

NAVAL SCIENCE AND TECHNOLOGY

FUTURE FORCE™

FALL 2016

SET-BASED DESIGN
RESHAPES SHIPBUILDING

COMPUTATIONAL
PROTOTYPING

SHIP DESIGN AND POWER
AND ENERGY



**PLATFORM
DESIGN AND
SURVIVABILITY**



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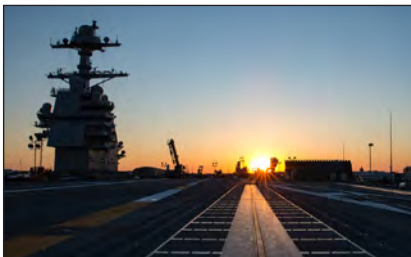
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Navy ships are moving to a new paradigm where electric power and energy supply are directly related to ship performance. Everyone wants power, speed, survivability, and upgradeability--all at an affordable price.

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

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Abraham Lincoln is often credited with saying, “The best way to predict your future is to create it.” When it comes to realizing warfighting capability for our fleet and our Sailors and Marines, that’s exactly what we do. We innovate future platform concepts and then deliver the best ships, submarines, combatant craft, and unmanned vehicles that not only bring tremendous warfighting capability, but also survivability and reliability—key aspects of the mission area of platform mobility. This issue of *Future Force* will capture the diverse team that advances platform mobility.

Who is this team? We all know designing and developing these ships demands collaborative efforts across the entire Naval Research and Development Establishment (NR&DE)—from bow to stern, mast to keel, on-board and off-board systems, manned and unmanned, from concept through in-service support.

The desired outcome of the chief of naval operation’s “Design for Maritime Superiority” is “a naval force that produces leaders and teams who learn and adapt to achieve maximum possible performance, and who achieve and maintain high standards to be ready for decisive operations and combat.” The word design was used deliberately, because the rapid acceleration of technology implies significant trade-space in moving toward the goal of “strengthening naval power at and from the sea.” Thus, we explore alternative fleet designs that will enable this attribute of the design into the future.

In this issue, you’ll read how set-based design is a game-changing approach for future platform design, and as Deputy Assistant Secretary of the Navy for Research, Development, Test and Evaluation John Burrow has argued, set-based design is a must because when we are designing large, complex systems, we have to make informed decisions and make them right—at the right time. This approach to ship design is a major change from traditional shipbuilding, allowing for a greater diversity of technically feasible and affordable solutions that will enable the Navy to be a much smarter customer when setting requirements and making design decisions.

You’ll also read about the Computational Research and Engineering Acquisition Tools and Environments (CREATE) Ships project, under the sponsorship of the Defense Department’s high performance computing modernization program office. The design and engineering analysis tools within the CREATE Ships project help to develop and explore design options and use full physics-based engineering analysis methods.

To enhance a culture of affordability, the Navy is increasing its use of physics-based modeling and simulation, a huge cost-cutting measure in the design and qualification of current and future ship classes. Modeling and simulation is a critical element of the new approach for ship shock qualification and shock hardness validation, thereby potentially removing the future need for full-scale shock trials to test the hardness of ships at sea.

The NR&DE community has committed to approaching problems in a specific way that is tailored to yield better, faster, more affordable, and more innovative solutions. Additive manufacturing using 3D printing technology is an instantiation of this type of high-velocity learning. As an example, using big area additive manufacturing, members of the NR&DE teamed up with Oak Ridge National Laboratory to create the Optionally Manned Technology Demonstrator test article, which is a 30-foot-long, large-diameter, proof-of-concept hull print. Creating the test article is allowing us to learn how to apply digital design to drive fabrication enhancements using these advanced manufacturing techniques to build survivable structures.

Organizations of the NR&DE have the most talented and innovative workforce within the military branches. The articles in this issue of *Future Force* are just a glimpse of their efforts in platform design and survivability.

Dr. Arcano is the technical director at the Naval Surface Warfare Center Carderock Division.



Dr. Tim Arcano (left) speaks with Garry Shields, director for Naval Surface Warfare Center Carderock Division's disruptive technology lab, and Rear Adm. Tom Druggan, commander, Naval Surface Warfare Center, about the Big Area Additive Manufacturing test article.

Platform Design And Survivability

Platforms can be ships, aircraft, vehicles, or other mobile emplacements for weapons, sensors, and other systems. Modern platform design seeks to develop and deliver platform concepts, systems, and component technologies that improve the performance of military platforms to meet operational requirements under all environmental conditions.



SET-BASED DESIGN USHERS IN A MODERN APPROACH TO SHIPBUILDING

By Kelley Stirling

NEW NAVAL PLATFORMS—SUCH AS THIS SHIP-TO-SHORE CONNECTOR BEING TESTED AT THE DAVID TAYLOR MODEL BASIN—ARE BEING FABRICATED WITH A PROCESS CALLED “SET-BASED DESIGN.”

Set-based design has become the preferred approach for early-stage ship design at Naval Surface Warfare Center Carderock Division, according to engineers working on the Navy's future ships and submarines.

Dr. Jason Strickland and Jeff Hough invited engineers and academics to Carderock to learn more about set-based design and how Navy engineers and designers can work together using this approach during a summit at Carderock Division's headquarters in West Bethesda, Maryland, in August.

"We wanted to start to have a really honest conversation about what is set-based design, what's not set-based design, how it's different than what we've done, and how we start to apply it with a common language," said Strickland, a senior naval architect from Carderock's future ship and submarine concepts branch. The summit was, in part, sponsored by the Office of Naval Research (ONR), and included engineers and designers from all the different naval warfare centers, Naval Sea Systems Command, Naval Air Systems Command, and Space and Naval Warfare Systems Command.

Two University of Michigan professors, Dr. Matthew Collette and Dr. David Singer, spoke to the group about the evolution of design and what set-based design is. Several Navy engineers presented examples of how set-based design already has been used for the Navy and how it could work for other naval design efforts.

Point-based design is the traditional approach to designing ships and other vehicles, meaning there are decisions being made at iterative points during the process. Singer said traditional design approaches may mean redesign for design failures or late changes in requirements.

"The core principle for set-based design is delaying the design decisions until trade-offs are fully understood," Singer said. "In set-based design, we want to establish feasibility before commitment."

This process allows for a diversity of solutions, especially if requirements change at some point in the process. If the requirements change during the design process, the designers can easily evaluate the new requirements against the sets of designs and systems they have already established for feasibility. In general, Singer said that both design approaches are successful and that point-based

design makes sense when the requirement is only a modification on an existing ship, vehicle, or system. But for more complex designs, set-based design could make more sense. Point-based design also functions best with a highly experienced workforce that has developed the engineering intuitions needed to make critical design decisions early on.

"Traditional design is done in stages," said Collette, who spoke about the evolution of design. "Complexity is addressed by not dealing with all aspects of the design at each stage." He added that this is often called "over-the-wall" design, where each stage gets thrown over the wall to the next stage and the stages are not communicating throughout the process.

Collette explained that, in some ways, set-based design is similar to concurrent engineering, where there is communication back and forth throughout the process. Concurrent engineering occurs when different stages of the design process are being worked at the same time. Set-based design allows the customer the opportunity to be part of the decision process as well.

"The reason we developed set-based ship design is to try to maximize your chance of success," Collette said. "It allows people to make more decisions later in the process."

Dr. John Burrow, deputy assistant secretary of the Navy for research, development, test and evaluation, and keynote speaker at the summit, is passionate about the benefits of set-based design.

"I lived it, I breathed it, I practiced it, I demonstrated it and I briefed it to the most senior people," Burrow said of his role in designing an amphibious combat vehicle for the Marines. He added that set-based design allowed the designers and the customers and everyone in between to have healthy discussions about the requirements.

There may be hundreds of thousands of possible sets of designs when initial requirements are put into a design tool to help process the information. As more design and analysis data is added to the design space, the sets can be reduced in size, and infeasible solutions removed. In the end, there still may be more than one design option, whereas in point-based design, the experienced engineers may already know at what point to start their design and ultimately will end up with one design to present to the customer early in the process.

Tools

Set-based design has become a more viable option with the host of technology that is available or becoming available. Singer said in the 1950s when ships were being designed, there was a lack of information and so the design space only included a small number of possibilities. By the 1980s, the design space was on information overload. But the ability to process the information was limited.

The Department of Defense's High Performance Computing Modernization program office sponsored, and Carderock developed, the Computational Research and Engineering Acquisition Tools and Environments (CREATE)-Ships tools to help process design options. Within CREATE-Ships, there are several design tools, such as Rapid Ship Design Environment (RSDE), Integrated Hydrodynamics Design Environment (IHDE) and Navy Enhanced Sierra Mechanics.

Dr. Alex Gray, a naval architect and set-based design expert with Carderock's future ship and submarine design tools branch, said as set-based design becomes more widely accepted, these tools are the key to making it a viable design methodology.

"When we have hundreds to thousands of points, how do you narrow that set?" Gray asked. "And how do you cross-analyze?"

The tools available allow Navy ship designers to add additional analysis beyond just basic ship stability. Right now, the RSDE tool helps ship designers generate concept points that are architecturally feasible for a naval vessel. Is the ship floating upright, is there enough displacement, is it structurally sound? The information gained can then be input into other tools that are not in the RSDE environment, such as the IHDE tool, which can then provide a resistance and seakeeping analysis. Carderock developed the Leading Edge Architecture for Prototyping Systems (LEAPS) data environment as the means to supply common engineering data between different engineering tools.

As the tools are being developed within the Navy, the idea is to integrate them all so that these computations on different levels become automatic, generating concepts within minutes.

Amy Markowich is the director of Naval Air Systems Command's battlespace simulation department and is also the Department of the Navy's modeling and simulation

executive. She wants to help the Navy's warfare centers develop and share the tools necessary to make set-based design usable across the Navy.

"We want a continuum, a computational prototyping environment or a common modeling environment, where we can assess designs early, make choices, start building the prototype, but then have all our capabilities tied together to be able to evaluate a prototype. That means tying our labs, our models, and simulations together in a common environment," Markowich said during the Carderock summit. "How can we collectively take this to the next level?"

Education

In most cases of ship or submarine design, engineers and architects have used a point-based approach, because this is what they learned in school.

"We as engineers were not trained to do set-based design in school," said Jeff Hough, the Navy Warfare Center Distinguished Engineer for Ship and Platform Design and Integration. "Ultimately, if the Navy is using set-based design, we have to get the universities to start teaching set-based design as an approach."

Singer said students receive lectures on set-based design in graduate school, and it is mentioned in undergraduate classes, but the majority of design that is taught is point-based design. In some cases, doctoral students have focused their dissertations on set-based design. Strickland is one of four Ph.D.s in Carderock's future ship and submarine concepts branch who studied set-based design under Singer at the University of Michigan.

Strickland said Singer is recognized as the person who developed set-based design as it applies to ship design, noting that Toyota gets the credit for creating the design approach originally. Singer trained the ship-to-shore connector (SSC) design team on set-based design and worked out the process for using set-based design on the amphibious landing craft. The SSC is being built as a replacement for the Navy's air cushion landing craft class of vehicles.

Part of the problem is that the schools do not have the tools necessary to use set-based design, such as LEAPS, RSDE, and IHDE.

"They don't have these tools at the universities right now," Gray said. "But I think it's possible, if they had a group of



Dr. Matthew Collette, a professor from the University of Michigan, speaks to engineers and architects from across the Navy about the evolution of design at a seminar focusing on set-based design in August 2016 at the Naval Surface Warfare Center Carderock Division.

engineering students that were interested in doing a naval vessel, they could teach a set-based process for that.”

