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RAPID PROTOTYPING EXPERIMENTATION

HOW DO WE ADD MORE REALISM TO RESEARCH?

NEW COMPOSITES FOR NEW PLATFORMS

ADDITIVE MANUFACTURING

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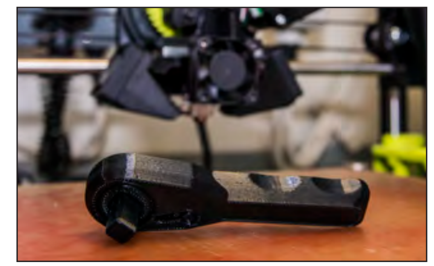


Future Force is a professional magazine of the naval science and technology community. Published quarterly by the Office of Naval Research, its purpose is to inform readers about basic and applied research and advanced technology development efforts funded by the Department of the Navy. The mission of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

Front Cover: Designed by Jeff Wright

PRINT THIS!

ADDITIVE MANUFACTURING IS BECOMING A KEY CAPABILITY

By Diane Owens

Photo by Joe Bullinger

AS THE DEMAND FOR FASTER PROTOTYPING AND LESS-EXPENSIVE REPLACEMENT PARTS GROWS, SPACE AND NAVAL WARFARE SYSTEMS CENTER ATLANTIC IS EXPANDING ITS CAPACITY FOR ADDITIVE MANUFACTURING TECHNOLOGY.

A research-and-development scientist at Space and Naval Warfare Systems Center (SSC) Atlantic wanted to create a compact, energy-harvesting support component not available commercially. He designed the component in computer-aided design software and, in a single day, used additive manufacturing (also known as 3D printing) to build a prototype of the product at minimal cost. After determining that the form, fit, and function of the initial prototype needed a few adjustments, he modified the original design and built a second component that met exact requirements.

On board a submarine, a keyboard video mouse switch had a high failure rate because of a substandard button design. Two sets of four buttons continuously broke under daily use on this submarine and in every common submarine radio room in the fleet. To resolve the issue, SSC Atlantic personnel reverse engineered the buttons and built them with a strengthened design using additive manufacturing. After fit testing, they contracted with an outside vendor to manufacture the buttons in a large quantity using a heavy-duty polymer. Depot employees then repaired the faulty units and the enhanced buttons were installed to meet fleet requirements.

These are just a few of the ways SSC Atlantic employees leverage additive manufacturing technology to save time and money throughout the engineering life cycle from research and development through maintenance and sustainment. This innovative technique provides optimal support to the fleet by putting the best information warfare solutions in the hands of warfighters.

"Additive manufacturing further enables SSC Atlantic to improve cost, schedule and performance in delivering and sustaining solutions to the warfighter in an environment where change is constant," said Chris Miller, SSC Atlantic's executive director. "It fundamentally changes how we think about manufacturing, enabling us to be more responsive and meet our commitments."

Traditional vs. Additive Manufacturing

Traditional production processes use subtractive manufacturing: a chunk of raw material, like metal or plastic, is milled using lathes and other equipment to extract pieces, leaving the final product. It often results in substantial material waste.

Additive manufacturing builds a product from scratch, in layers, based on a computer-aided design drawing with precise product specifications. The 3D printer build-plates are heated so the product adheres to them, and the raw material, generally one of various types of plastic filament, is heated and flows through tubing where it is compressed and extruded in a liquefied form through a nozzle. It is then distributed onto the printer bed in a fine layer and the nozzle oscillates across the build bed continuously until the product is complete. Depending on requirements, some plastic materials create rigid products, while others are flexible.

Because all products are tacky (sticky) when completed, they must cool until they harden. Therefore, designs for some 3D-printed objects contain built-in support posts to lift part of the object and support it during cooling. The posts are removed when the product hardens and the connection points are sanded.

Solid 3D products result from numerous passes of layers of material continuously dispersed across the designated area on the build bed. Infilled 3D-printed products have various patterns printed inside, such as honeycombs or triangles. Infill is created by printing a layer of plastic, then inserting a layer of air. Alternating layers of plastic and air result in open spaces in various patterns. The percentage of infill affects product weight, strength, and print time; infill also can be used for decorative purposes. Generally, the higher the percentage of infill, the stronger the product is.

Handles, knobs, and other appendages can be included in the basic design, eliminating the need to build them separately and connect them after the product is complete.

Although additive manufacturing can take hours, or even a week, to build a product, it is much faster than researching commercial product availability, creating and submitting contracting documents, soliciting bids, selecting a vendor, sending specs to a manufacturer, and waiting for the product to arrive. It is also much cheaper.

Modifications and Research and Development

If products created using traditional manufacturing do not possess exactly the right form, fit, and function, the design must be altered and updated drawings and contracting modification documents are sent to the manufacturer, which must create a new product or modify the existing product. The process might need to be repeated several times before the product is fully functional, and each modification costs time and money.

Additive manufacturing allows for design modification, editing of software drawings, and on-site building of modified products at a tremendously lower cost and in less time. New products and replacement parts—often reengineered to eliminate flaws, increase durability and reduce the number of connecting pieces—are generally created from low-cost durable plastics. Other materials, such as steel, titanium, bronze, brass, silver, gold, aluminum, wax, metal-infused plastic, and rubberized plastic, also can be used as needed.

Using additive manufacturing technology, a prototype of a product can be built once the design is conceptualized and tested to ensure it meets all constraints. Additional runs allow the design to be refined and improved.

In addition to producing an energy harvesting support component, science and technology employees at SSC Atlantic also developed an idea for a spherical-shaped intelligence and surveillance product. They designed the product in two interconnecting pieces, built it in a 3D printer, and placed an embedded system with sensors inside. Providing a prototype to military sponsors is immeasurably more effective than presenting a white paper.

Preproduction

Additive manufacturing also has enhanced capabilities in the preproduction phase, which starts with identifying a need for a product and generally ends with creation of a prototype.

SSC Atlantic preproduction employees designed and built an additive manufacturing prototype of a rack required by a customer to hold an intercom component. Numerous design iterations were built because of changing requirements, and the final version of the rack was installed to verify form and fit. Product specifications were sent to a vendor and the racks were produced in large quantities, saving a considerable amount of time and money on prototyping. This flexibility would not have been possible with traditional manufacturing methods because of metal fabrication lead times.

When employees integrate command, control, communication, computers, intelligence, surveillance, reconnaissance equipment in military land vehicles, it often involves designing mounting solutions to hold sensitive equipment in place. The team was tasked with designing a bracket to secure cryptographic equipment in a vehicle. However, crypto equipment has security sensibilities and can only be used in a secure lab or signed out for use under secure conditions.

The team's solution was to use additive manufacturing to design and build a full-sized plastic replica of the crypto equipment exterior, and to design and build the bracket to hold it. They were able to test form and fit, make necessary modifications and complete the project without delay in an open environment.

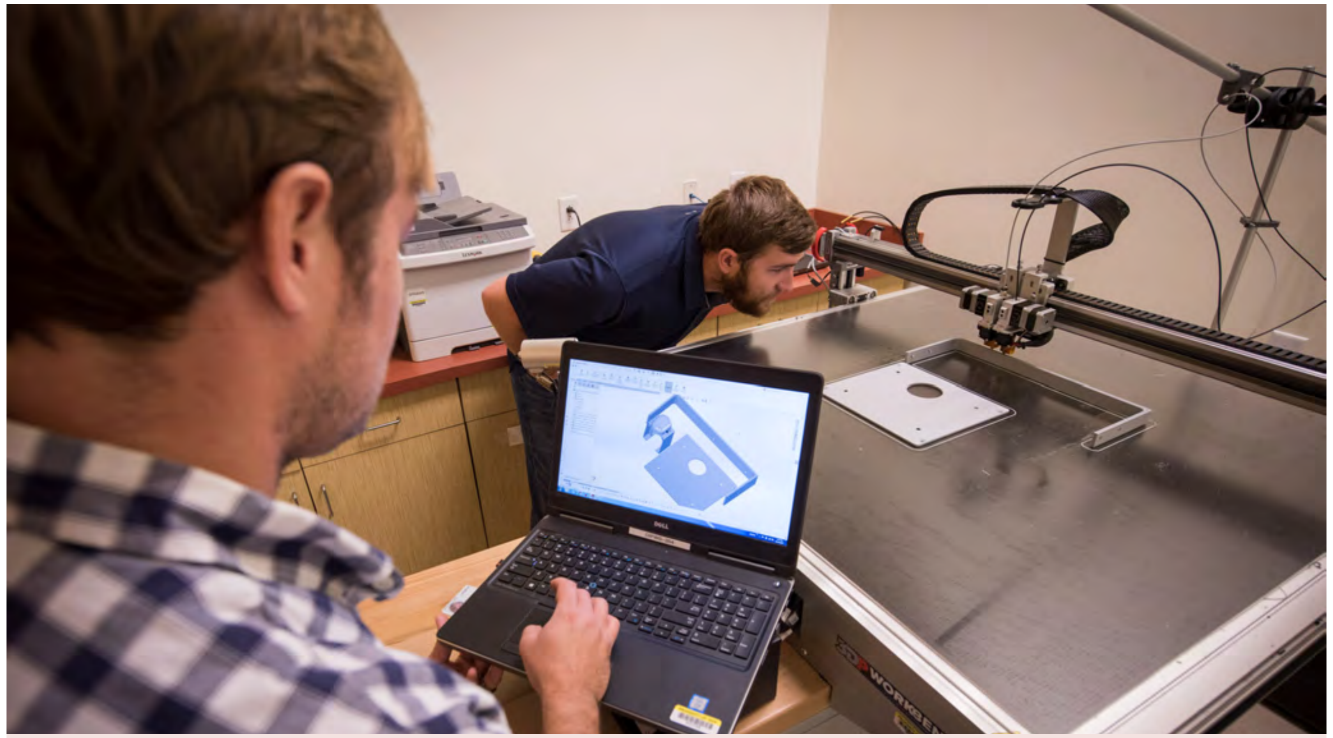
In other situations, the team must design mounting solutions for commercial off-the-shelf products that are not available because of vendor back orders. The team requests a computer-aided design model of the product from the vendor to determine the size, weight, connection layout and mounting interface patterns. They can then build a full-sized replica to design and build the mount required before the product arrives.

Preproduction employees built and used a system integrated lab (SIL) to analyze and test system equipment for the Joint Light Tactical Vehicle. Because components have exposed electrical contacts, the team used additive manufacturing to design and build a 3D safety cover to protect technicians and operators from electrical shocks when reaching around the SIL components. This proved to be an inexpensive solution to a potentially dangerous situation.

Production

During the production stage, when raw materials are transformed into a product, SSC Atlantic employees were tasked to design and create a protective case for a specific personal computer. The original case contained 13 interconnecting pieces. The team created a 3D scale model of a case from rugged plastic and designed a hooked Plexiglas top and bottom for it. After the customer approved it, they created a full-sized model built with only two pieces, instead of 13, for approximately $30.

On another occasion, employees needed to improve an existing metal cable support bracket attached to the back of a piece of submarine equipment. The cables



SSC Atlantic employee Josh Heller, left, reviews computer-aided design software created for additive manufacturing, while Ryan Wilhite verifies the printer is properly calibrated. Photo by Joe Bullinger

continuously sagged and caught on a nearby alert panel, disconnecting the power or damaging the intricate cable assembly. An enhanced design was drawn on a napkin in 30 minutes, input into design software in an hour, printed on rugged plastic in a 3D printer in 48 minutes, and fitted and tested with the equipment in 20 minutes. The resulting product confirmed the solution and led to revisions to the metal bracket.

Maintenance and Sustainment

SSC Atlantic operates a maintenance depot where employees repair circuit boards and equipment used by the fleet and other Navy entities. Maintaining and sustaining equipment entails a considerable amount of reverse engineering. Because repair and maintenance work often uncovers product flaws, additive manufacturing technology is extremely helpful in duplicating and modifying products to enhance function. Employees can hand-scan an object to generate continuous images or scan it on a rotating bed, which creates a software design for that item.

As part of one project, depot employees had to replicate a failed power supply on an obsolete product with components covered in tacky plastic. To buy a comparable new product required a minimum purchase of 10 items at $2,000 each. Rather than incur a $20,000 expense, they painstakingly peeled the plastic potting away with tweezers, redesigned the object and printed new parts on a 3D printer. They replaced more than 100 components in the product and the modified power supply has never failed.

By combining the expertise of its workforce and additive manufacturing capabilities, SSC Atlantic continues to move to the next level of repair and redesign needed to keep Navy systems functioning. Employees are creating rapid prototypes of innovative new products, duplicating existing products inexpensively, and enhancing existing design quickly and easily. By building lighter, cheaper and more effective parts to replace those that are no longer commercially available, SSC Atlantic is putting information warfare solutions in the hands of warfighters quickly, creatively, and cost-effectively.

