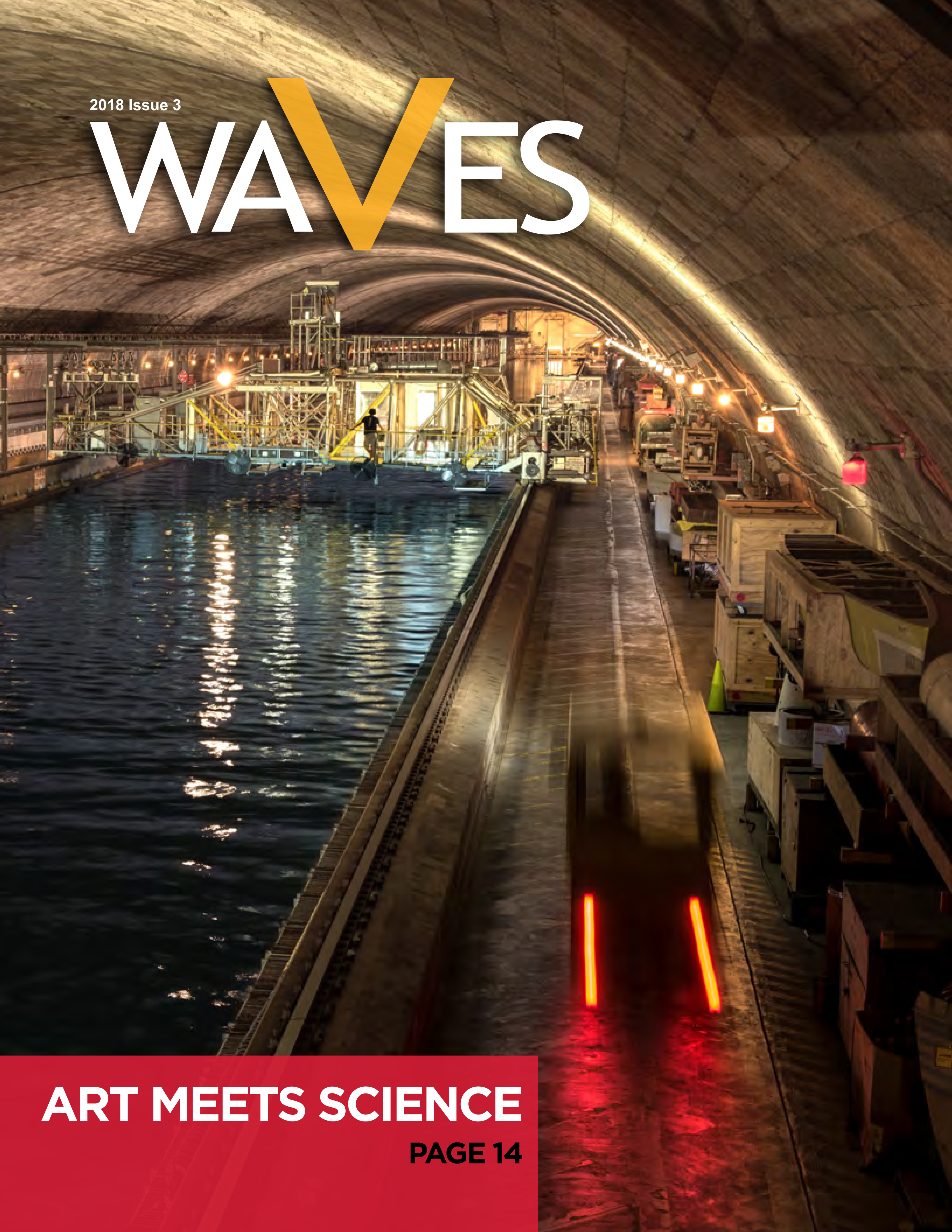
2018 Issue 3

WAVES



ART MEETS SCIENCE

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Content

In this issue

Despite being summer with many folks enjoying well-deserved time off, there is still a lot of activity going on all around NSWC Carderock. What's the reason for all this activity? As many of the visiting admirals and senior leaders have said, "You need to read the National Defense Strategy (NDS)."

The NDS says we're coming out of a period of strategic atrophy and that we have to raise our strategic game to really sharpen America's competitive edge. We have to hit the decks running to pursue advanced technologies, artificial intelligence/learning, autonomous platforms and develop the secure networks that allow our forces to communicate across the globe.

In the last issue of Waves, we talked about the impact of a tsunami of big data. We need big thinkers and talented innovators to take advantage of that tsunami. Recapitalizing old equipment, planes, ships, subs and tanks is costly and our adversaries are looking for new ways of dominating the battlefield. Many of our senior leaders grew up in a post-Cold War era. Like them, we all have to adjust to competing in a quickly changing international security environment. To keep pace, I recommend you pay attention to new programs like Digital Twin and I hope you are taking advantage of our brown bag speaker sessions, like the one on Data Wrangling in this issue of Waves, and the Rear Adm. David Taylor Lecture Series, two of which are covered in this issue. Also, take advantage of this magazine to share knowledge, scientific papers and new ideas.

Our STEM skills continue to be as important as ever in our nation, especially knowing the force we need in the future is a lot different than the force we needed in the past. We need people who are really smart and cyber savvy, who can write algorithms for artificial intelligence and coders for smart machine learning. In this issue are two STEM stories that remind us we need to continue to build the next generation of scientists and engineers. I thank all of you who devote time to support these important events.

All the best, and share this magazine with your friends and associates.

Paul Shang

Cover

The David Taylor Model Basin on July 30, 2018, at Naval Surface Warfare Center, Carderock Division in West Bethesda, Md., is used to test ship and submarine models in a variety of situations. (U.S. Navy photo illustration by Ryan Hanyok/Released – Due to the size of the model basin, several photos were compiled to create this photo illustration.)

Team

Dr. Paul Shang
Katie Ellis-Warfield
Ryan Hanyok
Justin Hodge
Brooke Marquardt
Roxie Merritt
Monica McCoy
Kelley Stirling
Kevin Sykes
Margaret Zavarelli

Dr. Jonathan Tu

Research scientist and engineer, Signatures Characterization and Analysis Division

By Justin Hodge, Carderock Division Public Affairs

Dr. Jonathan Tu, a research scientist and engineer, grew up in Seattle envisioning a career in academia until during his post-doctoral studies, when he realized there were other career options better suited to his skills and interests. He now works in the Signatures Characterization and Analysis Division at Naval Surface Warfare Center, Carderock Division's Puget Sound Detachment.

Tu grew up loving airplanes, especially fighter jets, which pointed him to the University of Washington, where he earned a Bachelor of Science in aeronautics and astronautics and a Bachelor of Science in mathematics in 2008.

"I have always loved to take things apart and figure out how they work, so I have long known I wanted to be an engineer," Tu said.

It was during this time Tu realized his talents lent themselves more to theoretical and mathematical work than hands-on engineering, though he never lost the passion for taking things apart and building things.

After obtaining his bachelor's degree, Tu enrolled in the mechanical and aerospace engineering doctorate program at Princeton University, with an emphasis on control and dynamical systems theory, and a minor focus in fluid dynamics.

Upon completion of his Ph.D., Tu completed a two-year post-doctorate program at the University of California, Berkeley. It was at the end of this time that he was looking for jobs and heard about Carderock from a friend. After an initial meeting, his growing interest led to an interview, and a subsequent job offer.

"I was attracted by the opportunity to do research and study basic science problems, but with a clear guiding goal, driven by Navy interests," Tu said.

Tu arrived at Carderock in January 2016 with a focus of becoming an expert in the techniques of machine learning, while also trying to see how those techniques might help solve problems at Carderock that either weren't able to be solved before, or that were difficult to solve, but might be easier now using new methods.

"I am interested in seeing how we might be able to apply these tools to problems relevant to Navy interests," Tu said. "For instance, we might previously have asked human analysts to look at sensor readings to determine if a machine is working properly. With the growing speed and lowering cost of sensors, now there are more sensor readings to look at than ever before, and often more than we could expect an analyst to look at. If we can automate this task, then we can let the computer handle the more standard cases, and only alert the human analyst when something especially strange is happening that the computer doesn't know how to handle. Then the human analyst is free to do more difficult and more interesting tasks, and the computer provides more complete coverage than the human analyst would have been able to."

Tu said he is happy with the fact that he has been able to collaborate with people across all disciplines at Carderock. He is the principal investigator on a Naval Innovative Science and Engineering (NISE) 219 project that involves people from all three technical codes at Carderock. He is also a member of the Carderock Data Analytics Community of Practice and participates in Navy Digital Twin efforts.

"All of these have given me the opportunity to work with people in different branches and codes at Carderock, as well as at different Warfare Centers, which I think is important to get a broad set of ideas and viewpoints," Tu said. "I am also happy that I have been able to do research in both basic science and applied science. I think it is important for the Navy to do basic research to support its long-term goals, adding to the applied work done in support of near-term Navy goals."

Through his research work, Tu has been able to interact with many people at universities and national labs, as well as Carderock engineers.

"I think it is important to strike that balance, so that Carderock gets an infusion of ideas from different communities," Tu said.

Tu believes it is important for people to become technically proficient at whatever it is they do in their everyday jobs, but if there is an opportunity to learn new skills, or work on special projects, they should give those a look and consider participating.

"You never know where your future career will take you, so it can never hurt to broaden your base of technical skills or the network of people you know and projects of interest," Tu said.

Independent Applied Research Program:
Modularization algorithm for additive manufactured parts

Principal investigator

Michael Robinson

Michael Robinson, is a technical engineering specialist for Naval Surface Warfare Center, Philadelphia Division stationed in Philadelphia.

Robinson has worked for the Navy for over 25 years in various positions in engineering, including research and development, shipbuilding, operations, testing, system engineering, modeling, simulation, and visualization. He is author or co-author on over a dozen papers and holds one patent related to the field of systems engineering.

Robinson is a professional engineer in areas of marine engineering and naval architecture, with a M.B.A. in technology management from the University of Phoenix, and a B.S. in marine engineering systems from U.S. Merchant Marine Academy.

Collaboration

Mentees

Scott Storms

Storms received his B.S. in mechanical engineering from Rowan University and an M.Eng. in materials science engineering from the University of Connecticut.

He currently serves as a member of the Advanced Machinery Systems Integration Branch of the Machinery Research and Silencing Division. His research focuses on applying laser metrology techniques to develop 3-D models for use in additive manufacturing applications.

He is also involved in collaborative research projects across the Warfare Centers and shipyards involving applying additive manufacturing and laser metrology in innovative ways to save time and increase readiness and performance.

Caroline Vail

Caroline Vail (Scheck) serves as a mechanical engineer in the Additive Manufacturing Project Office at NSWC Carderock Division. She is a principal investigator focusing in metals additive manufacturing while maintaining technical expertise in nonferrous welding and other advanced manufacturing methods.

Within Additive Manufacturing, Ms. Vail has worked on multiple naval-wide efforts including the Naval Additive Manufacturing Technology Interchange (NAMTI) and the development of the Department of the Navy Additive Manufacturing Implementation Plan. She also is the lead for the Naval Sea Systems Command Additive Manufacturing Warfare Center Working Group.

Susan Hovanec

Susan Hovanec serves as a materials engineer in the Additive Manufacturing Project Office at Carderock Division. She has been engaged in the additive manufacturing community for five years and has worked as coprincipal investigator for technical projects, as well as support strategic growth of additive manufacturing in the Navy.

Currently, Hovanec is the engineering manager for the additive manufacturing technical warrant holder at NAVSEA.

Motivation

Legacy equipment is being abandoned by original equipment manufacturers requiring reverse engineering and custom manufacturing of spare parts. Additive manufacturing (AM) could be used to reduce part cost, but without a process for redesigning the parts for supportability, significant cost and time savings could be lost.

Objective

Create a clustering algorithm for use in a design structure matrix to optimize redesign of legacy parts to reduce maintenance costs.

Background

The Navy is in constant inheritance of legacy equipment from manufactures that have gone out of business or have obsoleted a product line. Sustaining this legacy equipment requires acquiring spare parts from outside sources. In some cases the spare parts must first be re-designed, either from drawings or by reverse engineering. This IAR proposal addresses this problem as an opportunity to leverage two research areas, design structure matrix and additive manufacturing. This IAR will expand these research areas by addressing key challenges of redesigning and fabricating a ship parts via AM.

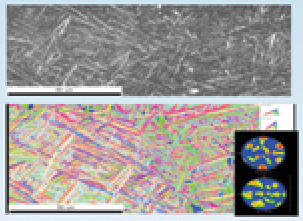
Clustering Algorithm in Design Structure Matrix

Lifecycle Value of the System =

$$\sum_{k=1}^{F}\sum_{j=1}^{C}\sum_{i=1}^{N} VoM\,i + VoMMi + VoCj + VoMCj + VoIk$$

Where VoM = Value of the Module
VoMM = Value of Maintenance of Modules
VoC = Value of the Component
VoMC = Value of Maintenance of Components
VoI = Value of the Interfaces

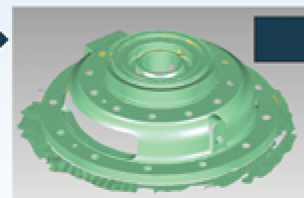
Material Testing



Test blocks of Ti-6Al-4V were printed in varying thicknesses to show microstructural variability based on varying thermal profiles

Reverse Engineering of Navy Standard Fire Pump Components

Photo Credit: Scot Pump Marine



High Resolution Scan of Housing

Scaled Metal Additive Manufactured Housing

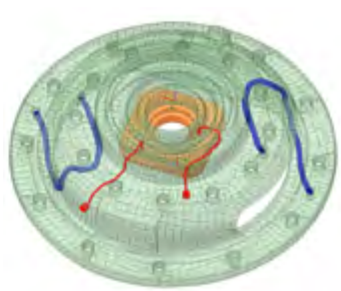
Future Work

Manufacture of samples with varying curvature and geometry to simulate effect of processing conditions over a range of material features to information requirements for qualification documents.

Baseline information for comparison of legacy components and materials information related to design modification and modularization.

Applications/pay-offs

- Reduced maintenance costs for legacy equipment
- Increased reliability and availability of legacy systems
- Defined value of modularization for legacy parts
- New algorithm for designing components



Redesigned Housing using Lifecycle Value Algorithm

Final deliverable(s)

- Master's degree
- Patentable algorithm for redesigning components optimized for AM
- Draft additive manufacturing requirements (decision tree) NAVSEA 05G/S
- Compiled list of applicable standards
- Naval Engineer Journal Article, Application of Laser Metrology for Reverse Engineering of U.S. Navy Obsolete Parts, September 2015 No.127-3 page 85-92

Independent Applied Research Program:

Seakeeping assessment procedures based on modern theory of extreme values

Principal investigator

Dr. Vadim Belenky

Naval architect Vadim Belenky received his doctorate in ship hydrodynamics and ship design.