From an “on-the-job-training” aspect, Hough said one of the benefits of set-based design that the Navy did not really anticipate was that it provides a means to do design with inexperienced engineers and architects. In point-based design, there generally needs to be someone with experience in ship design to offer up the first design that fits the requirements. On the other hand, as inexperienced designers work in the set-based process, they are looking at a multitude of options within the design space that allows them to gain knowledge on something they had never done before.

“To be able to develop and train, in stride, inexperienced people so they can support design is a huge benefit,” Hough said, adding that most engineers and architects will design one or two ships in their career, so everyone coming in to the ship-design workforce is inexperienced, including some that have been there for a decade.

For Burrow, set-based design is a must for the Navy. “It’s not about the textbook. It’s not about how they teach you to do it,” he said. “It’s about how you make sense of large, complex systems and make informed decisions and make them right. It’s not about giving me a requirement and swearing to it. It’s about working with me to develop the requirement.”

In Practice

There have been several designs that have been developed within the Navy using set-based design, the SSC being one of the first where Singer provided the framework for the Navy to use set-based design for that vehicle, as well as future vehicles. The SSC is set to be delivered to the fleet in 2017.

To help foster the idea that set-based design is the best option, Carderock held a demonstration project on early ship design in 2012. Two design teams were established: one using set-based design and the other using point-based design. Both teams were given the same requirements, as well as the same design tools, with the exception of the set-based design team also having the RSDE design tool. On the set-based design team, the engineers were mostly inexperienced and the point-based design team had one team member who was experienced in ship design.

The point-based design team came to a solution quickly, whereas the set-based team needed a little more time to build the sets before coming to a set of options they could provide the customer.

Most engineers recognize that there are more costs up front using the set-based design approach, but that the costs balance out, and in some cases will be less overall

This is what happened in the design demonstration project. The teams were given a requirement change late in the design process.

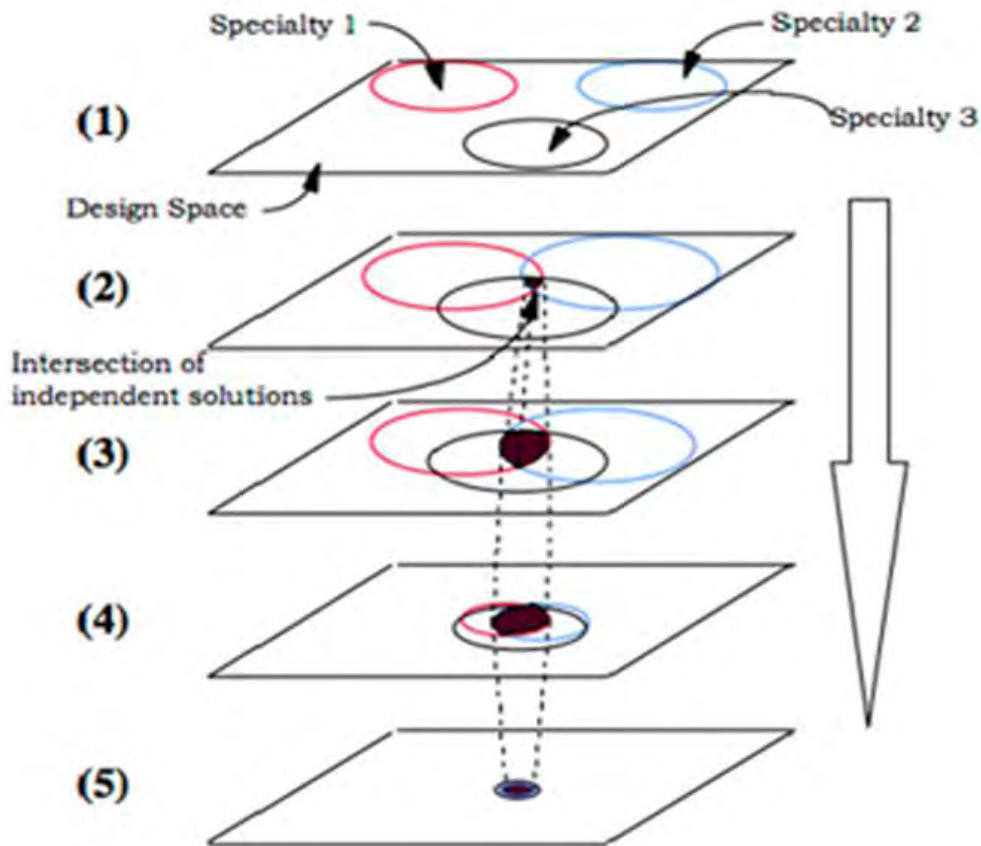
were able to do it quicker the second time, but they came up with another point design,” Hough said. “The set-based design team was able to plug it into the design space and come up with a design much quicker.”

Gray said that the Navy is evaluating using the set-based design process to look at technology insertion studies. As an example, if set-based design is being used to develop a combat system, the design space will include parameters such as area, volume, power, and cooling requirements. When designing for a particular combat system, minimum and maximum ranges of the requirements are assigned.

between,” Gray said. This will generate sets that don’t necessarily have real-life combat systems in them, but the design sets may still be useful in developing an understanding of how the ship behaves when toggling between different power and cooling requirements. “When someone comes to you from the outside, maybe someone from [Naval Surface Warfare Center] Dahlgren Division, and says, ‘we think this future weapon is going to have these properties,’ we can just pull from the set we’ve already developed and say, ‘I have a ship design that more or less has those exact physical properties.’”

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The set-based design approach to designing ships allows for communication throughout the process and across multiple specialties repeatedly before deciding on a viable design or designs.

A Community of Practice

"A community of practice for designers and practitioners is critical," Singer said of implementing set-based design across the warfare centers. He added that academia does not have the benefit of communities of practice.

Strickland and Hough hope the August summit, which was directed to naval engineers and architects who may actually be responsible for executing set-based design in their engineering organizations, was the first stepping stone for creating a community of practice that will help to establish a common language on how to use set-based design.

"This is a self-organizing community of practice," Strickland said, speaking of the group attending the summit. "I would like to see it become more formal and a more regular thing, maybe a larger quarterly meeting or monthly for project-specific things. But I think it needs to grow in that fashion."

"We are trying to inform people so that when you hear the term set-based design, you actually know what it is

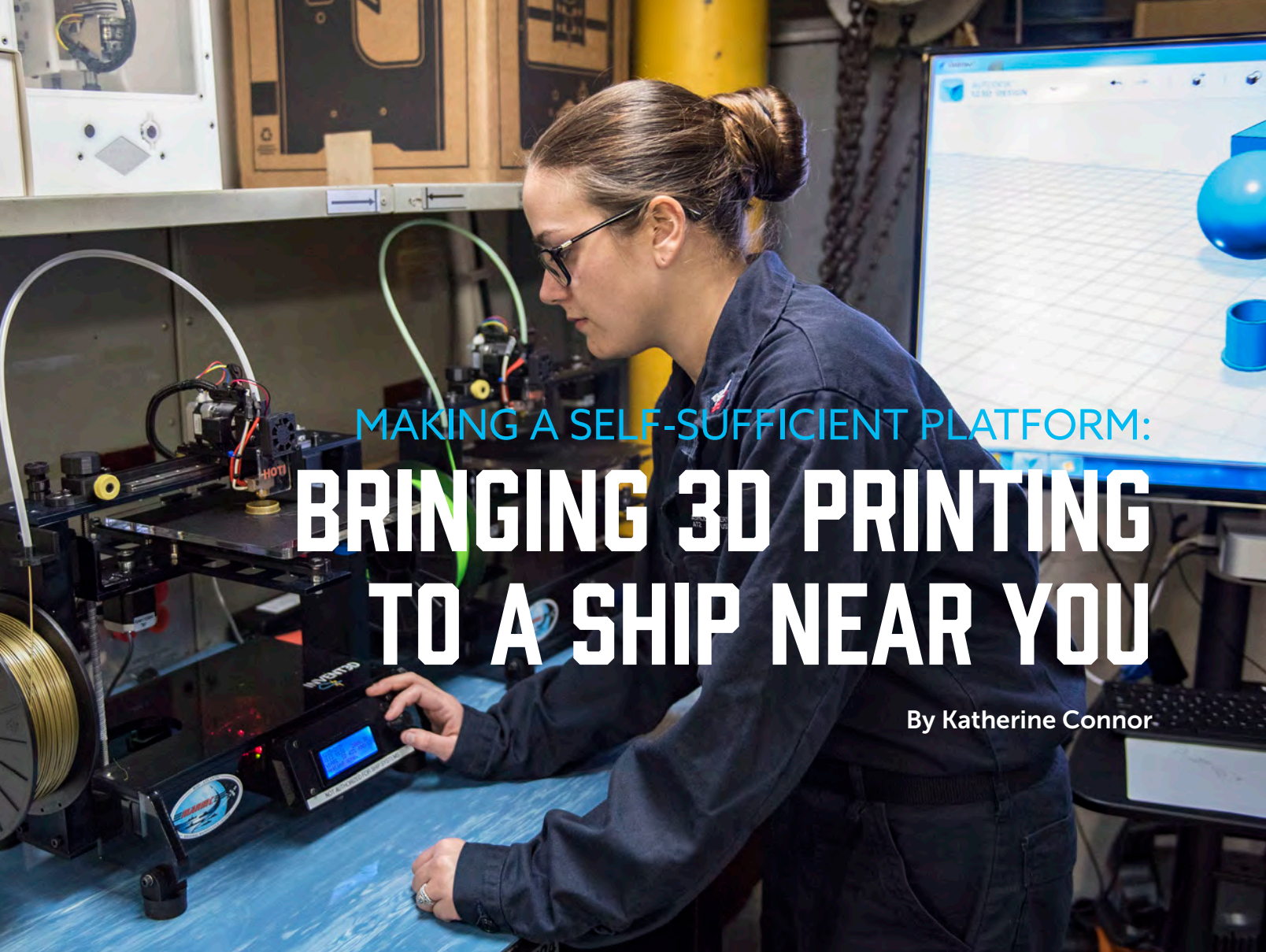
and you can apply it when it's appropriate, and you can become champions of it as I have," Burrow said.

Strickland says the next summit will be later this year and will include university affiliated research centers and federally funded research and development centers, both of which do a lot of the defense work. He said he expects the next summit will include "a lot less education, more application discussion."

To further the community of practice, Hough and Strickland established a Navy set-based design community of practice page on the Defense Department's milSuite site at: <https://www.milsuite.mil/book/groups/navy-set-based-design-community-of-practices/activity>. This will eventually migrate to NAVSEA's Fusion and Wiki sites. 🦋

About the author:

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MAKING A SELF-SUFFICIENT PLATFORM: BRINGING 3D PRINTING TO A SHIP NEAR YOU

By Katherine Connor

ADDITIVE MANUFACTURING IS MAKING PARTS REPLACEMENT AND OTHER TASKS EASIER, BUT A NAVY LAB IS HELPING TO BRING 3D PRINTING TO MORE OF THE FLEET BY MAKING IT POSSIBLE FOR SMALLER COMBATANTS TO CARRY PRINTERS OF THEIR OWN.

Three-dimensional (3D) printing is expected to play an increasingly important role in many aspects of life, with small, relatively inexpensive 3D printers printing everything from food, equipment, and even functioning human organs. The Department of Defense is not immune from this trend. Both the chief of naval operations' "A Design for Maritime Superiority" strategy and the Secretary of Defense's "Third Offset Strategy" reference 3D printing as a means of more quickly and efficiently providing parts and prototypes to the fleet.

At the Space and Naval Warfare Systems Center (SSC) Pacific in San Diego, California, the demand for 3D printed components has skyrocketed. To answer the call, the

center's 3D printing group is growing rapidly, with a new 2,500-square-foot lab space and new printers ranging from small hobbyist-type machines for prototyping all the way up to a large refrigerator-sized printer that prints in engineering plastics for installation on ships.

