research also supports the investigation of emerging data and decision-support tools, technologies, and capabilities.

Benefits of Managing Multiple Research Lines of Effort

These strategic research programs have been compared with research focus areas of sister DoD labs, DHS Science and Technology, and other DHS components and should provide strategic direction for years to come. The benefits of managing research lines of effort as larger strategic programs are numerous and include:

Impact and Significance
Larger research programs often address complex problems that require a multidisciplinary or multifaceted approach. This allows for greater impact and significance when compared to individual research projects and offers more opportunities to transition results to meet the mission needs of the Coast Guard.

Resource Allocation
With more enduring research programs, resources such as funding, equipment, and personnel can be allocated more efficiently. This can result in reduced redundancies and improved overall effectiveness. Research programs will also help the RDC align with the Coast Guard planning, programming, budgeting, and execution process to support zero-based budgeting activities and provide additional details in our annual congressional justification.

Collaboration
Larger research programs promote collaboration among researchers, often from different disciplines, backgrounds, and institutions. This fosters knowledge exchange, innovation, and cross-disciplinary learning. External collaboration and partnerships are key, especially in a resource-constrained environment.

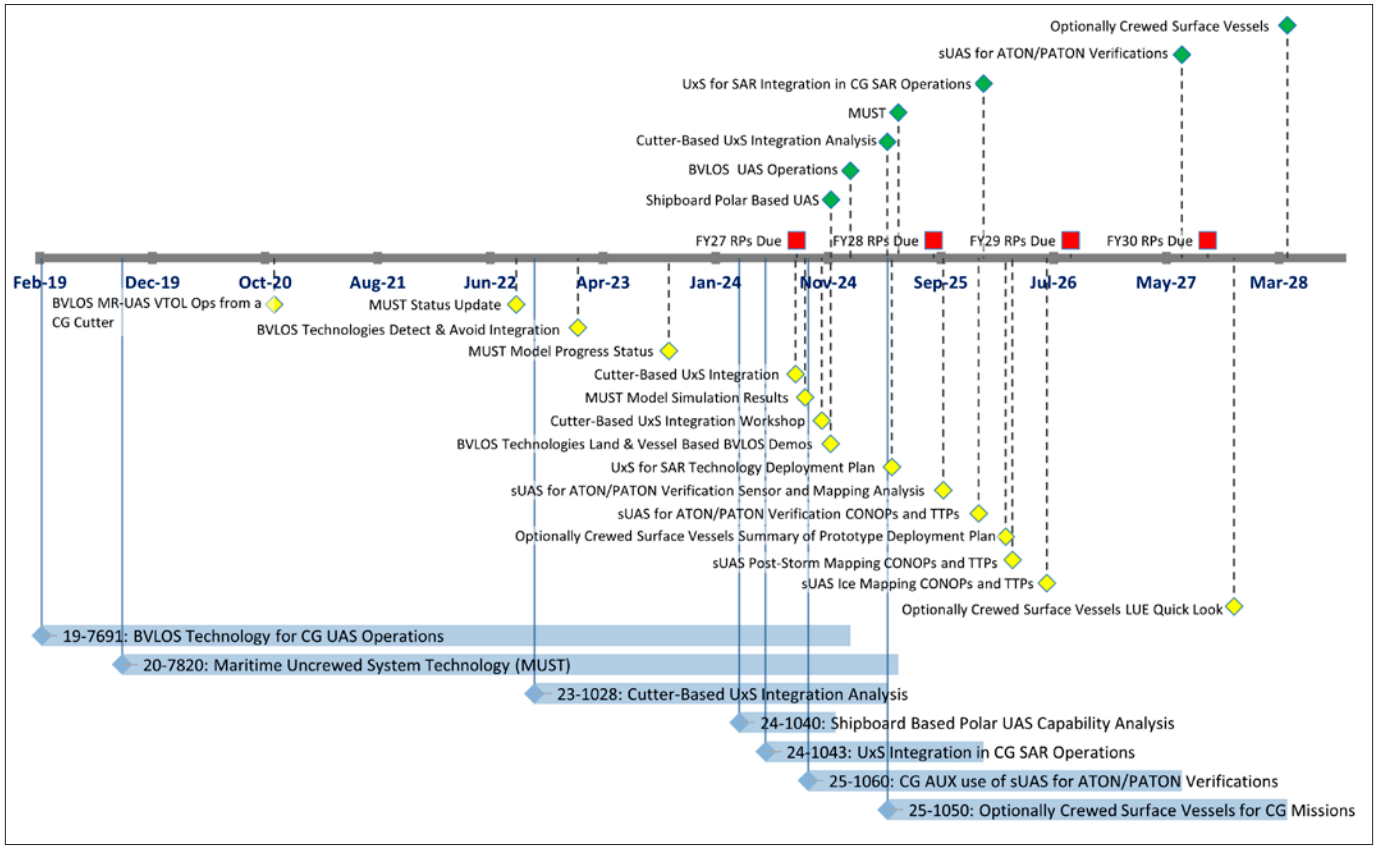
Consistency and Uniformity
Managing a larger research program allows for the development of consistent methodologies, standards, and protocols. This can lead to more uniform and comparable results, making analysis and interpretation easier. In addition, project management overhead will be eased by reducing the number of independently managed research efforts into five program areas.

Stability and Continuity
Large-scale research programs provide stability and continuity, often leading to a long-term commitment to addressing the problem at hand. This allows researchers to plan and build on past results rather than constantly starting from scratch. It also allows researchers the opportunity to collaborate with partners in a more sustained manner.

Capacity-Building and Career Development
Larger research programs offer more opportunities for researchers to gain experience, mentorship, and training. This can help build and sustain the expertise and talent necessary for ongoing research efforts.

Influence and Visibility
A well-managed, large-scale research program can have greater influence and visibility within an organization. Increased visibility can lead to more funding opportunities, research partnerships, and recognition for the researchers involved.

Risk Management
With larger research programs, the overall risk can be spread over multiple components. If one part of a project faces difficulties or failure, it may not result in the failure of the entire program. However, it needs to be



This sample program roadmap highlights program line-of-effort deliverables, high level financial milestones, and key technology achievements. Coast Guard table

understood that failure is a component of research. Not every experiment will derive expected results.

Synergy and Complementarity

By managing a larger research program, you can leverage the synergy and complementary nature of various individual projects working toward the same goals. This can result in a more comprehensive outcome than what could be achieved through individual research projects. This synergy will allow the RDC to build comprehensive technology roadmaps for each program area.