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Photo by Dave Collier

RAPID PROTOTYPING EXPERIMENTATION:
"TEST FAST, FAIL FAST, ADJUST FAST"

By Dave Collier and Patric Petrie

GETTING NEW TECHNOLOGY INTO THE HANDS OF WARFIGHTERS INVOLVES MORE THAN JUST FASTER PROTOTYPING—IT MEANS DEMONSTRATING THAT IT WORKS IN A REAL-WORLD ENVIRONMENT.

San Diego-based Space and Naval Warfare Systems Center (SSC) Pacific is a key component of the Navy's mission to provide cutting-edge technologies and capabilities for the fleet. The center's command, control, communications, computers, intelligence, surveillance and reconnaissance (C4ISR) department uses its Hawaii-based advanced development and experimentation branch to plan and execute demonstrations, experiments, and military utility assessments of new and developing technologies. To accomplish this, the team experiments as it exercises and operates, acts as an honest broker with no technology bias, and maintains minimal intrusion on operational forces.

Tom Peters, an author on business management practices and a former Navy Seabee, has proposed the mantra, "Test Fast. Fail Fast. Adjust Fast." This concept, which has inspired new procedures being tested by lab personnel, revolves around executing rapid prototyping in a timely manner.

Rapid prototyping experimentation is a fundamental necessity for accelerated development and should begin with the original technology concept. Detailed planning and coordination are required to conduct an assessment and can't be an afterthought. Timely execution requires a solid understanding of what the specific missions the new technology is addressing and why current methods are insufficient.

In other words, we need to understand both the mission and the capability gap. These can come from a military expert or a thorough understanding of military doctrine (such as manuals, concepts of operations, and techniques and procedures) or, preferably, a mixture of both.

Identifying capability gaps is not necessarily an easy process. A one-stop shop does not exist for identifying all the gaps. Some sources that identify capability gaps are in specific, well-defined documentation such as initial capability documents or urgent needs statements. Other sources are indirect, such as journals and conferences.

Next, to execute rapid prototyping experimentation in a timely manner, one must develop a close collaboration between the developers and warfighters. Warfighters understand the requirements and can best assess the capability of a technology to meet their needs.

Warfighters have full-time jobs and must prioritize their efforts to accomplish the most important missions.

Developers can successfully battle for priority through the significant effort of socializing the value of rapid prototyping to warfighters' missions.

"Test Fast, Fail Fast, Adjust Fast"

"Test Fast" simply means putting the technology in the hands of the user early to get feedback on capabilities and limitations. Early in the development one may not be looking at a system-of-systems capability, but only at a component of the system; "Test Fast" eliminates this problem.

There are two parts to the "Fail Fast" definition. The first is giving warfighters the opportunity to say, "This won't work." Developers can be too emotionally involved in their projects. A third-party testing organization is a good way to avoid this issue. The organization can act as an honest broker with no technical bias and serve as the bridge between developers and users.

The second part of the "Fail Fast" definition could be best rephrased as "Fail Well." Embrace constructive criticisms and learn from them. Work with the operator to prioritize these criticisms, then change the technology to overcome shortfalls. Even big companies such as Apple, Samsung, Dell, and Google make mistakes.

Finally, "Adjust Fast."

Begin the process to correct these criticism and work diligently to overcome them. There is a phrase used in the Army: "Always improve your foxhole." Your foxhole is never finished. A more powerful bomb or better marksman may defeat the cover your foxhole provides. So don't just wait for them, be proactive.

Seabees construct a building in the Philippines using specially treated Styrofoam that allows the structure to withstand typhoon-force winds. Photo by Dave Collier

Know the Warfighter and Deliver Innovative Technologies

The first prerequisite for rapid prototyping experimentation is a science and technology value or knowledge gained from conducting the experiment.

Second, an experiment must have warfighter "pull," meaning a warfighter or warfighting command must request this type of technology because of a capability shortfall or a requirement gap. Conducting prototyping experimentation just for the sake of prototyping experimentation alone is a waste of resources.

The third prerequisite of prototyping experimentation is a funding sponsor, which is the organization that is willing to fund the prototyping experiment to its logical conclusion. The funding sponsor could be within the same command, an external Department of Defense organization, or an external federal government organization.

Scoping, Planning, Executing, and Close Out

There are four major steps that need to be addressed when conducting rapid prototyping experimentation: scoping, planning, executing, and close out. Of course, not all projects will require each step to be addressed to the same level of detail, but this information should serve as a path for identifying and planning activities for a given project.

The first step, scoping, involves understanding the capabilities of the proposed technology and the expectations of the sponsor within the context of allocated funding.

The initial inputs associated with a project should be obtained by the program manager through the initial sponsor project point of contact. These inputs should include the technology capabilities, expectations of the sponsor, and expectations of military leadership, if applicable. Outputs, or bottom-up refinements, that contribute to the scoping process include the identification of the project type, proposed mission/concept of operations, potential venues, scenarios, and resource requirements.

There are many different types of experiments, each with their own technical and analytical rigor. The first step in the scoping process is achieving a mutual understanding from the sponsor and the experimentation project lead on the type of experiment to execute. Frequently the type of experiment is dictated by the level of funding, but occasionally disparate understandings of the types of experiments lead to confusion and different expectations.

A venue is an experimentation-focused field event such as a recent exercise held by the Marine Corps at Camp Pendleton (Ship-to-Shore Maneuver Exploration and Experimentation Advanced Naval Technology Exercise) with multiple technologies and stakeholders. Projects may be related by common themes (e.g., unmanned systems), users (e.g., infantry squad), scenarios (e.g., person-of-interest identification, tracking, and locating), or physical location (e.g., airfield, jungle).

A demonstration is an organized, choreographed display to show how something works in terms of technology capability and use. A "trade show," a term many are familiar with, is a good way to describe a demonstration.

A warfighter feedback-type of experimentation event gathers operator first-look responses to new technology or enhancements to fielded capabilities.

An experiment is a semi-controlled, practical event to measure and investigate the performance of early developmental capabilities, for example Technology Readiness Level (TRL) 3-5.

An assessment evaluates the military/operational utility of a technology at a given stage of development. For relatively mature systems this may be at TRL 6 or 7. This may also be a capability-level assessment and/or system-level assessment.

The second step, planning, is probably the most time- and work-intensive part of the experimentation process, and it is by far the most important step for successful experimentation. During the planning step the demonstration and assessment lead will identify team members, task team members according to project requirements, help develop necessary metrics and measures, identify execution venues, coordinate with all relevant parties to ensure successful execution events, and provide oversight to the project team and updates to the program manager as necessary.

Consideration should be given to requirements for people, facilities, equipment, and instrumentation. Personnel requirements beyond a lead analyst might include a data manager, data collectors, logistician, and general project support. Any shortfalls with regard to labor and funding should be addressed accordingly.

Many documents created during the planning process are known as "living documents," and will continue to develop and change throughout the planning process. As a result, deadlines for final drafts are not applicable to many of these types of documents. Suggested times for a quick look and final reports are provided, but the scale of projects should be considered when determining final deadlines.

Along with planning the event, the project lead must build the experimentation team. The ideal composition for an experiment team is a trio of demonstration and assessment lead, lead analyst, and project support. As each project or experiment is different, support requirements will vary depending on need.

The third step, execution, is where the project team puts their plans into action to address the identified project goals. It is imperative during this phase that data collection objectives are addressed and recorded to support reporting of capabilities and limitations. The last step, close out, involves socializing, sharing, and creating a final report.

An important but often overlooked aspect of experimentation is socializing the emerging technologies with stakeholders and other interested parties. Oftentimes the technology providers would like to advertise their systems to the operating forces' senior leadership to generate a technology pull from the warfighting community to program offices.

Operational force leadership also is enthusiastic about sharing their participation in research, development, test and evaluation with distinguished visitors of the exercise. This is an important way for rapid prototyping experimentation to remain prominent in the minds of the warfighting community that embraces new technology and change.

The final report for a project or event should include details on all aspects of that project or event. The report should be tailored to reflect the type of project that was executed, including information such as venue, demonstration, warfighter feedback, experiment, or assessment.

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Photo by Lance Cpl. Angel D. Travis

REALISM IN RESEARCH:

HOW CAN WE BUILD STRONGER CONNECTIONS TO NAVAL OPERATIONS?

By Lt. Adam T. Biggs, MSC, USN

HOW DO YOU MAKE RESEARCH MORE REAL, AND RELEVANT? BRING THE LABORATORY INTO THE FIELD—OR MAKE THE FIELD YOUR LABORATORY.

Naval science may encompass a broad range of topics, including issues on sea, air, and land, but these projects have one goal in common—improve operations within the Department of the Navy. This distinction makes naval research organizations, especially the Office of Naval Research, different from other funding organizations. The goal is not to advance our understanding of the universe or increase our general knowledge about a particular topic, but to support the mission of the Navy: "to maintain, train, and equip combat-ready Naval forces capable of winning wars, deterring aggression, and maintaining freedom of the seas."

Emphasizing this mission is not hyperbole—there is a real cost to pursuing naval science and technology. Namely, every tax dollar spent on a research project is a dollar that did not go directly to supporting a Sailor and Marine. Rather than spending funds to maintain an aircraft or send supplies to ships at sea, that dollar (and many more) went to a laboratory somewhere in support of naval innovation. Research is a force multiplier, and each dollar invested in research can and should yield a significant return on investment in the form of enhanced operational capabilities or improved quality of life. The value of research is real, but so is the cost. We owe it to every Sailor and Marine to ensure these resources are well utilized in support of the fleet and force.

These responsibilities then bring up one of the greatest hurdles in naval research: How do we ensure the tasks conducted during studies sufficiently replicate actual naval challenges? The objective of research is translating findings into operational effects, and when the links between the laboratory and the fleet are not clear—just as when a conversation is mistranslated—the message gets garbled and could become meaningless. Our responsibility as naval researchers is to ensure the smoothest possible translations from the laboratory to the field as much as it is to produce high-quality, reliable research conclusions.

The current discussion will focus on the role of realism in research by highlighting several methods to ensure that research findings are suitable for widespread fleet use. Most of the discussion will center on an investigation into lethal force decision-making funded by the expeditionary maneuver warfare and combatting terrorism department of the Office of Naval Research under program manager Peter Squire's direction, although other examples will be drawn from ongoing studies at the Naval Medical Research Unit Dayton. In truth, the examples could be derived from topics as varied as physiological episodes to undersea medicine, yet the translation issues will likely remain comparable throughout. The goal here is to provide a better understanding of three challenges to translating naval research into operational impact as well as several methods to overcome these challenges.

Making the Tasks Real

The first challenge is one that scientists will probably recognize the easiest—how do you make sure the experiment suitably tests the hypothesis? This experimental design step requires selecting the right tasks and equipment to evaluate a given hypothesis. Merely using a new task or device can revolutionize a field, particularly if it is the right task. Although devices represent a potent opportunity to leap the science forward by collecting information in a new way, altering the task can yield an equally large benefit with much less investment. Significant translational hurdles can be overcome when the right tasks are used in the evaluation if the experimental tasks being assessed are also the tasks that operators must perform in the field.

Therein lies the real challenge when picking experimental tasks: How do you know what the best tasks are for evaluation? For example, let's assume we want to examine lethal force decision-making within an operational scenario such as room clearing in an urban setting. The task could be very realistic if it involves putting up pictures of hostiles onto bullet traps, gearing up a squad of Marines, and having them kick in one door at a time to decide whether or not they should fire on that target. The scenario gets high marks for realism, especially if the Marines are using live ammunition. However, there are a host of experimental problems with this one particular task:

- Every Marine following the first one through will likely notice bullet holes if the target is hostile, which provides extremely influential contextual cues. Participants may not be making lethal force assessments, but instead merely looking for bullet holes.
- The target image on the bullet trap may not realistically depict the size of a human target. Participants may fire on the hostile, but they are not aiming at the areas where they should aim because the physical size of the target is inaccurate for that distance.
- Specific images may have too much of an effect on the results. Some images may seem more hostile, or at least more obviously hostile based on the image's expressed emotion or position of the gun, and any conclusions about lethal force decision-making might not be based on any stimuli but on these stimuli specifically. The results may then be too narrow to be useful.

Other issues could include the trial count being too small to produce reliable information, peripheral stimuli in the room having a latent effect on results, or even the lighting conditions having an undue influence. The list continues, but the point becomes clear. Sometimes the most realistic example is not producing the most reliable experimental design or actionable results. Sometimes more artificial tasks have to be included for specific assessments.