Stephen Cox, lead engineer at SSC Pacific's Reverse Engineering Science and Technology for Obsolescence Repair and Evaluation (RESTORE) lab, said the demand is huge.

"For a sense of the scope of business we have," said Cox, "the Naval Supply Systems Command has 3,000 items that are 'no bid'—that means they're considered urgent

requirements aboard many Navy platforms, including relatively modern vessels, but the items are obsolete. Although the Navy solicited bids from industry to have a few more made, no one in industry bid because it's hard to make a profit on small runs of such parts. So they turn to us."

The RESTORE lab uses a novel engineering process to design more efficient versions of older military machinery. Soon, thanks to the upgrade in lab space and equipment, the facility will be able to print the actual components and send them directly to Navy platforms, without depending on someone else to manufacture their models. Two new Stratasys Fortus 450 printers make that capability possible because they can print items in engineering-grade plastics with the fire-smoke-toxicity rating required for use on Navy ships. Cox said there are 1,200 items considered urgently needed that are registered in the SSC Pacific repair depot, which provides repair and replacement services to the fleet. Until this printer arrives, however, the lab cannot produce the parts. Most other 3D printers use ABS plastics, which do not have the fire ratings the Navy requires.

Cox made it clear that manufacturing is not SSC Pacific's intended role. Ideally, the center focuses on creating the technical data package of a part, which can then be reproduced by any manufacturer or supplier. But for cases where no one else will source the component, this printer is capable of printing end-use parts and will prove useful.

What is included in this package? Since simply reproducing the required parts does not suffice for Cox and his team, they find a way to bring the component (which was typically made in the 1960s or 1970s) into the 21st century. They do this using a LiDAR laser to scan the piece of equipment that needs to be replaced. This 3D model is uploaded to computer-aided design software, where the engineers and scientists tinker with it until they find a way to upgrade its fit, form, and function, but still maintain the same physical footprint as the original piece, ensuring it will fit into its home on the ship, plane, or other platform.

The digital technical data package includes all the specifications of the piece, as well as information on how to configure it and reinsert it on its platform.

In addition to using the lab to redesign, prototype, and print replacements for the fleet, RESTORE also will be used as a maker space open to the center. Any technician with an engineering issue can use the lab, printers, and scanners to model potential solutions and quickly print prototypes for testing.

Cox said Navy leaders see tremendous benefits in 3D printing for several important reasons.

"It's so fast, so cheap, and because the cycle is completely controlled, you don't need a financial acquisition device," he said. "You don't need a simplified acquisition form, for example, which significantly speeds up the cycle."

Not ready to rest on their laurels, the additive manufacturing team is working to push the boundaries yet again. Instead of having to send Sailors the completed, upgraded new part, why not just send them the renderings, and allow them to print it themselves on the ship, making the process even faster and cheaper?

The reason this does not happen today is that 3D printers require stability to accurately lay down the plastic in the designated patterns and amounts. The sway and pitch of most vessels makes 3D printing at sea challenging.


"The deck of a small ship, say a guided-missile destroyer, for instance, moves too much to print effectively at sea," said Andrew Schalin, a scientist in the mission systems engineering group who proposed finding a solution to this challenge, and will work with Cox to make it happen. "USS Essex [LHD 2] has a printer—but that's a massive ship with little sway, and it's still not certain how printing at certain sea states will work. We need to enable the warfighter to reproduce parts—for temporary or long term fixes—but there's currently no way to do that because printers don't work or haven't been properly tested on Navy ships."

What is Schalin's solution? Do away with the problem of ship sway entirely by creating a gyroscopic platform that moves with the ship, counterbalancing the motion and creating a stable printing environment.

While this has been done by private industry—ever played pool on a cruise ship?—the Navy has more challenging constraints, namely space and cost. There's not enough room on a Navy ship for these platforms to take up a whole room. Schalin, Cox, and the SSC Pacific additive manufacturing team are prototyping and testing possible solutions now, preparing the fleet for a more self-sufficient future. 

About the author:

Katherine Conner is a staff writer with Space and Naval Warfare Systems Center Pacific.

A large aircraft carrier is positioned on the left side of the frame, its complex superstructure and radar masts silhouetted against a clear blue sky. The foreground shows the dark, flat surface of a shipyard deck with white and yellow painted lines. In the distance, a bright sun is setting on the horizon, creating a strong orange glow and lens flare effects. Various industrial structures and cranes are visible in the background under the warm light of the sunset.

WHAT IS A TOTAL SHIP TECHNOLOGY IMPACT ASSESSMENT?

By Jeffrey Smith



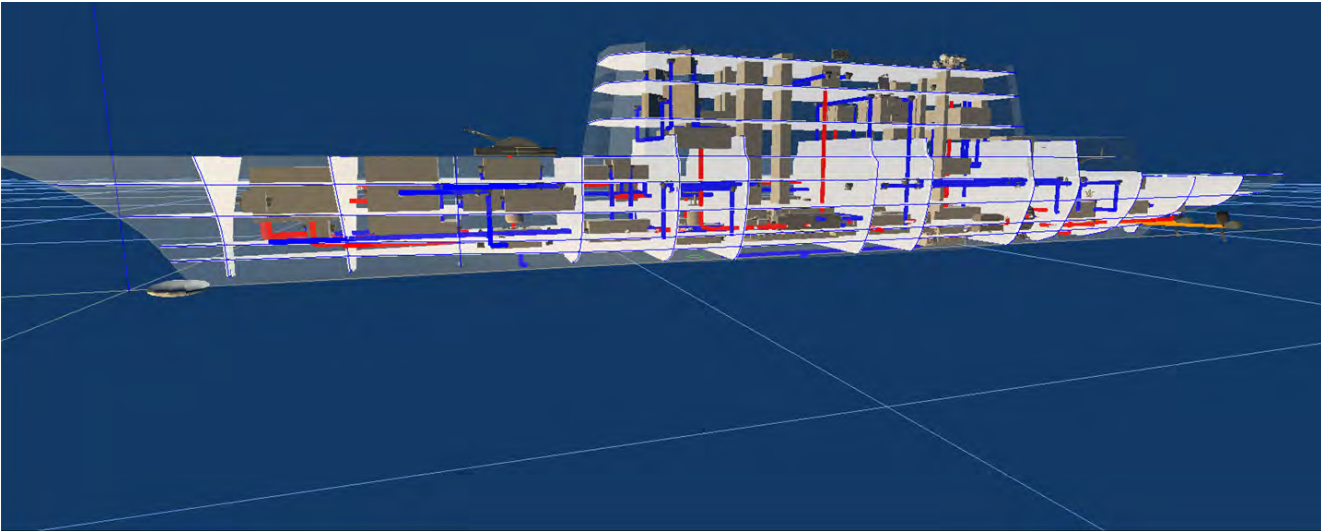
Photo by MCSN Ryan Carter

NEW TECHNOLOGIES, SUCH AS THE ELECTROMAGNETIC LAUNCH SYSTEM ABOARD USS *GERALD R. FORD* (CVN 78), CAN TAKE YEARS TO DEVELOP. TECHNOLOGY IMPACT STATEMENTS CAN ADDRESS THE CHALLENGES OF WHAT EFFECTS SUCH SYSTEMS WILL HAVE ON A SHIP BEFORE EITHER IS BUILT.

Whether providing naval platforms with new capabilities, improving current capabilities, or making platforms more affordable, new technologies have potential benefits that need to be evaluated for U.S. Navy applications. Because of the complexity of naval platforms and the strategy of integrated battle force operations, potentially beneficial technologies can have both positive and negative effects on platforms and systems. These effects must be fully characterized before a decision on transitioning a technology can be made.

Technologies developed by the Office of Naval Research (ONR) that are intended to be integrated into Navy ships typically are subject to a total ship technology impact assessment. Naval Sea Systems Command (NAVSEA) and the Naval Surface Warfare Center Carderock each have the capability to perform these assessments through NAVSEA's concept design process. For example, this process was used recently to assess the effect of incorporating ONR's electromagnetic rail gun and solid-state laser into several existing ship classes. These technology impact assessments help Navy leaders make multibillion-dollar decisions about the future fleet. The technical warrant holder for advanced ship concept design resides in the NAVSEA surface ship design and systems engineering group, NAVSEA 05D.

A simplified analogous process would be that of a homeowner deciding to have a large, double-decker hot tub with electromagnetic drive water thrusters and a 4K holographic entertainment system installed in the home. Even though this hot tub technology has not been fully developed, it is still necessary to estimate the impacts of its installation. A thorough impact assessment and cost estimate should be completed prior to starting



Graphical output from Smart Ship Systems Design naval architecture tool.

any modifications. The assessment would estimate the extent of any required structural, electrical, plumbing, and arrangement modifications and any upgrades required to be compliant with construction codes.

Ship concept design is the art of translating a set of desired operational capabilities into feasible acquisition options. It is part of the systems engineering process of articulating functional requirements, identifying constraints, and synthesizing solutions to the complete problem. Concept design studies are performed to provide Navy and defense leaders with the data needed to make informed decisions on how to spend limited funds. Typically, these early concepts are key inputs to formulating the requirements that will be used in later phases of the acquisition process.

Concept studies are performed to varying levels of detail, based on what is needed to answer the customer's questions. At the bottom of the scale is a quick "rough order of magnitude" study that is concluded within a week; at the top is a year-plus "feasibility study" conducted as part of a ship acquisition program analysis of alternatives. The level of detail varies with the needs of the customer. The results may be needed for a data point in a presentation or may be required for a budget-quality estimate to deliver to Congress. Very few concept designs end up being the ship that is constructed. Demonstrating that a concept is a poor choice is as valuable as proving an elegant solution. Typically, the final design will have features derived from requirements that were based on the early concepts.

In past five years or so, ONR, NAVSEA, and Carderock have been involved in the CREATE-Ships program to develop software that runs on the Defense Department's high-performance computing network and allows ship designers to investigate thousands of alternatives to find the best compromise of cost and performance.

Technology Impact Assessment

Technology impact assessments are concept studies focused on a specific technology or subsystem, whether existing, in development, or envisioned. The Office of the Chief of Naval Operations and ONR periodically request technology impact assessments from NAVSEA in order to prioritize research and development spending. NAVSEA is the subject matter engineering expert that determines the true effects of integrating these technologies into current and future naval platforms. Technology impact assessments are conducted to determine how a specific technology or subsystem would affect the current and projected force structure, as well as the specific naval platforms into which the technology might be advantageously integrated.