He has authored a monograph and 105 other publications and has edited five volumes of proceedings/collections.

He is a member the International Standing Committee for International Conferences on Stability of Ship and Ocean Vehicles and a member of the U.S. delegation to Ship Design and Construction Subcommittee of International Maritime Organization. He is also a member of the Society of Naval Architects and Marine Engineers.

He joined Carderock Division in 2008. He previously held positions in the maritime industry and academia.

Collaboration

Associate investigators

Kenneth Weems

Naval Architect Kenneth Weems received his Master of Science in naval architecture and marine engineering from MIT. He has over 28 years of experience in the development and application of numerical simulation tools for ship hydrodynamics.

He is a principal developer of the Large Amplitude Motions Program time domain nonlinear ship motions and loads code. He spent 27 years with Science Applications International Corporation (SAIC) and its successor, Leidos, before joining Carderock Division.

He has contributed to over 100 technical reports, conference papers and journal articles.

Applications and payoffs

- Superior capability for analyzing the dynamic stability of advanced, non-conventional hull forms and severe loads for novel structural designs and materials
- Tools and techniques for the development of heavy-weather guidance and safe operating envelope
- Facilitating development of IMO second generation intact stability criteria

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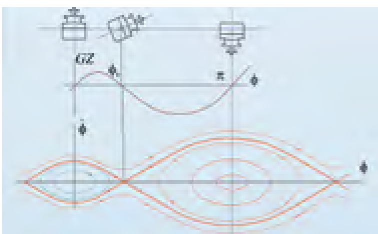
Motivation

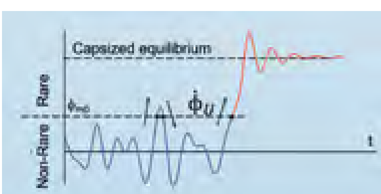
- Capsizing of an intact ship has serious consequences but is too rare for Monte-Carlo simulation with advanced tools

Background

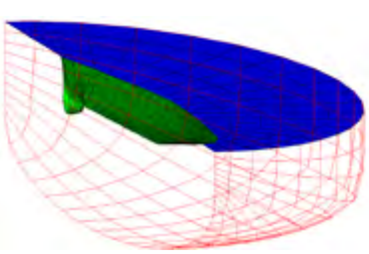


Separate problem into two parts:

- Upcrossing of intermediate roll threshold in random ocean waves
- Metric of risk of capsize at each upcrossing computed using motion perturbation analysis

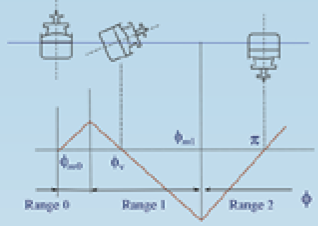


LAMP: Large Amplitude Motions



Results

Theory:



$\phi = Ae^{\lambda_1 t} + Be^{\lambda_2 t} + p_1(t)$ Critical roll rate

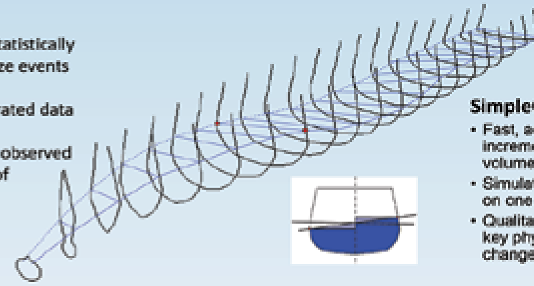
Capsizing metric $y = 1 + \dot{\phi}_U - \dot{\phi}_C$ $\quad \dot{\phi}_C \approx -\lambda_2 \phi_V$

PDF of roll rate at upcrossing $pdf(\dot{\phi}_U) = \frac{\dot{\phi}_U}{\sigma^2_{\dot{\phi}}} \exp\left(-\frac{\dot{\phi}^2_U}{2\sigma^2_{\dot{\phi}}}\right)$

Exponential tail $pdf(y \mid y > u) = 1 - \exp(-\beta y)$

Statistical Validation:

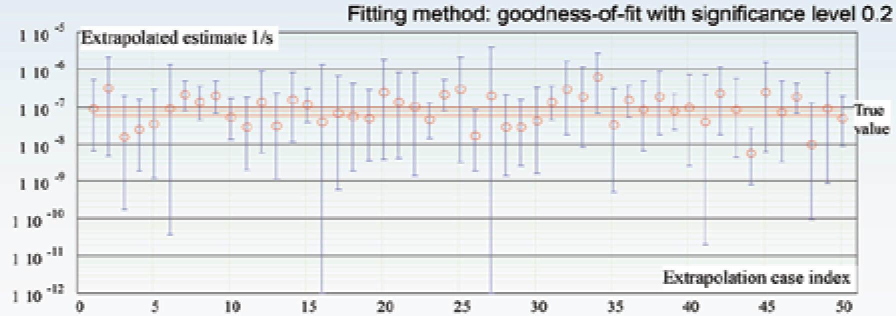
- Run very fast code until a statistically significant number of capsize events are observed
- Use a small subset of generated data for extrapolation
- Compare extrapolated and observed estimates of number/rate of capsizing



SimpleCode:

- Fast, accurate calculation of incremental submerged volume and volume center
- Simulates 100 hrs in 7 sec on one core
- Qualitatively valid, capturing key physical phenomena of change of stability in waves

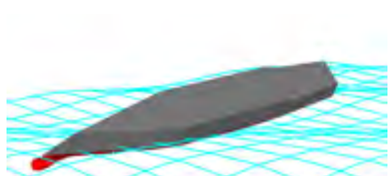
Fitting method: goodness-of-fit with significance level 0.2

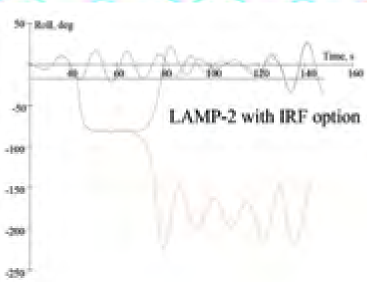


Heading, degrees	"True" estimate of capsizing rate, 1/s	Number of capsizings	Passing rate	Heading, degrees	"True" estimate of capsizing rate, 1/s	Number of capsizings	Passing rate
35	4.71E-09	12	1.00	55	3.25E-07	69	0.98
40	1.70E-08	12	0.98	60	2.49E-07	176	0.98
45	7.20E-08	51	0.98	65	1.13E-07	80	0.98
50	9.89E-08	7	1.00	70	8.48E-09	6	0.96

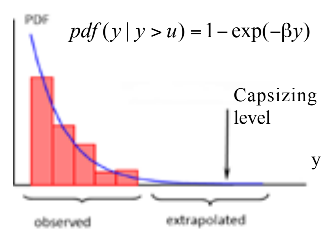
Approach

- Perturbed motion simulations to determine roll rate at upcrossing which leads to capsize



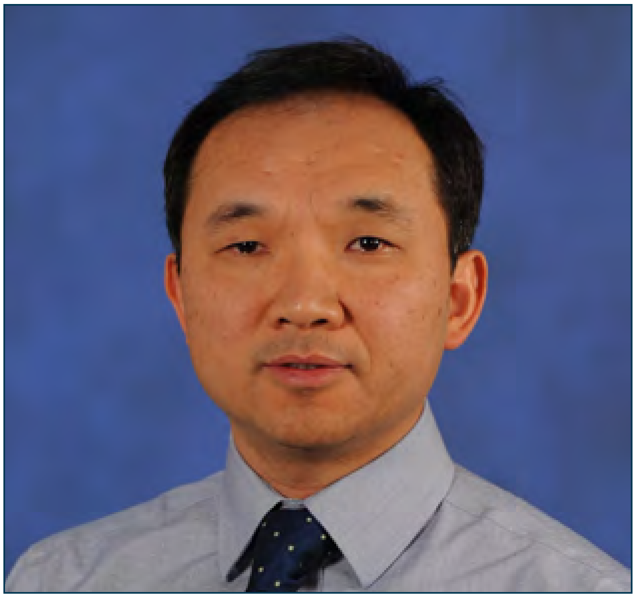


- Extrapolation of metric to level



In-House Laboratory Independent Research Program:

Space-time mapping of turbulent cavitating flows and correlations with erosion and noise generation



Principal investigator

Dr. Hua Shan

Hua Shan received his doctorate from the Tsinghua University in China. He is currently serving as Carderock Division's lead engineer in the area of turbulence and acoustics of the Computational Hydrodynamics Division. He was formerly an assistant professor at the Department of Mathematics, University of Texas, Arlington.

Dr. Shan's main areas of interest include computational fluid dynamics software development, numerical simulation for turbulent flows in predicting acoustic source strength and far-field sound level and numerical simulation and modeling for cavitating flows.

Associate investigators

Dr. Sung-Eun Kim

Sung-Eun Kim is currently serving in the Naval Architecture and Engineering Department at Carderock Division, heading the Computational Hydromechanics R & D Branch. For the last nine years, he has led the high-fidelity computational fluid dynamics (CFD) software development project under the CREATE SHIPS program funded by DOD High-Performance Computing Modernization Program. The software product of effort, NavyFOAM, is being widely used for science and technology and acquisition programs.

Kim has authored more than 70 peer-reviewed conference and journal papers in the area of ship hydrodynamics and fluid mechanics.

Before working for the U.S. Navy, Kim worked for Fluent, Inc. as a principal engineer and a product manager. He received his doctorate in mechanical engineering from the University of Iowa. Dr. Kim has been involved in numerous CFD development and research projects in the areas of turbulence modeling and simulation, finite-volume discretization, numerical algorithms, turbulence modeling, cavitation modeling and simulation and flow-induced noise.

Research payoffs

- Gain a much deeper understanding and quantification of the interaction between turbulence and cavitation in various stages of cavity life-cycle
- Numerically reveal/reaffirm the key physical mechanisms leading to cavitation erosion and noise, and will ultimately enable us to predict and control them
- Significantly upgrade/modernize Navy's analytical/numerical tools by adding a state-of-the-art, physics-based computational capability for cavitation prediction

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Objective

- Develop a computational methodology to efficiently and accurately resolve the salient physics of turbulent cavitating flows with a broad range of length- and time-scale by leveraging modern HPC

- Study interaction between turbulence and cavitation with focus on vortex-stretching, dilatation, shock waves, pressure fluctuation, vapor volume-fraction and rate of phase change (vaporization and condensation)

- Characterize and quantify cavitation noise and erosion potential using finely resolved, space- and time-maps of turbulent cavitating flows obtained from high-fidelity simulations such as LES and hybrid URANS/LES approaches

Background

- Controlling cavitation requires sound understanding of its underlying physics. Critically important, yet often overlooked, are the effects of turbulence on bubble/interfacial dynamics such as cavitation inception, breakup of sheet cavity, and collapse of cloud cavity.

- Physics-based numerical simulation can give much insight into the salient physics involved, allow accurate prediction of cavitation and help characterize and quantify its consequences such as noise generation and erosion

Approach

- Large eddy simulation (LES) and hybrid URANS-LES using space-filtered, compressible two-phase Navier-Stokes equations

- Homogeneous mixture concept with volume-of-fluid method

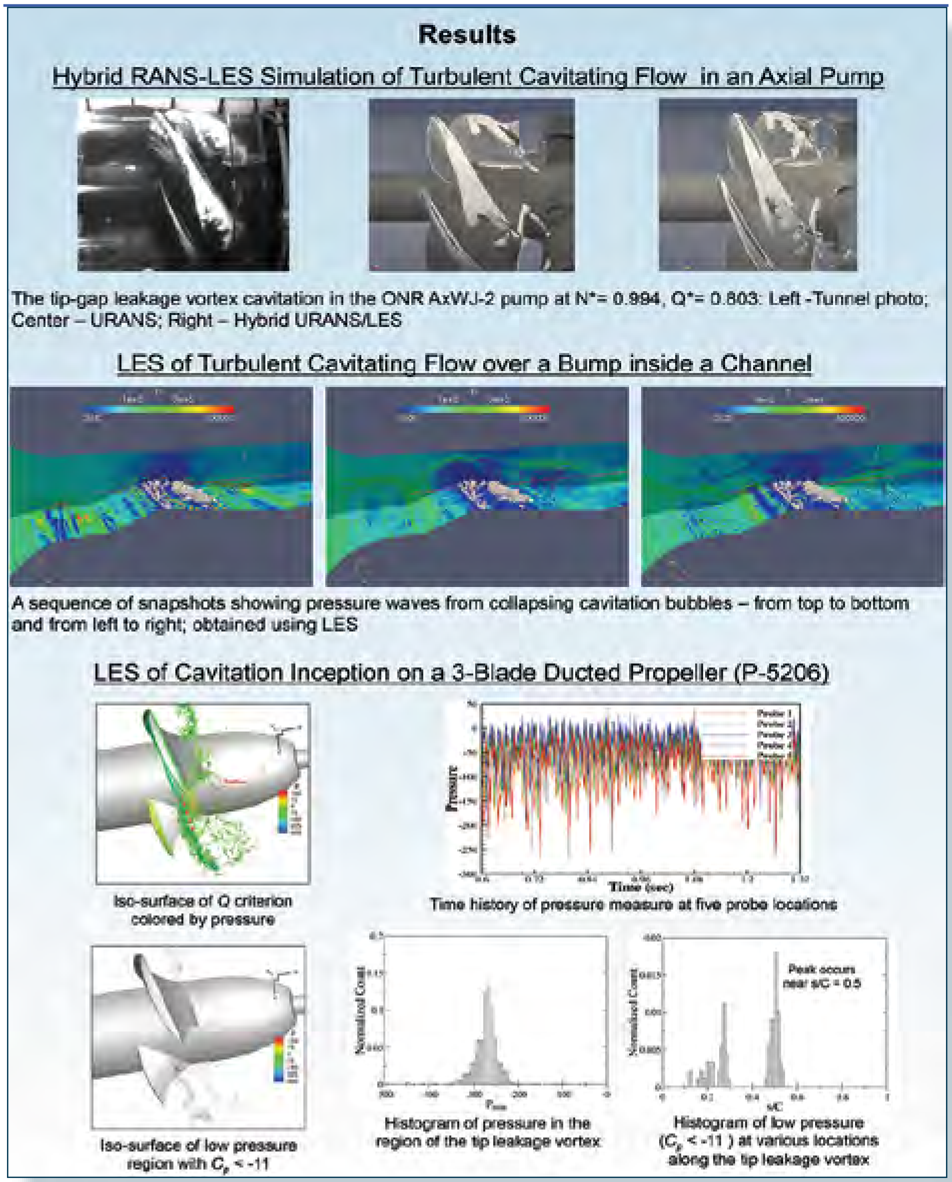
- Characterization of cavitation, erosion potential/power and noise source using the instantaneous flow fields

Progress

- Formulation and implementation of a space-filtered, compressible two-phase Navier-Stokes solver and physical models (turbulence, phase-change) in NavyFOAM

- Validation of compressible two-phase flow solver for canonical compressible flow problems (e.g., shock-tube,)

- Hybrid URANS/LES computation of cavitating flow in an axial waterjet pump (ONR AxWJ-2) and a ducted propeller



In-House Laboratory Independent Research Program:
Underwater explosion behavior of black powder for forensic evaluation of H.L. Hunley attack

Principal investigator

Dr. Ken Nahshon

Ken Nahshon serves as a senior research engineer in the Hull Response and Protection Branch, Survivability and Weapons Effects Department at Carderock Division.