One example of this would be how our lethal force decision-making research uses classic go/no-go tasks out of cognitive psychology. In a go/no-go task, stimuli could be as simple as one square appearing on-screen that is colored either blue or orange. Participants are told to hit the space bar for blue, and don't hit anything for orange (or vice versa). The goal is to assess and quantify specific aspects of inhibitory control abilities in a more precise and controlled way than could be done when kicking in a door and shooting (or not shooting) at a target. Simple stimuli allow for control of the decision-making components of the response time, which allows the scientists to differentiate between individual inhibitory control abilities and the process involved when making the decision.

The key translational issue is then finding the right task for the situation. Well-controlled, computer-based experiments have their place when used at the right time and for the right purpose. When quantifying cognitive abilities, for example, there is no good way to get a reliable assessment of attentional capacity or working memory without going back to controlled experiments on computer—not yet anyway. There needs to be caution, however, when extrapolating from a computer-based task to the room-clearing scenario. There is no equivalent keyboard button to mimic the motor mechanics involved when kicking in the door, and that step could dramatically affect cognitive biases and expectations in ways the computer task might not predict—not to mention the anxiety someone will feel when kicking in a door and knowing there could be someone on the other side waiting to shoot you.

There are two good solutions to this conundrum. First, only use the controlled tasks when looking at a very specific purpose. Want to examine reaction speed when pilots are incapacitated due to hypoxia? You could have them trying to initiate emergency procedures, but maybe an assessment of speed and motor control is more important for a hypothesis, which requires more experimental finesse than having people pull green rings while wearing a mask. Limit the controlled tasks to specific hypotheses, but incorporate realistic procedures (e.g., initiate the emergency procedure by pulling a ring rather than slapping a space bar on a keyboard) whenever possible. There could very well be a difference in how hypoxic aviators reach for rings versus press buttons that affects the conclusion. Second, if you are having trouble thinking of a good method, find an operator from the community of interest and bring them into the room. Too many scientific designs suffer from a lack of real-world expertise among the scientists. Room clearing procedures are not a typical part of a cognitive psychology Ph.D. even if attention and decision-making studies are. Still, if you find a few Marines with close quarters combat experience, they can help fill in the blanks. ONR can—and should—be in the business of facilitating these relationships. The combined expertise of the scientist and the operator working together is likely to yield the best design for widespread operational impact.

Finding the Real Population

The next challenge seems a bit more obvious, although it can be a significant issue when translating university research to an operational setting. Specifically, military populations may have or require specialized training that is difficult to find elsewhere. This caveat in turn makes the individuals participating in the research especially important. For example, if the concern is cognitive processing speed of individuals aged 18-22 years, then either new service members or college students could suffice as a test population. There will likely be other factors to consider, especially education, although the base translation remains accurate. If the study is investigating lethal force decision-making, however, there are likely to be many critical differences between these two populations. College students may never have fired a weapon, whereas military service members are much more likely to have had firearms training. Any study involving a weapon must address this fundamental difference in training.

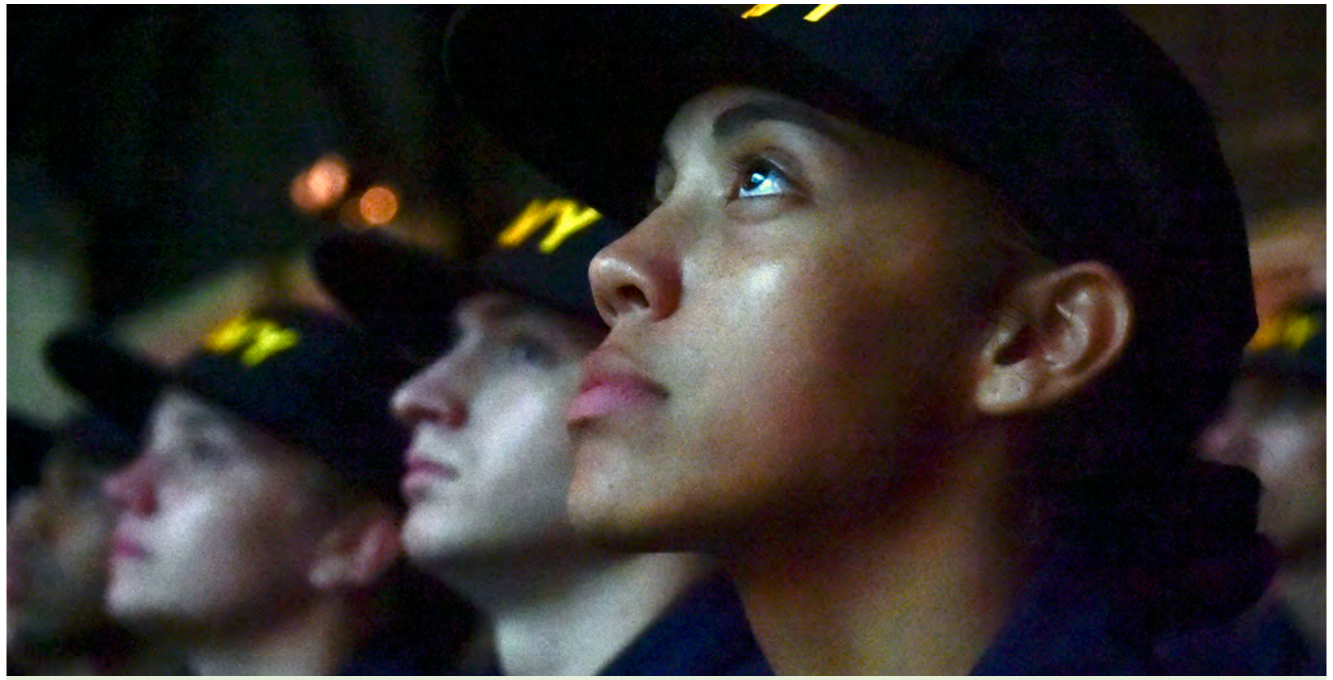
So, the critical issue is whether the population being tested during the experiment represents a comparable group to the military operators for which the study is intended. There are a few approaches here that could be beneficial. First, use a readily available population (e.g., college students for university-based research) for any study that does not require specialized training. This approach sounds logical, although many military communities require so many different forms of training that this approach would likely prove to be a significant hindrance to any translational value. Such easy access populations, however, could be useful in piloting experiments or refining procedures. Service member time and access tends to be more limited, and preparing for those critical data collections is a prudent step.

Two additional methods raise additional issues. The first method involves turning an easy access population into your trained population. This approach is not feasible for special forces training, but for some more simpler trainings it could be a viable method. For example, most college students will probably have no idea how to perform a "FOD" (foreign object damage) walk, which are standard preparation in aviation to ensure landing areas are free from debris that could cause damage to aircraft. Training for this task is largely visual search, and some very simple training could thus turn a laboratory search for target "Ts" among distractor "Ls" into something with far greater operational relevance. The second method is difficult, although not technically complicated—test the population intended to benefit from the research. If the study is supposed to benefit pilots, then test pilots. If the study is supposed to benefit special forces, then test special forces. The challenge is access, but the value is immense. Many translational issues disappear when the population from which you sample is the group who would benefit from your research.

Making it Feel Real

Human performance research, like all psychology research, must be carefully controlled to avoid producing a misleading result. For example, participants might change their behavior simply because they know they are being observed—something known as the Hawthorne Effect. Military research only amplifies this existing challenge by requiring the findings be applied to some of the most difficult, dangerous, and stressful scenarios known to mankind. So, the perennial challenge becomes whether the research team can make a laboratory setting feel like the real deal.

Lethal force decision-making is an especially difficult area in this regard. With hypoxia, and many other physiological phenomena, the way to make these tasks feel real is to safely induce the corresponding symptoms in the laboratory. Fatigue and sleep deprivation have similar solutions where participants are safely and carefully fatigued under the watchful eye of experimenters. For combat conditions, however, there is no way to truly replicate the anxiety and importance of making lethal force decisions. In these cases, the research challenge comes in isolating key parts of the behavior so that certain elements can be as realistic as ethically possible.



Finding the right population to test is important. Using college students for university-based research targets the right demographic for most military populations. Photo by MC1 Amanda S. Kitchner

The anxiety in particular is a key concern with an interesting solution. Specifically, simulated ammunition allows operators to use their service-issued weapons during training. Specialized equipment is inserted into the pistol or rifle, and the weapon can now fire simulated rounds that are effectively lightweight ammunition with a paint or wax tip. They are still fired out of real weapons, and their impact creates a strong physiological sensation that allows people to safely train without the lethal consequences. Still, there is no mistaking the simulated round for anything else—you know you have been shot. In turn, the anxiety created serves as the most realistic corollary we have when performing force-on-force training. These simulated rounds are already in widespread use among military and law enforcement, although comprehensive medical evidence does not exist regarding the superficial ballistic trauma inflicted by these rounds. It is a critical part of the matter we are exploring from a medical angle as well as a human performance angle, which also brings the discussion back to the main point. That is, there may be a way to induce some of these effects and make it feel realistic, but we as researchers always have a responsibility to ensure the safety of our participants in addition to ensuring the translational value of our research.

Summary

These three challenges—making the task real, finding the real population, and making it feel real—are only a few examples of the many challenges faced in transitioning research and development to operational use. Lethal force decision-making has various components more relevant to this topic than other research areas, such as how best to use virtual environments for training, yet the challenges are by no means unique to this issue. As such, the solutions discussed here provide a reasonable overview of the available opportunities and the importance of making any transition as seamless as possible.

If there is to be one ultimate takeaway from this discussion, here it is: Naval science and technology is unlike other forms of research—our studies have an end goal as well as end users whose lives may depend on our findings. Every dollar we spend on research is a dollar not spent on a Sailor or Marine directly, which is why we must ensure that the products and conclusions of our research apply outside the laboratory.

About the author:

Lt. Biggs is a research psychologist at the Naval Medical Research Unit Dayton.

Photo by Joe Bullinger

UNMANNED SYSTEMS RANGE PUTS NAVY AT THE FOREFRONT OF SWARM TECHNOLOGY

By Maison Piedfort

PRACTICE MAKES PERFECT—BUT FIRST YOU HAVE TO HAVE A PHYSICAL SPACE TO TRY OUT NEW IDEAS AND TECHNOLOGIES.

Ask physicist Brad Knaus how he got into unmanned systems and he'll tell you he started out working for the Space and Naval Warfare Systems Center Atlantic air traffic control division, focusing on counter measures and detection for small unmanned systems. Ask him how he got into drones and he'll tell you, "It just kind of snowballed into more interest from there. It's addicting."

Now Knaus works on something a little different: drones, using autonomous systems to pilot them and getting a swarm of them to work in tandem. Operating an unmanned aerial vehicle (UAV) safely in the air is no easy feat, but it takes even more planning and ground support to operate a swarm of 30 of them.

That's the task for the SSC Atlantic Unmanned Systems Research Range team, led by Knaus. Since its inception in 2010, Knaus' team has worked with the Defense Advanced Research Projects Agency (DARPA) to get autonomous technology in the hands of warfighters. Most recently, that autonomy has taken the shape of a fleet of dozens of remote-controlled drones.

"We're exploring the capabilities of unmanned systems and the potential threats to the warfighter," said Knaus when asked to describe his team's core mission. But what exactly are unmanned systems, what does "swarming" entail, and how can all of this thwart threats to warfighters?

Unmanned aerial, ground, and underwater vehicles have been used for intelligence, surveillance, and reconnaissance missions for more than a decade, but not without a human operator at the helm, guiding the vehicle's every move from the control room. UAVs are particularly useful for giving troops "an eye in the sky" and delivering payloads. Until recently, performing tasks like these with a single drone required an operator.

What makes the range team's work different is there is no need for a one-to-one, drone-to-operator ratio. There are dozens, or a "swarm," of them per pilot, and that pilot's primary role is backup support.

"For the last two years we've focused a lot on the swarming aspect of drones, so we're trying to see how a single operator can operate multiple UAVs simultaneously and what sort of strategic benefits that can bring the warfighter versus the standard one person per asset model," said D.J. Tyree, a software developer for the team.

Tyree likes to explain drone swarms in the context of basketball. "Imagine you're playing one on five. What can you do when you're one guy, one asset, going up against five, or 50, or 100? You've got to increase your number of assets without increasing manpower. That's where swarming comes in.

Swarming capability means getting a flock of drones up into the air that can act autonomously and as a team to carry out a preprogrammed mission. It means one or two pilots on the ground instead of 50. It's a feat that requires a highly skilled, multifaceted team of engineers and scientists. Knaus, unmanned aircraft systems expert; Tyree, software developer; Josh Carter, software developer; and Chad Sullivan, mechanical engineer, all work together to keep the Navy on the forefront of swarm technology.