In FY 2025, the RDC will transition 35 independent projects into 35 lines of effort spread across five research programs. In addition to this program-mapping, the rigid project intake process will also be reinvented. Project/line of effort intakes will still involve targeted crowdsourcing activities, but will also involve more direct communication with Coast Guard program offices and senior headquarters and operational leadership to best determine mission needs across the service and how best to apply our limited R&D resources.

In parallel with strategic research, the RDC will also continue to identify and test high technology readiness level solutions to meet the Coast Guard's more immediate needs. This "tactical" R&D is carried out with short-term goals in mind or to address an immediate challenge facing the service. Activities include problem-solving, enhancing existing government and commercial off-the-shelf products, rapid prototyping, and field experimentation. This also includes the RDC's Sector of the Future concept, which established local testbeds in Coast Guard District 1—the Northeastern United States—for the exploration and integration of advanced

Florida's Aqua Alert

The Aqua Alert system was first enabled in Okaloosa County, Florida, in September 2021. Similar to an Amber Alert, the system notifies boaters in the area of a missing or distressed boater in the vicinity with the hope that they may be able to assist authorities in locating them. This system is operated in partnership with the City of Destin, Okaloosa County, the Okaloosa County Sheriff's Office, and the Coast Guard.

solutions to help the Coast Guard understand, prepare, acquire, and operationalize tomorrow's technologies. In support of this concept, the RDC has deployed a new Very High Frequency Data Exchange System, or VDES, a next-generation Automatic Identification System, to facilitate the transmission of search-and-rescue search patterns directly to Coast Guard response assets. The RDC has also tested a new marine alerting system similar to Florida's Aqua Alert under this concept.

Conclusion

The RDC plans to revalidate the five research program areas on a recurring basis by leveraging the Coast Guard's Project Evergreen program as well as other Coast Guard Headquarters strategic outlook studies. Project Evergreen is the Coast Guard's strategic foresight program designed to identify long-term risks and opportunities across many plausible futures over the next 25 years. Working with our government, industry, and academic partners at a targeted Evergreen event will ensure the breadth and scope of research program focus areas remain aligned with the Coast Guard's future opportunities and challenges.

Strategic R&D provides long-term growth, advances technology, creates innovative solutions, provides cost-reduction efficiencies, attracts top talent, mitigates risk, and forms key partnerships. By leveraging strategic R&D, the Coast Guard can ensure it remains at the cutting edge of technology with our DoD service partners, is prepared to address emerging threats, and maintains a competitive advantage over potential adversaries. By remaining agile and approaching R&D in a focused and deliberate manner, the RDC can continue to remain relevant in a resource-constrained environment well into the future.

About the author:

Retired Coast Guard CAPT Al Arsenault served on active duty for 27 years, last serving as the commanding officer of the Coast Guard Research and Development Center (RDC). He has served in many capacities including various engineering and major acquisition project management roles. He has been a civilian at the RDC for 10 years.

Coast Guard Human Research Protection Program

by Judith Connelly
Institutional Review Board Chair
Research and Development Center
U.S. Coast Guard

Federal regulations outline the ethical principles and guidelines for human subjects in research through the Department of Health and Human Services (HHS). In the Code of Federal Regulations (CFR) that covers the protections of human subjects in research, these regulations, policies, and guidance are enumerated in regulation 45 CFR 46. It is more commonly known as the Common Rule. This set of regulations outlines the ethical principles of justice, respect for persons, and beneficence and includes several key provisions, such as requirements for informed consent and for ongoing monitoring to ensure the continued protection of human subjects.

Each project in the RDC portfolio is assessed yearly by the RDC Institutional Review Board (IRB) using the Common Rule regulations and evaluated for level of risk. Each IRB member is certified to perform this duty per the HHS regulated training. Depending on the outcome of the RDC IRB assessment, principal investigators for projects submit a research or test protocol package for evaluation against compliance with the 45 CFR 46 regulations and the Commandant Instruction M6500.1 (Series).

Commandant Instruction M6500.1 (Series) further ensures that the rights, welfare, interests, privacy, confidentiality, and safety of human subjects is always paramount. Additionally, it states that all research projects will be conducted in a manner that avoids all unnecessary physical or psychological discomfort, and economic, social, or cultural harm. Upon completed review of formal test protocols, the IRB makes a recommendation to the unit commanding officer who is the official signatory for the compliance to federal regulations.

About the author:

Judith Connelly has 23 years in civil service as an operations analyst, space scientist, and aerospace engineer for the Coast Guard and NASA. She holds B.A. and M.S degrees in physics from the University of New Hampshire/Lawrence Berkeley Lab.

Focused on the Future

First Responder Research

Supporting public safety across land and sea

by Alice Hong
Laboratory Director
National Urban Security Technology Laboratory

The National Urban Security Technology Laboratory (NUSTL) plays a crucial role in supporting America's first responders. Organized within the Department of Homeland Security (DHS) Science and Technology Directorate (S&T), NUSTL is renowned for its contributions to the national first responder community, providing tools, technology, and guidance to help them address both persistent and emerging threats.

Based in downtown New York City, NUSTL operates in one of the most complex and densely populated urban environments in the United States, serving a city of over 8.5 million residents, nearly 1 million structures, and mass transit systems that span air, land, and sea corridors. In parallel, the Coast Guard's Research and Development Center (RDC) focuses on research for protecting America's 95,000 miles of maritime borders and 15,000 miles of waterways. Together, NUSTL and the RDC have formed a strong partnership, leveraging each other's expertise to enhance public safety across land and sea.

The two labs share a two-pronged common purpose—striving to keep the nation safe and securing it from a multitude of threats and hazards. NUSTL's specific focus on supporting front-line responders drives a partnership marked by collaboration and trust, as well as the sharing of resources, risks, and knowledge.

NUSTL serves a range of public safety sectors, including the fire service, law enforcement, and emergency management. First responders are actively involved throughout research, development, and test and evaluation (RDT&E) projects, offering crucial insights at focus groups and evaluating technologies during field tests. The challenges faced by state and local first responders are often mirrored by the Coast Guard, leading NUSTL and the RDC to deploy similar tools in the field, such as laser protective eyewear, thermal imagers, and real-time language translation tools. By cross-pollinating technological solutions, NUSTL and the RDC achieve mutually beneficial outcomes. The power of the NUSTL-RDC partnership within the Homeland Security Enterprise is invaluable, as it unlocks synergies, mitigates risks, and drives innovation to advance the front-line missions of our customers.

Additionally, many of NUSTL's customer agencies also have maritime responsibilities, and for these projects, the lab turns to the RDC for expertise in maritime technology and response. That is because the RDC is not just building a better buoy—though they have that covered—but is also executing future-focused research to improve situational awareness and crisis response capabilities that safeguard our waterways and maritime resources. This partnership is critically important when NUSTL works with first responders who must be properly equipped for maritime assignments, which include search and rescue, crime prevention, law enforcement, and medical support.