He has more than 14 years of experience in testing and analysis of dynamic response and failure of materials and structures. He has published and presented extensively in these areas.

Since joining Carderock in 2007, Nahshon's efforts have been focused on the response of ship structures to both air and underwater explosions and the response of Marine Corps vehicles to underbody blast. He has led a multi-year research program in blast effects on welded aluminum structures; developed and applied modeling and simulation (M&S) to numerous complex problems in non-linear structural response; and most recently furthered the application of Uncertainty Quantification methods to high-fidelity M&S of ship structures. In addition, he has either been involved with or led several real-world testing and analysis efforts, including performing forensic engineering of the attack on the M/V M-Star, designing and analyzing a fielded ballistic hatch, performing explosive testing of port security systems and investigating the historical sinking of the H.L. Hunley submarine.

Nahshon received his bachelor's degree in mechanical engineering from Cooper Union and his M.S. and Ph.D. in applied mechanics from Harvard University.

Research payoffs

- Inform conservation effort of potential damage mechanisms
- Assist in determining cause of Hunley's loss
- Advance Navy's capability to perform M&S of crew response to near-field explosions
- Advance Navy's capability to model propellants in weapons effects codes

Collaboration

NSWC Indian Head EOD Technology Division

Warren Lasch Conservation Center

University of Michigan

Project sponsors

Motivation and background

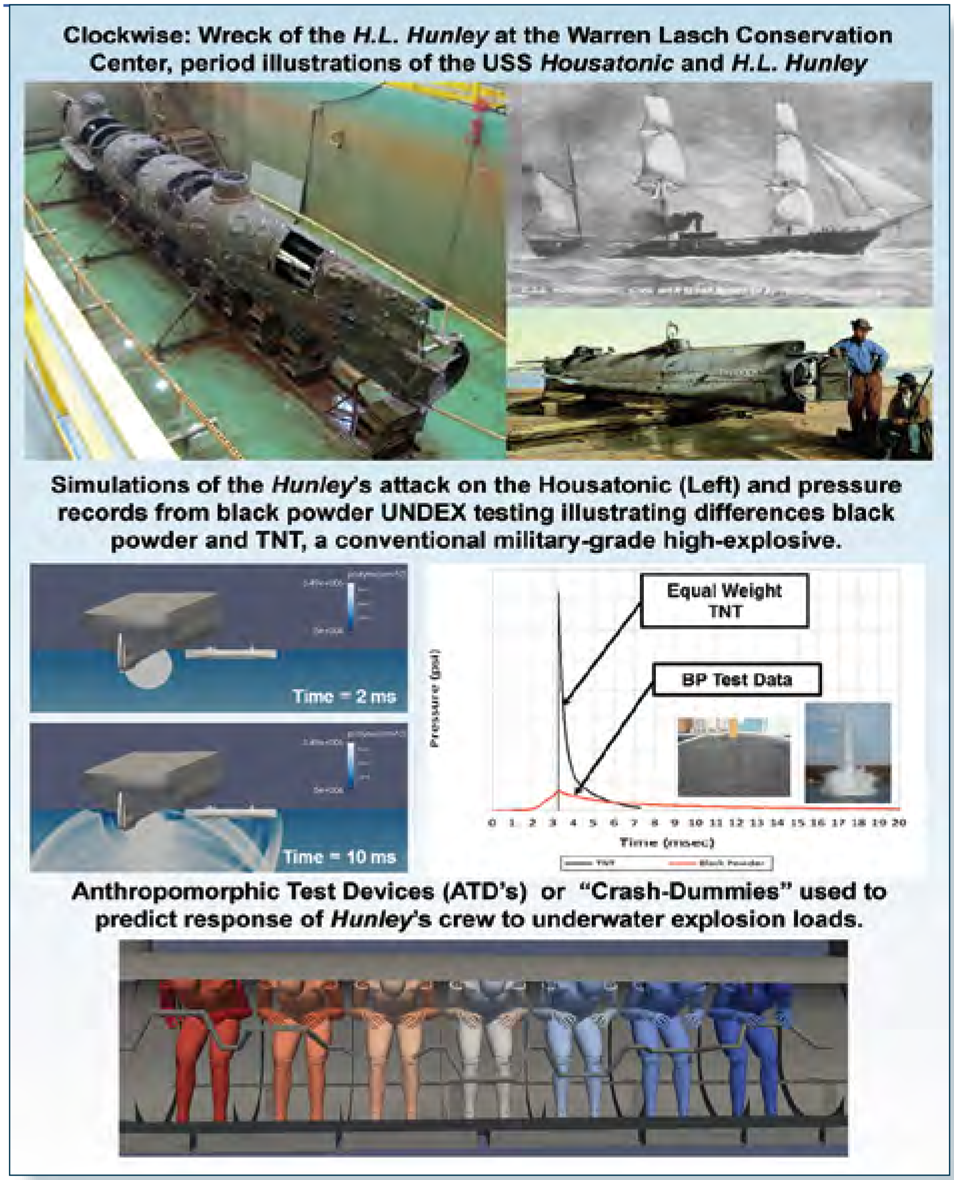
On Feb. 17, 1864, H.L. Hunley, a Confederate submarine, attacked and sank USS Housatonic using a black powder-filled torpedo. Although the attack on the Housatonic was successful, the Hunley was lost at sea with no survivors. New archaeological information indicates Hunley was closer to the explosion than previously thought. Therefore, analysis of the more severe explosive effects on the submarine and its crew are required to asses if Hunley was lost due to the explosion.

Objectives

- Use high-fidelity M&S tools to capture the engagement between Hunley and Housatonic
- Perform UNDEX testing of historical black powder to generate data required for model development
- Develop an advanced reactive burn model for black powder to further Navy capabilities in modeling propellant explosions
- Capture response of Hunley to the explosive load through high-fidelity M&S tools
- Utilize M&S to asses probability of injury to Hunley's crew using virtual Anthropomorphic Test Devices (ATD's), a.k.a. "crash dummies".
- Inform historians and conservators; guide future efforts

Procedure

- Utilize available finite element model of Hunley developed from geospatial point cloud data.
- Develop, calibrate and implement a reactive burn model for black powder in DYSMAS hydrocode
- Conduct fully coupled, explosion-target analysis of engagement and evaluate results.
- Perform simulations of crew response. 50th percentile male ATD found to accurately represent crew based on excavated remains



Clockwise: Wreck of the *H.L. Hunley* at the Warren Lasch Conservation Center, period illustrations of the USS *Housatonic* and *H.L. Hunley*

Simulations of the *Hunley*'s attack on the Housatonic (Left) and pressure records from black powder UNDEX testing illustrating differences black powder and TNT, a conventional military-grade high-explosive.

Anthropomorphic Test Devices (ATD's) or "Crash-Dummies" used to predict response of *Hunley*'s crew to underwater explosion loads.

Future research

Assist Navy Heritage & History Command with a survey and analysis of USS San Diego wreck leading up to the 100-year anniversary of its sinking by German U-Boat during WW1.

In-House Laboratory Independent Research Program:

Nonlinearity-based wave steering

Principal investigator

Saliou Telly

Saliou Telly holds dual bachelor's degrees in applied mathematics and mechanical engineering from American University and University of Maryland College Park. He completed a master's degree in mechanical engineering at the University of Maryland College Park before joining Carderock Division.

Telly is a part of the Structural Acoustics and Target Strength Branch. His primary responsibility is acoustic target strength. He has additional experience in target strength modeling, analysis and measurement. While working at Carderock Division, Telly completed his Naval Post Graduate School Anti-Submarine Warfare Certificate. He is currently a doctoral candidate in mechanical engineering at the University of Maryland College Park focusing on acoustic wave redirection and metamaterials research.

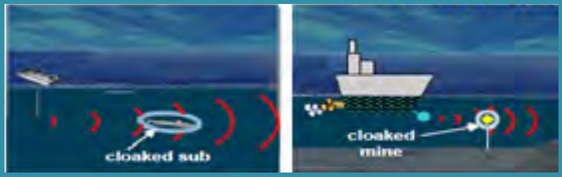
Applications and payoffs

Basic science contribution to several fields

- Acoustic wave propagation in solid materials
- Nonlinear waves phenomena and their applications
- Metamaterials technology and their applications

Novel approaches for control and redirection of acoustic waves using solid metamaterials

- Pathway for practical acoustic cloaking
- The Navy has a long-term need for acoustic signature control
- A practical acoustic cloak would provide a significant tactical advantage to the Navy



Associate investigators

Dr. Jason Smoker

Jason Smoker received a doctorate in mechanical engineering at the University of Maryland. He currently serves in Carerock Division's Structural Acoustics and Target Strength Branch. Smoker's dissertation research was in the area of active acoustic metamaterial and was supported by Office of Naval Research through the University Laboratory Initiative, which pairs university graduate students with mentors from naval laboratories to develop naval related technologies.

Dr. Alexey Titovich

Alexey Titovich serves a an engineer in the Structural Acoustics and Target Strength Branch. He received a doctorate in mechanical and aerospace engineering from Rutgers University. His primary research interest is acoustic metamaterials for underwater applications encompassing: structural acoustics, sonic crystals, phononic crystals, gradient index devices and resonance-based devices.

Collaboration

Dr. Balakumar Balachandran
Minta Martin Professor and Chair
University of Maryland

A. JAMES CLARK
SCHOOL OF ENGINEERING

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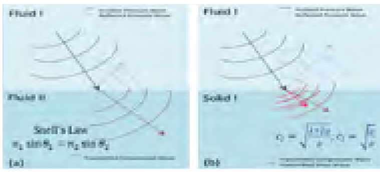
Motivation

Controlling acoustic wave propagation path has proven challenging in solid media where competing longitudinal and transverse wave energy transport mechanisms complicate the picture.



Objectives

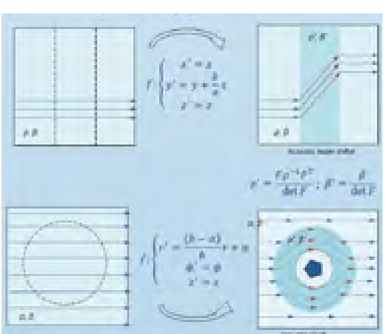
Exploit nonlinear effects and metamaterial technology to formulate a hyperelastic material amenable to acoustic wave control and redirection

Background

Metamaterials are engineered to exhibit properties (e.g. negative index of refraction) seldom available in natural or conventional material

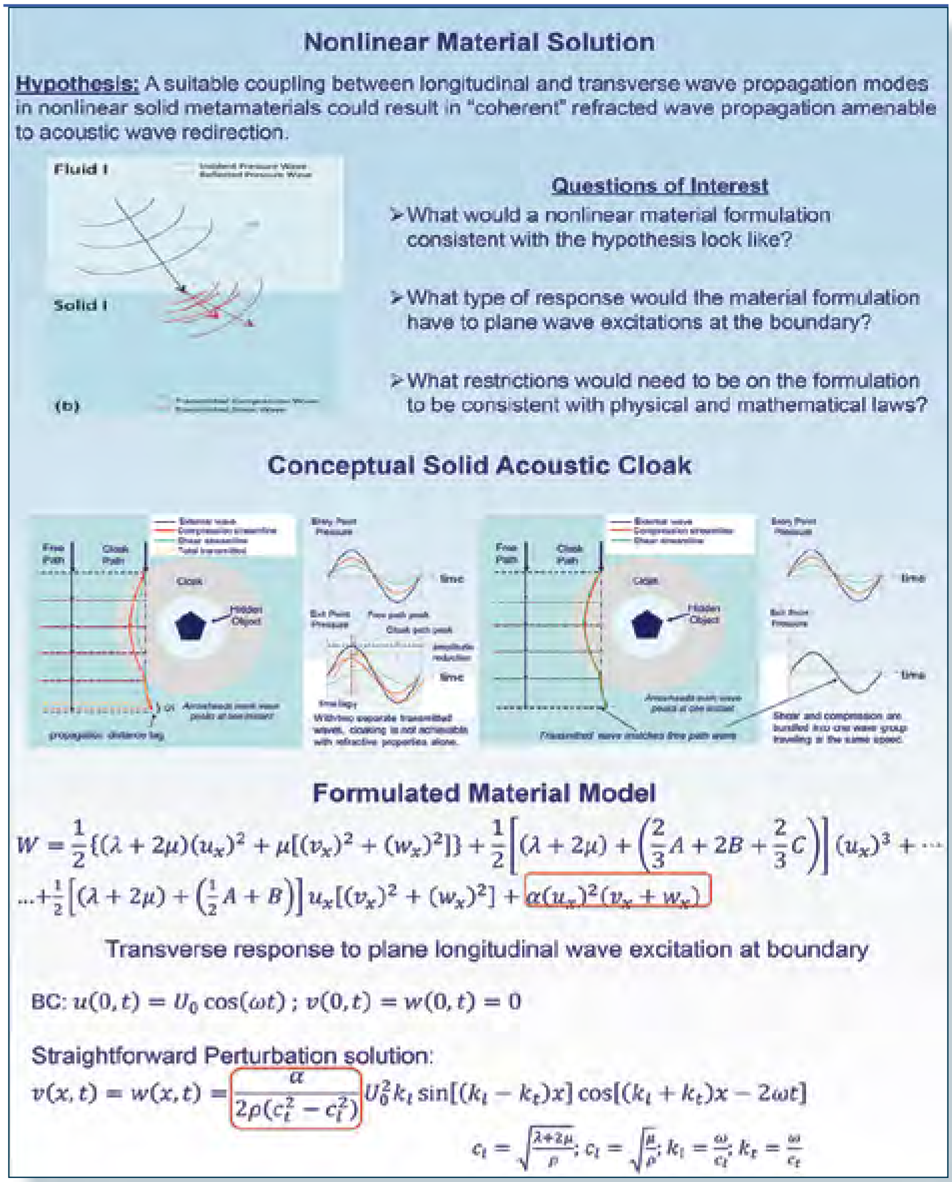
Transformation acoustics provides a systematic means of formulating devices for acoustic wave redirection by exploiting geometric transformations

Transformation-based acoustic wave redirection is limited to fluid-like metamaterials

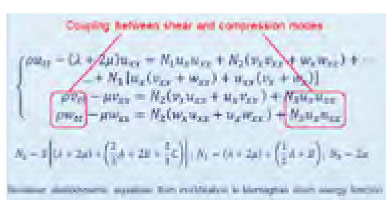


Approach

- **Year 1:** Understand underlying physics behind strain energy formulation, including mathematical constraints and physical requirements.