The following are typical tasks involved in a typical total ship technology impact assessment:

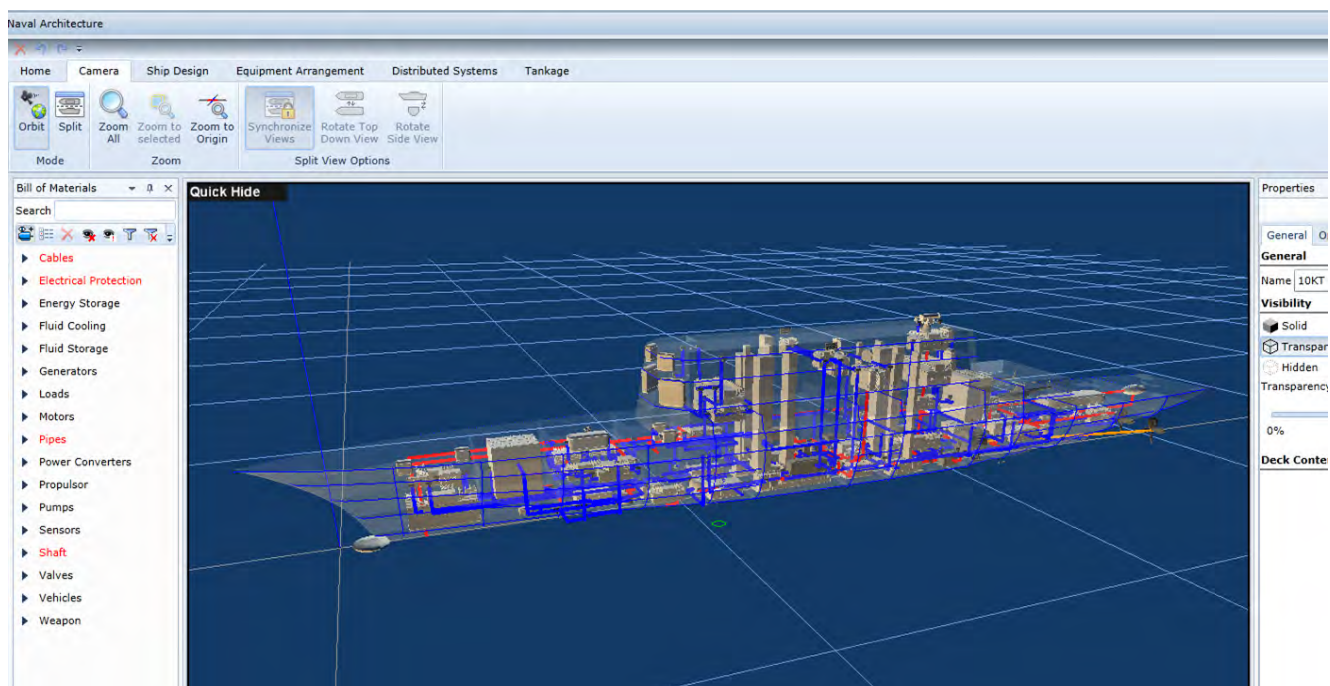
- Data is obtained on the technology to be incorporated. This usually includes the total space required, weight, power required, cooling required, center of gravity, and access and manpower requirements

- Any equipment or systems that will be removed as a result of incorporating the new technology is identified
- Initial ship sizing, configuration, and arrangement analysis is determined
- A ship synthesis using software design tools is performed, which includes:
 - Weight estimate
 - Space estimate
 - Hull form development (if required, may be constrained to existing hull)
 - Resistance and powering estimate
 - Electric load impact estimate
 - HVAC impact
 - Stability analysis
 - Structural design
- The ship synthesis is then refined
- Cost estimates are developed

- Ship capability is assessed

- Risks and proposed mitigation strategies are identified and quantified.

For technology impact assessments, ship arrangements of affected areas are typically a key component of the study to assess the feasibility of incorporating new equipment into an existing design. The arrangements also are an important tool in communicating the necessary changes to decision makers. The location of the new equipment within the ship can have a significant effect on the extent of the overall ship impact. For example, new versions of the Advanced Missile Defense Radar have an amplified effect on the ship because so much of the equipment is located very high above the ship's center of gravity. The additional weight high in the ship is severely limited by the need for the ship to meet the stringent stability standards of a naval combatant. Depending on the nature of the study, other areas such as signatures, seakeeping, or topside arrangements may need to be investigated in detail to determine feasibility. For example, if the platform being studied has a low signature requirement, the study would need to identify effects to the platform signature from installation of new equipment. The study also might investigate ways to mitigate negative effects.



User interface of the Smart Ship Systems Design naval architecture tool.

Design margins and service life allowance are usually added to the estimated changes. Design margins account for unknowns that are inevitably discovered as more information is uncovered and the technology to be integrated is better understood. The amount of the margin varies with the level of uncertainty and confidence in the results. Design margins are applied to estimates of weight, center of gravity, electrical loads, cooling/heating, resistance, and space. The purpose of these margins is that they can be consumed to accommodate necessary design changes without having to completely redesign the ship. Initially, the application of margins results in larger system impacts and resulting larger cost estimate. However, as the margin is consumed by design development, the cost should not increase since the changes already have been included.

The purpose of service life allowance is to allow for system growth after the delivery of the ship. This allowance can significantly reduce the overall ship impacts of future upgrades. The amount of service life growth allowance to be included in the design into the ship is specified by the chief of naval operations and varies by ship type. A typical technology impact assessment of an existing ship class would use some or all service life allowance to accommodate the new equipment.

Risk and Cost

The characterization of risk is another key output of a technology impact assessment study. The Defense Acquisition University defines risk as “a measure of the inability to achieve program objectives within defined cost and schedule constraints.” Risk can have many sources, not all of which can be quantified at the concept design stage. Early identification of known risks, however, can help the Navy make informed decisions regarding technology development, requirements setting, study process investment, and program budgeting. In general, the cost of risk mitigation is less in the earlier design phases. In general, the cost of risk mitigation is less in the earlier design phases. For example, if a risk can be mitigated by modeling and simulation early on, this will be less expense than full-scale testing. In the concept study process risk usually results from integration complexity, technology development, and requirements maturity.

Cost estimation is a specific area of expertise in the Navy. NAVSEA has its own cost estimation group that can produce budget quality cost estimates. The cost estimate

is probably the most important piece of information and is one of the primary reasons to produce the technology impact study. The cost estimate, however, is only as good as the technical data produced from the impact study, and the impact study is only as good as the input parameters provided by the technologists. The study will identify and itemize all required changes to the ship, including additions and removals. The cost of distributed items like piping, structure, and ducting are estimated based on the weight of material to be added and removed. Typical current shipyard labor rates are used to estimate the cost of the work. The cost of major equipment is likely to come from vendor quotes or recent purchases of similar equipment. Because of the numerous variables involved, the estimate is usually presented as band of probable costs.

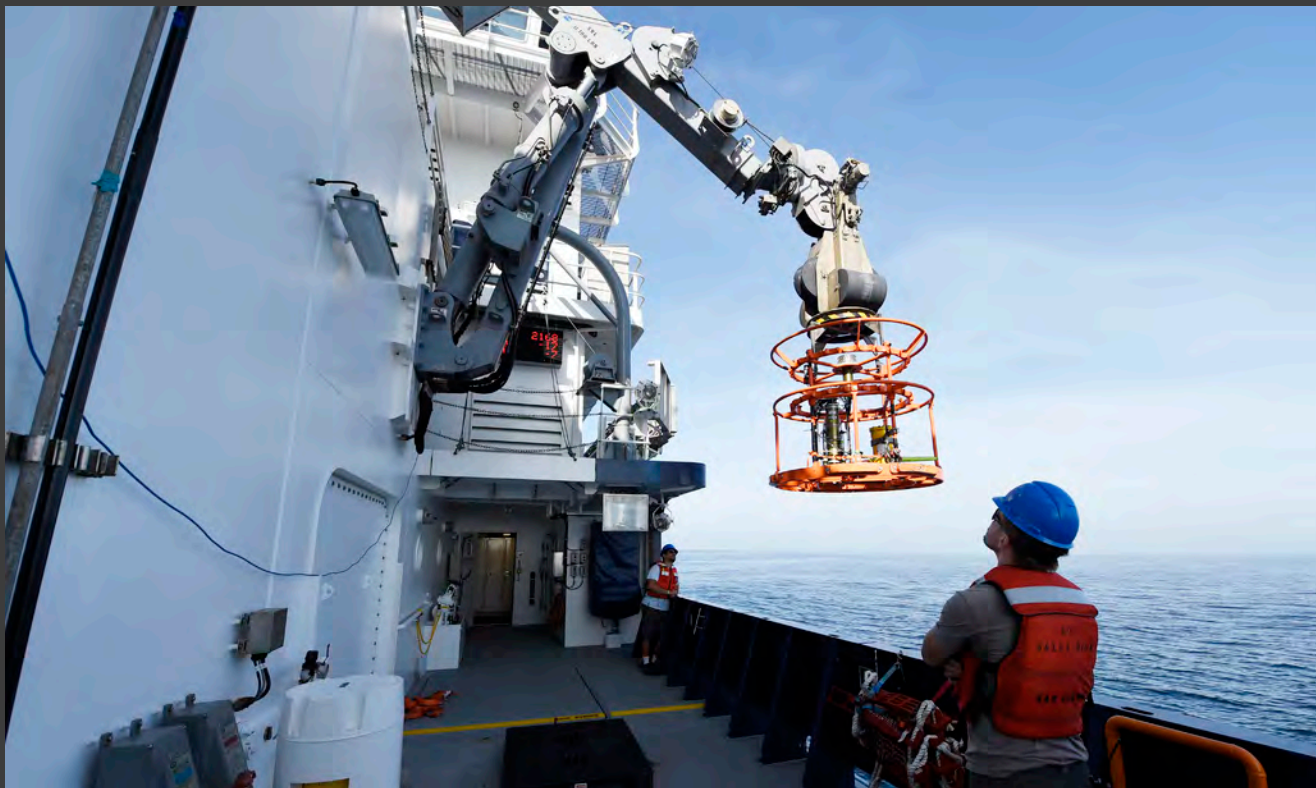
In sum, before a new platform-based technology can become reality, the total platform effects must be assessed and the total cost and performance impact estimated. ONR and NAVSEA need to work together closely to ensure that the technology impact study is accomplished using the best estimate of the technology characteristics. The results of the technology impact assessment are provided in the form of presentations, final reports, and certified cost estimates that are sufficient for Navy and Defense Department leaders to determine if they want to pursue the current path further, change direction and look at a different platform, modify the technology, or perhaps design a totally new ship. ✈

About the author:

Jeffrey Smith is a systems engineer with American Technology Solutions International. He provides technical support to the Office of Naval Research ship systems and engineering research division.

AROUND THE ENTERPRISE

news and events in naval s&t



On 14 December 2016, a robotic arm aboard oceanographic research vessel R/V *Sally Ride* (AGOR 28) is used to retrieve a scientific instrument that measures underwater conditions in the La Jolla canyon off the coast of California. Operated by Scripps Institution of Oceanography under a charter lease agreement with the Office of Naval Research (ONR), *Sally Ride* was delivered to Scripps in July 2016. The advanced research vessel has the latest in sensors, sonars, and communications systems. *Sally Ride* replaces the long-serving R/V *Melville* (T-AGOR 14) which has been transferred to the Philippine Navy as BRP *Gregorio Velasquez*. Photo by John F. Williams



On 12 January 2017, Tom Boucher (second from right), program manager for the electromagnetic railgun at ONR, talks to Rear Adm. David Hahn, chief of naval research, during a visit to the railgun facility aboard Naval Surface Warfare Center Dahlgren Division. Photo by John F. Williams



On 25 January 2017, Chief of Naval Operations Adm. John Richardson reviews new technologies being developed and tested at the High Energy Laser Systems Test Facility and USS *Desert Ship* (LLS 1), a land-based launch facility designed to simulate a ship at sea. Both facilities are located on White Sands Missile Range in New Mexico. The facility operates the nation's most powerful laser in support of Department of Defense laser research, development, test, and evaluation. Photo by MCC Elliott Fabrizio



INTELLIGENCE IN THREE DIMENSIONS:

AIDING BATTLESPACE AWARENESS WITH 3D VISUALIZATION

By Patric Petrie

A NEW PORTABLE WORKSTATION CAN VISUALIZE THE BATTLESPACE, CONDUCT DATA ANALYSIS, AND MONITOR UP TO 12 VIDEO FEEDS SIMULTANEOUSLY.

When seeking safe passage sailing through high threat areas such as the Strait of Hormuz in the Arabian Gulf, or the South China Sea, the U.S. Navy faces multiple challenges on the surface, from below, and from the air by regional adversaries.

Having a three-dimensional view of the entire battlespace can inform commanders about an evolving situation and help drive decision making to ensure that naval forces are ready and able to execute any mission.

A New Way to Disseminate Intelligence

Space and Naval Warfare Systems Center Pacific developed the Intelligence Carry on Program (ICOP), a variant of the Distributed Common Ground System-Navy for unit-level ships and expeditionary units operating ashore. The ICOP team is finding ways to analyze, fuse, and disseminate intelligence directly to warfighters, saving time and dramatically increasing the understanding of the threats around them.