One example of this collaboration is the enhanced rescue hoist gloves project. Existing gloves used by responders for specialized helicopter hoist rescue operations can degrade quickly due to friction from the cable, which exposes the wearers' hands to injury or creates debris that can compromise the cable system. Responders required gloves that offered extended durability without sacrificing safety or hindering rescue operations, while also ensuring improved flexibility and comfort. DHS S&T sponsored the research and development (R&D) of abrasion-resistant glove materials and alternative designs that resulted in two prototype fingerless glove designs. NUSTL executed an operational field assessment to evaluate the prototype gloves against a range of search and rescue scenarios under realistic conditions, such as wind and rain. Not only did the RDC coordinate the test venue at the Coast Guard's Aviation Technical Training Center in North Carolina, but it also provided valuable insights during the test planning and assessment.

Findings from the operational field assessment were provided to the developers to make improvements before the enhanced hoist gloves are commercialized and available for use by emergency response agencies, search and rescue teams, the U.S. military, and others.

While NUSTL's test and evaluation (T&E) influences technology development, it also informs acquisition and deployment decisions. NUSTL manages the System

A Coast Guard evaluator simulates a hoist rescue while wearing a prototype glove. NUSTL photo

Assessment and Validation for Emergency Responders (SAVER) Program. Over its 20-year history, SAVER has produced more than 1,200 reports for first responders, including impartial, practitioner relevant, operationally oriented assessments of commercially available emergency response equipment and technologies. SAVER's goal is to provide cost and time savings to federal, state, and local responders as they decide which equipment to purchase.

As first responder equipment is increasingly sophisticated and complex, SAVER helps demystify commercially available products in the marketplace by providing the responder community with product information in plain language, using a Consumer Reports format. SAVER assessments provide comparisons of technology and capture end-user feedback. Each report highlights the salient product features for operators to consider before making an investment. This makes it easier for first responders to understand the pros and cons, review the specifications, and make a better purchasing decision as a result.

For maritime-related SAVER projects, NUSTL collaborates with the RDC to leverage its expertise. Recently, the lab conducted a market survey of maritime surveillance technologies that can detect small surface intrusions on the water. The survey identified 20 products, including six electro-optical/infrared systems for day and night visual detection, eight radar systems, three software solutions, and three integrated systems. These capabilities provide agencies with situational awareness and actionable insights concerning potential safety or security hazards of small surface intrusions. NUSTL teamed up with the RDC for a subject-matter review of the market survey report, published on the SAVER website

NUSTL also shared its SAVER Maritime Radiation Detectors TechNote with the RDC. This document provides unique considerations when using radiation detectors in a marine environment, including varying levels of background radiation, intermittent power, and the need to protect against electromagnetic interference, vibration, water, and corrosion. The TechNote is available to agencies charged with detecting illicit radioactive materials while searching ports and marinas, scanning traffic at ferry terminals, scanning vessels during surveillance and interdiction operations, and monitoring marine border crossings.

The nation is witnessing a period of breakthrough technology advancements, from uncrewed aircraft systems (UAS) to artificial intelligence and robotics. UAS, in particular, are revolutionizing emergency response operations by providing real-time aerial views that help identify dangerous hazards in areas that ground teams may struggle to reach. However, recent legislation restricts funding for certain foreign-made drones, creating a need for secure, high-performance systems from the United States or allied nations. In response, NUSTL tested four UAS from the Department of Defense's Blue List of approved cyber-secure drones. RDC experts flew to the assessment in rural Texas to observe the UAS in action and offer their technical expertise.

In addition to a portfolio of T&E projects, NUSTL manages R&D through its radiological/nuclear response and recovery program, which equips first responders with tools and guidance vital for responding to radiological emergencies. RDC has used NUSTL's radiological expertise for technical analysis on the radiation safety of backscatter X-ray devices that can be used for at-sea accountability along the southern border, further strengthening the partnership between the two organizations.

Conclusion

NUSTL's partnership with the RDC is built on complementary strengths—NUSTL's expertise in real-world technology testing for state and local first responders and the RDC's analogous expertise for the Coast Guard. Over the years, both organizations have cross-leveraged technical experts for various projects. This strong history of reciprocal support, whether its augmenting field teams for executing a counter-UAS test, or sharing referrals for potential staff recruits, is grounded in a shared commitment to serving the front lines of homeland security. This partnership expands access to resources, knowledge, and networks that might otherwise be out of reach, enabling the timely delivery of superior RDT&E solutions to Coast Guard operators as well as state and local first responders nationwide.

About the author:

Alice Hong is the laboratory director of the Department of Homeland Security, Science and Technology Directorate's National Urban Security Technology Laboratory (NUSTL) in New York City. She has been with the department for almost 20 years, helping to stand up the Science and Technology Directorate in Washington, D.C., and then moving to New York City to establish NUSTL.

Read the interactive synopsis and download the full hoist glove OFA report here: https://bit.ly/OFAReport

SAVER reports are free to download from the SAVER website at: https://bit.ly/SAVERLibrary

U.S. Coast Guard Research and Development

The next 50 years

by Bert Macesker
Executive Director
Research and Development Center
U.S. Coast Guard

CAPT Craig Allen
Chief
Office of Emerging Policy
U.S. Coast Guard

In ADM Linda L. Fagan's 2022 Commandant's Intent, she said, "Tomorrow looks different. So will we. We will be a more adaptive and connected Coast Guard that generates sustained readiness, resilience, and capability in new ways to enhance our Nation's maritime safety, security, and prosperity."

The Coast Guard Research and Development Center (RDC) lives this every day, helping the service prepare for tomorrow. This statement guides every project we undertake. It is our North Star.

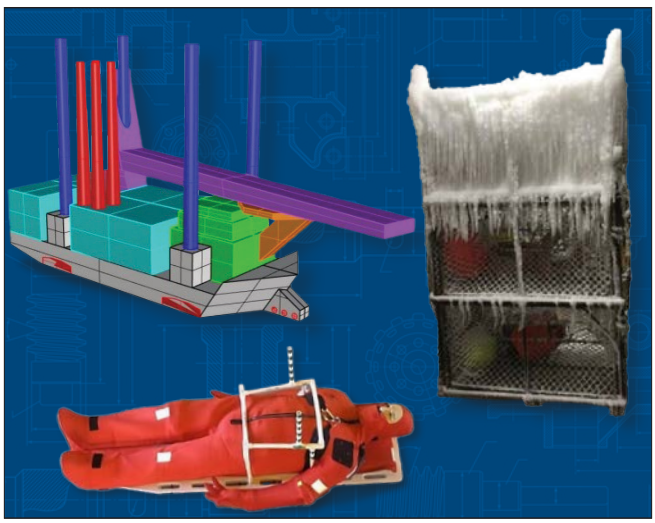
What Will the Research Workforce Look Like?