- **Year 2:** Modify classical Murnaghan strain energy function to develop an analytical solution consistent with the hypothesis.
- **Year 3:** Assess and refine formulation. Explore physical realizable material solutions based on advances in metamaterials technology.



Art meets science:

How Warfare Center photographers visualize data

By Ryan Hanyok,
Corporate Communications Division

When the camera shutter snaps close, time becomes frozen; reality is held still so we may ponder that moment a bit longer. To the artist, the image is an evocation. To the scientist, the image is a data point. To the Graphics and Imaging Branch photographers at Naval Surface Warfare Center, Carderock Division, capturing the image is their mission – but it takes more than a GoPro on a stick to achieve it.

"Even if our technical customers have mountains of data, if there is no photo, it didn't happen," said Monica McCoy, Visual Information Branch head. "That's an inside joke, but it's important to consider supporting visual up front. Anomalies in data can be confirmed, qualified and, most importantly, communicated in a visually engaging way. It's much better to collect photos and videos during a project and not use them right away, than to need the material and not have it."

Carderock's scientific and technical (S&T) photographers record experiments, illustrate scientific information and use a variety of equipment and techniques to achieve their mission. The arsenal of tools at their disposal includes everything from custom underwater housings, high-speed cameras, blimps, data-merging software and even a few GoPros for good measure.

The most important tool, however, is their knowledge. Forged by their close-working relationship with the technical community, the S&T photographers specialize in planning and designing image-capturing solutions. Their contributions can range from a few photos to spruce up a report to critical projectile-velocity measurements. Knowing what tools to use and how to deploy them add value, credibility and visual impact for the experimentalists they serve.

"These guys were critical for testing new polymers to combat roadside bombs," said Phil Dudt, senior research scientist of Carderock's Hull Response and Protections Branch. "We couldn't get new armor to our vehicles in the field unless we

Navy photographers (from left) Nicholas Brezzell, James Contreras, Devin Pisner, Ryan Hanyok and Neubar Kamalian pose for a picture July 30, 2018, after taking photographs and video in the David Taylor Model Basin at Naval Surface Warfare Center, Carderock Division in West Bethesda, Md. (U.S. Navy photo by Nicholas Brezzell/Released)


Nikon D4

could show how the bombs interacted with the test targets."

The value of S&T photographers is not strictly confined to their contributions as data collectors. They can take what is inherent to a scientist and make it more clear and meaningful to a sponsor, an admiral or the public without obscuring the facts.

"The impact these photographers provide is huge," said Kiet Ung, a technical area leader in Carderock's Solid Waste and Hazardous Material Management Branch. "We develop processes in the lab before deploying them to the fleet. Thirty seconds into an Imaging (Branch) produced video, our customers get it. That's way more persuasive than 30 minutes of talking."

Showing the value of work conducted by Warfare Center engineers requires a core storytelling craftsmanship and a deep understanding of the scientific process. Breathing life into numbers is the art of science.

With the demands on the naval enterprise, accelerating the imperative for the technical community is not only to state what their data says, but also why their data matters. If a picture is worth a 1,000 words, what is the picture saying?

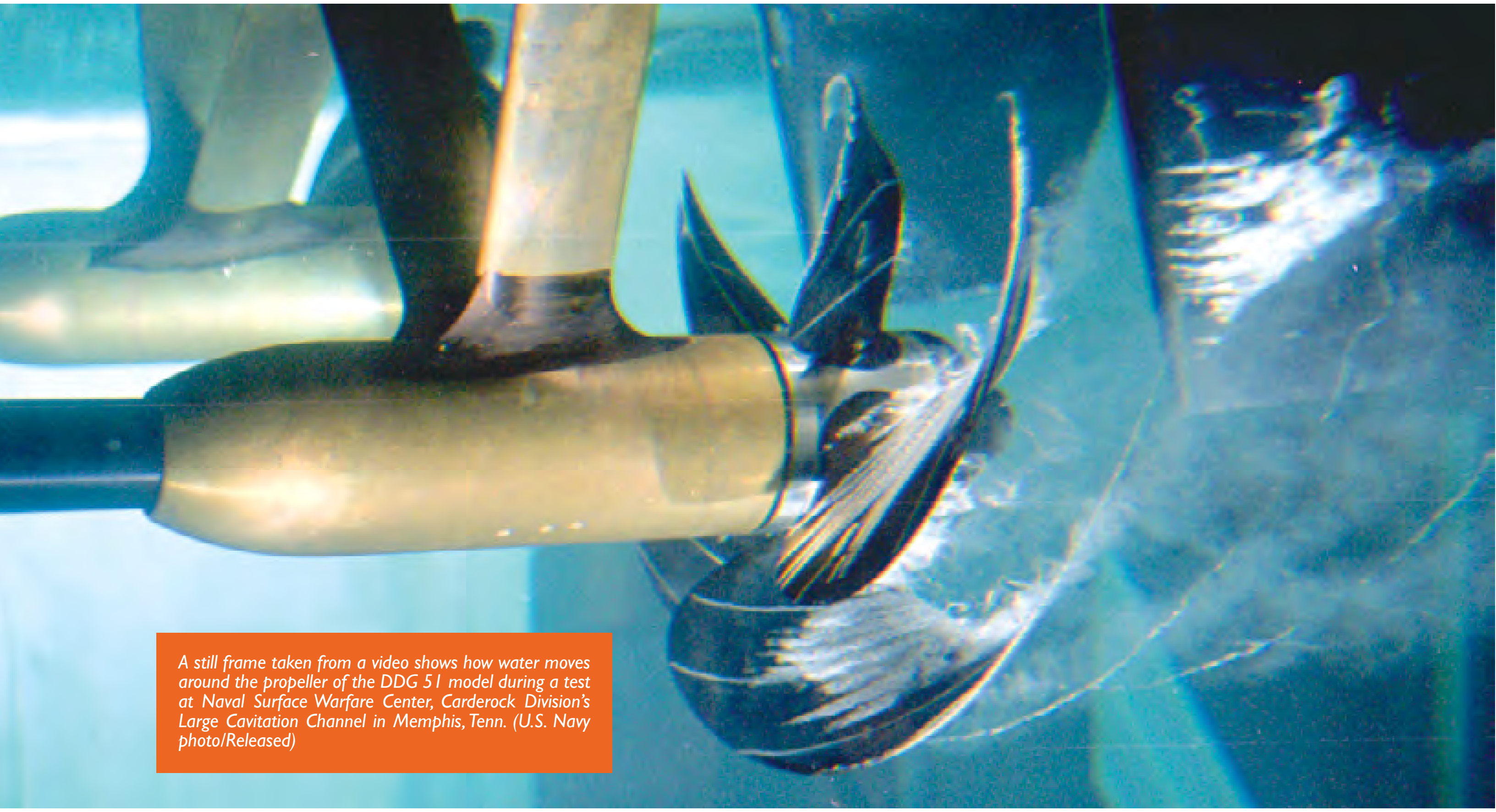
"Very often we do big tests so we can have a video to show," said Jeff Green, a trials director in Carderock's Ship and Submarines Acquisition Engineering Division. Green has led many efforts to literally bring ships together to transfer vehicles and equipment at sea. The at-sea transfer concept is not without risk. Wind, waves and currents conspire to pull ships apart or misalign the bridge between them. "A series of at-sea transfer exercises with numerous types of ships led to the design and commissioning of the new Expeditionary Transfer Dock (ESD) class of ships, formerly the Mobile Landing Platform. The video documentation was instrumental in getting the word out that the at-sea transfer concept works."

Proof of managed risk gives credibility to engineers like Green who are seeking approval from resistant stakeholders. In Green's case, collecting the proof required a lot of planning and cameras. Visual documentation of these high-stakes trials needed to convey respect for their complexity, whatever the results.

The S&T photographers often have only one chance to get the shot. Events like a tank crossing a bridge between two ships bobbing in the middle of the ocean are not exactly common, nor would it have become part of the Expeditionary Transfer Dock's mission profile had the video evidence not been so abundant and clear.

"You can't understand the whole story until you can understand the real process and the challenges involved," said Joe Spezio, a mechanical engineer in Carderock's Criteria and Assessment Branch. "You can argue all day what can and cannot be done, but video is the proof that ends the debate."

S&T photographers know it doesn't take a multi-ship sea trial to make a big visual impact. Giuseppe Iorio, an engineer from Carderock's Physical Metallurgy and Fire Performance Branch, wanted a visual way to characterize how the fabrication process affected materials. To the naked eye, Iorio's handful of small



A still frame taken from a video shows how water moves around the propeller of the DDG 51 model during a test at Naval Surface Warfare Center, Carderock Division's Large Cavitation Channel in Memphis, Tenn. (U.S. Navy photo/Released)

A still frame taken from a video shows a scale-model ship being tested in the David Taylor Model Basin at Naval Surface Warfare Center, Carderock Division, in West Bethesda, Md. (U.S. Navy photo by Neubar Kamalian/Released)

plastic ingots were nothing special. The uniform notches cut into each translucent ingot were barely perceptible. In the Imaging Branch's studio, however, the ingots exploded with color. Using a tightly controlled method of lighting with specialized filters, known as photoelasticity, the optical properties of the ingots revealed stresses emanating from the notches.

"The visual results were amazing," Iorio said. "I can show that different fabrication methods used to create the notches cause stress fields that make some ingots more brittle."

Brittleness in materials is important for the Navy to understand, especially with the advent of 3-D printing. The high-visual impact of this methodology opened opportunities for Iorio to collaborate with other academics at Lehigh University and the Massachusetts Institute of Technology.

With all the high-impact imagery produced, it may come as a surprise that Carderock's S&T photographers spend most of their time in the dark. Carderock's world-class hydrodynamic facilities are housed in huge windowless buildings – one is over a half mile long – to protect them from the elements, allowing the facilities to be used year round. Model-scale experiments in these facilities range from tiny wave propagations to scale-model performance testing of the newest ship classes. On many experiments, visual documentation can produce hundreds of hours of footage. With thousands of data runs it's impossible for observers to remember every instant.

"When we have a spike in the data, like a ship's bow slamming into a wave, video will confirm what actually happened," said Chris Kent, chief engineer and director of S&T in Carderock's Ship Hydrodynamics Department. "Slowing the video down or viewing frame-by-frame contextualizes these data spikes."

For S&T photographers, visual impact provides context and data. For frequent customers like Martin Donnelly, head of the Surface Ship Hydromechanics Division, the visual impact also provides insight into design performance.

"Imaging's support has led to a greater understanding of cavitation inception," said Donnelly, explaining that cavitation is the undesirable formation of tiny imploding bubbles that can wear down propellers and make submarines bigger targets. "Verification of model-scale performance predictions and diagnosis of cavitation erosion problems is extremely difficult without visual confirmation."

Can a photograph improve the performance of a ship? Or build support for a technology? See what our sensors cannot see? Say what you need it to say? Carderock scientist and engineers working with their S&T photographers can answer in the affirmative – a photograph can do all of those things and really is worth a 1,000 words.

Carderock inventors partner with entrepreneurs and students in Fed Tech program

By Kelley Stirling, Carderock Division Public Affairs

Naval Surface Warfare Center, Carderock Division's Technology Transfer Office just sent the command's third employee through the Fed Tech program, a national program based in the capital region to promote the smooth transfer of technology from federal labs to market or industry.

As part of the Fed Tech program this year, which ended May 8, Stephen Shepherd, a mechanical engineer with Carderock's Maritime Systems Hydromechanics Branch, teamed up with entrepreneurs from different organizations in New York City to find out how a specific Navy technology might be useful in another market outside of the Navy.

Shepherd was initially approached by his supervisor at Carderock, Steve Ebner, to join this year's Fed Tech cohort because of an invention of Shepherd's that is currently in the patenting process. After he provided several technologies developed by the Navy, specifically Carderock, as potential projects for the program, Fed Tech ultimately chose an invention that was patented years ago by Dr. David Coakley, who works in Shepherd's branch. The invention is for underwater towing of marine vessels, U.S. Patent No. 6,416,369.

"It's just an idea," Shepherd said of the technology, rebranding it as a self-contained underwater engine pod that provides power to marine vessels. Shepherd said his Fed Tech team talked to nearly 50 experts in the marine field to see if it can be applied in commercial industry, focusing on the shipping companies that move large barges.

The Fed Tech program is sponsored by MD5 National Security Technology Accelerator, an innovation and entrepreneurship initiative run out of the Department of Defense's Office of Manufacturing and Industrial Base Policy. Ben Solomon, founder and managing partner for Fed Tech, said he's seen more than 60 federal technologies come through the program.

"Seeing the connection between entrepreneurs and the DOD Lab community is amazing," Solomon said. "These two groups don't traditionally interact but there's so much mutual value for everyone when they come together. Everyone learns and great things can happen."

Dr. Joseph Teter, Carderock's director of technology transfer, said the Fed Tech program is just one way Carderock tries to get its technology introduced to the marketplace, and that it has been a very interesting process.

"It's an engaging, highly innovative program," Teter said, adding that Carderock's Fed Tech researchers are sponsored by the Office of Naval Research's Technology Transfer Program. "The benefit for Carderock is that we're exposing our scientists and engineers to a new way of thinking about how they interact with companies and get their technology to the point where it's usable by the Navy. It's great to come up with a new idea and then patent that idea. But then you have to take that idea and see if you can get it to the fleet. That's difficult."