ICOP consists of a high-end portable workstation configured with three monitors for visualizing the battlespace, conducting data analysis, and monitoring up to 12 video feeds simultaneously. This data comes from a variety of manned and unmanned airborne platforms as well as the ship's own camera systems. All provide real-time situational awareness not only to the ship's combat team, but also to higher headquarters at the maritime operations center level.

Tom Johnson, ICOP's lead engineer, said the project is all about providing dominance in information warfare.

"At a high level, ICOP is about putting the ship in the right place, at the right time, to effectively conduct its mission," Johnson said. "The capability is very much in a plug-and-play state with minimal network configurations to work across multiple classification domains. The key thing is that not only are we helping with the tactical fight, but we're helping make the ship part of the greater intelligence, surveillance, and reconnaissance enterprise and directly supporting operational decision making."

The ICOP Suite

Beginning as an Office of Naval Research rapid technology transition effort in 2011, more than 100 ICOP prototypes are now deployed within Navy units, both afloat and ashore.

From a prototype perspective, the ICOP team provides support to a wide variety of operational users such as U.S. 5th Fleet, Navy Expeditionary Combat Command, and the National Geospatial Agency.

The ICOP team successfully demonstrated to the Marines the workstations' incredible capabilities, portability, and adaptability across multiple shipboard and expeditionary networks, and as a result, the Marines are now acquiring systems for their use.


The ICOP program office continues to receive positive feedback regarding the significant role ICOP capabilities played in the highly successful 2015 Maritime Theater Missile Defense Forum. This at-sea demonstration included a live-fire engagement of a ballistic missile target by an SM-3 Standard Missile interceptor off the coast of Scotland.

ICOPs installed on USS *Mount Whitney* (LCC 20), USS *Ross* (DDG 71), and USS *The Sullivans* (DDG 68) simultaneously streamed video feeds from the ships to the Unified Video Dissemination System portal for near real-time viewing to a host of Navy and NATO viewers around the globe.

During this event, ICOP enabled an integrated end-to-end intelligence, surveillance, and reconnaissance architecture for both U.S. and Allied nations by successfully streaming live full-motion video and ballistic missile telemetry data of the launch.

The Way Ahead

ICOP capabilities were highlighted at the Armed Forces Communications and Electronics Association West conference, where the ICOP team provided demonstrations to the chief of naval operations and other flag-level Navy officials.

Following a successful initial demonstration on USCGC *Legare* (WMEC 912) in the summer of 2016, the ICOP team is currently conducting further testing aboard USCGC *Tahoma* (WMEC 908). 

About the author:

Patric Petrie is a public affairs writer with Space and Naval Warfare Systems Center Pacific.



SHIFTING SHIP DESIGN INTO HIGH GEAR: A NEW POWER AND ENERGY FUTURE IS COMING

By Bob Ames

**ELECTRICAL SYSTEMS ARE MORE IMPORTANT THAN EVER ABOARD SHIPS.
PLATFORM DESIGN AND ENERGY MANAGEMENT MUST GO HAND IN HAND.**

Electric cars, renewable energy, autonomous vehicles, and consumer electronics are evidence that a new power and energy future is emerging in both the civilian and military worlds.

Recent developments in weapon systems have delivered the next-generation in defense capability and these systems are challenging existing ship design practices, theory, and engineering tools. Like hybrid or all-electric cars, Navy ships are moving to a new paradigm where electric power and energy supply is directly related to ship performance. Like smartphones, everyone wants high-power density, energy-efficient systems, speed, control, survivability, and upgradeability—all at an affordable price in a functional package.

The promise of these new weapon systems is so compelling that it will set the stage for warships for the next 50 years and push naval design toward a future centered around high levels of power and energy that can be directed wherever it is needed, whenever it is needed.

The great divide between the old and the new is the way modern systems use energy. Systems such as rail guns, electronic warfare, and lasers bring new high electric loads that have high pulse energy demands. This will require new power system architectures that include energy storage, thermal management, and specialized power converters. To make ships with these systems affordable, it also will require higher power density. Acquiring that density likely will force a change in the ships' primary

electric bus current from alternating current to direct current. The management of energy in this new system architecture will require critical controls that must operate without fault in a few milliseconds of time and interface the ship machinery systems with the combat control system. These controls must manage mission system loads, ship propulsion, auxiliary systems, and all power and energy needs for an entire ship for all conditions. It will manage the energy supply from energy storage magazines and manage the ship generators that supply it.

Ship controls also will be critical to recoverability in the event a ship is damaged and a portion of its systems are down. A ship's vulnerability can be reduced by redundancy and redirection much like the internet. In the case of Navy ships, these systems are designed to operate across multiple zones. A zone is typically a physical subdivision of the ship. The naval architect assigns mission functions to specific zones of the ship in a manner that enhances survivability. The boundaries of the zone can be arbitrary, but to improve survivability the distributed systems zones and damage control zones are usually aligned.

Designing ships for these combinations of mission systems requires an understanding of how the ship will be operated and emerging tactics and doctrine; and requirements for power, energy, thermal management and computing.

In this new ship design paradigm, ship operations will drive power needs. The power and energy systems must deliver on this need with power dense electronics. These systems also must be arranged in the ship by zone, with all systems managed by time critical controls. The ship platform design and ship systems design are more interdependent and critical than ever.

How we leverage advanced weapons and sensors in a new ship design is best understood earlier in the engineering/ integration process where major trade studies are performed. Early-stage design is about getting the best balance between capability and affordability.

Software is at the heart of any research or design activity. In the Navy engineering community, modeling and simulation software spans many domains of knowledge at varying degrees of detail; using many software products from both the government and commercial sectors. In the case of new technology insertion, modeling and simulation tools tend to lag as knowledge must be acquired before it can be coded for analysis and decision support. The challenge is twofold. First, tools must be created or upgraded to capture the physics of the problem. Second, decisions are made from data, and this ship design data must be integrated and

universally understood among stakeholders. To address many of these issues, the Office of Naval Research (ONR) formed the Electric Ship Research and Development Consortium to combine academic research institutions to address the physics of the problem, and then initiated a software development program to design and analyze system architectures. This application is called Smart Ship System Design (S3D). ONR is now integrating S3D into a common software framework used by the Navy's early stage design tools providing data compatibility between design and analysis tools.

Recognizing the importance modeling and simulation for design tools and system simulation and testing, the 2014 Defense Department Research and Engineering Enterprise identified these relevant science and technology priorities and communities of interest:

Data to Decisions: The primary focus areas of this community of interest are human-computer interfaces, analytics and decision tools, information management, advanced computing and software development, and networks and communications. Data to Decisions incorporates the science and applications to reduce cycle time and manpower requirements for analysis and use of large data sets.

Engineered Resilient Systems: Engineering concept, science, and design tools to protect against malicious compromise of weapons systems and to develop agile manufacturing for trusted and assured defense systems.

Weapons: Develops technology-based options for weapons, and seeks excellence in weapon technologies and related research, including guidance, navigation, and control; ordnance; propulsion; undersea weapons; high-energy lasers; radio-frequency weapons; nonlethal weapons; and modeling, simulation, and test infrastructure.

The DoD Research and Engineering Enterprise also stated: "[Modeling and simulation] is a key enabler of capabilities supporting real world applications that underpin innovative technology solutions, act as force multipliers, save resources, and save lives by: promoting cooperation and collaboration to remove barriers to interoperability and reuse; and providing a common technical framework (architectures, data standards, and common [modeling and simulation] services) that improves interoperability, reuse, and cost-effectiveness."

Data integration challenges go hand-in-hand with interorganizational communication challenges. Navy senior leaders recognized that power and energy systems research was showing great promise and individual

►► SHIFTING SHIP DESIGN INTO HIGH GEAR: A NEW POWER AND ENERGY FUTURE IS COMING

Photo by John F. Williams



Today's naval forces already are beginning to see the incorporation of systems that will significantly increase their electrical needs, from the installation of Laser Weapons Systems, such as the one deployed aboard USS *Ponce* (ASB[II] 15), to the railgun soon to be tested at sea.



US Navy photo illustration

technology was being demonstrated, but an integrated approach was needed that required coordination among several stakeholders to pursue common and more affordable solutions. The Navy feared that without coordination, stove-piped approaches would produce redundant point solutions on the same platform, thereby increasing acquisition costs and resulting in complex system integration challenges.

In 2014 the Naval Sea Systems Command's executive steering group directed the formation of an overarching integrated project team called Combat Power and Energy Systems. Within this team are several working integrated product teams aimed at solving specific energy-related problems for high energy pulse load mission systems. One of the six teams was the Design Tools and Methodology (DTM) team headed by ONR.

The DTM team produced a comprehensive roadmap that identified modeling and simulation requirements and development activities needed by the entire combat power and energy systems community. The community concluded that the development and integration of new power and energy technology must be assessed within the constraints of total ship design using modeling and simulation software. The requirements of operations, power and energy systems, and total ship design are interdependent.

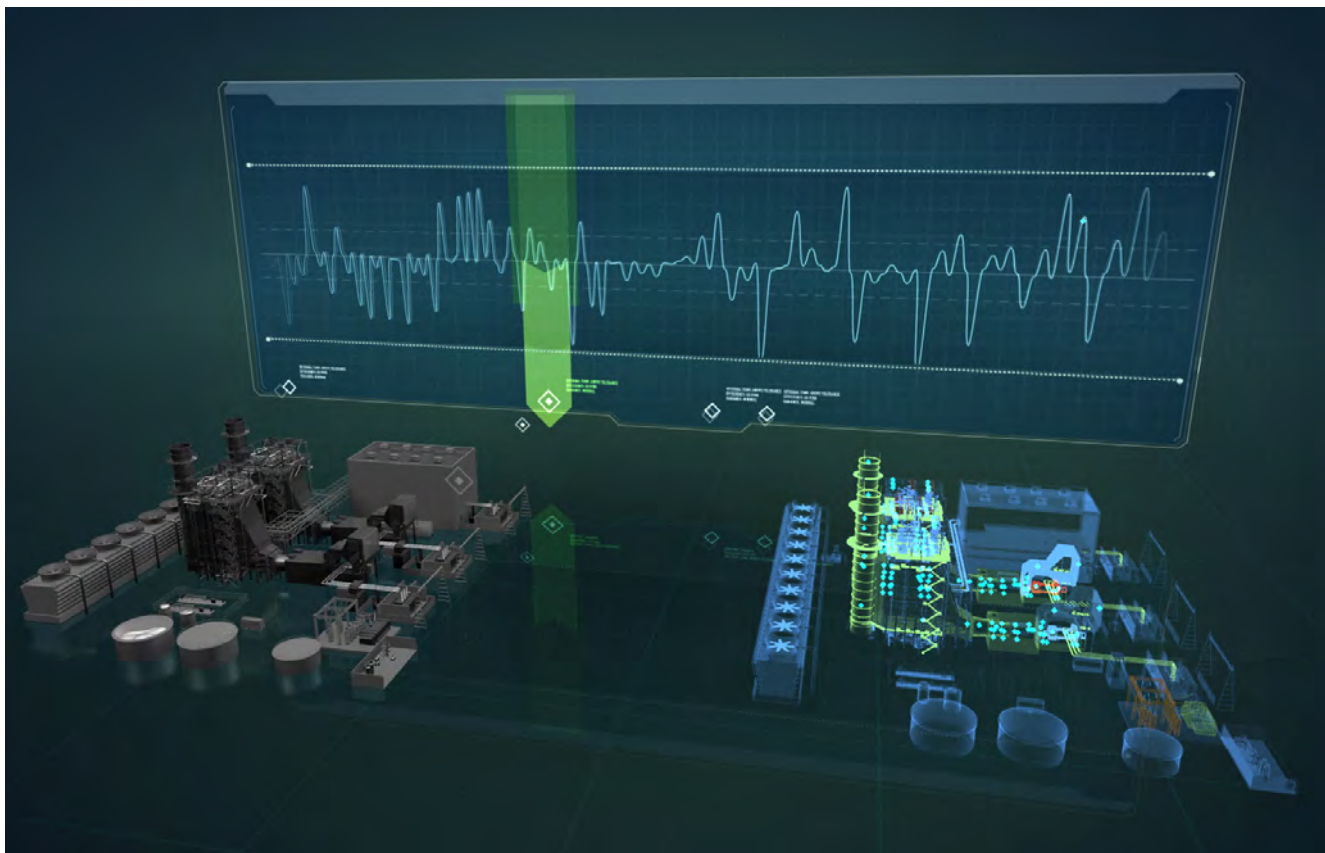
The proposed strategy for discovering the needed methods and interface standards for these new systems is through prototyping. This would involve building a portion of the system that tests the behavior of critical components and their interactions. In addition, modeling and simulation

software would be developed that mimic prototype performance. This software product is commonly referred to as a "digital twin" in the industry. General Electric, for instance, uses a digital twin for many studies from wind energy power plants to wind turbines and jet engines.