The future research organization will be highly skilled, motivated, mobile, diverse, interconnected with other federal labs and international research partners, and fully supported in talent management to execute research priorities. Today, the RDC workforce is more diverse, more curious, more willing to take on tough challenges and will continue to welcome talent from every walk of life, military service, agency, and academia. Those with the desire to have a clear mission and workplace family in civil service alongside Coast Guard operators will be rewarded with meaningful and impactful work that reduces the risk and raises the value of introducing new technology into the Coast Guard.

The RDC will continue a hybrid model combining in-person research with that of Coast Guard researchers possessing highly specialized skills who are working remotely at the Department of Defense (DoD) and the Department of Homeland Security (DHS) labs across the nation. Researchers in the future will be equipped with new knowledge-enabling tools including artificial intelligence (AI) assistants, extended reality to envision and print 3D prototypes, and reliable enterprise data to enable secure analytics in the cloud. They will also have a host of collaborative tools that connect them with DoD and DHS researchers like the recently developed Air Force Research Lab researcher collaboration tool called SMEConnect. The tool, which the RDC has access to through its DoD Laboratory Commander's Sync membership, has already connected 10,000 researchers across DoD. The Homeland Security Innovation Hub called HSWERX is another example of a collaborative tool that RDC employs to advertise public partnering opportunities.

While the new mobile workforce may not make a full career in one location, the exposure to hands-on research, skills, and responsibility acquired during their time with RDC will serve them well in their future public service or private maritime sector careers. RDC researchers are brokering their unique expertise and disciplines into key jobs at Coast Guard program offices.

Researcher position descriptions will be updated to reflect the highly specialized skill sets needed to bring transformation technologies into the Coast Guard. The RDC researcher will also have the skills to navigate public-private partnerships, facilitate technology



The Coast Guard Research and Development Center routinely supports Marine Board of Investigations when there are challenging technology questions. Examples include the *Seacor Power* capsize simulations, SS *El Faro* immersion suit research with mannequins and FV *Scandies Rose* ice accretion research. Coast Guard graphic

transfer/transition, and accelerate commercialization. The research talent pool will not only need to support the day-to-day execution of the research portfolio but also be ready to respond as subject matter experts in time-sensitive Marine Boards of Investigation and/or the next spill of national significance—especially when the federal on-scene commander needs to evaluate new technology solutions.

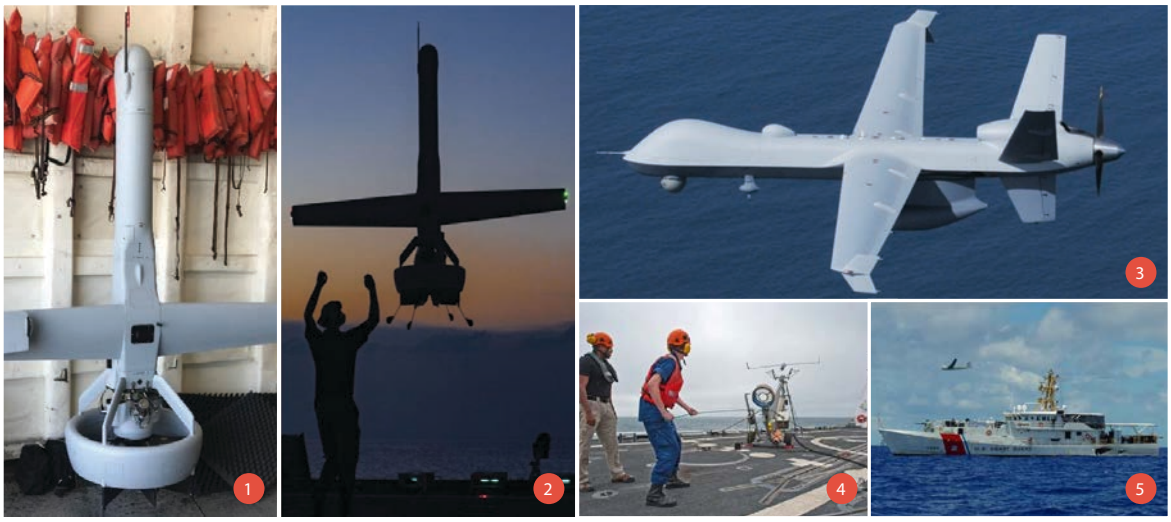
Will Research, and the Disciplines That Come With It, Be Needed 50 Years from Now?

The research team of the future will continue to unlock the promises of new science and technology. History is a good predictor of the future, and the RDC's history

U.S. Coast Guard Research and Development and Uncrewed Aerial Systems

The RDC has been active in uncrewed aerial systems (UAS) platform and sensor evaluations since the 1990s, working on projects that include:

- 2001 shipboard testing of a catapult-launched delta-wing UAS from the CGC *Harriet Lane*.
- Operational testing of Predator drones in high seas drift net missions—early versions had no radar and operated on simple line-of-sight control—and a maritime variant in the warmer waters of the Florida Straits.
- In-depth engineering analysis of the technology readiness of Eagle Eye, a tilt-rotor vertical takeoff and landing (VTOL) aircraft similar to the crewed V-22 Osprey.
- Testing a surface-search, radar-equipped Northrop Grumman MQ-8B Fire Scout uncrewed helicopter on our first national security cutter. This testing demonstrated that wide area surveillance could be effectively supported by the smaller and more cost-efficient Boeing ScanEagle UAS. At that time, the Navy was in the process of developing and acquiring a fleet of uncrewed gunships as part of the Fire Scout Program.
- Conducting the first UAV V-BAT testing in 2020 on the CGC *Harriet Lane*. The V-BAT is an uncrewed VTOL aerial vehicle that was developed by Martin UAV.
- Numerous short-range UAS testing of sensing payloads, including Puma testing on non-flight deck-equipped cutters including fast response cutters.



The V-BAT (pictures 1 and 2), Guardian UAS Maritime Variant Predator B (3), ScanEagle (4), and Puma LE (5), are shown in Coast Guard testing and operational environments. Coast Guard and Customs and Border Protection photos

of introducing transformative technologies is undeniable. Consider an example of the promise of uncrewed aerial systems (UAS). This is a technology area that has seen rapid advancements with increased automation and miniaturization of sensors. The promise of uncrewed systems (UxS) is that they can enhance all Coast Guard missions, especially those dirty and dangerous jobs. The RDC has been there every step of the way in unlocking the potential of these technologies.