"Swarming has not been researched in depth, so there aren't a lot of tools out there and there are not a lot of people doing research in these areas," said Carter. "So we're not only having to create these tools and research as we go, but we also must create new concepts for how to autonomously control drones."

Knaus called enemy drone swarming one of the biggest emerging threats to warfighters before pointing out the potential for a homeland threat as well, which is why it is crucial that SSC Atlantic stays in the forefront of drone swarm technology.

"By exploring that threat, I think we can all get a better understanding of how to combat it. It's the next frontier for the warfighter," said Knaus. "It's the evolution of warfighting that we need to be ahead of and understand better than they do."

There are tactical advantages to using unmanned drone swarms. It's more cost-effective, especially compared to some popular UAV models that cost upwards of $25,000 each for just the hardware. It's cheaper and more logistically feasible to use a lighter-weight drone system flexible enough for rapid prototyping.

"As these drones become more and more commercially available, the costs are going to be driven down," said Carter, who added that the team's own research will also help drive costs down. "So instead of spending $100,000 on one UAV to send up for surveillance information, you can send up drones that cost a few hundred dollars and get the same information."

Another tactical advantage is what Carter described as a "sheer show of force." A swarm of many drones acting in tandem paints a more powerful picture than one larger drone. "The idea of 'power in numbers' is definitely a factor in using drone swarms to thwart threats to the warfighter," Knaus added.

Scalability is another big advantage in using unmanned systems over manned ones. Scaling up the number of assets in the air, without having to increase the number of bodies on the ground, keeps risks low. SSC Atlantic has the capability to do the research required to drive down those costs and improve scalability. "We have a mechanical engineer, an electrical engineer, a software developer, and an expert on unmanned systems," said Knaus. "We all work together as a team."

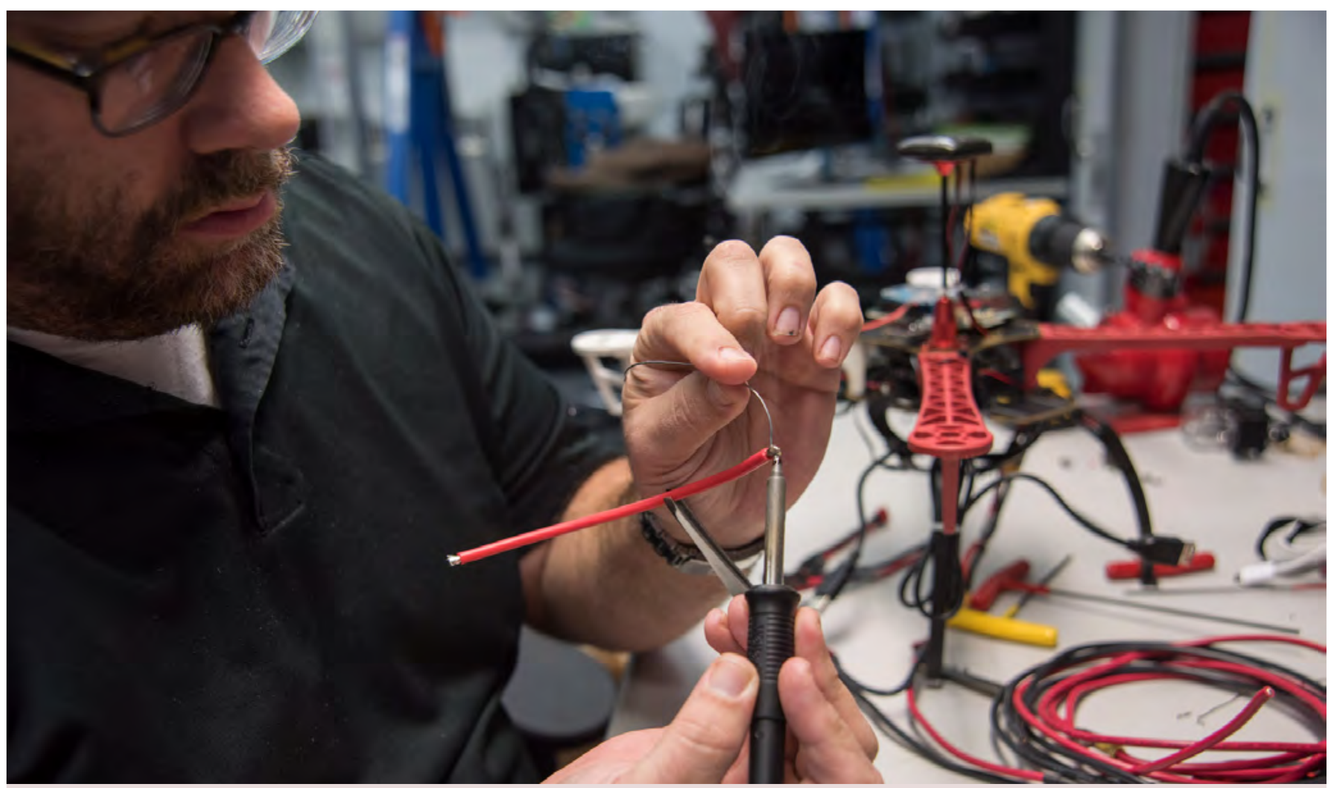
The team also credits its support from DARPA. "Because of our work with DARPA, we have a lot of assets and a lot of experience," Knaus said.

Carter pointed out that, while DARPA originally played a key role in kicking off the drone swarm project, SSC Atlantic has given them the support they need to continue innovating and working to get this technology in the hands of warfighters. Internal funding through the Navy Innovative Science and Engineering program is what has made the development of this technology possible. "We're a good facilitator for special projects like this because of the unique capabilities we have here," Carter said. "It's capabilities like these that help SSC Atlantic hone in and focus on autonomy and cybersecurity.

"Autonomy is 85 percent of this. Cybersecurity with this technology presents a whole new challenge: we must learn how to secure these systems," said Knaus, referring to SSC Atlantic's Red Team who aim to infiltrate security systems to uncover cybersecurity problem areas.

"We are working on the forefront of autonomy," Tyree said. "What we're doing is advancing autonomy at its very core, figuring out how to use autonomy and swarming in ways it hasn't yet been utilized with UAVs. So that is absolutely one of the growth areas we work directly towards."

The range team got a chance to see their hard work in action in April 2017 at DARPA's quarterly Service Academy Swarm Challenge. An eight-month-long event that included multiple virtual challenges in which the academies developed tactics and competed against each other to gain expertise in the field of swarming, the challenge concluded with a live-fly competition at Camp Roberts in California in which the armed services and their research teams used real-life scenarios to observe how warfighters interact with new drone swarm technology, providing crucial hands-on training.



SSC Atlantic employee Chad Sullivan tins the wire for a new battery lead to install on an unmanned aerial vehicle. Photo by Joe Bullinger

SSC Atlantic Unmanned Systems Research Range team members (left to right) Brad Knaus, Richard Kelly, Josh Carter, Chad Sullivan, and D.J. Tyree prepare a swarm of unmanned aerial vehicle's for a practice mission. Photo by Joe Bullinger

Supporting swarm challenge has given the team the experience they needed to become experts in the field of swarm technology. Now they're well equipped for their work on integrating a heterogeneous swarm of unmanned vehicles into the Marine Corps Tactical Training Exercise Control Group integrated training exercises. During these quarterly exercises, Knaus and the team are exposing operational forces to the capabilities and threats that a swarm of unmanned vehicles can present to warfighters.

According to Tyree, building relationships directly with warfighters has been indispensable in his team's quest to build the best, most user-friendly swarm of drones. "The integrated training exercise events are their last stop before being deployed," said Tyree. "So it's our job to show them what's possible with a UAV, what to expect when they're seeing it in the field and what benefits it could provide them in theater."

"Marines love it," Knaus added. "They say it's some of the best training they've had."

Knaus's team will be able to return from California and immediately use what they learned working in the field with Marines on further innovation in heterogeneous swarms of unmanned systems.

"We're getting out ahead of the game, and we're grateful we have the tools and opportunities we need to do that," said Knaus. Lead time between prototypes has certainly decreased since the project first kicked off two years ago, before their work space at the unmanned systems research range was built. "We used to work out of a trailer. We've come a long way since then," Knaus said.

There's still work to be done when it comes to minimizing the logistical work it takes before even getting a swarm of a dozen or more UAVs off the ground.

"Current technology is a net reduction of force. If you want one drone in the air, it may take 10 people on the ground supporting it," said Sullivan. "What we're trying to do with swarming is achieve a net multiplication of force where you need less people than you have assets in the air."

Knaus and his team continue to work on minimizing human risk while maximizing the usefulness of swarm technology. Knaus calls this the "50,000-foot view" of the team's mission. "The more safely and efficiently we can get these autonomous drones up in the air, the safer our warfighters will be on the ground."

About the author:

Maison Piedfort is a writer with Space and Naval Warfare Systems Center Atlantic public affairs.

Photo by Jonna Atkinson

WARLOCKS HELP TURN GROUND-BASED IDEAS INTO AIRBORNE REALITY

By Lt. Joey Case, USN

THE NAVAL RESEARCH LABORATORY'S SCIENTIFIC DEVELOPMENT SQUADRON (VXS) 1 PROVIDES A UNIQUE CAPABILITY WHEN SCIENCE AND TECHNOLOGY RESEARCH NEEDS TO TAKE TO THE SKIES.

Scientific Development Squadron (VXS) 1 is the airborne research arm of the US Naval Research Laboratory using military and commercial-derivative aircraft for science and technology development to support the advancement of Navy capabilities. Located aboard Naval Air Station Patuxent River in southern Maryland, the VXS-1 Warlocks specialize in taking scientists and their projects airborne.

The relative proximity of the squadron to Washington, DC, the Naval Research Laboratory (NRL), and the Office of Naval Research (ONR), as well as the Naval Air Systems Command (NAVAIR) flight test facilities, makes VXS-1's current location the perfect venue for hosting Naval Research Enterprise airborne science and technology activities. The test facilities owned and operated by NAVAIR, co-located with VXS-1 at Patuxent River, provide access to state-of-the art instrumentation and dedicated open airspace to accommodate a broad range of operating altitudes and airspeeds.

Research scientists are able to install their equipment directly into specialized aircraft and then fly missions to collect data. This hands-on method of scientific research is vital in today's ever-advancing technological environment. Being able to quickly test radars, cameras, and other types of technology in a representative environment is crucial to making time-critical strides in multiple fields. Flying with VXS-1 is a unique experience because of the squadron's ability to quickly get scientists and projects into relevant environments for more accurate testing.

The Aircraft

The squadron boasts three modified P-3C Orion aircraft, an RC-12M Huron, a fleet of ScanEagle unmanned aircraft systems, and is expected to welcome a UV-18 Twin Otter in the coming months. The diversity of squadron aircraft and their unique science and technology modifications provide a wide range of platforms from which scientists may choose to meet their specific project needs.

All squadron aircraft provide research scientists the opportunity to fly with their research equipment. This allows them to view their data in real time, and if required, to adjust their equipment inflight for optimal use of their flight time. If the system under test is malfunctioning or simply not responding as expected, the scientist can make on-the-spot modifications, which increases the speed and cost effectiveness of the project by foregoing the need to land and retest on a different day.

The most-used aircraft in VXS-1 inventory is the all-weather, worldwide deployable P-3C. Its large flight envelope, 12-hour flight endurance, and modularity allow for research of all scales with plenty of space to install all required equipment. This aircraft has been deployed around the world, including combat theaters, to meet the specific needs of the research team. The aircraft interior is extremely adaptable, adding to its usefulness in the field of airborne scientific research.

For scientists with smaller projects, the RC-12M is a more cost-effective solution to meet their respective project needs. This aircraft is also premodified with a science and technology framework to accommodate necessary research equipment and has an endurance of up to six hours. It has flown projects that have included Tactical Common Data Link, buoy surveillance, and a plethora of radar and camera systems.

The squadron has one aircraft that is smaller still. VXS-1 works with the small and only unmanned aircraft in its inventory, the ScanEagle. This aircraft is a Type III unmanned aerial system able to carry light payloads, can be launched from anywhere using its mobile launch and recovery system. It is a versatile platform for testing small research payloads such as cameras, GPS systems, or any small sensor package. VXS-1 oversees a small team in Dahlgren, Virginia, that operates the ScanEagles and can conduct flight tests for prospective research scientists.

In the coming months, a UV-18 Twin Otter with similar science and technology modifications will be added to the squadron inventory providing an additional platform for customers to fulfill their respective research needs. The UV-18 will be a very cost-effective and capable platform for the advancement of naval research over a wide range of specialty fields.