When a federal laboratory develops certain technologies, it can take up to 20 years for the technology to be fully developed, tested and introduced to the non-federal market, according to Dr. Alexey Titovich, an acoustician in Carderock's Structural Acoustics and Target Strength Branch. Titovich was part of the second cohort, which completed the Fed Tech program last year.

By pairing up with entrepreneurs or business students, Titovich said the Fed Tech program helps inventors, like him, to determine the market value and potential customers of a technology.

"As the name (Fed Tech) suggests, the idea is to quickly transition technologies developed at federal labs, all federal labs, to essentially the world to market," said Titovich, who invented an aircraft infrasonic sensor designed to sense low-frequency acoustic waves in the atmosphere, potentially for weather and turbulence predictions. "Throughout the eight-week program, we interviewed about 30 viable customers or partners that might be interested in using this technology."

Carderock's Office of Counsel filed a patent application for the aircraft infrasonic sensor developed by Titovich, who has been at Carderock for almost three years. He said it's important for Navy engineers to patent their technology, and also to discover ways that the technology might be used outside of the original intention for the Navy.

"This Fed Tech program was the perfect way to do this," said Titovich, who was paired with students from the University of Maryland's Robert H. Smith School of Business in College Park Maryland said. "I learned a lot about the business side of marketing the technology and the students learned a lot about the technology, in general."

Stephanie Bo, one of the Master of Business Administration students

Dr. Alexey Titovich (third from right), an acoustics engineer in the Structural Acoustics and Target Strength Branch at Naval Surface Warfare Center, Carderock Division, poses with other participants from the 2017 Fed Tech cohort on May 15, 2017. Titovich collaborated with students from the University of Maryland (UMD) Smith School of Business to develop a market value proposition and identify potential industry partners for a technology that employs a very low frequency, acoustic sensor-based optical fiber interferometer designed for installation on aircraft to localize severe storms, as well as clear air turbulences. From left to right: Bob Smith, director Fed Tech I-Corps Program (2017); Stephanie Bo, UMD Smith School MBA student; Jamie Watson, defense science and technology counselor; Jeremy Rechtien, UMD Smith School MBA student; Titovich; Ben Solomon, founder and managing partner for Fed Tech; and Dr. John Rein, Office of Naval Research Technology Transfer Office. (Photo by Samson Binutu/provided by Fed Tech/Released)

working with Titovich, said the program allowed her to learn and understand the government's process to obtain investments in technological developments.

"While working with Dr. Titovich, our team was able to connect with top scientists and researchers throughout the country," Bo said. "We were able to learn firsthand about our technology's current market and how the market will be evolving in the near future from both a military and commercial viewpoint."

Bo said the hands-on experience in working directly with the federal labs made her realize how important technology advancement is for both military and civilian use.

"The Fed Tech program opened my eyes to a world I did not know existed and the challenges federal labs face to promote their technologies," Bo said.

The first cohort involved Jonathan Kruft, an engineer with Carderock's Non-Metallic Materials Research and Engineering Branch, going into the program with a patented electromagnetic functionalized composite material developed for use in multifunctional armor. Kruft's Fed Tech team came out of the program with a potential medical use as an effective shield for electromagnetic radiation for medical devices, which could help prevent hacking of small devices like pacemakers and provide better shielding in some of the bigger X-ray or CT scan machines.

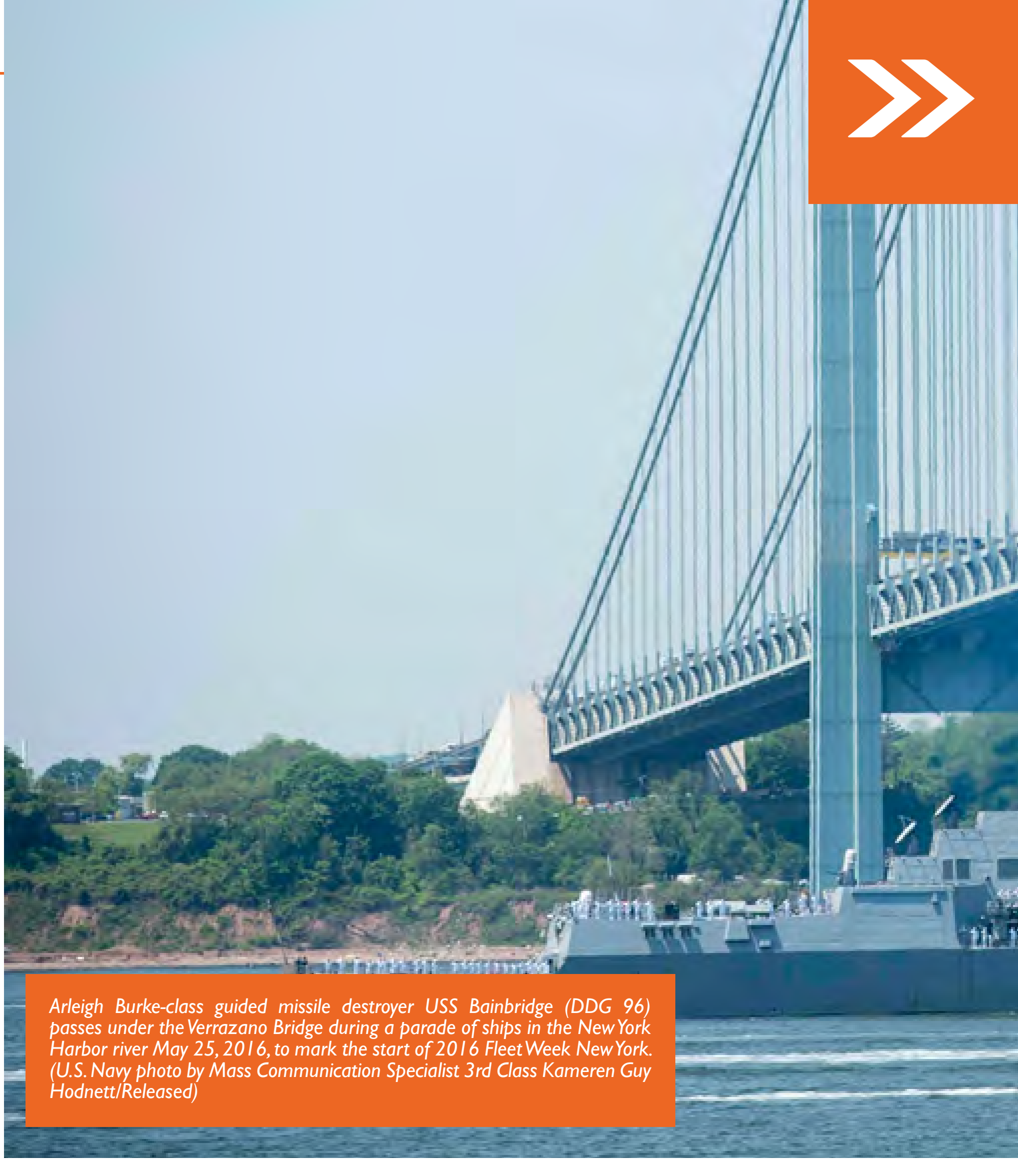
"This was a thought-provoking, yet intensive project to view patentable technologies from a fast-track commercialization perspective," Kruft said of working with the Fed Tech program. "This experience has enhanced my ability to view materials development from the occasional non-defense application."

Teter said that by commercializing the technology developed during the basic research levels, someone else could build it and put it forward as a commercial product. The Navy can then acquire the commercial product and use it.

"You don't know what your true market is when you go in," Teter said. "And once you've gone through the program you have a much better idea of where the market is for your technology."

Carderock engineer's work on risk assessment in bridge benefits shipbuilding

By Katie Ellis-Warfield,
Corporate Communications Division



Arleigh Burke-class guided missile destroyer USS Bainbridge (DDG 96) passes under the Verrazano Bridge during a parade of ships in the New York Harbor river May 25, 2016, to mark the start of 2016 Fleet Week New York. (U.S. Navy photo by Mass Communication Specialist 3rd Class Kameren Guy Hodnett/Released)

Dr. Alysson Mondoro, a recently hired engineer with the Performance Evaluation Branch at Naval Surface Warfare Center, Carderock Division, is finding ways to "bridge" together her academic skill sets on the job.

Mondoro started at Carderock in December 2017 after completing her doctorate in structural engineering from Lehigh University in Bethlehem, Pennsylvania. She received her bachelor's degree in civil engineering from Johns Hopkins in Baltimore.

Her work during her doctorate was recently published in Engineering Structures volume 159, 2018 edition, in an article titled, "Risk-based cost-benefit analysis for the retrofit of bridges exposed to extreme hydrologic events considering multiple failure modes."

Mondoro, along with Lehigh University Professor Dan Frangpool, created a comprehensive risk-assessment framework for the three most common failure modes (deck, pier and foundation) for bridges exposed to flooding, hurricanes, tsunamis and other extreme water-related events.

This research was achieved by using probabilistic modeling, analysis and advanced computer simulation using a riverine bridge as their example with the end goal being to find cost-effective retrofit solutions.

"Dr. Mondoro's work in probabilistic modeling of structural systems, fatigue damage and structural health monitoring are key skill sets needed by the ship structures community to maintain and expand our technical health," said Jeff Mercier, Carderock's Platform Integrity Department head.

Though this portion of her doctoral research is more geared toward the civil engineering field, Mondoro explained that bridges and boats are actually very similar when looking at risk assessment and management strategy and that for both, a framework to support decisions based on potential failure modes must be developed.

"Risk management considers both the probability of failure and the consequence of failure. You may have a structural component that has a high probability of failure but may have a negligible impact on the overall ship performance; this may be a low risk component. Another structural component may have a smaller probability of failure but a large impact on ship performance; this component would have a high associated risk," Mondoro said. "The goal of minimizing risk applies to both bridges and ships."

She said the way civil structures are designed and constructed is very similar to the way ships are, the major difference being in constraints and the uncertainty loads.

"We know car loads a little bit better than we know wave loads. And, we have a better understanding of the constraints for bridges, they are tied in to foundations in the group," Mondoro said. "For ships, you have ships sitting in water which leaves a high uncertainty in the loads and constraints."

Nancy Adler, Carderock's Performance Evaluation Branch head, said Mondoro's role at Carderock would be to support ship performance assessments and evaluations in support of new construction and service-life extensions.

"Dr. Mondoro's knowledge of risk

assessment, coupled with her background working with ship structural health monitoring, can add a new perspective to our work," Adler said.

Mondoro's work for her doctorate was split between civil engineering and naval structures. The naval structure work was funded through the Office of Naval Research, which is how she came to learn about Carderock.

"I met the then-division head Jeff (Mercier) there and talked to a number of the employees. He got a sense of what I did; I got a sense of what he did and then came in to interview," Mondoro said.

At Carderock, Mondoro is currently working on fatigue assessments and understanding the lifetime bending loads applied to a ship. "One cycle of load doesn't necessarily fail the structure, but repetitive cycles might fail the structure," she said. "We look at the lifetime loads on the ship to understand its fatigue performance."

Mondoro said that they use analytical models and model tests data to inform their fatigue assessment. "The goal is to get the best representation of structural response to predict fatigue life and use it to inform ship operations and management," she said.

"If we can reduce the amount of uncertainty we have, we can reduce the amount of risk," Mondoro said. "The best way to reduce uncertainty is to use structural health monitoring data, because it gives us a better understating of how the structure is preforming in the condition that it encountered."

Mondoro said that she likes where Carderock sits amongst the Navy and particularly where she is. "I bridge the gap between the experimental work and the analytical work that ties together the ship assessment as a whole in order to better support life-cycle design of ships and life-cycle management," she said.

Mercier said Mondoro's doctoral research developed an understanding and relationship between risk, reliability, cost and competing failure modes, which are also issues dealt with in ship structures.

"Dr. Mondoro's development of those relationships in civil structures is only a short leap for ship structures," Mercier said.

Adler said that bringing a new and knowledgeable person such as Mondoro to the branch not only reduces the learning curve time, but also increases the productivity and efficiency of the work on projects.

"She learns from us how we view and address structural integrity and we learn from her how she has addressed structural integrity, albeit on a different kind of structure. Bottom line, we both speak the same language," Adler said.

Mondoro said she likes that Carderock is a research, development, test and evaluation organization and operates in the program support side.

"I can be working on research and development projects, as well as doing direct-to-program support for ships," she said. "I may only work on a piece of it, but I at least know and can see the bigger picture."

Data wrangling

By Justin Hodge, Carderock Division Public Affairs

Trisha Shields, an aerospace engineer with the Sea-Based Aviation and Aeromechanics Branch, is on a mission to help Naval Surface Warfare Center, Carderock Division, establish a fundamental capability and understanding of the best practices of data science and analytics.

"Naval Sea Systems Command (NAVSEA) wants to be a data-driven organization doing data-driven engineering and design," Shields said. "There is a lot of value from data science and analytics and the development of techniques and software that can be a time saver by automating what we are doing manually."

Through her own vision, and at the request of former Technical Director Dr. Tim Arcano and Deputy Technical Director Larry Tarasek, Shields has created a Data Science and Analytics Community of Practice (CoP) that is supported, resourced and empowered to maintain technical proficiency of the past, present and future state of data science and analytics at Carderock, as well as their application to the Navy's ships and ship systems.

"The generation of data has become so cheap and easy that the Navy needs to embrace the data/digital universe in order to maintain technological advantage over our adversaries and support the fleet," Shields said. "In order to prepare our workforce this project will lay the groundwork to address the long-term need for a Carderock-wide data science and analytics competency."

The CoP will foster collaboration between individuals, groups and projects in relevant areas both internally and externally. External collaborations will include other Warfare Centers, Department of Defense agencies, industry and academia. Networking across different disciplines will bring together practitioners, enthusiasts and interested parties in the area of data science and analytics to address some of the most pressing issues the fleet faces today.