The UAS research path is filled with milestones including the 2008 establishment of a Joint Project Office with Customs and Border Protection for Predator drone operations. RDC research helped the Coast Guard pivot to explore options other than the Integrated Deepwater UAS solution after $100 million in sunk costs. The RDC received a big thank-you from senior leadership for its efforts supporting a $1 billion UAS cost avoidance in pursuing a Navy solution called Fire Scout.

Most of the Coast Guard is unaware that the RDC introduced ScanEagle into Coast Guard operations helping to achieve milestones involving counterdrug interdictions supported by cutter-based UAS and ultimately creating a program of record. The cutter-based medium-range V-BAT 2024 contract—replacing the Scan-Eagle with a VTOL system—was technology first tested by the RDC.

The RDC also developed the first shore-based Federal Aviation Administration Coast Guard Certificate of Authorization for UAS operations testing over Cape Cod, Massachusetts. The RDC's persistence in developing a detect-and-avoid (DAA) solution for beyond-visual-line-of-sight operations resulted in the Coast Guard outfitting cutters with AeroVironment Pumas, small UAS platforms, and the Passive Acoustic Non-Cooperative Aircraft Collision Avoidance System (PANCAS) DAA technology developed by the RDC and its partners.

While UAS is one example, the RDC has a long track record of unlocking the promise of technology. The RDC credits include early prototypes of Vessel Traffic Services, a portable system for identifying trace amounts of narcotics called IONSCAN, and Coast Guard application of satellite-based Differential Global Positioning System (GPS). Search and Rescue Optimal Planning System (SAROPS) and other survival decision support tools also had their starts as RDC research projects. Oil spill fingerprinting was first an RDC project before being spun off into today's Marine Safety Laboratory. The RDC led the incremental but significant march toward the modernization of aids to navigation including Automatic Identification System (AIS). Vessel fire safety technologies and new regulations resulting from RDC full-scale experiments improved mariner safety on both recreational and commercial vessels. RDC identification and evaluation of new fleet assets, along with the development of fleet mix simulation capabilities, were used to assess their operational effectiveness and defend budget decisions with Congress.

Uncrewed systems, or UxS, is a broadly focused term that includes autonomous platforms above, on, and below the surface, as well as on land.

Would this have happened without a research center? It is plausible, but having the RDC apply its discipline, persistence, and partnering powers on the future list of technology opportunities will most assuredly position the service for the next transformational technology.

To read the Coast Guard's Unmanned Systems Strategic Plan, visit https://bit.ly/UxSStrategy.

The Coast Guard hears a great deal about innovation, which is complimentary in nature. Research and development (R&D) and innovation play key roles to ensuring the future success of both private sector and government organizations. R&D and innovation position an organization to compete in the marketplace, mitigate threats, and/or create organizational efficiencies for its shareholders and stakeholders. However, innovation cannot supplant the disciplines and importance of applied research in the Coast Guard's future. Certainly, the culture of innovation should be supported and recognized for the immediate improvements it can have on existing processes and empowering the workforce to innovate solutions to problems at the unit level, usually with available resources. An example of an innovation complement is an RDC project undertaken to help accelerate the adoption of robotic process automation (RPA). RPA is a rules-based technology that automates repetitive, labor-intensive tasks. The RDC demonstrated RPA's potential with nine different bots to replace the methodical work of turning weekly, manual data pulls into reports. This has saved the Coast Guard thousands of manhours helping manage billions in funding transactions. The importance of this capability was recognized with the creation of an RPA Center of Excellence at the Coast Guard C5I Service Center (C5ISC) in Alexandria, Virginia.

The Coast Guard has come a long way in search and rescue sensor technology from its very early novel research with pigeons and color conspicuity research (See Pg 37, Evaluating International Orange Alternatives). Coast Guard photo

While innovation is valuable, its misguided to believe that it is magic and can help an organization innovate its way out of performance gaps. Real solutions come with hard work, discipline, validated requirements, the systematic search for material and nonmaterial solutions, and, typically, a whole-of-Coast Guard effort that engages the relevant enterprise authorities, product lines, service centers, and governing policies to successfully transition.

The RDC will always do both research and evaluations of commercial and/or government off-the-shelf technologies because they are often complimentary and because operators can reap immediate benefits from the rapid repurposing of available technology. Technology that can be quickly adapted for Coast Guard use is especially important in the case of countering adversaries that have access to the same technology innovation ecosystem.

Started in 2021, the RDC's research to improve network connectivity for cutters operating at high latitudes is another example of innovation being complimentary to research. The RDC worked closely with the Air Force Research Laboratory, Space Force, Coast Guard cutters including the *Healy* and *Polar Star* icebreakers, and the C5I Service Center to introduce a new satellite-based technology solution called Starlink. Today, the capability is being rolled out to the fleet. In 2023, the RPA and Starlink examples were recognized as the Captain Niels P. Thomsen Innovation Award winner for Administration, Logistics or Support and the DHS Secretary's Award for Innovation, respectively.

What Are Some of the Coming Transformative Technologies?

The Coast Guard will be impacted by many transformational technologies in the next 50 years that will improve its operations, maintenance, and overall mission readiness. AI and machine learning will certainly be game-changers. They will facilitate the processing of vast amounts of data collected by UxS, sensors, and other sources to provide real-time insights, predictive maintenance, and decision-making support. For example, the generative AI technology emerging today that can exploit large language models will serve as smart assistants to RDC researchers. The RDC is already evaluating alpha versions provided by DoD partners.

Other technologies include space-based technology, robotics, applications of exoskeletons, immersive technology, renewable energy, material advancement

applications in the form of more durable, lightweight vessels and equipment, quantum computing, and many novel technologies like jet suits. These and many more will need to be evaluated to maintain a technological advantage to deter and counter bad actors and to adapt to evolving mission requirements.

What Are the Alternative Futures That Will Focus Coast Guard Research Priorities?

Predicting future challenges and operational requirements is a bit like forecasting the weather. One can study current trends and make a reasonable prediction about what the near future will bring, but there are too many variables to accurately project beyond a limited horizon. How then should the Coast Guard approach the daunting task of envisioning the requirements needed to remain Semper Paratus 50 years from now? One answer is by applying the art and science of strategic foresight.

Strategic foresight provides a systematic process for "future-proofing" concepts and capabilities by testing them against a wide variety of plausible futures. It is quite different from forecasting, which endeavors to accurately predict one specific future or trend. By identifying and tracking weak signals, evidence of emerging patterns that have not yet developed into mainstream trends, and applying analytical reasoning to envision how those drivers might influence our future reality, we can build detailed models to identify risks and opportunities. By building and examining a variety of plausible futures, we can identify common elements required for the Coast Guard to succeed and potential pitfalls to avoid, thus distilling insights into how to build lasting organizational resilience.