The Navy prototype is formally called an advanced development model (ADM). The ADM will require real-time electric and control system simulation capabilities, including power mission systems and hardware-in-the-loop options for critical capabilities for multiple ship variants. Power and energy system design requires transient, fault, harmonic, stability, and quality of service analyses, as well as the incorporation of control system behavior. In addition, design studies will require dynamic simulation of thermal management systems to explore and determine appropriate system designs that support advanced weapons and sensors.

With appropriate forethought and resourcing, the individual software development verification and validation activities can be coordinated to result in a digital twin of the ADM. An additional requisite for a digital twin is that sufficient foundational research has been executed and data generated such that technologists understand the physical phenomena to be evaluated and may thereby model it.

This architecture has complex controls and interface details that must be resolved. Controls are critical to the success of this technology, but vulnerability and recovery also will be design requirements from the earliest stages. ONR has an upcoming Future Naval Capability intended to address controls and design integration. This will set the stage for system characterization for the early stage



A "digital twin," such as the one used by General Electric shown here, uses modeling and simulation software to mimic prototype performance.

design tools and can be used in later stages of design, construction, operation, and service life support.

During the early stages of design, new designs are modeled by a tool called the Rapid Ship Design Environment (RSDE) where tens of thousands of designs are generated in what is called a design of experiments. These tools are expanding the decision support process, and with recent deployment on Defense Department high-performance computers the opportunity for discovery is unprecedented. Unfortunately, this design of experiments presumes that the characterization of any single design in the trade space of solutions is feasible and that the theory employed by the tools is validated.

With combat power and energy systems-equipped ships, the RSDE model is dependent on the details of the ship system power architecture and interface standards. What will be required is an iterative process of design and analysis from systems architecture to concept design to dynamic analysis returning design modifications to the system architectures, where the process repeats itself until the

solution is feasible. Doing this for many ship designs and many system architectures can only be accomplished through data integration across the community. The ship design methodology must be efficient. It must be about design and analysis, not nonproductive, labor-intensive activities such as data migration, translation, and data entry.

The Navy will need to engage industry to build these complex components and systems and provide their respective digital twin models for simulation. With this new design paradigm comes many challenges. With new tools and supporting research, new warship designs for at least the next 50 years will increasingly reflect the advantages of these new power and energy systems. ✈

About the author:

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CREATE THIS!

Using Computational Prototyping to Improve the Process of Design

By Dr. Thomas Fu

PROTOTYPES AND LIVE TESTING NO LONGER DOMINATE PLATFORM DESIGN. TODAY'S VESSELS, SUCH AS THE FUTURE USS *MICHAEL MONSOOR* (DDG 1001), ARE BEING BUILT USING SOPHISTICATED MODELING AND SIMULATION SOFTWARE.

We live in a globalized, highly interconnected world that is witnessing a major technological revolution in warfare—in the air, at sea, on land, in space, in the cybersphere, and in the electromagnetic spectrum. Our technological superiority is a key element to our national security, and our ability to design, procure, and field new equipment and associated new capabilities is critical to that security. How does the Defense Department maintain that security in the face of shrinking budgets and narrowing gaps in our technological superiority? Where can we conduct the research, development, testing, evaluation, modeling, and simulation needed to field the new technologies we need in a timely and cost-effective manner?

Computational design tools are very effective methods for capturing engineers' corporate knowledge and new research results. This capability greatly facilitates the development of innovative designs. The science and technology research community is working with the Defense Department's High Performance Computing Modernization Program and its Computational Research Engineering Acquisition Tools and Environments (CREATE) team to incorporate research results into the CREATE suite of design codes. CREATE provides a very effective and efficient method for transitioning research results to acquisition programs.

CREATE's goal is to develop and deploy physics-based, high-performance computing software applications for the design and analysis of military aircraft, ships, radio frequency antenna systems, and ground vehicles through the construction and analysis of virtual prototypes for those systems. Code development began in 2008; today, CREATE is beginning to realize its goals. The military ship design effort is developing accurate physics-based models of naval vessels that address three key capabilities: ship shock response, hydrodynamics, and design space exploration for concept design. This new generation of computational design tools will enable acquisition systems engineers to produce optimized designs for complete systems and make better design decisions more quickly than has been possible with prior design tools. This capability enables design engineers to construct realistic virtual ship prototypes and make accurate predictions of their performance by solving the physics equations that govern their behavior.

In the past, it was necessary to rely on physical prototypes and use live tests to assess their performance and find the design flaws. With simple systems, and incremental changes, there was adequate time to follow the traditional product development paradigm of "design, build, test, fail, redesign" iterated cycles. For the standard systems

engineering product development process, the design of new products is based on “rule of thumb” extrapolations of existing products. Sub-system physical prototypes are tested during the engineering design phase, and full system physical prototypes are tested just before full-scale production. With today’s more complex systems, these live tests occur too late to provide timely data on design defects and performance shortfalls. Expensive and time-consuming rework is required to fix the problems uncovered by live testing.

Since the end of World War II, the computing power has grown exponentially, and for the first time in history we have the ability to make accurate predictions of the behavior of complex physical systems. Optimized engineering designs developed early in the acquisition process using CREATE’s tools can substantially reduce costs, shorten schedules, increase design and program flexibility, and, above all, improve acquisition program performance by reducing design flaws, developing sound engineering designs quickly, and beginning the systems integration engineering process much earlier in the acquisition process.

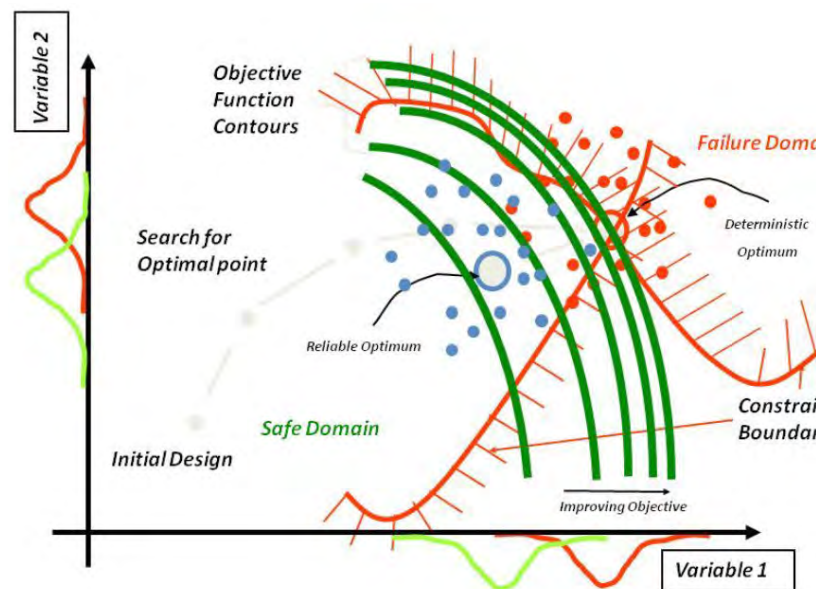
The High Performance Computing Modernization Program oversees CREATE. The program provides critical modeling support in the world of computational prototyping and is maintaining a steady pace of adoption and acceptance of its physics-based engineering software tools across an expanding customer/client base. CREATE is the program’s premier vehicle for addressing current and future design and analysis efforts for major acquisition programs.

CREATE is composed of five major defense weapon systems procurement project areas: aviation, shipbuilding, antenna design, meshing and geometry, and ground vehicles. The program has developed a total of 11 physics-based engineering software tools that perform critical design space exploration and assessments, using the high-speed computing systems that are found at the five Defense Department supercomputing resource centers located around the country at various government research laboratories. The critical success of the CREATE program is the result of a solid business plan, an innovative hybrid management system that embeds the software developers within the service research and development organizations, and a steady annual delivery of product development and releases that are

specifically focused on meeting the needs of the research and development clients.

The Office of Naval Research ship systems and engineering research division director sits on the CREATE-Ships (shipbuilding) board of directors. This ensures that the latest modeling research developments are incorporated into the CREATE-Ships software. The CREATE-Ships project is currently fielding four specific physics-based engineering software programs:

- **Rapid Ship Design Environment (RSDE):** Provides rapid development, optimization, assessment, and integration of ship designs
- **Navy Enhanced Sierra Mechanics (NESM):** Provides performance prediction of shock and damage effects, and reduces the need for tests to assess ship shock and damage effects
- **NavyFOAM:** Provides accurate and detailed calculations to accelerate and improve all stages of ship hydrodynamic design (e.g., seaway loads, seakeeping, resistance, powering, etc.)
- **Integrated Hydrodynamics Design Environment (IHDE):** A user interface to facilitate use of the Navy Leading Edge Architecture for Prototyping Systems (LEAPS) product model database and the suite of Navy hydrodynamic design tools.



Multidisciplinary synthesis using the CREATE-Ships Rapid Ship Design Environment (RSDE). RSDE is a ship concept-design tool that allows engineers and naval architects to assess the trade-offs inherent in designing ships to meet a range of competing key performance parameters. It can generate tens of thousands of candidate ship designs with varying hull forms and subdivision and machinery arrangements in a very short period of time.

►► CREATE THIS! USING COMPUTATIONAL PROTOTYPING TO IMPROVE THE PROCESS OF DESIGN

Each of these software tools has been heavily involved in recent major Navy testing and evaluation assessments, as well as in major shipbuilding acquisition program design analysis efforts.