Anywhere in the World

In addition to the diversity of aircraft, flying with VXS-1 is beneficial because of its ability to fly projects anywhere in the world. In fiscal year 2017 alone, the squadron flew a multitude of missions locally in the Patuxent River operating areas, in the Atlantic Test Track Range, as well as all across the globe from Colorado to Guam to Kuwait. The ability to have worldwide presence further serves the needs of the Naval Research Enterprise by placing the aircraft in the required environment to best test the respective system and collect the necessary data.

A project nicknamed "Operation Duracell" is an example of VXS-1's worldwide responsiveness to meeting customers' needs. The squadron was called on short notice by an ONR scientist requesting delivery of a vital set of batteries for a research project occurring in Guam in two weeks' time. VXS-1, not normally capable of performing cargo transport operations, was able to modify their aircraft and deliver the batteries on time leading to a successful unmanned undersea vehicle demonstration for the Pacific Command staff.

Rough Widow is another ONR-sponsored project that the squadron regularly supports. Implementing cutting-edge data fusion algorithms and a mix of sensors installed on the aircraft including electronic support measures, electro-optical sensors, and radar, the Rough Widow scientists were able to fuse the information from each system to create a comprehensive tactical picture. Using the squadron, Rough Widow completed preliminary testing off the coast of Maryland and flew the project to El Salvador to assist 4th Fleet in drug interdiction and to test the system in an actual operational environment. Proving the system's worth, the squadron aircrew and ONR research team were able to use the sensor suite to transmit useful information off the aircraft that led to the seizure of more than $70 million in illegal cocaine. Not only were the scientists on board able to test and modify their equipment, they were able to contribute to a key line of effort for the Navy and US Southern Command, a task not easily achieved using contracted air services.

VXS-1's association with deployed fleet squadrons enables access to worldwide locations making them a unique resource for the Naval Research Enterprise. A final example of the squadron's capability to deploy

In addition to manned aircraft, VXS-1 also operates several unmanned systems, such as this ScanEagle. Photo by Jonna Atkinson

aircraft in unique environments was project SNOWEX, a collaborative research initiative with NASA. During this project, the squadron aircrew used their expertise in deliberate operational risk management techniques to conduct research flights at low altitudes over mountainous terrain to measure water content of the snow in the Rocky Mountains of Colorado. They were also able to seamlessly integrate NASA's specialized needs including the addition of a whole new nose radar dome.

VXS-1 is extremely adaptable in the types of projects it can perform and the diversity of locations from which it can operate. Whatever scientists and engineers need to advance their field, VXS-1 can assist.

Serving Science and Warfighters

VXS-1 exists for a simple mission—to advance science and technology research and to accelerate future capabilities to the Navy and Marine Corps. With that singular focus in mind, the squadron provides professional aircrews and extremely capable aircraft to serve scientists and engineers and to help accomplish their missions. Passion of service drives the military and civilian members of the command, allowing them to flex and respond to better support each project's specific, and often revolutionary, needs.

Projects can be installed in days, which is critical because of the fast-paced nature of the research and development field. This was never better exemplified than when the Warlocks flew an NRL team to Kuwait to advance scientific research in an operational environment and assist ground units engaged in combat. The squadron spent two months in theater flawlessly executing project SARGON using synthetic aperture radar to provide environmental information to ground forces. Rarely can scientists conduct their research in actual operational conditions, but flying with VXS-1 affords them that unique and invaluable opportunity.

As a division of NRL, VXS-1 can align its missions and goals with those of NRL, ONR, and the greater science and technology community. The squadron benefits from the administrative and financial support of NRL ensuring that personnel and aircraft are ready to safely execute future research missions. VXS-1 is at the forefront of accelerating technological research for the US Navy. It is one of the few places where research scientists can literally "takeoff" and watch their ideas turn into reality.

About the author:

Lt. Case is a naval flight officer and acting public affairs officer for VXS-1.

Photo by Joe Bullinger

TEAMING WITH SMALL BUSINESS SPURS INNOVATION

By Maison Piedfort

SMALL BUSINESS AND GOVERNMENT PARTNERSHIPS—SUCH AS THESE SPACE AND NAVAL WARFARE SYSTEM CENTER ATLANTIC CONTRACT PERSONNEL PRODUCING CABLES FOR MRAPS—CAN BE A REAL ENGINE FOR GENERATING NEW IDEAS AND GETTING THINGS DONE.

It takes flexibility, innovation, and efficiency to put the best information warfare products in the hands of warfighters. Small business partnerships play a big role in meeting these needs at Space and Naval Warfare Systems Center (SSC) Atlantic.

This is what drives SSC Atlantic's Office of Small Business Programs (OSBP) to meet, and usually exceed, a goal of awarding at least 32 percent of all total eligible obligated dollars on prime contracts to small business concerns each year.

According to Robin Rourk, OSBP's deputy director, small business partnerships play a crucial role in staying agile enough to support the warfighter mission.

"Typically our small business partners are more innovative and flexible, and are more focused on meeting our warfighter mission," Rourk said. "Helping the warfighter—that's their passion."

Chris Miller, SSC Atlantic executive director, agrees. "Small business partnerships are key in our mission to stay on the forefront of delivering the best [command, control, communications, computers, intelligence, surveillance and reconnaissance] solutions to our nation's warfighters," said Miller.

The purpose of the small business program is to set aside certain acquisitions exclusively for small business participation to permit a fair opportunity to compete for government contract dollars. Under the Small Business Act, the Department of Defense has statutory targets, and acquisition agencies such as SSC Atlantic have proposed targets for a percentage of all eligible obligated dollars on prime contracts awarded to small business concerns.

SSC Atlantic's OSBP achieves these targets by cultivating relationships through clear and transparent communication with small businesses looking to win government contracts. SSC Atlantic also facilitates networking and training through their quarterly Small Business and Industry Outreach Initiative symposiums in Charleston, South Carolina.

"The first thing I say to small business at these gatherings is, 'We can't do it without you!' These are great opportunities for industry to network with other small businesses in a neutral, noncompetitive environment," said Miller.

Rourk attributes much of the OSBP's success to the variety and extent of its outreach events. "Our quarterly small business outreach is specific to SSC Atlantic and specific to contract opportunities," said Rourk. "We host monthly industry luncheons with local nonprofits. We have quarterly technical exchanges, which include a panel discussion and one-on-one sessions."

The deputy director for SSC Atlantic's Office of Small Business Programs, Robin Rourk (left), speaks with a small business representative at the Charleston Defense Contractors Association's 46th quarterly Small Business and Industry Outreach Initiative Symposium. Photo by Joe Bullinger

These outreach programs and the wealth of information they provide are no doubt major contributing factors in the OSBP exceeding its small business award targets for the past five years. The percentage of total available contract dollars awarded to small business continues to increase: 35 percent in 2015, 38 percent in 2016 and 41 percent in 2017. Still, for the small business, navigating through the government acquisition process can present roadblocks.

"A lot of small businesses will come to me and say, 'I don't have any past performance, I don't have any experience.' They feel like they can really make a difference, yet they don't know how to get started because past performance is a factor for winning contracts," Rourk said.

When asked how she advises small businesses to work around this challenge, Rourk says her number-one recommendation is to get in touch with an experienced company and work with them as a subcontractor. "We encourage them to attend a quarterly outreach event, and network with a company that understands our model. For those new entrants, we encourage them to build relationships through a subcontract," she said.

Another way to stand out as a young small business capable of taking on government contracts is to hone in on a niche. It's small, specialized firms like these that help SSC Atlantic succeed in its technical growth areas such as cyber, cloud computing, and data science analytics. Rourk recounts one of the OSBP's biggest success stories, a woman-owned, small, disadvantaged business that became a niche-based manufacturer specializing in supporting SSC Atlantic's Marine Corps division. They manufactured cables for the Mine Resistant Ambush Protected (MRAP) All-Terrain Vehicle program.

"They were awarded an 8(a) contract through the Small Business Administration's 8(a) program. An 8(a) contractor is a business that is either minority or woman owned (usually at least 51-percent ownership). This contract enabled them to grow over the years and obtain other DoD contracts. It's rewarding to watch that growth," said Rourk. Mutually beneficial relationships such as these are essential for enabling SSC Atlantic to provide better information warfare solutions to warfighters. "Another example of a small business that has had long term success supporting our mission is a veteran-owned small business that has supported our information warfare mission for over nine years across six integrated product teams supporting network defense and our Red Team," said Rourk.

SSC Atlantic contract personnel from an 8(a) small business manufacture cables for the Mine Resistant Ambush Protected (MRAP)/All-Terrain Vehicle program. Photo by Joe Bullinger

Space and Naval Warfare Systems Command (SPAWAR) won the Department of Defense Verdure Award for its efforts to promote small businesses in fiscal year 2015. The Verdure Award is a part of the Vanguard Awards program, which recognizes the exemplary contributions of small business professionals or members of acquisition teams that influence small business participation in defense procurement. Space and Naval Warfare Systems Command's OSBP was also awarded the Department of the Navy Secretary's Cup in 2017 for its contributions to the Navy's small business mission. SSC Atlantic is an important arm of SPAWAR's overall small business plan as majority of small business for all of SPAWAR contracting happens through SSC Atlantic.

"The small business program is extremely important to our overall contracting strategy," said Steve Harnig, SSC Atlantic director of contracts. "We utilize a robust market research process to determine where we can leverage small businesses to meet our requirements. Our partnerships with small businesses have allowed this command to increase its agility and innovation. As a command that works in a domain (information warfare) that demands agility and innovation, those partnerships are a key contributing factor to our overall success. I am proud of the number we deliver in terms of small business awards, and we will continue to work closely with the OSBP to ensure we meet or exceed our goals."

But an award-winning small business program is not possible without executive support. Rourk attributes the OSBP's success in hitting small business targets to leadership buy-in.

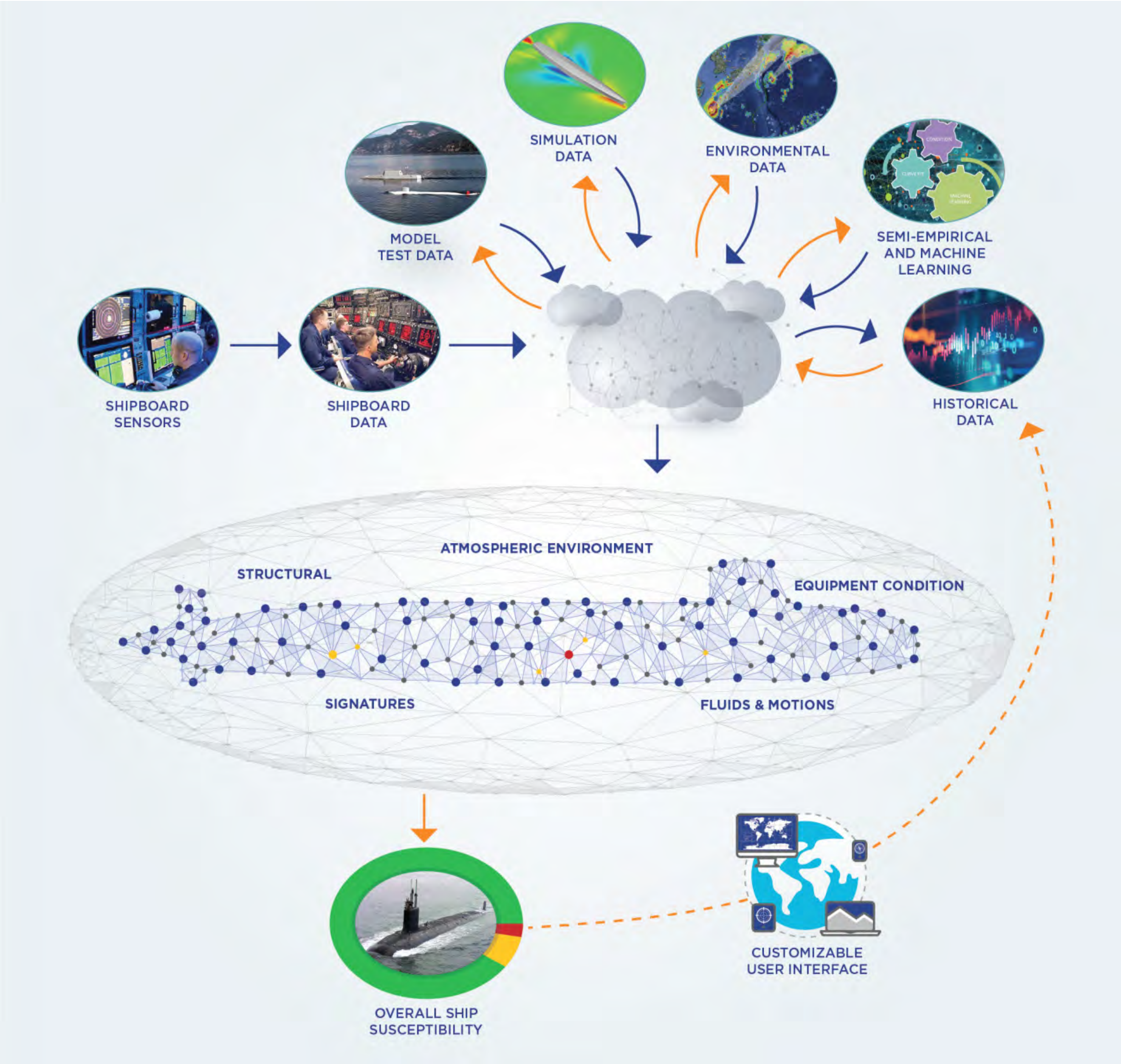
"With the commanding officer and executive and deputy executive directors emphasizing our mission internally and externally, publishing articles, speaking at quarterly events and luncheons, and supporting the Contracts Industry Council, it's clear we have leadership's full support," she said. "And it's this leadership support that sets us up to succeed."