Through the Office of Emerging Policy (DCO-X), the Coast Guard helms one of the longest-running strategic foresight programs in the federal government, Project Evergreen. Through its partnership with RAND Corporation's Homeland Security Operations Analysis Center, the Coast Guard is currently at the halfway point of its sixth four-year Evergreen cycle.

Following is a short description of four Evergreen V—the 2018-2022 cycle—scenarios that were initially

Petty Officer 3rd Class John Cartwright, a CGC *Stratton* crewmember, releases a ScanEagle UAV during a demonstration approximately 150 miles off the Pacific Coast in August 2012. The ScanEagle is being tested for capabilities that will create a reliable reconnaissance system for the Coast Guard. Coast Guard photo by Petty Officer 2nd Class Luke Clayton

crafted, and recently updated, to reflect new trends.

Scenario 1, Networked to the Nines: This scenario focuses on a hyperconnected future in which nation-state actors pose an increasingly dangerous threat to the cyber systems the U.S. economy depends on. There is rampant competition for resources, especially critical minerals, which drives territorial disputes over seabed mining. The U.S. military is growing overall, and has embraced human-machine teaming. An example of human-machine teaming is field research with autonomous surface vessels following a Coast Guard vessel, much like autonomous drones with onboard AI that fly alongside manned aircraft to scout ahead. However, the Coast Guard remains stretched thin across its diverse mission portfolio, to which a 12th statutory mission—economic security and protection—has been added.

Scenario 2, Southern Discomfort: Environmental and social upheavals pose major operational and personnel challenges to the Coast Guard. The United States simultaneously faces increased frequency and magnitude of major storms along with a massive influx of irregular migration activity. Across the nation, a major wave of resignations makes it increasingly difficult for many companies and organizations, including the Coast Guard, to retain skilled personnel. Political schisms within California, Oregon, and Washington state lead to speculation about their possible succession. On the plus side, recycling processes have improved remarkably, driving economic growth in that sector. Relations with China have improved substantially since the low point in the 2020s.

Scenario 3, I've Got the Power: The U.S. economy is strong, driven in part by a concerted effort to better harness renewable energy. Offshore wind and wave projects have proven highly successful. However, increased demand for critical minerals causes tensions between seabed mining advocates and environmentalists who oppose the practice. Tensions are high with Russia and China, particularly in the space and maritime domains. The United States has reversed its declining birthrate trend with a new baby boom. Meanwhile, autonomous technology increasingly replaces human labor in many occupations.

Scenario 4, Angst and Adaptation in the Americas: Geopolitical tension with China is acute, driven in part by China's expansive fishing and resource harvesting practices in the high latitudes. AI-enhanced fishing practices have pushed many fisheries to the brink of collapse. DoD and DHS have reorganized, and the new U.S. Department of Homeland Defense places the Coast Guard and U.S. Customs and Border Protection in the same department as the Army, Air Force, Marine Corps, Navy, and Space Force. The United States has increased its presence in the Western Hemisphere to counter Chinese influence in the Caribbean and South America. AI is omnipresent across media and workplaces, contributing to a nationwide mental health crisis that has directly impacted the Coast Guard workforce. The United States is a primary destination for a surging global immigration wave, adding large numbers of highly educated and skilled personnel to the U.S. workforce.

These scenarios provide context for long-term planning initiatives, force design, and investment priorities. Additionally, they help instill strategic thinking through their employment in a turn-based strategic game called Paratus Futurum that DCO-X and RAND facilitate for Coast Guard senior leaders and, more recently, in courses for midgrade officers and senior enlisted leaders taught by the Coast Guard Leadership Development Center.

For more detailed information about the process for constructing the scenarios and the future worlds, visit https://bit.ly/EvergreenV.

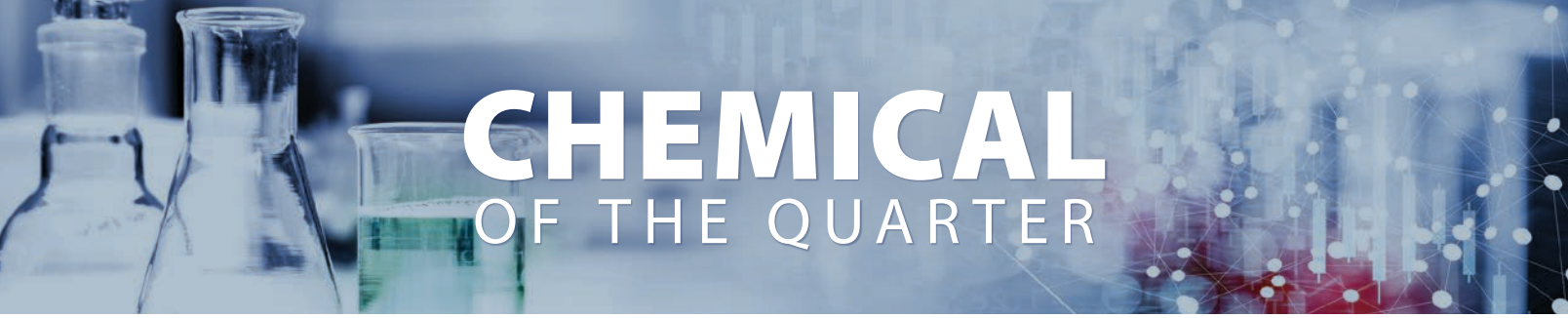
Why Being an RDC Researcher is One of the Best Jobs in the Coast Guard

The most important asset in a research center will always be its people. Yes, more research funding and a permanent top-notch facility would be great, but it is the talent that works closely together that will find creative ways to execute priority research for the Coast Guard. RDC researchers have one of the best jobs in the Coast Guard because they get to develop and try out science and technology solutions in Coast Guard operations. In the next 50 years, RDC researchers, Coast Guard sponsors, and stakeholders will be able to look back as collective plank owners of many game-changing technologies that had their start in the research community.

About the authors:

Bert Macesker serves as the Coast Guard Research and Development Center's executive director. He holds an M.S. in ocean engineering and has performed Coast Guard research for the past 30 years.

CAPT Craig Allen leads the Coast Guard's Office of Emerging Policy. A career cutterman, he is a graduate of the U.S. Coast Guard Academy and U.S. Marine Corps University's Command and Staff College and was a Harvard national security fellow in the 2022-23 cohort.



Diluted Bitumen

by Benedette Adewale, Ph.D.
Research Physical Scientist, Research and Development Center
U.S. Coast Guard

The growth in North American oil production is partially due to the increase in the production and distribution of Canadian oil sands products (OSP), like diluted bitumen, or dilbit, an OSP transported from Canada to the United States. Recent dilbit events have demonstrated that these OSPs generally behave differently than conventional crude oil during a spill.