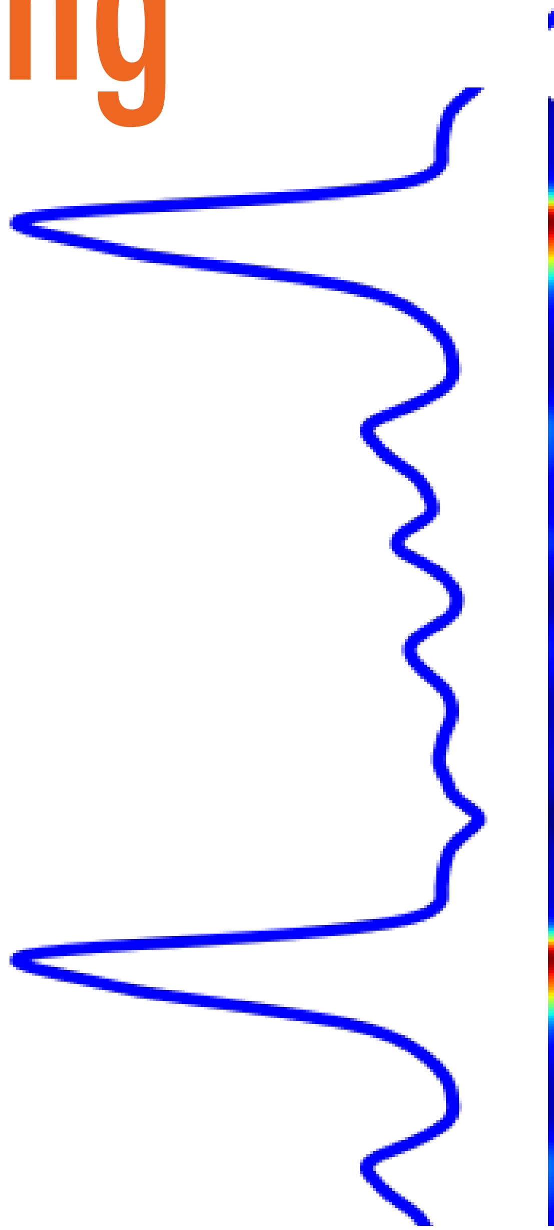
"As engineers we are working in a realm where, as individuals, we may or may not have sound fundamentals in statistics or computer science to work with the techniques available, so building a community with others who have experience is easier than trying to send someone to get an additional degree," Shields said. "This allows us to share knowledge and build up capabilities more effectively."

Two key initiatives the U.S. Navy is undertaking are: Digital Twin and Digital Thread, which create massive sets of data, and finding the right people who understand and know how to work with the data is paramount.

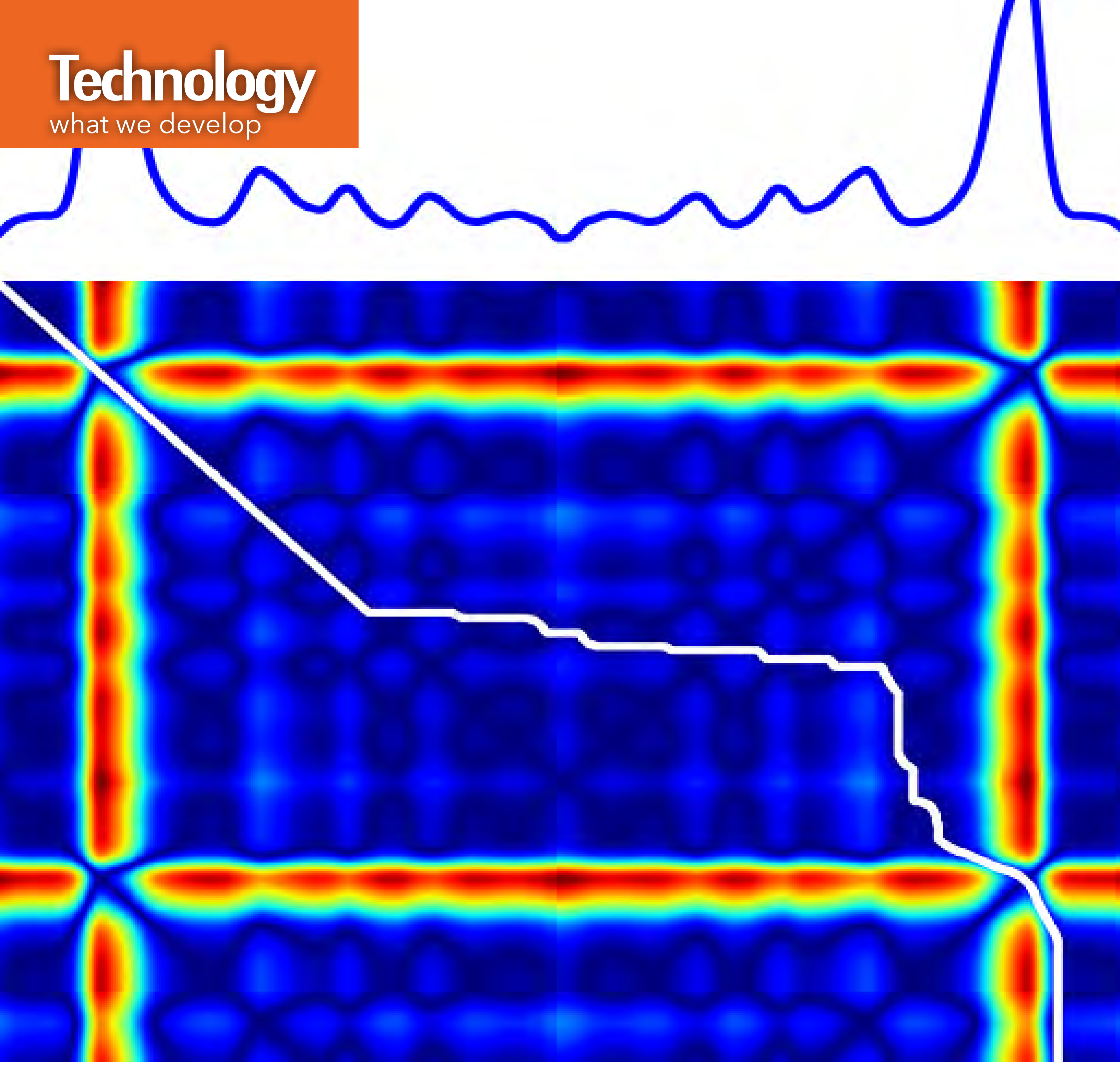
"In my experience, 90 percent of working with data is cleaning, conditioning and understanding the source data," Shields said. "If you don't do this properly you will get erroneous results because the computer will not tell you it's wrong. It will only give you results based on the data you input."

The project was initially funded for one year through Naval Innovative Science and Engineering (NISE) 219 for fiscal 2018; and has since been allocated additional funds through NISE 219 fiscal 2019. To date, the CoP has demonstrated that it meets a critical need within the workforce and has provided the Division with a big picture perspective of the data-related efforts and needs within Carderock.

Since its inception, Shields has worked diligently to establish regular meetings for the CoP — featuring seminars on data analytics tools, methods and techniques — but is cautious about the ability to sustain the momentum of initial success, and realizes there are barriers that could hinder its growth into the future.



"It's great initially for people to volunteer their time, but we're all busy with our directly funded work, and at some point volunteers may burn out," Shields said, noting that the CoP relies on volunteers. "One way to prevent this is to continually add to the pool of active volunteers, so we are trying to find more individuals who have knowledge and time to speak at our monthly meetings or attend relevant meetings and bring back the information, for example."



Providing widespread training and awareness across the workforce is also a challenge.

"Since we don't have the opportunity to send every new employee to three months of data science boot camps we are trying to leverage the resources we have available," Shields said. "I believe as our digital strategy grows, different branches will determine their specific application needs and will see the benefit of developing relevant skills amongst their personnel, which can then be shared across the community of practice."

With the continued support of leadership and the growing community, Shields is working to expand the CoP to provide more training, networking and collaboration opportunities to the workforce and develop a strategy to ensure the CoP remains a long-term resource for Carderock.

Children from Hawassa, Ethiopia, participate in a human-centered design process March 10, 2018, to determine the ultimate soccer academy they hope to build. Yared Amanuel, originally from Ethiopia and an engineer from Naval Surface Warfare Center, Carderock Division, taught the children how to use human-centered design to help them solve problems while he was there on personal travel in March. (Courtesy photo/Yared Amanuel/Released)

Ethiopian children learn human-centered design from Carderock engineer

By Kelley Stirling,
Carderock Division Public Affairs

Yared Amanuel spends his spare time using skills he has learned on the job at Naval Surface Warfare Center, Carderock Division – not his engineering skills, but what he has learned in human-centered design.

Amanuel, an engineer on a one-year detail with Carderock's Naval Architecture and Engineering Department, (he normally works in the Structural Criteria and Assessment Branch), spent a couple of weeks in March on personal travel volunteering in his home country of Ethiopia, in the Horn of Africa. While there, he gave several human-centered design seminars to local companies. He also extended his human-centered design knowledge to his non-profit organization, EthioAthletics, which has a mission to "advance lifetime wellness through participation in athletics in Ethiopia."

According to Garth Jensen, Carderock's director of innovation, human-centered design starts by putting people at the center—observing and understanding human experience: how people's complex behaviors, mental models and needs (articulated and not) inform the problem and the solution. It blends design, strategy, qualitative research and entrepreneurial thinking.

How did Amanuel use human-centered design? It started with a bunch of kids wanting to play soccer and not liking their jerseys.

As part of EthioAthletics, the soccer club brings about 120 children, ranging in ages 10 to 15, together to play soccer. But Amanuel said it's about more than just soccer.
"I'm going to use it to teach leadership, science and technology, working out problems, trying to come up with a solution," Amanuel said. "Because the thinking is that the person who is closest to the problem is the one who should be bringing the solution to that problem."

And that's where human-centered design comes in. When Amanuel started this league three years ago, he expected to have a three-fold mission: soccer activity, health and teaching. The soccer players did not like the jerseys, though. Amanuel assembled the kids last year and asked them, "What is the problem?" The kids said they didn't like the uniforms because they weren't "cool." But the cool ones, like the Messi or Barcelona brands, were too expensive. So, the real question became, "Why do you not want to wear the less-expensive uniform?"

"The focus on human-centered design is that it forces you to ask the root question, because it's a process," Amanuel said. "You don't come to the answer because you want to; you come to the answer because you went through the process of asking, the why, the why, the why and the how, and then you go back and ask the why again. And more importantly, you're involving the people who are affected by it."

Amanuel said the solution with the uniforms was not what he expected. They decided to have a contest, which puts the solution in their hands, a key element of human-centered design.

"Well, it turned out they were very excited," Amanuel said. "I think the underlying story is that if they have a say in what they are going to wear, they start to own it."

Amanuel paired the children up with a fashion designer in Ethiopia, who is helping them with design and color selection, as well as money management.

"We started it in basic terms of how do we get a shirt made in Ethiopia for the kids to wear, and then the kids are wanting to design and wanting to wear." Amanuel said.

The first human-centered design session with the children was so successful, Amanuel decided to do it again. During the trip in March, he had a group of them work through the process to determine what kind of facilities they should have.

"The boys and girls were told that the city of Hawassa has given them unlimited

Yared Amanuel (left) retrieves his luggage after his arrival in Hawassa, Ethiopia, on March 9, 2018. Amanuel, an engineer at Naval Surface Warfare Center, Carderock Division, was in Ethiopia on personal travel to help run his non-profit organization, EthioAthletics, which he normally does from his home in Maryland. (Courtesy photo/Yared Amanuel/Released)

land and funds to build their own soccer academy to live, play, learn and work," Amanuel said, adding that the scenario was hypothetical in that he has requested the land from the city, and he will be raising funds to build it.

He said the daylong project involved team-building activities, lessons in brainstorming, the fundamentals of human-centered design and how to respectfully discuss disagreements and come to a resolution. By the end of the day, the children came up with plan options that would be decided in the following weeks. With the help of some local architects, a final reconciled plan will be submitted to the city of Hawassa.

Besides playing soccer, designing their uniforms and soccer academies, the children are expected to improve their grades in school as part of the EthioAthletics program, according to Amanuel. He said they intend to teach the children leadership, vocational and technical skills. Still in its early stages, the program has three possible outcomes for the children in the long term.

"If they have the ability to go play pro, they play pro, but they will also have the aptitude for college," Amanuel said. "And if they don't, they have a life skill they use to be hired to earn a living wage, a vocation."

There were other ways Amanuel said they used human-centered design, one of which was determining a way to make sure the children were staying clean, something that was not only good for their health and well-being, but also helpful to the parents. They decided to have them leave their uniforms behind every day. So, when they came to play soccer, they would change out of their regular clothes, put on their uniforms, and then their regular clothes would be laundered while they were playing.

He said the children's next assignment is to document any complaints they hear and develop the root cause and the real question that should be asked in order to work toward a solution to the problem.

"Human-centered design is the perfect tool. It asks you, 'What is your problem?' It doesn't say, 'What is the help you need?'" Amanuel said. "Once you get to the core of the problem, then it becomes a little bit obvious where the solution should come from and what the solution should be.

Former sub designer says naval architects need curiosity, perseverance in their work

By Kelley Stirling, Carderock Division Public Affairs

John Leadmon, a former submarine designer, spoke about the history and future of submarine design for the second Rear Adm. David W. Taylor Naval Architecture Lecture Series at Naval Surface Warfare Center, Carderock Division, March 8, in West Bethesda, Maryland.

Leadmon was the director of submarine design and systems engineering for Naval Sea Systems Command (NAVSEA 05U) from 1995-2007. Currently, he is a consultant to several organizations on strategic planning, program management, engineering and technology development of underwater vehicle design.

The new, monthly Taylor lectures are proving to be popular, and Leadmon's talk was another standing-room only event. In February, Carderock Commanding Officer Capt. Mark Vandroff spoke about his experience as the former program manager for the Arleigh Burke-class destroyer (DDG 51) program.

"The goal of these lectures is to get people in that have historical experience, lessons learned," said Jeff Hough, Carderock's distinguished engineer for ship design and organizer of the Taylor lectures.

Leadmon started by describing what he thinks are the attributes of a submarine

John Leadmon, director of submarine design and systems engineering for Naval Sea Systems Command from 1995-2007, speaks about the history and the future of submarine design as part of the Rear Adm. David W. Taylor Naval Architecture Lecture Series at Naval Surface Warfare Center, Carderock Division in West Bethesda, Md., on March 8, 2018. (U.S. Navy photo/Released)

naval architect and engineer, with some of the obvious ones being a team player, and having attention to detail, technical rigor and a sense of urgency. But curiosity, perseverance and a good reputation are characteristics to strive for, as well, he said.

"I learned something new every day of my life working in submarine design and submarine naval architecture," Leadmon said of being curious. He described perseverance as "a steady persistence in the course of action or purpose, especially in spite of difficulties, and there were plenty of them; obstacles, and there's plenty of those; and discouragement by people who would say 'You can't do that.' You hear all that, but you must persevere through it."