Miller's support is highly visible at all SSC Atlantic sites through his appearances at outreach events or his blog posts on the benefits of working with small business.

"At end of the day, we are looking for partnerships that help us promote and recognize innovative ideas and translate them into information warfare solutions for our warfighters. What we need from industry is what small business gives us: agility, efficiency, and innovation," Miller said. "Together, we form an amazing team."

About the author:

Maison Piedfort is a writer with Space and Naval Warfare Systems Center Atlantic public affairs.



WARFARE CENTERS USE DATA ANALYTICS TO ENHANCE CAPABILITIES

By Nicholas Malay

WITH THE GOAL OF A "DIGITAL NAVY" IN MIND, THE WARFARE CENTERS ARE INVESTING IN DATA ANALYTICS TO BUILD TECHNICAL CAPABILITY AND DEVELOP A DIGITAL WORKFORCE.

The Naval Sea Systems Command (NAVSEA) warfare centers are helping to improve processes across the Navy and Marine Corps to better exploit digital technologies, make the most of available assets, and leverage commercial partnerships to demonstrate the power and return on investment of data analytics.

By being more agile and flexible across the enterprise—and by harnessing the power of new technologies—a truly "digital Navy" with a digital workforce is rapidly becoming a reality.

"Emerging technologies can enable an incredible expansion in the range of tactical possibilities," said Dr. Megan Fillinich, Naval Surface Warfare Center (NSWC) chief technology officer, as part of the centers' "Integrating to Win" panel discussion during the 30th annual Surface Navy Association National Symposium in January. "We must evolve our requirements and testing methodologies to account for these new technologies and technological possibilities at the platform and at the force level."

For example, the continual monitoring and capturing of data across multiple frequencies can better enable the electromagnetic warfare command and control necessary to respond to changes in the electromagnetic environment and warfighter requirements in command, control, communications, computers, and intelligence systems.

"This dynamic frequency management can therefore enable optimization of resources to maximize warfighting performance and freedom of action across all mission areas," said Fillinich. "It is absolutely essential that we evolve in these two areas—requirements setting and model-based testing—if we are to control the spectrum, pace the threat, embrace artificial intelligence, and expand the range of tactical possibilities for the warfighter."

Navy digitization couples modeling and simulation with data analytics, which aims to improve outcomes through a combination of technologies. That includes networked sensors, cloud computing, information security, machine learning, and artificial intelligence.

This digital framework provides the Naval Research & Development Establishment and combatant commanders with an increasingly lethal, interoperable, and more affordable fleet, officials contend. And it's one that's delivered through more informed, integrated, and agile decision-making by NAVSEA's workforce across all functions and phases of product life cycles.

"The warfare centers are researching and developing analysis and engineering capabilities that will enable a 'digital twin' of engineering systems and businesses processes by coupling modeling and simulation output with decision aids made possible by data analytics," said Nathan Hagan, NSWC Carderock Division naval architect and NSWC Headquarters digital strategy lead. In the latter role, Hagan coordinates efforts across NAVSEA to build a community of practice across the warfare centers geared toward disciplines of big data analytics, digital twin modeling and simulation, model-based simulation engineering, and digital/additive manufacturing and production.

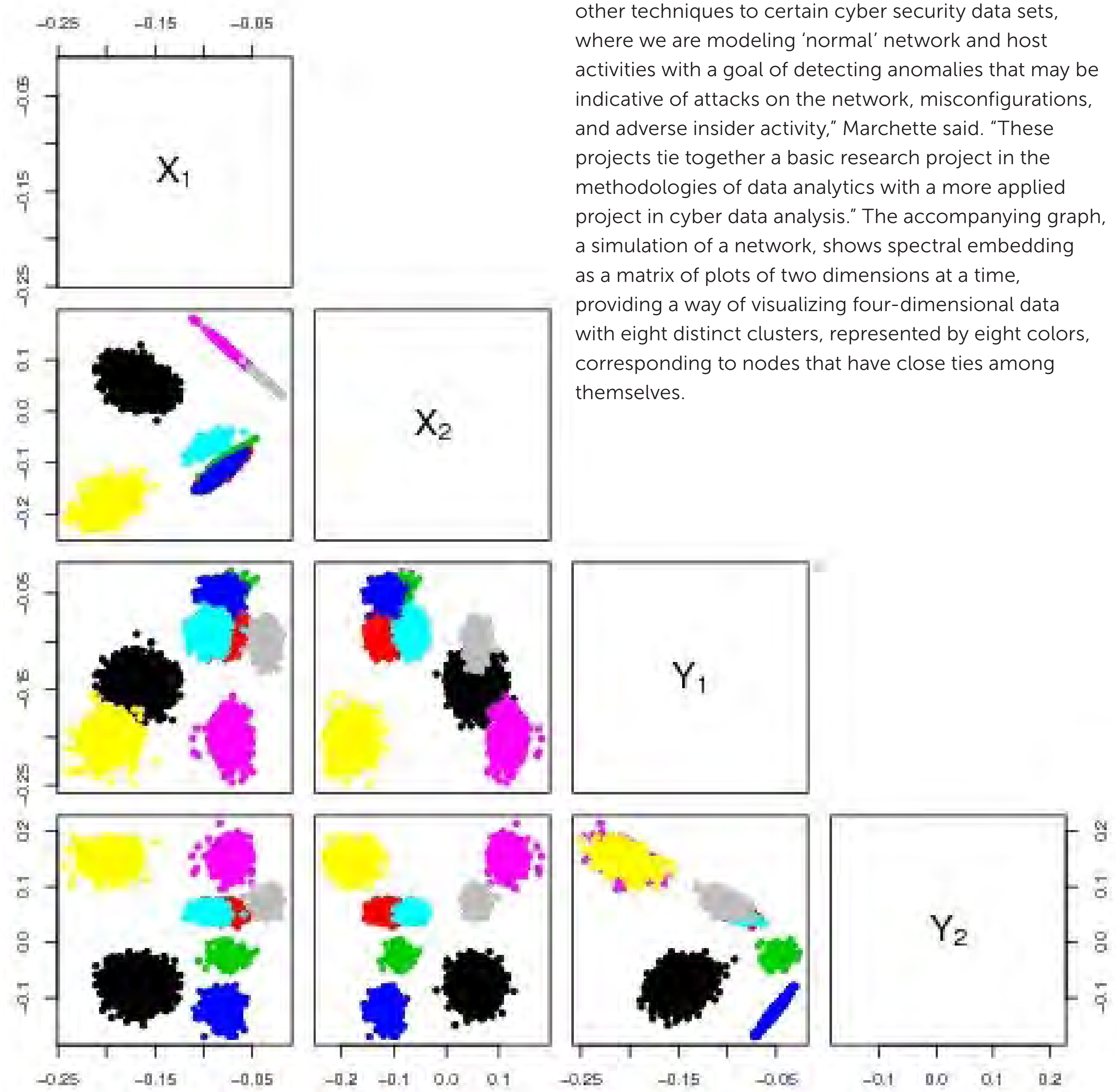
A "digital twin" is an integration of data and models with machine-learning algorithms to enhance the Navy's ability to understand and predict ship, system, and system-of-systems performance; essentially, a digital replication or a digitized model of the actual product or process.

"The digital twin concept is critical, not only from a requirements-setting perspective, but also from the perspective of rapid validation of those requirements," said Donald F. McCormack, the warfare centers' executive director. "To pace the threat, we must have an agile testing methodology, which allows for the complexities presented by new automation and technologies. We need to understand how we test in the future with artificial intelligence."

With the end goal of a "digital Navy" in mind, the warfare centers have prioritized current investments in data analytics to build technical capability and develop a digital workforce, Hagan said. Some examples include:

Digital Twin Submarine Condition-Based Maintenance

NSWC Carderock Division is developing and exercising a framework for applying distributed analytics to predict the contribution of hull, mechanical, and electrical components to a ship's acoustic signature through an FY18 Naval Innovative Science and Engineering/ Section 219 project. The Office of Naval Research is developing Navy digital twin technology to support signature management. This effort seeks to leverage that investment by investigating potential inputs such as sensors and data, communication channels, and data display concepts capable of supporting and exploiting distributed analytics. This will support workforce development as well as lay the foundation for the essential parts on the submarine Navy digital twin research. "A key component of signature management is Navy digital twin and the robustness of the Navy digital twin products depend on the information provided by shipboard sensors and historical data," said Richard Loeffler, NSWC Carderock Division engineering program manager. "Additionally, rapid transition requires easy integration into NAVSEA's acoustics rapid COTS insertion build process. This task supports both of these key components, enabling ONR to focus on the science and NSWC Carderock Division to build the workforce to develop and apply Navy digital twin."

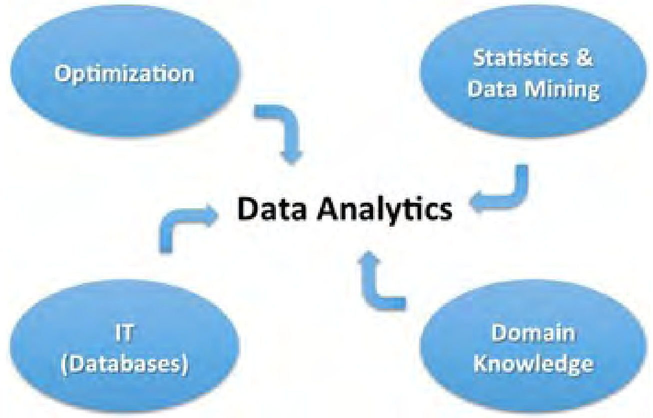


Data Analytics Capabilities Development

NSWC Dahlgren Division principal scientist Dr. David Marchette is currently working on two data analytics efforts. The first is an attempt to develop methods to use the mathematical structure of data to design a deep-learning artificial intelligence architecture to solve a specific problem, Dr. David Johannsen is using techniques that fall under manifold learning and topological data analysis to analyze the structure of the data in a way that allows better implementation of deep-learning models. "On the more applied side, we are applying these and other techniques to certain cyber security data sets, where we are modeling 'normal' network and host activities with a goal of detecting anomalies that may be indicative of attacks on the network, misconfigurations, and adverse insider activity," Marchette said. "These projects tie together a basic research project in the methodologies of data analytics with a more applied project in cyber data analysis." The accompanying graph, a simulation of a network, shows spectral embedding as a matrix of plots of two dimensions at a time, providing a way of visualizing four-dimensional data with eight distinct clusters, represented by eight colors, corresponding to nodes that have close ties among themselves.