What is Bitumen?

Extracted from natural oil sands, bitumen is a semisolid form of petroleum that is sticky and highly viscous, meaning it does not easily flow or pour, which makes it difficult to transport through pipelines.

What is Dilbit?

Dilbit is typically composed of 70% to 80% bitumen and 20% to 30% dilutant. The dilutants can include gas condensates, synthetic crude oil, synthetic naphtha—petroleum—and added butane (C4) or pentane (C5) compounds. The purpose of the dilutant is for easy transport and handling through pipelines or in tanks. Though typically conveyed by rail or pipeline, dilbit is also transported by barges or tank ships. Each method carries an inherent risk of spillage.

What has the Coast Guard done about it?

The Coast Guard's Great Lakes Oil Spill Response and Cleanup Activities Assessment to Congress, published November 21, 2018, identified knowledge gaps in the behavior of dilbit in the freshwater environment. Specifically, it stated less is known about the transport and fate of dilbit pollution in the Great Lakes in comparison to other navigable U.S. waters.

In 2021, the U.S. Coast Guard Research and Development Center (RDC) performed an in-depth literature review of dilbit research to determine additional knowledge gaps and identify research areas to improve dilbit spill response.[1] This resulted in the RDC performing three experiments at the U.S. Army Engineer Research and Development Center Cold Regions Research and Engineering Laboratory facilities in Hanover, New Hampshire, to further characterize the behavior of dilbit products in freshwater. The experiments assessed the physical and chemical properties of two common dilbit products, Western Canadian Select and Cold Lake Blend, using varied seasonal environmental conditions—temperature and solar exposure and waterbody sediment concentration—to determine their impact on spilled dilbit.

Guidance for Planners and Responders

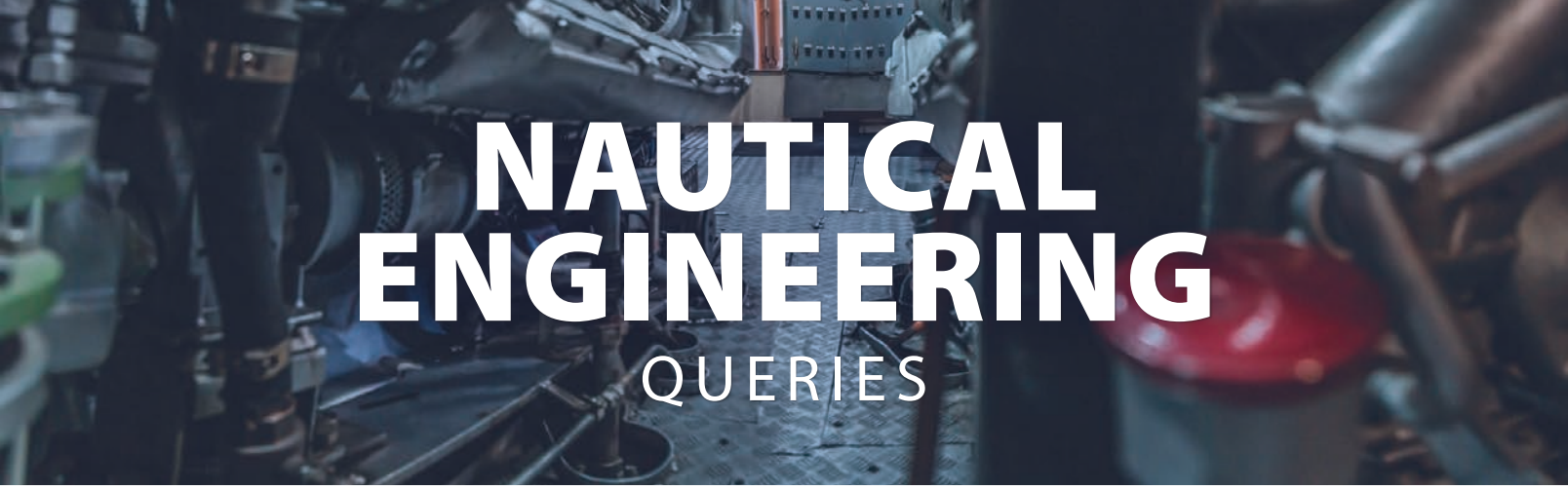
The RDC's literature review and experiments found that dilbit generally floats after initial release into freshwater. When conditions are calm with no agitation or sediment in the water, dilbit may generally stay afloat for six to 10 days in both freshwater and saltwater. The same containment and recovery tools used for medium to heavy crude oil can be used on dilbit when floating. However, by comparison to traditional crude oil, dilbit weathers rapidly in freshwater. As the dilutant evaporates, the density and viscosity increase, and the remaining oil exhibits behavior similar to heavy oil.

The fate of spilled dilbit depends on the type of diluted bitumen products, whether its Western Canadian Select or Cold Lake Blend, its characteristics, the environmental conditions during and after a spill, and the nature of the waterbody—the amount of suspended sediment. Response plans should focus on containing and removing the surface slick before it becomes more difficult to collect with skimmers or weathers sufficiently to sink.

About the author:
Benedette Adewale, Ph.D., is a research physical scientist and project manager at the Coast Guard Research and Development Center. She earned a Master of Science degree in chemistry from the City University of New York, City College of New York and a Doctor of Philosophy degree in chemistry from Stony Brook University. She is a member of American Chemical Society.

Endnotes:

1. Adewale, B., Cisternelli, M., Gonin, I., Wurl, M., and Tusia, M. (2021). Literature Review of Diluted Bitumen (dilbit), USCG Research and Development Center, Report No. CG-D-03-21, June 2021.



NAUTICAL ENGINEERING QUERIES

Prepared by NMC Engineering Examination Team

1. In a diesel engine exhaust system, the cooling of the exhaust gases below their dew point will result in _____ .

A. Increased engine back pressure
B. Sulfuric acid corrosion
C. Surface pitting of the turbocharger compressor blades
D. Moisture impingement on the turbocharger compressor blading

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2. In the presence of an open flame or hot surfaces, chlorinated fluorocarbon refrigerants decompose and form what chemical substance?

A. Carbon monoxide
B. Water vapor
C. Phosgene gas
D. Petroleum crystals

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3. An open primary coil in a voltage transformer (VT) will be indicated by which of the listed conditions?