During his career with NAVSEA, Leadmon led the technical aspects of the Virginia-class submarine program from design to build. He noted that prior to the Virginia class, the traditional spiral design process had been used for decades. While it was a successful iterative process that produced the Los Angeles and Seawolf classes of submarines, he said there were many disadvantages such as longer design times and greater levels of re-work, mostly due to the process stopping for review at the different levels of design.

"It had the throw-it-over-the-wall mentality," Leadmon said, meaning once a level of the process was complete, it's given to the next level without collaboration. "There was minimal participation by the people who ultimately do the manufacturing, and it's difficult to keep the workload uniform over the time of the design because of the stops."

When starting the Virginia-class submarine design, he said a question from a senior leader made him rethink the way they had done submarine design in the past. That question was, 'How do other people do complicated things?' Leadmon hadn't been asked that question before, and the basic premise was instead of doing things the way they always had, find out if other people are doing it better or easier. So, he did, and they were. He came back with the seamless design process, which they called integrated product and process development, and used new terminology such as the engineering and specification development phase.

Leadmon said this new design process brings all the stakeholders in early, including contract personnel and builders, making it a much more collaborative event.

"It's beginning with the end in mind," Leadmon said of the new process. "We want to establish ownership with the producers as opposed to tossing it over the wall to them."

One of the main points Leadmon wanted to convey to the naval architects in the room is that they have to continue to change with the times, especially given the rate of change. Thinking back to when submarine designers used slide rules and pencils, he noted that little changed between 1930 and 1985, but it did change slowly with the onset of nuclear-powered submarines. He said there has been significant change since 1985 with the development of different tools and technology, specifically computer-aided drawings and computations. He said he expects there to be revolutionary change into the future, and it will happen fast.

"When you talk to your shipbuilders and other people that will be involved in designing your future submarines, they talk about the digital transformation and the digital revolution, where everything is digital, all their tools and methodologies, including concept design," Leadmon said.

Leadmon said that while the rate of change in the way submarines are designed is increasing, the timeline for the submarine design from concept to construction start also seems to be increasing. He said he thinks it's the responsibility of the future designers to get a handle on that, especially with the rapid pace of technology development.

"It is up to you folks to change that," Leadmon said, addressing the naval architects in the room. "If it can be done faster, you need to use your curiosity, your perseverance and desire to be 'known for something' and figure out how to do that."

Leadmon ended with further guidance for the up-and-coming designers of submarines.

"Take the initiative yourself; when someone tells you it can't be done, find out why and make sure it still applies; if you don't understand the technical details, go learn them; surround yourself with people who are a lot smarter than you; don't stand around waiting for the future vision to come down from on high, go create it, and help those above you understand it and embrace it; when you see a hole, instead of complaining, go fill it."

Wanted: Experienced ship designers

By Kelley Stirling, Carderock Division Public Affairs

Having experienced designers on the ship design team who have worked together on other designs was the main theme of Bob Keane's presentation during the Rear Adm. David W. Taylor Naval Architecture Lecture on April 12 at Naval Surface Warfare Center, Carderock Division in West Bethesda, Maryland.

"We need to build and maintain an experienced design workforce," said Keane, who retired in 2002 as a member of the Senior Executive Service, last serving as the executive director for surface ship design and systems engineering at the Naval Sea Systems Command (NAVSEA).

The third in the series of naval architecture lectures highlighted history in ship design and acquisition processes over the course of Keane's extensive career, including what he sees as strengths and deficiencies.

Even since retiring, Keane, who started his career at Carderock in the seakeeping facility, has stayed acutely involved in the world of ship design. He leads his own consulting firm, Ship Design USA, Inc., which supports the U.S. Navy's Center for Innovation in Ship Design (CISD) and the Computational Research and Engineering Acquisition Tools and Environments (CREATE)-Ships project, a design software-development project performed by Carderock in collaboration with the Navy's technical authorities in NAVSEA and under the sponsorship of Department of Defense's High Performance Computing Modernization Program Office. The CREATE-Ships design tools allow a ship designer to develop and explore a large number of design options in a timely manner in order to improve and streamline the design and acquisition process.

Keane's lecture was based on a Ship Production Symposium paper he and other ship designers, including Carderock's Jeff Hough, wrote under the auspices of CISD in 2008 called "Ready to Design a Naval Ship? Prove It!" In it, Keane said that studies have shown that the No. 1 factor contributing to increasing ship construction costs and timelines was the design of the ship design process and unnecessary complexity in the resulting design.

Bob Keane, former executive director for Surface Ship Design and Systems Engineering at the Naval Sea Systems Command, speaks to engineers and naval architects on April 12, 2018, at Naval Surface Warfare Center, Carderock Division, for the third in the series of Rear Adm. David W. Taylor Naval Architecture Lectures. (U.S. Navy photo/Released)

He said the paper is still timely, especially with the Navy ramping up to build a 355-ship fleet, including the design of future surface combatants.

"Most shipbuilders will tell you it's all the pre-production processes that really contribute to how well and how efficient they can build ships," Keane said, adding that more recent studies have shown that the highest need is to design for production, and that there is a lack of production knowledge and experience within design teams (First Marine International, 2014 U.S. Naval Shipbuilding and Repair Industry Benchmarking, 2016).

Highlighting the success of recent submarine designs with their design-build process, Keane said the submarine community focuses on sustaining an experienced design force with a "transformational" Navy-shipyard partnership.
Mike Brown, head of Carderock's Naval Architecture and Engineering Department, has been a submarine designer for most of his career, and he gave his thoughts on why recent submarine designs have been so successful at implementing a design-build process.

"In the sub world, they design for production," Brown said. "So, from early-stage preliminary design, your trades are part of the IPT (integrated product team), and it's all built toward optimizing your production while meeting your requirements."

Citing the DDG 51 acquisition program as a surface-ship example to be emulated, he said the collaboration during early ship design between the Navy and industry was crucial in the early design. The concept and early design for DDG 51 was led by NAVSEA and began in the 1980s at the height of the Cold War, when the nation was building a 600-ship Navy. He said the experienced NAVSEA design workforce collaborating with users, along with new computer-aided tools, contributed to a successful acquisition program and a highly effective warship.

"It was one of the first designs we had wide use of computer-aided design and computer-aided engineering tools," Keane said, reminding the audience that when he first started there were no computers in design and all designs were by hand. He showed a couple of examples of integrated design environments that CREATE-Ships is developing that are streamlining the design and acquisition process. "I've seen such a tremendous change. I wish I could be around to see what all of you come up with throughout your career and how ship design will be done 15-20 years from now."

Keane offered five foundational capabilities for successful naval ship design: an experienced ship design workforce; lean, concurrent design processes; integrated validated design tools; mature specifications and standards; and enterprise-wide communications.

"The key is the people, and the challenge is how do you build and maintain that experienced ship design workforce," he said, noting that it takes 10-15 years to develop a ship design leader.

Going forward, Keane said the Navy needs to ensure the basic "design recipe" is followed before starting any ship design (Reinertsen, Managing The Design Factory, 1997): design of the design organization; design of the design process; and design of the design tools.

"We need to make more investments up front," Keane said, adding that it's also important the users of the product — the warfighter — be part of the early design process because they know what they need and that is where the most critical decision on cost and performance are made. "Let the users define their needs, let the users drive the design."

Keane said NAVSEA was the design factory for the 600-ship Navy, with more than 35 contract designs in the 1980s and 1990s with far less cost growth than recent ship acquisitions; however, a lot of experienced ship designers left NAVSEA in the drawdown after the Cold War ended, so the challenge then and today is how to build and maintain that experienced ship-design workforce.

"You have a big challenge ahead of you," Keane said. "The country has decided we need a 355-ship Navy. We have the future surface combatants coming down the pike. A lot of engineering goes into those ships. This is an opportunity, a NAVSEA team with Carderock and the other Warfare Centers, for you all to be that design factory for the 355-ship Navy."

Materials forum at Carderock

Employees look at posters during the 5th Naval Materials Community of Interest Materials Forum on April 24, 2018, at Naval Surface Warfare Center, Carderock Division in West Bethesda, Md. The forum, held April 24-26, brought together representatives from Naval Sea Systems Command (NAVSEA) Warfare Centers, NAVAIR, SPAWAR, NAVFAC, NRL and the USNA to discuss the current and future needs of naval systems and showcase important material technical contributions. (U.S. Navy photo/Released)


Three-Dimensional
3D Techniques at NRL
Serial Sectioning
X-Ray Microtomography

High-velocity learning key to expanding the advantage

By Kelley Stirling, Carderock Division Public Affairs

The two top leaders of Naval Sea Systems Command (NAVSEA) bookended the first high-velocity learning (HVL) summit to show their commitment to HVL, one of the pillars of the Campaign Plan to Expand the Advantage.

Jim Smerchansky, executive director for NAVSEA, opened the HVL summit held at Naval Surface Warfare Center (NSWC), Carderock Division in West Bethesda, Maryland, May 15-16. NAVSEA Commander Vice Adm. Thomas Moore closed the event, which brought representatives of NAVSEA commands together to discuss HVL tools, successes and opportunities.

With similar messages about the importance of high-velocity learning, both men described the need to increase the United States' capabilities over its adversaries. The country is in an era of great power competition, namely with Russia and China, and according to both Smerchansky and Moore, NAVSEA's vision to "expand the advantage" means contributing to the overall effort of the secretary of defense's National Defense Strategy to broaden that capability gap.

"High-velocity learning is about mission accomplishment," Smerchansky said. "Our obligation, our mission to the Navy and the nation is to deliver and provide warfighting systems and ships to the men and women of the country to never allow them to be in a fair fight. Our obligation to our workforce is to provide meaningful work and the right tools they need to be successful."

Each of the speakers took questions from the audience, many of which were concerning the loss of knowledge that is expected as the more experienced employees retire.

In response to one such question, Smerchansky said instead of thinking of it as a transfer of knowledge to the next generation, people should consider a transfer of experience, meaning the more senior employees need to start turning their work over to the junior employees, allowing them to gain the experience necessary to work through problems.

"High-velocity learning can go right to the heart of that," Smerchansky said. "This is the generation coming up that has to be able to look right; they have to count on the 75,000 people (within NAVSEA) to be part of their network to help them be successful."

The idea of high-velocity learning originated from the book "The High-Velocity Edge," by Steven Spear. Chief of Naval Operations Adm. John Richardson adopted HVL as something every level of the organization should be

Vice Adm. Thomas Moore, commander of Naval Sea Systems Command, speaks during the high-velocity learning (HVL) summit at Naval Surface Warfare Center, Carderock Division, May 15, 2018, in West Bethesda, Md. (U.S. Navy photo by Justin Hodge/Released)

achieving, as laid out in his plan "Design for Maintaining Maritime Superiority."

High-velocity learning can be explained with the four "S's": see, swarm/solve, share and sustain. Within this framework, decision-making can be pushed to the lowest levels of the organizations, thereby empowering employees to gain the experience Smerchansky said they need.

During the summit, which included remarks by Rear Adm. Doug Small, Program Executive Office Integrated Warfare Systems, the attendees were able to experience their own "swarm." NAVSEA's PMS 391 (Team Subs) identified three challenges they have, specifically in modernization, acquisition and maintenance.

"We use these philosophies in hopes of becoming a true learning organization," said Jana Patterson, a senior acquisition product engineer for Team Subs. "We are trying to figure out how to not only increase the throughput of modernization, but to improve upon our maintenance situation, the processes already in place."

Patterson said the knowledge is at the waterfront with the people actually turning wrenches or ordering parts, and the people in service support, like her, need to hear from them.

"We are looking for ideas on how to empower that level of personnel out at the shipyards, whether they be private or government, to identify issues," Patterson said.

The attendees split into three groups and spent about 45 minutes brainstorming the issues presented by Team Subs, working towards possible solutions, which is precisely what "swarming" is. They then came back together to share their results. Even though most of the people in the groups did not work in the submarine world, it was their own experiences that led to the possible solutions.

Patterson came away with several ideas, which she said she will take back to her work environment and see if there are opportunities to incorporate some of the possible solutions.

The idea of HVL is not only improving processes by seeing the problems and swarming them for solutions, but it's also about sharing across the enterprise so the workforce is working smarter and continuing to expand the advantage.

"If you can't spend a little bit of time doing strategic planning, high-velocity planning on what the future workforce needs to look like, then we are kind of doomed to do what we've been doing over and over again," said Don McCormack, executive director for NSWC and Naval Undersea Warfare Center.

One of the common themes at the summit was communication as a barrier to high-velocity learning.

"The biggest challenge I have every day is effectively communicating to a workforce of 75,000 people," Moore said, acknowledging that sharing is going to naturally be the hardest part about HVL. "But if we really want to be a high-velocity learning organization, we have to be able to communicate and get it down to where it's culturally important for us to be working on this; it has to become second nature."

Moore said he expects the attendees of the HVL summit to become the change agents, relying on them to force the culture to change.

"The two things on the Campaign Plan that require the most work and that we've made the least amount of progress on, they are both ideas that are culture issues, a culture of high-velocity learning and a culture of affordability," Moore said. "Why are those thigs the hardest? Because culture in an organization is the absolute hardest thing to change, without a doubt."

Moore challenged the summit attendees to take the principles of high-velocity learning to the next level and find a way to get them ingrained into the culture, so that everybody is thinking about HVL.

"The high-velocity learning piece is probably the most key element to eventually getting to the vision to expanding the advantage," Moore said.

Anderson assumes command of Naval Surface Warfare Center

From NSWC Public Affairs

Rear Adm. Thomas J. Anderson assumed command of Naval Surface Warfare Center on April 30 at the Washington Navy Yard.

"It is an honor to serve as the 13th commander of the Naval Surface Warfare Center," Anderson said. "I look forward to leading the nearly 19,000 scientists and engineers who serve as the foundation of the Navy's technical capability as we pursue the Navy the Nation Needs through execution of the NAVSEA Campaign Plan."

Anderson, a surface warfare officer and a native of North Brunswick, New Jersey, was commissioned through the Navy ROTC Program at Boston University where he received a Bachelor of Science degree in mechanical engineering in 1991. Upon selection to the Engineering Duty Community in 1996, he attended the Naval Postgraduate School, where he earned a Master of Science degree in mechanical engineering. He also completed the total ship systems engineering curriculum and became a California state licensed professional engineer.