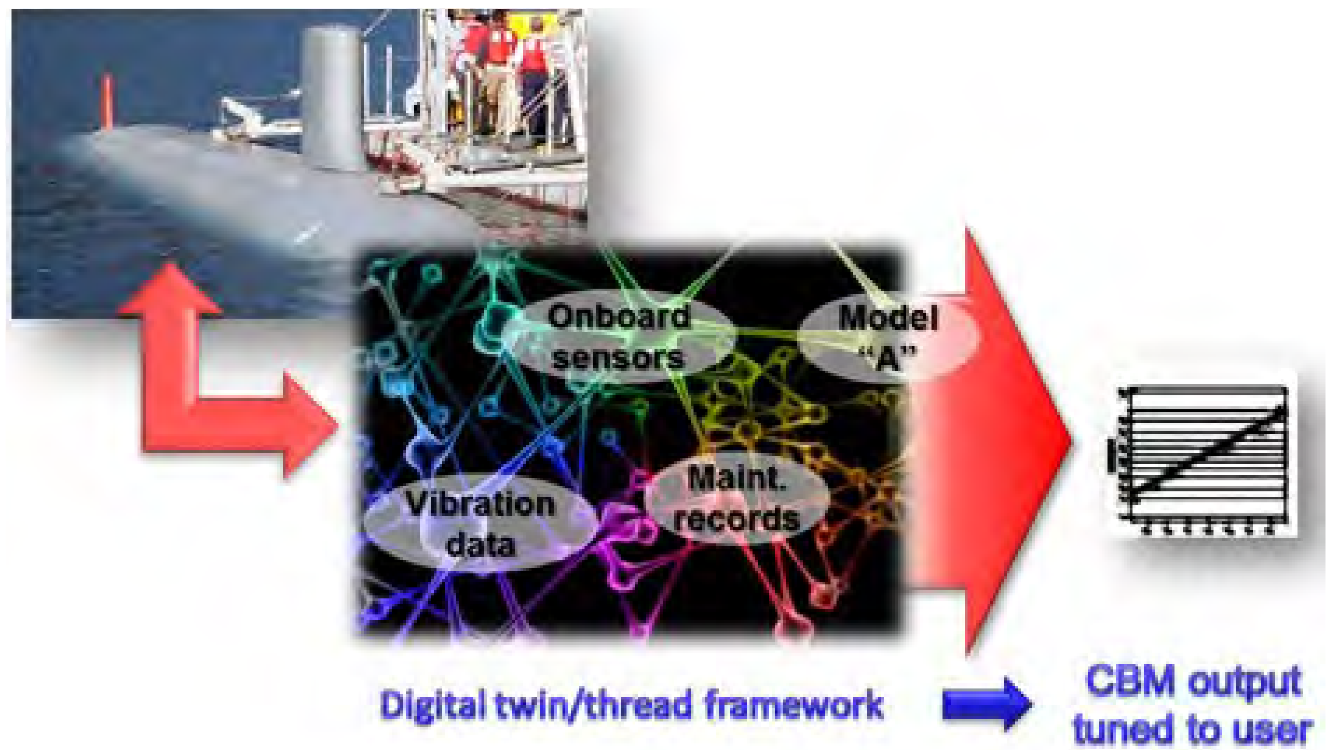
Digital Twin Large Scale Vehicle Demonstration

NSWC Carderock Division, in collaboration with NSWC Philadelphia Division, is setting objectives to develop and implement digital twin framework on the Large Scale Vehicle (LSV) to demonstrate and quantify the effectiveness of a predictive condition-based maintenance capability for hull, mechanical, and electrical systems. Michael Robert of NSWC Carderock Division and Dr. Craig Merrill plan to identify LSV systems that have data and can be modeled as a surrogate for full-scale ship systems, with the intention of developing and exercising digital twin analytical processes. "This will support workforce development as well as lay the foundation for the Columbia-class' [the next ballistic-missile nuclear submarine] Navy digital twin," Merrill said. Instead of making assumptions and using empiricism to analyze data, "using big data techniques, you don't have to do that," he said. "You can take all of the data and gain another level of insight that you may never have had. You can apply mathematical techniques that have been in existence for 50 or 100 years, but we simply didn't have the tools to do it, and maybe gain new physical insights. Now through more advanced hardware and technology, data analysis has become easier than ever."



Data Analytics Using Shipboard Extraction

NSWC Corona Division and NSWC Crane Division are collaborating to design, develop, and implement a database architecture to support storage of combat system data. This is expected to allow engineers to conduct automated data analytics on large volumes of data to identify system performance over time scales and fleet diversity never before possible. "The US Navy needs a more sophisticated and powerful data analytics capability to support analysis of naval warfighting capability and the systems that support it," said Dr. Andrew Christianson,



chief technologist of NSWC Crane Division's electronic warfare advanced concepts group. "The overall objective of this effort is to achieve ready access to data; to investigate the use of modern data analytics practices and tools to discern combat systems patterns, anomalies, and errors in data collected from shipboard operations; and to apply lessons learned to improve analysis of naval warfighting capability and systems."

Community of Practice/Community of Interest

A data analytics community of practice (CoP) and community of interest (CoI) were established in November 2017 to network NSWC and Naval Undersea Warfare Center employees and to support workforce development and knowledge transfer.

The data analytics CoP and CoI team has several objectives to employ a digital strategy across the enterprise.

The first objective is to implement acquisition and sustainment management practices, which will improve the warfare centers' ability to meet fleet capability and availability requirements for NAVSEA platforms and combat systems. These practices will improve warfighting, operational and interoperability effects in manned and unmanned systems, and the timely modernization and maintenance of in-service ships and submarines.

The second objective is increasing business efficiency to enable on-time delivery of ships and submarines. This will be achieved by: improving NAVSEA military and civilian employee knowledge and operational effectiveness through improved digital processes, systems, and services; employing improved cyber-safe technology and multilevel security activities to pass data and information across security boundaries and domains, without violating security requirements; and fostering a culture that advances digital efforts by acquiring, cultivating, engaging, and empowering digital talent in the warfare center workforce.

The third objective is identifying human-machine warfighting effects to optimize Navy, joint, and coalition capabilities executing the core concepts of US Fleet Forces Command's "Fleet Design in the Current Environment" and the Chief of Naval Operation's "A Design for Maintaining Maritime Superiority." This will require automating the manual processes that could be more efficiently performed by machines and exploiting machine learning, artificial intelligence, and autonomy as capability multipliers in platforms and systems.

"The idea here is for subject matter experts and technical operators to no longer make decisions based off of an instinct, but rather an informed, fact-based solution," Hagan said.

The warfare center data analytics leads are developing workshops to address varying fleet issues, while socializing warfare center analytics capabilities with those from private industry. One of those workshops was held in Cambridge, Massachusetts, in October 2017. The workshop was a sponsored partnership with NAVSEA's Technology Office (SEA 05T), which administers HACKtheMACHINE events. The data analytics challenge during the workshop was associated with condition-based maintenance.

"We provided teams' publicly releasable maintenance and operational data of three navy platforms with known maintenance failures, and challenged teams to develop data analytics tools which could successfully identify and predict the system mechanical failures," Hagan said. "Based on the success of the HACKtheMACHINE event, the warfare center data analytics team will be planning and coordinating another data analytics challenge on collision-avoidance in summer 2018."

Digital Focus Areas

The warfare centers are continuing to invest in the development of technical capabilities and engineering tools aligning those projects to demonstrations that fit into the following focus areas: digital human resources and business, digital acquisition, digital test and certification, digital life-cycle maintenance, and digital shipyard.

The warfare centers' digital transformation will encompass technical areas of opportunity for artificial intelligence, such as electromagnetic maneuver warfare, to leverage data-driven decision making, modeling, and simulation capabilities, and computational and technical resources within NAVSEA.

"With the goal to gain decisive military advantage in the electromagnetic spectrum and enable the ability to conduct critical Navy mission areas, emerging data science approaches for unstructured data, such as deep learning and spiking neural nets, can enable the application of machine learning and artificial intelligence algorithms to this growing data set," Fillinich said at the Surface Navy Association symposium. "Cognitive [electronic warfare] and advanced automation can provide the ability to maintain positive control of the spectrum within a tactical environment."

"The development and maintenance of an [electromagnetic maneuver warfare] digital twin is a key component of an overall future architecture that can leverage emerging [artificial intelligence] technologies and optimize frequency utilization within a dynamic [electronic warfare] context," she said. "Dynamic control of the electromagnetic spectrum is a critical part of architecting a force level design to enable distributed maritime operations."

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WARFARE CENTER ENTERPRISE DATA WAREHOUSE

The Enterprise Data Warehouse (EDW) is the information resource management tool supporting NAVSEA general fund, warfare center headquarters, and the ten NAVSEA warfare center divisions. The fundamental data and information requirements are aligned to the financial execution, workload planning, workforce management, program/project management, and contract management business functions.

EDW provides key business intelligence products, including metrics, workforce demographic analytics, workforce skills projections, workload demand signal assessments, technical capabilities health assessments, and funding and execution reporting and analysis. Enterprise Resource Planning (ERP) and non-ERP data sources are fully integrated across multiple subject areas. The data foundation is composed of transactional data from each of the 14 major source systems and is aggregated up to various levels for analysis.

EDW focuses on business data analytics and digital initiatives that support the Chief of Naval Operation's guidance for the digital Navy. "Key processes and methodologies that contribute to the success of EDW include: data architecture and data governance, requirements definition and prioritization, methodology for adding new data sources, and delivery of validated and documented products to customers," said Linda Hutt, NSWC Headquarters EDW program manager. "The warfare center data warehouse community of practice has members from each warfare center division who meet regularly to work new requirements definition and prioritization, as well as validation of new products. The business data transparency and efficiency have enabled our workforce to meet related mission goals through the use of data, visualization, and reporting."

The EDW information products provide capabilities that include reporting (e.g., funding, project status, procurement, travel, personnel, planning), analytics (e.g., trend analysis, decision support, data mining, and adhoc query), and performance (e.g., metrics, dashboards, forecasting).

This suite of capabilities satisfies requirements for a range of warfare center enterprise and division users, including program managers, business managers, line managers, project managers, business analysts, and headquarters staff. The established processes of EDW have been efficiently leveraged and scaled to support requirements from the directorates and program executive offices for executive summary reporting and metrics capabilities, as well as providing standard customer reports.

Inherent in the EDW design is the overarching goal for agility and flexibility of the toolset and capabilities developed. This benefits all users by allowing rapid response to new information requirements, integration of new data sources, and the delivery of new products.

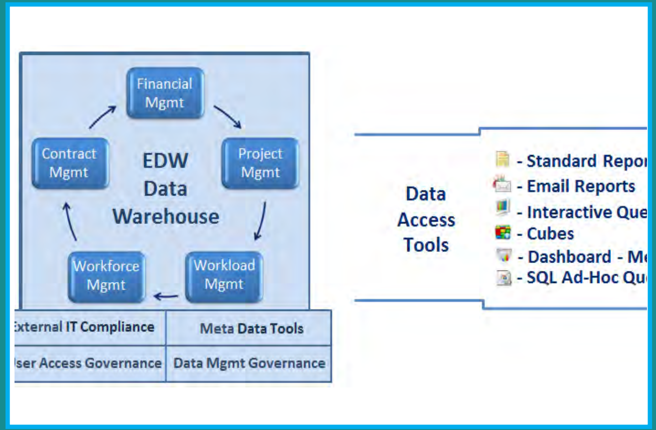


Photo courtesy of Boeing Corporation

NAVAL RESEARCH LAB DESIGNS COMPOSITES FOR NEW PLATFORMS

By Boris Dyatkin and Matthew Laskoski

PLATFORMS AND VEHICLES OF THE FUTURE—SUCH AS THIS NOTIONAL HYPERSONIC AIRCRAFT UNVEILED EARLIER THIS YEAR—WILL REQUIRE NEW MATERIALS THAT CAN RESIST HIGH TEMPERATURES AND EXTREME PUNISHMENT.

The US Navy and Marine Corps need new critical materials and engineering solutions for their land-, sea-, air-, and space-based platforms. Hypersonic aircraft, which will exceed the speed of sound fivefold, will allow for rapid strike capabilities and deliver unparalleled strategic advantages. New lightweight vehicle and personnel armor will protect our soldiers and make them more mobile on the battlefield. Satellites with better propulsion systems will enhance our intelligence-gathering operations. Durable airframes and ship modules, from aerial drones to submarines, will run on less fuel and offer improved operational capabilities and safety.

These vital applications require materials that flawlessly operate at high temperatures and withstand corrosion, flame, plasma, and various types of damage while traveling through the atmosphere, in outer space, or in water at high speeds. These materials must be mechanically strong and withstand impacts from small-arms fire and armor-piercing rounds. They must have finely controlled electrical and thermal conductivities and facilitate sensitive communications or weapon payloads. They must provide protection against radiation or electromagnetic impulses. These materials also must be lightweight, inexpensive, and abundant. These demands pose significant technological challenges, which the US Naval Research Laboratory (NRL) is empowered to overcome.

The use of composite materials will minimize vulnerability points and ensure the safety, reliability, and mission effectiveness of the next generation of Navy and Marine Corps vehicles, ships, airplanes, and spacecraft. Composite materials offer a broad range of superior technical properties and are essential building blocks of the next generation of military hardware. Three different classes of composite materials—polymer-matrix composites, ceramic-matrix composites, and metal-matrix composites—are each well suited to meet rigorous electronic, thermal, or mechanical demands of different components.

While metal-matrix composites show promise for future applications, NRL has particular expertise now in bringing forth several new high-performance designs for polymer-matrix composites and ceramic-matrix composites that are economical and customizable to operate in harsh environments, improve mission safety, and maximize operating capabilities of field units. Polymer resins, including reinforced thermosets (materials that usually are liquid or malleable before being hardened with heat and pressure), are a material class that can meet some of these sophisticated and highly technical requirements. For lightweight panels and airframes, polymer resins that cross-link, once heated, yield stable thermoset components. The resulting composites are strong and durable, and the manufacturing method, which typically uses a mold-injection procedure, can produce virtually any shape.