A. No voltage on the output of the secondary coil
B. Low resistance value on the primary coil
C. An infinite resistance value on the secondary coil
D. Overloaded secondary coil

---

4. Circulation of water and the steam/water mixture within a natural circulation boiler is retarded by _____ .

A. Back pressure in the steam drum acting on the user tubes
B. Large changes in steam density
C. Fluid friction in the downcomers, drums, generating tubes, and headers
D. High feedwater pressure

Engineering Answers

1. A. Increased engine back pressure — Incorrect answer

B. Sulfuric acid corrosion — **Correct Answer:** "Where charge air coolers are cooled by jacket water, it is frequently possible under these conditions to elevate the charge air temperature well above ambient … and to help avoid sulfuric acid attack in the cylinders."

C. Surface pitting of the turbocharger compressor blades — Incorrect answer

D. Moisture impingement on the turbocharger compressor blading — Incorrect answer

Modern Marine Engineer's Manual, Vol. II, Hunt, page 16-112

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2. A. Carbon monoxide — Incorrect Answer

B. Water vapor — Incorrect answer

C. Phosgene gas — **Correct Answer:** "In the presence of heat from an open flame or electric heating element they may break down into phosgene gas. This gas is toxic to the point of being poisonous."

D. Petroleum crystals — Incorrect answer

Principles of Refrigeration, Marsh & Olivio, 2nd ed., p. 54

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3. A. No voltage on the output of the secondary coil — **Correct Answer:** "When the primary winding of a transformer is open, no primary current can flow and there is no voltage induced in any of the secondary windings."

B. Low resistance value on the primary coil — Incorrect answer

C. An infinite resistance value on the secondary coil — Incorrect answer

D. Overloaded secondary coil — Incorrect answer

Basic Electronics, Grob p. 373

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4. A. Back pressure in the steam drum acting on the user tubes — Incorrect answer

B. Large changes in steam density — Incorrect answer

C. Fluid friction in the downcomers, drums, generating tubes, and headers — **Correct Answer:** "When the rate of increase in these losses (caused primarily by the increase in specific volume in the riser circuits) becomes greater than the gain from increasing density difference, the flow rate begins to drop."

D. High feedwater pressure — Incorrect answer

Steam, Its Generation and Use, Babcock & Wilcox, p. 3-14

Correction

In the Fall 2024 issue, there was a error in the first Engineering Queries question. The answer options should have read:

A. Compression ratio of the engine
B. Volume of the engine
C. Relationships between pressure and temperature during one stroke of the engine
D. Relationships between pressure and volume during one cycle of the engine **(Correct answer)**

NAUTICAL DECK QUERIES

Prepared by NMC Engineering Examination Team

1. **BOTH INTERNATIONAL AND INLAND: What is the duration of each blast of the whistle signals used in head-on and/or crossing situations?**

   A. About 1 second
   B. 2 to 4 seconds
   C. 4 to 6 seconds
   D. 8 to 10 seconds

---

2. **The midships house of your cargo vessel is constructed with an interior stair tower from the main deck to the bridge. Under what circumstances may the doors from each deck to the stair tower be kept open when underway?**

   A. They are to be kept closed at all times
   B. They may be kept open if the ventilation or air conditioning system is shut down
   C. They may be kept open if they can be automatically closed from the bridge
   D. They can be kept open if the Muster List (Station Bill) has personnel designated to close them in case of fire

---

3. **Which of the following is a hook that will release quickly?**

   A. Longshore hook
   B. Margin hook
   C. Marginal hook
   D. Pelican hook

---

4. **All persons or vessels within the lock area, including the lock approach channels, come under the authority of which person?**

   A. The dockmaster
   B. The dock captain
   C. The lockmaster
   D. The lock foreman

1. A. About 1 second — **Correct Answer:** "The term 'short blast' means a blast of about one second duration."

B. 2 to 4 seconds — Incorrect

C. 4 to 6 seconds — Incorrect

D. 8 to 10 seconds — Incorrect

Reference: Inland/International Rule 32(b)

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2. A. They are to be kept closed at all times — Incorrect answer

B. They may be kept open if the ventilation or air conditioning system is shut down — Incorrect answer

C. They may be kept open if they can be automatically closed from the bridge — **Correct Answer:** "The doors shall be of a self-closing type. Holdback hooks, or other means of permanently holding the door open will not be permitted. However, magnetic holdbacks operated from the bridge or from other suitable remote-control positions are acceptable."

D. They can be kept open if the Muster List (Station Bill) has personnel designated to close them in case of fire — Incorrect answer

Reference: 46 CFR 92.07-10

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3. A. Longshore hook — Incorrect answer

B. Margin hook — Incorrect answer

C. Marginal hook — Incorrect answer

D. Pelican hook — **Correct Answer:** "A hinged hook held together by a ring for quick release."

Reference: American Merchant Seaman's Manual, Hayler, 7th Ed., page G-21

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4. A. The dockmaster — Incorrect

B. The dock captain — Incorrect

C. The lockmaster — **Correct Answer:** "The lockmaster shall be charged with the immediate control and management of the lock area, including the lock approach channels."

D. The lock foreman — Incorrect

Reference: 33 CFR 207.160

IN THE NEWS

A Coast Guard Air Station Clearwater helicopter crew rescued a man and dog from a disabled 36-foot sailing vessel that was taking on water 25 miles off Sanibel Island, Florida, on September 26, 2024. The man and his dog were reportedly in good health and taken to Southwest Florida International Airport to meet with EMS. Coast Guard photo

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Navigating the Future of Safety and Sustainability

Congratulations to the winners of the 2024 North American Marine Environment Protection Association's annual student art contest! Students in kindergarten through 12th grade were invited to artistically interpret *Navigating the Future of Safety and Sustainability* to highlight the importance of advancing maritime safety and environmental protection in the era of emerging technologies and alternative fuels. The contest was co-sponsored by the U.S. Coast Guard and The Inter-American Committee on Ports of the Organization of the American States. To learn more, go to *https://namepa.net/education/art-contest*

Amanda C., Grade 4
Flushing, New York

Andrea K., Grade 2
Fort Lee, New Jersey

Benjamin G., Grade 6
Vancouver,
British Columbia, Canada

Yinge C., Grade 8
Vancouver,
British Columbia, Canada

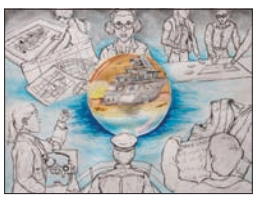
Vivian L., Grade 6
Flushing, New York

Jacob K., Grade 6
Poway, California

Kyle S., Grade 3
Vancouver,
British Columbia, Canada

Valentina C., Grade 7
El Dorado Hills, California

Tansy C., Grade 3
Gulfport, Florida



Rosa L., Grade 9
Cupertino, California

Louise L., Grade 1
Fort Lee, New Jersey

Cynnie C., Grade 6
Vancouver,
British Columbia, Canada