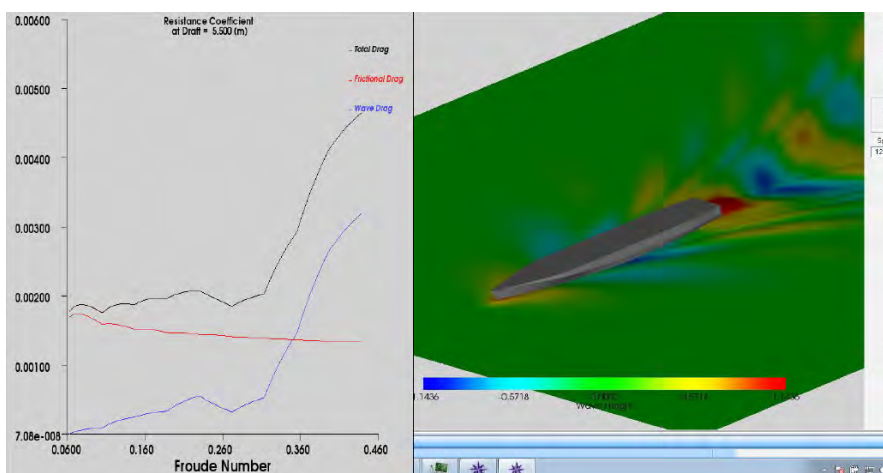
RSDE is a ship concept-design tool that allows engineers and naval architects to assess the trade-offs inherent in designing ships to meet a spectrum of competing key performance parameters. Employing the concept of design space exploration, engineers and naval architects can provide data for decision makers on the effect of trade-offs in areas such as range, speed, armament, and aviation support on the size and, in large measure, the cost of a proposed ship concept. RSDE can generate tens of thousands of candidate ship designs with varying hull forms and subdivision and machinery arrangements. An initial assessment of stability, resistance, and an initial structural design and analysis is done for each ship design. RSDE has been used to enable set-based design on Navy acquisition programs. This design method allows down-selection of a ship design to occur later in the process when the trade-offs are more fully understood. RSDE supported the LX(R) next-generation amphibious ship analysis-of-alternatives study through design space exploration of 22,000 concept designs in only three months, as well as identifying major cost vs. capability trades. The tool also was used to support the small surface combatant trade study.

NESM builds on the Department of Energy's shock analysis tool, Sierra Mechanics, to provide a means to assess ship

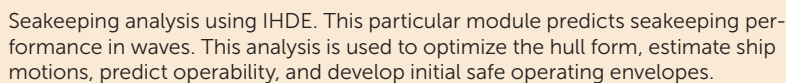
and component response to external shock and blast using accurate high-performance computational tools. NESM can reduce the time and expense required for physical shock testing of ship classes, and also improves the initial ship design process by assessing planned component installations for shock performance prior to final arrangement and installations decisions. The tightly coupled multiphysics capabilities include: structural dynamics (implicit linear-elastic solver: static, modal, transient, acoustics, and more); solid mechanics (explicit plasticity solver: failure, high-strain, multigrid, and more); fluid dynamics (euler solver: shock propagation, load environments, and threat modeling); and fluid-structure interaction. The solution algorithms in NESM can exploit massively parallel computers, and can scale to thousands of cores, enabling efficient computer use and the ability to address full-sized naval vessels up to and including next-generation aircraft carriers and submarines. This critical analysis tool has been used as a full ship shock trial alternative and live-fire test and evaluation support system for design analysis on the Navy's littoral combat ship and the Navy's CVN-78/79 carrier programs.

NavyFOAM is based on the OpenFOAM software libraries and code architecture. The CREATE program has added a number of features and capabilities that enable the simulation of the air-sea interface and other effects important for naval vessels. NavyFOAM provides high-fidelity hydrodynamics to accelerate and improve all stages of the hydrodynamic design for surface ships and submarines.

These design elements include the impact of seaway loads, seakeeping, resistance, and powering loads on various ship design models. The NavyFOAM program has supported the Ohio replacement program, using a custom physical model for flow predictions and rotating-arm simulations to better understand the underlying physics used in design decisions. The Zumwalt (DDG 1000)-class guided missile destroyer used NavyFOAM to determine hull forces, and provided related hull maneuvering coefficients to support safe operating envelope design decisions. In addition, NavyFOAM supported both the Marine Corps amphibious combat vehicle programs,



Resistance analysis using CREATE-Ships Integrated Hydrodynamic Design Environment (IHDE). IHDE is a desktop application that integrates a suite of Navy hull form design and analysis tools that allows users to evaluate performance in a simplified and timely manner from a single interface. This particular IHDE module predicts hydrodynamic resistance in calm water. The resistance analysis is used to optimize the hull form and estimate the power required to move the ship at various speeds.



IHDE is a desktop application that integrates a suite of Navy hullform design and analysis tools that allows a user to evaluate performance in a simplified and timely manner from a single interface. Prior to the development of IHDE, naval architects and marine engineers often had to learn how to use a dozen or more individual design tools, each with a different user interface and input format. IHDE provides a single interface for access to all of the tools. In a few days to weeks, a single user with IHDE can finish projects that took several highly experienced users many months to complete. Current capabilities are geared toward surface ships, both monohulls and multihulls—including catamarans and trimarans. Typical uses include predicting: resistance in calm water, seakeeping behavior in waves, hydrodynamic loads due to wave slamming, and operability (i.e., the percentage of time a ship can carry out its particular mission in various parts of the world based on historic sea state data). The most recent successes for IHDE have involved the Arleigh Burke (DDG 51)-class Flight III bow bulb design assessments, and support to the Navy's small surface combatant task force in evaluating multiple ship designs in a very short timeframe.

The future of the CREATE program is focused on building on its steady success of high-fidelity, physics-based engineering tools that meet the needs of the defense research and development community, as

New technology areas such as hypersonics, directed-energy weapons, future submarine and multihull ship design, and unmanned vehicle design and analysis are all prime candidates for CREATE tool applications. As the capability and capacity of these hardware and software systems progress by several orders of magnitude in the next 30 years, computational prototyping, such as the products being developed by the CREATE program, will become an integral part of major acquisition programs.

Dr. Fu is the division director of the Office of Naval Research ship systems and engineering research division.

PHYSICS-BASED MODELING AND SIMULATION FOR THE PREDICTION OF SHIP SHOCK RESPONSE AND DAMAGE PREDICTION

By Dr. E. Thomas Moyer and Jonathan Stergiou

THOUGH SPECTACULAR IN EXECUTION, SHIP SHOCK TRIALS ARE COSTLY AND HAPPEN WHEN A SHIP IS COMPLETE. MODELING AND SIMULATION CAN REPLICATE MUCH OF THIS PROCESS, ALLOWING ISSUES TO BE IDENTIFIED MUCH EARLIER IN A SHIP'S LIFESPAN.

Navy ships and submarines, which are designed to operate and fight in hostile environments, have specific survivability performance requirements. These requirements can include shock hardness, postengagement structural capabilities, and protection features required to meet mission needs. While such requirements are not new to ship design, traditional practices employed extensive physical testing supported by various engineering analysis approaches. While these practices are successful, the required physical testing is often time and cost consuming. In addition, the testing process typically occurred (out of necessity) late in the design process when implementing changes is constrained by the acquisition schedule and available funding.

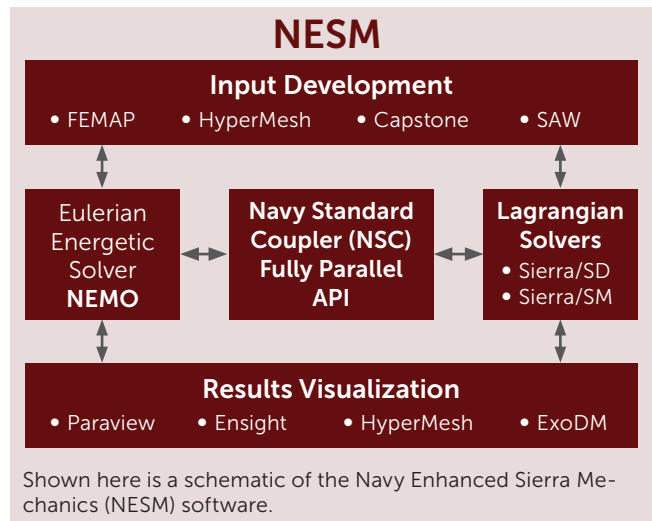
The continued evolution of higher fidelity modeling and simulation is providing ship acquisition programs with opportunities to determine design features and limitations early in the acquisition cycle, when both schedule and funding for design modifications is planned minimizing their effect on the overall acquisition program. While modeling and simulation do not eliminate the need for physical testing, they often facilitate the determination of essential physical testing as well as identifying opportunities for reduced complexity testing, providing the opportunity for some cost avoidance in the overall test and evaluation process.

Ship Shock Response and Damage

The High Performance Computing program office initiated the Computational Research and Engineering Acquisition Tools and Environments (CREATE) program in 2008 to develop physics-based modeling and simulation tools. These tools take optimal advantage of modern high-performance computing platforms to address key technology requirements for the acquisition community where modeling and simulation could potentially significantly reduce the risk in acquisition programs. Each of the services provided priorities to CREATE that were used to identify the program's initial funded projects. The CREATE-Ships project was initiated to address those priorities that Naval Sea Systems Command (NAVSEA) identified for ship design: ship shock response and structural damage due to weapon engagement, ship hydrodynamics, and early-stage ship design. The Naval Surface Warfare Center Carderock Division was tasked to lead the development of the required software products to support these needs.

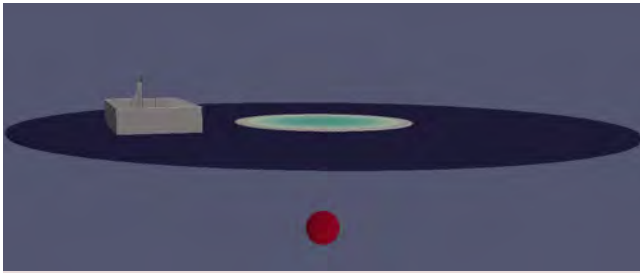
Carderock partnered with Sandia National Laboratory to develop Navy Enhanced Sierra Mechanics (NESM, a CREATE-Ships product) for the prediction of ship shock response and structural damage prediction. The team is supported by engineers from Thornton Tomasetti-Weidlinger Applied Science Practice. NESM is a suite of analysis tools modeling both the physics of threat weapon engagement as well as the ship response to that engagement. These tools are fully coupled to capture the interaction between the weapon-driven environmental loading and the responding structure. NESM development leverages the Department of Energy's investment in the Sierra Mechanics suite being developed by Sandia under the Advanced Scientific Computing program. Initially, NESM development focused on enhancing Sierra Mechanics with additional capabilities required for ship structural response and damage modeling. For weapons loading and interaction effects, NESM leveraged the Office of Naval Research (ONR) investment in the Dynamic System Mechanics Advanced Simulation code developed for the Navy lethality community by Naval Surface Warfare Center Indian Head Explosive Ordnance Disposal Technology Division. Subsequently, ONR funded a Future Naval Capability program researching the underwater explosive response and implosion of submerged structures. Supported by this program, the research group of Prof. Charbel Farhat at Stanford University developed a new, efficient, and stable media interaction algorithm.

Leveraging the work from Stanford, Carderock developed the Navy Energetic Modeling Oracle (NEMO), a highly modular Eulerian hydrocode using the new media interaction algorithm and fully parallel coupling in NESM. A schematic of the NESM software is shown below.



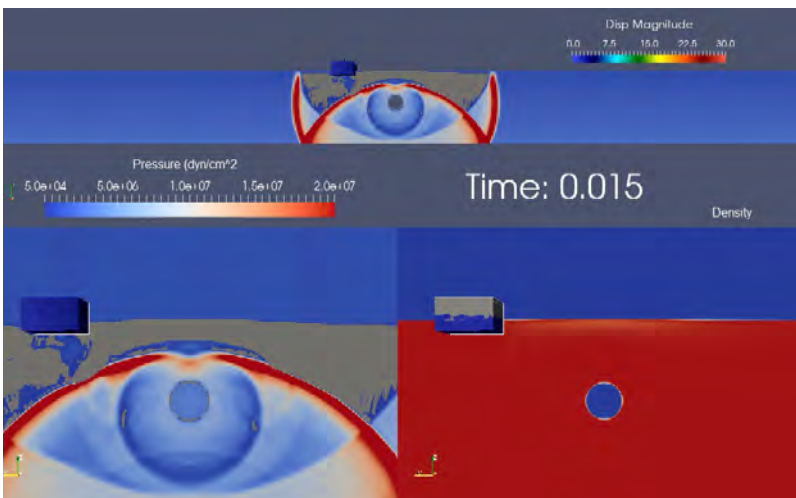
Shock Hardening

One major application of NESM is in the shock hardening of ships. Combatant craft require most systems to meet either Grade A (operational after prescribed shock event) or Grade B (structurally intact after prescribed shock event) requirements. Shock qualifications to meet these requirements are primarily based on physical testing, but modeling and simulation often is employed where full testing is either impossible or impractical. In addition, modeling and simulation often is sufficient for Grade B qualification. Traditionally, total ship shock hardness validation has been accomplished using the full-scale shock trial. While trials are a very successful method to demonstrate shock hardness, they are performed late in the acquisition process when shock deficiencies are difficult to address because of cost and schedule constraints. One of the major requirements for NESM development was to provide sufficient modeling capability to support an alternative to shock trials. Partially because of the great success of NESM, the Navy was able to release OPNAVINST 9072.2A in 2013, which provides the option for future ship classes to perform a modified shock qualification process that eliminates the need for the full-scale shock trial. This new process identifies shock deficiencies earlier in the acquisition cycle, making it easier to remedy these deficiencies prior to the completion of a ship.