However, the conversion of these materials into rigid composites requires high curing temperatures of more than 500 degrees Fahrenheit. In addition, the nature of resulting thermosets does not allow for cracks to be easily repaired. Therefore, components are typically made as a single piece and must be completely replaced once they fracture or delaminate. This cost-prohibitive and cumbersome roadblock impedes development of new unmanned aerial vehicles and littoral combat ships at a time when conventionally used metal alloys are no longer adequate and must make way for novel material alternatives.

To overcome this roadblock, researchers in NRL's advanced materials section have designed several families of thermosetting polymers that cure below 200 degrees Fahrenheit, a cost-cutting manufacturing advancement that also improves the quality of resulting polymer composites. Several different chemical configurations of phthalonitriles exist, and the structure of each influences its eventual chemical physical properties. During mold injection (after gelation but before curing), NRL has introduced carbon fibers into composites and achieved excellent binding between the reinforcing materials and the thermosetting matrices.

NRL's novel phthalonitrile resins rely on environmentally safe reactants and use a simple, one-pot synthesis. They are soft at low temperatures and can be molded into any customized shape. Fully cured phthalonitriles are the only known family of thermosetting polymers that fully maintain their structural stability and neither deform nor melt during heating. Resins cure at low temperatures through addition reactions, and (since they do not off-gas any products) yield denser, void-free finished products. Additive manufacturing reinforces phthalonitriles with carbon fibers, and yields inexpensive, durable polymer matrix composites with even more superior properties.

Polymer matrix components are lightweight and mechanically strong. They are flame-retardant and offer fire resistance up to 930 degrees Fahrenheit. The fire performance of NRL's phthalonitrile-carbon and phthalonitrile-glass composites are superior to those of any other thermosets currently in use in ships, submersibles, and aerospace vehicles.

The chemistry of the phthalonitrile composites makes them impervious to corrosion by seawater, oil, and chemicals. Unlike many conventional polymers, cured thermosets do not absorb water or swell in humid environments. Manufacturing of these materials relies on inexpensive reagents and is much less energy-intensive than any other composite fabrication. Prepolymerized formulations are unreactive until use and have a multidecade stable shelf life under ambient conditions. NRL is finding use for these inexpensive materials in ship components above and below deck, in fire- and oil-proof coatings, electronics casings, and structural components of aircraft fuselages.

While phthalonitrile-based polymer-matrix composites meet the needs for lightweight components that operate in relatively common environments, a whole different class of materials must address extreme environments of space, hypervelocity travel, and ballistic protection.

These systems demand that materials can withstand 4,500 degrees Fahrenheit without melting or deforming and resist erosion or chipping from heat or atmospheric particles. To withstand kinetic penetrators, these materials must be hard, mechanically tough, and fracture-resistant. Hypersonic engines and space propulsion systems, like those used for satellites, require specific electronic and thermal properties that either conduct electricity or shield enclosed components. Even advanced metal alloys are unable to meet all of these demands. But refractory ceramics, such as metal carbides, metal nitrides, and metal borides are sufficiently lightweight and durable to excel in such extreme environments. Unfortunately, their synthesis and densification is prohibitively energy-intensive (as it requires high pressures and temperatures greater than 3,600 degrees Fahrenheit) and expensive. Furthermore, pure refractory ceramics are too brittle for use in naval platforms.

To combat these problems, NRL has applied its resin expertise to design a new route to synthesize and densify ceramic-matrix composites using a reactive melt infiltration and reaction bonding process in a way that reduces manufacturing costs yet retains superior performance. NRL has developed a carbon-rich resin that shares many of its properties with phthalonitriles. This polyphenol-type polymer chemistry only includes carbon and hydrogen, and NRL has developed various polymer precursor blends by ball-milling together this polymer with metallic powders. The resulting preceramic material can be compacted into application-specific shapes such as discs, cones, spheres, rods, and other form factors. Examples of these are shown in Figure 1.

These shapes convert to fully densified carbides during a 2,500 degrees Fahrenheit pressureless heat treatment in an argon-filled tube furnace. The polymer thermoset, which has a high char yield, acts as a meltable carbon precursor source that reacts with adjacent metal particles. The resin is viscous enough to maintain embedded metals in the preceramic matrices and evenly convert precursor greenbodies into pure, homogeneous carbides. NRL has used this method to synthesize boron carbide, silicon carbide, titanium carbide, tungsten carbide, tantalum carbide, and many other refractory materials.

This unique approach offers several critical advantages over existing ceramics synthesis and sintering methods. NRL's pathway yields dense carbides in a single-step reaction and requires 1300 degrees Fahrenheit lower processing temperatures than conventional hot pressing techniques. This pressureless approach is much less energy-intensive and avoids the cumbersome, expensive, and dangerous hot isostatic pressing. Since the typical crystallite size of resulting carbides is very small, less than 40 nanometers, resulting ceramics are not as brittle as commercial materials with coarser grains. Finally, the meltable powder-like nature of the precursor material facilitates reinforcements of ceramics with key inclusions. Metals, carbon fibers, secondary ceramics, and infiltrated polymers all provide further control over the mechanical, thermal, electric, and ablative properties of resulting ceramic matrix composites.

These ceramic matrix composites find use in a broad array of applications that are critical for multiple US military platforms, from protecting against battlefield threats to improving the lethality of deployed Navy and Marine Corps systems. Boron carbide is more lightweight than conventional ceramic armor. In addition, NRL's reinforcement method empowers boron carbide armor composites to offer better protection for infantry and vehicles against tungsten carbide or depleted uranium projectiles, sabot rounds, and tapered bullets with sharp ogive geometries. Dense ceramic shapes can also effectively act as kinetic penetrators and are particularly useful as railgun warhead tips.

In addition to mechanical hardness, refractory carbides such as zirconium carbide and titanium carbide are unaffected by extremely high temperatures and are impervious to fire, plasma, or atmospheric heating during hypervelocity travel. Consequently, these materials are exceptionally useful as leading edges in missiles and spacecraft, and effectively protect sensitive platform components from heat and ablation. Boron carbide, which already resists oxidation and chemical corrosion, readily withstands ionizing radiation and effectively absorb neutrons. Composites made from this material are exceptionally useful for new generations of nuclear reactors on submarine platforms.

Figure 1: (a) Silicon carbide sphere (10-mm diameter); (b) Boron carbide tile (40-mm diameter, 10-mm thickness); (c) Zirconium nitride disc (25-mm width). All three ceramics were prepared using the Naval Research Laboratory's reactive melt infiltration/ reaction bonding synthesis approach.

NRL's polymer-derived ceramics method extends beyond carbides and includes other refractory materials. While chemistries that rely on blends of boron, secondary metal (such as titanium or silicon), and minor inclusions of the meltable polymer as a binder yield metal borides, NRL has developed similar nitrogen-rich resins that, under flowing nitrogen gas, react with metals to form metal nitrides. NRL has developed silicon nitride, zirconium nitride, and titanium diboride composites and developed methods to reinforce resulting ceramic-matrix composites with tough fibers.

In addition to high strength and thermal stabilities, these refractory ceramics also exhibit variable electrical and thermal conductivities. These properties allow them to meet the demands of hypersonic vehicle components. Engines that allow travel at such high speeds absorb large quantities of heat and must effectively dissipate it, and even the most advanced metal alloys cannot do so without losing strength or maintaining structural integrity. Metal nitride and boride components are more apt to solve this challenge. Radomes of these vehicles also require similar high-strength, oxidation-resistant materials that allow uninterrupted communications. Silicon nitride composites demonstrate exceptional promise in these systems. NRL is actively developing an additive manufacturing method that will incorporate nanostructures into these materials and further tune dielectric, thermal, and electromagnetic shielding properties of resulting ceramics at a finer level than available materials processing alternatives.

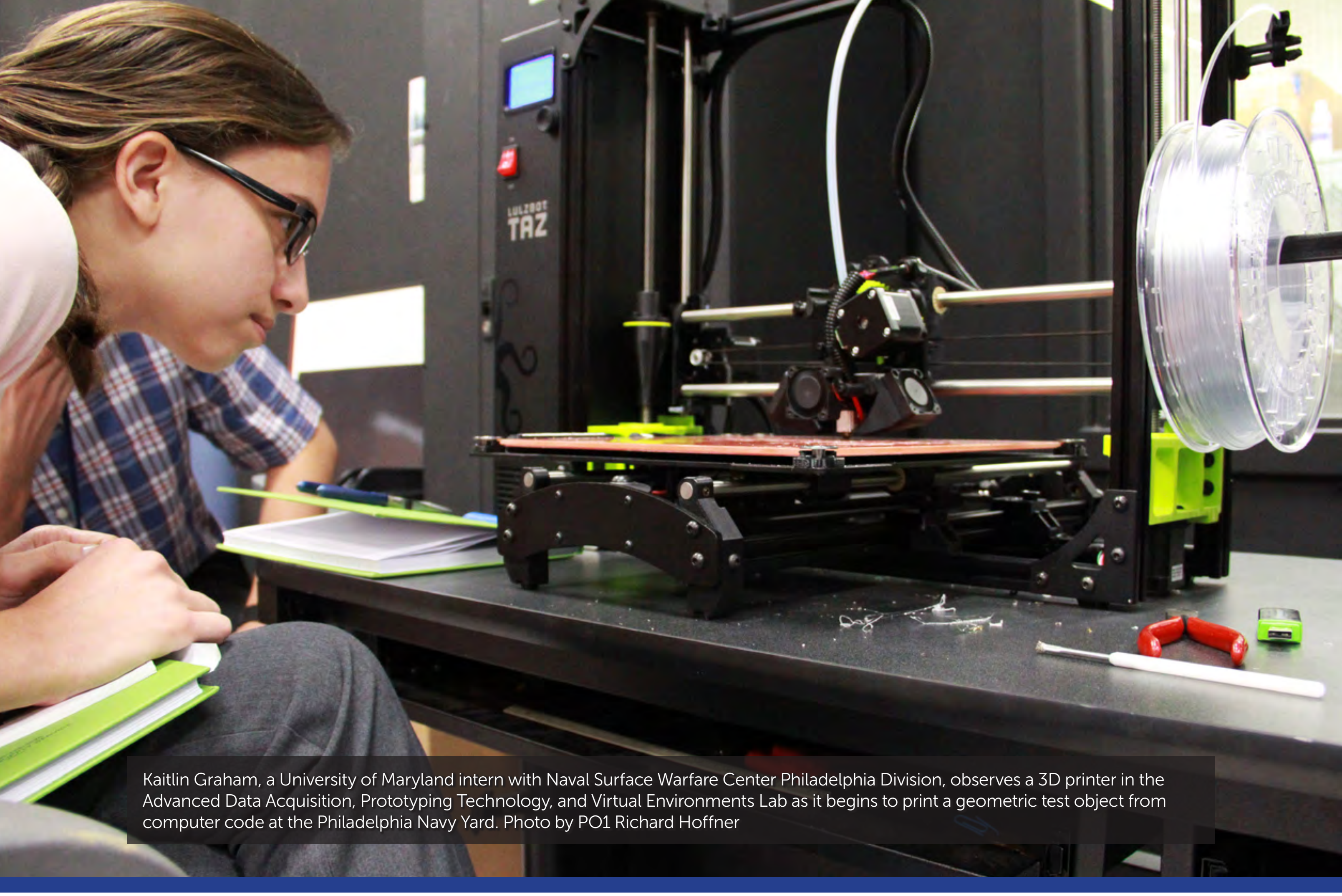
As the Navy and Marine Corps develop new strategic capabilities, they must address the need for the next generation of high-performance materials. Various types of composites will constitute a critical part of the solution. Lightweight polymer matrix composites function up to 900 degrees Fahrenheit and will become vital components of airframes and ships. Ceramic matrix composites stand up to 4,000 degrees Fahrenheit and provide even greater strength and protection against extreme environments.

NRL's materials synthesis method provides new, commercially viable solutions for both applications. For both polymers and ceramics, composite materials allow greater capabilities for land, sea, air, and space applications.

About the authors:

Dr. Dyatkin is a National Research Council postdoctoral researcher in the advanced materials section of the US Naval Research Laboratory.

Dr. Laskoski is the acting head of the section and team leader of these research efforts.



Kaitlin Graham, a University of Maryland intern with Naval Surface Warfare Center Philadelphia Division, observes a 3D printer in the Advanced Data Acquisition, Prototyping Technology, and Virtual Environments Lab as it begins to print a geometric test object from computer code at the Philadelphia Navy Yard. Photo by PO1 Richard Hoffner

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