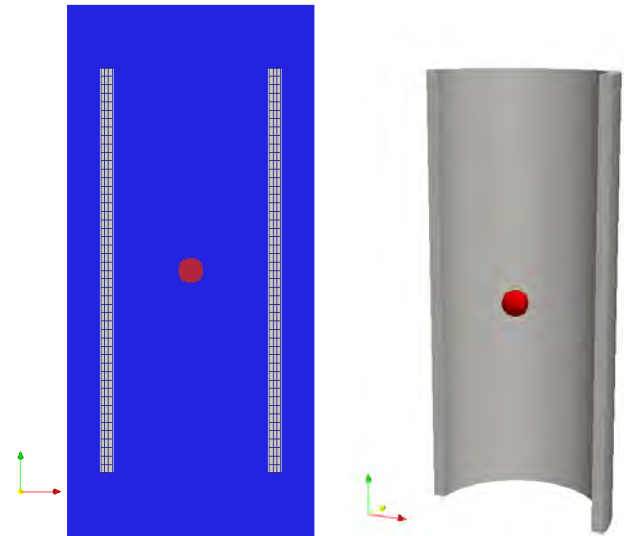


This is a modeling and simulation representation of an underwater explosion event during a ship shock trial, the standard test used for shock qualification in accordance with MIL-S-901.

NESM continues to pursue a significant verification and validation program. This is described in more detail in a recent invited journal publication. One example is the response of the floating shock platform to underwater explosive loading, which is the standard heavyweight test used for shock qualification in accordance with MIL-S-901. A modeling and simulation representation of the test is shown above. The figure below shows an example of the shock wave produced by the explosion event, as simulated by NESM. These predictions provide an example of acceptable correlation between NESM modeling and simulation and physical testing to approve NESM usage shock qualification and hardening support. This example and the balance of the NESM verification and validation results facilitated the NAVSEA technical warrant for shock-ship determination that “NESM is the appropriate and technically acceptable M&S [modeling and simulation] tool which meets the M&S requirements to support current and future surface ship shock applications.”



This shows an example of the shock wave produced by the explosion event, as simulated by NESM.



Shown here is the NESM prediction of the structural response (left) compared with physical measurements of the deformed structure (right).

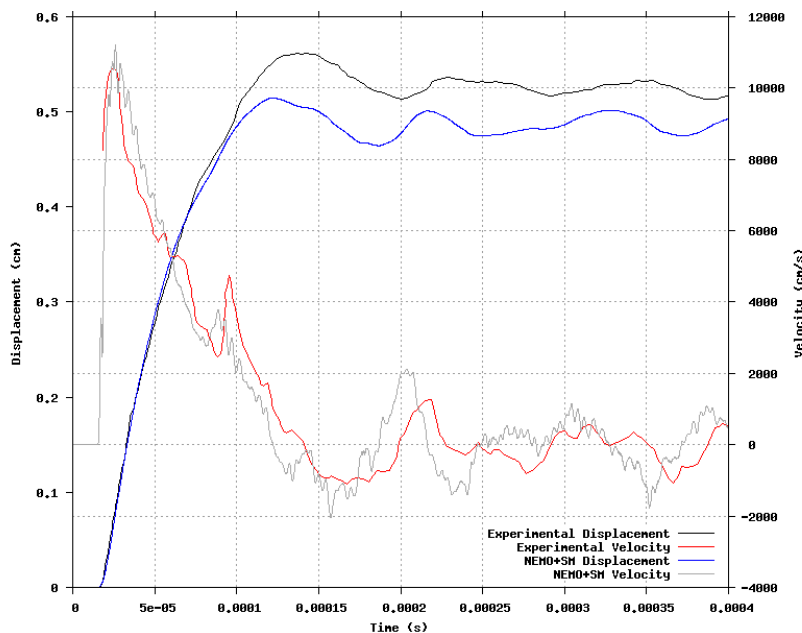
Structural Hardening

In addition to equipment and system shock hardening requirements, many warships are structurally designed to withstand other specific weapon effects in addition to shock loading. One example is ship whipping caused by cyclic loading from a gas bubble caused by an underwater explosion. The whipping loads often are a design driver for primary hull structures. In addition, some combatants also are structurally hardened to survive other specific threat-weapon-induced events. One example is the DDG 1000 Peripheral Vertical Launcher System (PVLS)

protection design. “Each PVLS cell provides defense for a Mk-57 VLS. This protection design improves survivability and isolates crew and equipment from the weapons.” The PVLS design relied heavily on modeling and simulation but was restricted to the capabilities of the available software in the 2000-2005 timeframe. NESM provides all the past modeling and simulation capability required to support the initial fielding of the PVLS design as well as the additional capabilities that could have saved significant cost and schedule in the PVLS development because of the advances in hardware performance and software configured to exploit it to gain more powerful and efficient capabilities.

Modeling and simulation for structural hardening typically requires the modeling of the plastic deformation and subsequent damage of structural hull materials. One classic benchmark example problem is the “hydro-bulge test,” where a small explosion is detonated in a water-filled cylindrical aluminum test structure. The figure at left shows the NESM prediction of the structural response compared with physical measurements of the deformed structure. The figure below shows the loading profile caused by the underwater explosion event along with the plastically

the Navy undertakes an extensive program of surrogate testing (often including component testing), modeling and simulation, as well as expert survivability assessment. These assessments are used in addition to the physical testing and modeling and simulation used to confirm design compliance of ship survivability performance requirements (e.g., shock, whipping, etc.). NESM development and V&V are addressing many of the needs for current and future ship program live-fire testing assessments and reporting.




The loading profile caused by the underwater explosion event along with the plastically deformed structural configuration at a point in time.

NESM provides the most complete and robust set of modeling and simulation capabilities available today; it is currently being used to support the CVN 78 live-fire test program and also is planned for use on all future ship platforms. Full ship model requirements to predict the response and damage to ships exposed to weapon effects tend to be extremely complex requiring massive computational resources. NESM is optimized to take full advantage of current and future High Performance Computing platforms providing the state-of-the-art modeling and simulation toolset for the computationally difficult problems encountered during the live-fire testing process, which is likely to drive the direction and investment in NESM for the foreseeable future.

deformed structural configuration at a point in time. NESM includes the required capabilities to predict the ship structural response and damage caused by a threat weapon engagement and is currently being used to support the design of the aircraft carriers USS *Gerald R. Ford* (CVN 78) and USS *John F. Kennedy* (CVN 79).

Live-Fire Test and Evaluation

U.S. law (Title 10 U.S.C. § 2366) requires military systems and platforms to be evaluated for their performance and survivability when engaged by credible threats in theater. Many assets can be evaluated by full-system engagement with threat weapons by physical testing, but it would be prohibitively expensive and unrealistic to subject operational ships to such testing. To meet these reporting requirements,

The CREATE program provides the financial, management, and computational support requirements necessary to develop computational tools for the acquisition community. NESM provides the Navy with a unique toolset that is facilitating the more efficient, affordable, and accurate design and assessment of ship survivability when exposed to threat weapon effects. Continued development and expansion of NESM usage will facilitate the cost-effective design of highly survivable ships for future acquisition programs. 

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A LOOK AHEAD

POLAR SCIENCE AND TECHNOLOGY

►► By Dr. Scott Harper

Since the founding of the Arctic Research Laboratory in 1947, the Navy has played an important role in fostering arctic science and technology. Historically, the Navy has had an interest in polar exploration, but it was during the 50 years following World War II that the Navy established itself as a significant sponsor of basic research in the Arctic and a provider of logistical support for polar research. Over this time the Navy supported dozens of scientific field experiments in the Arctic, studying the environment and developing technology in support of arctic operations. The first nuclear-powered submarine, the USS Nautilus (SSN 571), made the first subsurface transit of the Arctic Ocean in 1958, and the threat presented by the Soviet Union's submarine and surface forces in the Arctic kept the Navy's interest in understanding this region high for much of the 20th century.

After the end of the Cold War, the operational Navy's interest in the Arctic waned and the investment in research to support of high-latitude naval operations declined significantly. As Arctic sea ice has steadily declined over the last 40 years, however, it has resulted in record minimums in sea ice cover in recent years and the Navy is once again paying attention to the Arctic as an area of responsibility. As the waters of the Chukchi and Beaufort Seas open up for longer periods during the summer months, there has been a noticeable uptick in maritime activity, ranging from tourism and scientific research to shipping and resource exploration, by both Arctic and non-Arctic nations alike. With the retreat of sea ice providing easier access to the Arctic Ocean, the Navy released its first Arctic Roadmap in 2009 to provide guidance on how the Navy must prepare to operate in the region as potential changes in the security environment might elevate the need for an enhanced naval presence. The Arctic Roadmap, updated in 2014, gives direction on the necessary preparatory activities in both the near term and far term as the Arctic becomes an area of increasing strategic importance.

In the next issue of Future Force, we will focus on the naval science and technology community's efforts that will support future naval operations in the Arctic (and, to a lesser degree, the Antarctic as well). Despite the retreat of sea ice during the summer, the Arctic remains a challenging operational environment for a variety of reasons. With respect to surface operations, sea ice remains a serious impediment to ships in the Arctic Ocean, and observing and forecasting of the ice conditions at all times of the year will be a critical enabler of maritime activities. Ships must be specifically designed to operate in the presence of ice, whether they are dedicated icebreakers that can operate year round or vessels with ice-strengthened hulls that can safely operate in marginal ice conditions. Sea ice is not the only environmental threat to platforms; changes in the winds, waves, and the atmospheric boundary layer may all impact surface operations, including the danger of superstructure icing. These physical processes involve the complete environment—ocean, atmosphere, and sea ice—and new numerical models of the entire Arctic system are needed to appropriately forecast them. In addition, the changes observed in the physical environment also are altering the ecosystem, and the increases in ship traffic will both impact and be impacted by changes in marine life in the Arctic.

All of these challenges are amplified by the difficulty of access to the maritime Arctic. Long distances, uneven communications, and a lack of support infrastructure are all characteristics of operating in the Arctic. With foresight, the science and technology community can help address these issues and perhaps assist in turning the challenges of the Arctic into opportunities.

Dr. Harper is a program officer with the Office of Naval Research.

Photo by MC2 Tyler Thompson



USS *Hampton* (SSN 757) surfaces through the Arctic ice during Ice Exercise 2016. As the poles become more ice free for longer periods throughout the year, and the old dream of a "Northwest Passage" for commerce between Europe and Asia increasingly becomes a reality, naval forces are returning to the Arctic.



An unmanned rigid-hull inflatable boat equipped with electro-optical and infrared sensors operates autonomously during an Office of Naval Research (ONR)-sponsored demonstration of swarmboat technology held at Joint Expeditionary Base Little Creek-Fort Story in October 2016. Photo by John F. Williams

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