At sea, Anderson qualified as a surface warfare officer aboard USS Capodanno (FF 1093), where he served as machinery and boilers division officer, main propulsion assistant and first lieutenant; he also served aboard USS Arleigh Burke (DDG 51) as auxiliaries and electrical officer, where he coordinated the first two CNO availabilities of the DDG 51 class.

Ashore, he has served in a variety of industrial, fleet, program office and headquarters assignments in ship design and construction, maintenance, budgeting and requirements. Those assignments included: executive assistant to COMNAVSEA; LCS production officer (PMS 501); OPNAV requirements officer (N86); chief engineer and post-delivery branch head for the DDG 51 Class (PMS 400D); COMNAVSURFLANT mine warfare type desk officer (N43); and ship superintendent and DDG/FFG

planning yard officer at Supervisor of Shipbuilding, Bath, Maine.

Anderson served for five years as program manager of the LCS Shipbuilding Program (PMS 501). During his tenure he transitioned two tier-two shipyards from single ship to serial production (facilities, design and manpower); achieved IOC and conducted LFT&E for two ship variants; and is largely credited with stabilizing the LCS shipbuilding program. He was selected as the 2017 Navy Program Manager of the Year while serving as the LCS program manager.

The NAVSEA Warfare Centers are comprised of Naval Surface Warfare Center (NSWC) and the Naval Undersea Warfare Center (NUWC), and represent approximately 30 percent of the Navy's engineering and scientific expertise. NSWC is comprised of eight echelon-four divisions: Carderock, Corona, Crane, Dahlgren, Indian Head Explosive Ordnance Disposal Technology, Panama City, Philadelphia and Port Hueneme, as well as one echelon-five command, Dam Neck Activity (part of Dahlgren). NUWC is comprised of two echelon-four divisions: Newport and Keyport, as well as one echelon-five command, Naval Sea Logistics Center (part of Keyport). With more than 100 years of history, the NAVSEA Warfare Centers provide full-spectrum technical advice and solutions to its partners in support of naval platforms and systems.

Rear Adm. Thomas Anderson assumes command of Naval Surface Warfare Center during a change of office ceremony on April 30, 2018, at the Washington Navy Yard. In attendance were Naval Sea Systems Command Commander Vice Adm. Thomas Moore (second from right) and Executive Director Jim Smerchansky (third from right). (U.S. Navy photo by Laura Lakeway/Released)

Rear Adm. Anderson visits Carderock

Rear Adm. Thomas J. Anderson (right), commander, Naval Surface Warfare Center, listens to engineer Stephanie Ferrone as she describes equipment in the Electromagnetics Facility at NSWC Carderock Division during his visit on May 24, 2018, in West Bethesda, Md. (U.S. Navy photo by Devin Pisner/Released)

Why doesn’t the Navy have battle cruisers?

By Kelley Stirling, Carderock Division Public Affairs

If the battle cruiser has all the best elements of a battleship and a cruiser, why doesn’t the Navy have a fleet of them?

James Harrison, division director for the Expeditionary Warfare Ships Division at Naval Sea Systems Command (NAVSEA 05D3), set out to explain why some ships just didn’t make it in to the Navy fleet, during his history presentation May 9 at Naval Surface Warfare Center, Carderock Division in West Bethesda, Maryland.

“Not Even Once!” was about ships or ship programs that were initially supported by Navy leadership, but were ultimately cancelled before being built or launched, and the battle cruiser was in that lineup.

“Battle cruisers have the fighting power of a battleship with the speed of a cruiser,” Harrison said in his eighth talk at Carderock.

The Navy did make an attempt to build its own battle cruiser in response to the Soviet nuclear battle cruiser of the 1970s. Harrison said the Soviet battle cruiser was considered a ship killer, and the U.S. Navy had nothing like it, so the Navy initiated a model test program of a nuclear-powered strike cruiser in 1976. By 1977, Congress didn’t authorize the Navy’s request for funding for this strike cruiser and instead funded the new version of the Virginia-class nuclear guided-missile cruiser, CGN 42, which ironically, also didn’t get built.

“You can’t just build cool stuff. You have to build military equipment that supports your overall national strategy,” said Capt. Mark Vandroff, Carderock’s commanding officer. It was Vandroff who invited Harrison more than a year ago to give these somewhat humorous historical presentations at Carderock.

USS Virginia (CGN 38) was built, and there were four of that class of ship built

Rear Adm. David W. Taylor (left), chief of the Bureau of Construction and Repair, and Rear Adm. John K. Robinson (right), chief of the Bureau of Engineering, hold a model of the battle cruisers (CC-1 class) then under construction, March 8, 1922. In the foreground is a model of an aircraft carrier design converted from the battle cruiser hull. This photo illustrates the genesis of the Lexington (CV-2) class aircraft carrier design. Standing in the background are (from left to right): Rear Adm. William A. Moffett, chief of the Bureau of Aeronautics; Rep. Frederick C. Hicks of New York; Rep. Clark Burdick of Rhode Island; and Rep. Philip D. Swing of California. (Photographed at the Navy Department by Harris & Ewing. Photograph from Department of the Navy collections in the U.S. National Archives)

with state-of-the-art combat systems. However, newer combat systems were quickly changing what "state-of-the-art" was, specifically the AEGIS weapon system and vertical launching systems. According to Harrison, the also-planned DDG 47, or what was at the time to be the Spruance-class destroyers, was cheaper and more modular, meaning it could retrofit newer systems as they became available, unlike the cruiser.

The 20 new CGN 42-classes of cruisers were scrapped to make way for 27 new DDG 47-class of destroyers, which also didn't get built. Well, they were built, but not as destroyers. Harrison said Congress was concerned because cancelling the CGN 42 meant the Navy would have no cruisers being built at all.

"So, a simple solution was found for that. They took DDG 47 and rebranded it as CG 47, and voila, you don't have 27 new destroyers, you have 27 new cruisers," Harrison said.

While the CGN 42 program was halted in the late 1970s in favor of the Ticonderoga-class cruiser (CG 47), it was brought back in the 1980s in support of the buildup of the 600-ship Navy, but again halted before one was built.

Back to battle cruisers. The Navy's first attempt at a battle cruiser was actually in 1920. USS Lexington (CC-1) didn't have quite the fighting power of a battleship at the time, but was going to be a lot faster at 34 knots. The Navy's plan was to build six of them at the same time in four different shipyards. Keels were laid in 1920 and by March 1922, all work stopped, very short of completion, as a result of the Washington Naval Treaty.

"After World War I, there was a lot of angst in the U.S. about all the money being spent to build the fleet," Harrison said. "The world powers got together in 1922 and decided to place limits on the size of their navies and stopped building further battleships."

But Lexington and Saratoga (CC-3) did survive in a different form. The battle cruisers were redesigned to be aircraft carriers on the same keel. So, USS Lexington became CV 2 and USS Saratoga became CV 3.

Ultimately, aircraft carriers really became the U.S. Navy's answer to the battle cruiser.

"Since WWII, the Navy has not used ships to kill capital ships," Harrison said, defining capital ships as key assets of any navy. "We use carriers, we use aircraft, which fly out hundreds of miles and kill your capital ships way out there, not letting you get close enough where you can shoot at our key asset."

But the Navy almost lost even its ability to build carriers. At the end of World War II, the Navy wanted to build USS United States (CVA 58), which was a carrier designed with the mission of delivering nuclear-armed bombers. The design had no island to make room for these bombers, as well as fighters. A model was even built and tested for seakeeping at Carderock's David Taylor Model Basin in 1947.

"The idea was the fighters would protect the carrier to get in close enough to launch the bombers that were thought to be needed to carry the heavy nuclear weapons to deliver a nuclear strike against your adversary," Harrison said.

The Navy was pretty serious about building it, even laying the keel April 18, 1949, at Newport News Shipbuilding in Virginia. Then, on April 23, 1949, the secretary of defense cancelled the program, sparking the secretary of the Navy to resign. Harrison said the secretary of defense's actions against the U.S. Navy at the time ultimately led to what's called the "Revolt of the Admirals."

President Harry S. Truman and Secretary of Defense Louis Johnson decided on a defense strategy that basically eliminated the U.S. Navy and the Marine Corps, believing that all wars of the future would be solved with nuclear weapons, which the Air Force's bombers could deliver. The secretary of the Navy and several other admirals went behind Johnson's back to Congress to ask for funding and this led to the CNO's resignation.

"In 1949 the ship gets cancelled," Harrison said. "Then in 1950, North Korea invaded South Korea."

When Truman wanted to blockade North Korea, the Navy said they didn't have the ships and the naval forces necessary to conduct a blockade of a nation so large as North Korea. Also in 1950, the Navy demonstrated it could use smaller aircraft to deliver nuclear weapons using a Midway-class carrier.

"There was a sea change and a realization that not every war was going to be nuclear exchange, that we were going to need forces across the full range of options," Harrison said. "So, in 1951, USS Forrestal, CV 49, the first of our super carriers, was ordered and delivered in 1959."

Marine Maj. Gen. Coffman visits Carderock

Nathan Desloover (center), an engineer with the Additive Manufacturing Project Office at Naval Surface Warfare Center, Carderock Division, describes the 3-D printing of a small drone to Maj. Gen. David Coffman (right), deputy commanding general, I Marine Expeditionary Forces. Coffman was visiting the West Bethesda, Md., headquarters on March 16, 2018, to learn more about Carderock's role in expeditionary improvements. (U.S. Navy photo by Monica McCoy/Released)


HOW 3D PRINTING WORKS
IN THE WORLD OF FREE SOFTWARE
AND OPEN SOURCE HARDWARE
PRINTING YOUR DESIGN

Rep. Wasserman Schultz visits Carderock's Florida facility

U.S. Rep. Debbie Wasserman Schultz (FL-23) visits Naval Surface Warfare Center, Carderock Division's South Florida Ocean Measurement Facility in Dania Beach, Fla., on April 9, 2018, to talk about Navy work and partnership with Nova Southeastern University. From left, Prof. Alexander Soloviev; Brian Osgood, SFOMF project manager; Wasserman Schultz; Mike Farrar, SFOMF site director; and Prof. Richard Dodge. (Courtesy photo provided by NSU)

Retired Capt. Paul Rinn delivers speech on leadership and success to Carderock

By Justin Hodge, Carderock Division Public Affairs

Retired Navy Capt. Paul Rinn gave a speech on leadership and success at Naval Surface Warfare Center, Carderock Division on April 19 where he spoke about how ordinary U.S. Navy Sailors achieved the impossible and kept their ship from sinking.

In the early evening hours of April 14, 1988, the frigate USS Samuel B. Roberts (FFG 58) struck an Iranian mine in the Persian Gulf while on patrol to protect and escort oil tankers. The explosion broke the ship's keel and blew a massive hole in the hull below the waterline. A fireball ripped through the stacks, setting fire on four decks. Rinn said the 220 Sailors fought with courage, bravery and heroism for four hours to save the ship and themselves from a sea full of sharks and sea snakes. Incredibly, not a life was lost.

Rinn said preparedness, courage, innovation and teamwork decided the outcome.

"I wanted to be the best in the Navy," Rinn said. "So leading up to that event, we conducted drill after drill to ensure we were ready, and we knew that if we worked together, we worked hard and we trained, we could overcome anything."

Rinn said that goal setting; teamwork; courage and character; communication; management by walking around; training; innovative thinking and problem solving; diversity; heritage as inspiration; preparation and the pursuit of excellence; and keeping a sense of humor are all key elements of good leadership.

"Always make sure you empower your people, and train them in multiple jobs, so they can do them well," he said.

Rinn said as a commander he focused on being personable and showing a clear understanding for every Sailor on the ship. He said the need for those working

Retired Navy Capt. Paul Rinn speaks at Naval Surface Warfare Center, Carderock Division on April 19, 2018, about his experience on USS Samuel B. Roberts (FFG 58) when the frigate hit an Iranian mine 30 years ago. (U.S. Navy photo by Justin Hodge/Released)

side by side to understand and appreciate each other is of utmost importance.

"Trust works both ways," Rinn said. "You demand trust from your Sailors, but you have to earn it first. You have to earn trust; you can't force it. You want to trust them, and they want to trust you; and they want to make sure you won't sacrifice them for no reason. In business and in war, allow the men and women working for you to always know the reason why you are doing what you are doing. If you do, they will follow you."

Rinn said it isn't just about leading, but also listening and making sure those under your command are aware that they are adding value.

"Listen to what your Sailors say and hear what they say," Rinn said. "Some of the best ideas I ever received in the Navy came from some of the lowest-level Sailors on the ship. Why? Because they are the ones with their hands on things."

Rinn continued, in detail, his account of the events that unfolded that day 30 years ago, and how even though the situation was dire, his men remained calm and worked through each obstacle together.

"Everyone knew what they needed to do, and they just did it," Rinn said. "You cannot discount the drive of a man when his life and the lives of those around him are in the balance."

Rinn also spoke about how tradition and heritage helped to push the men forward through this extreme circumstance.

"You may not think too much about tradition and heritage, but on April 14, 1988, we were in trouble," Rinn said. "We had new fires starting every 10 to 15 minutes, the nearest ship was 120 miles away, we were surrounded by sharks and we are in the middle of a mine field. When I was on the mid-ship station I noticed Sailors were coming by touching this plaque we made on the ship that had the names of every Sailor that served in the Battle off Samar (1944, in the Philippine Sea). All of them were touching it — they were reaching back — they were not going to give up their ship. This act was because of the tradition of the Navy, the linkage of our past and the history of our country."

Rinn's career in the Navy spanned almost three decades and encompassed challenging positions in a multitude of key operational assignments and combat encounters, as well as significant Pentagon postings. He retired in 1998.

Rinn was the recipient of the United States Congress's 1989 National Day of Excellence Award, the 1989 Stephen Decatur Award for Operational Excellence and the 1995 U.S. Navy League John Paul Jones Award for Inspirational Leadership.

Rinn has shared his inspirational story on Good Morning America, The History Channel and the Military Channel.

Rinn was voted into the Surface Navy Hall of Fame in 2008.

Carderock hosts LEGO Robotics challenge

Students from local schools participate in the LEGO Robotics challenge on April 27, 2018, at Naval Surface Warfare Center, Carderock Division in West Bethesda, Md. Carderock hosts the LEGO Robotics challenge for the region each year as a science, technology, engineering and math (STEM) outreach event. (U.S. Navy photo/ Released)

Investing
in our future

Carderock hosts Naval Engineering Education Consortium

By Kelley Stirling, Carderock Division Public Affairs

Students, professors and Navy engineers and scientists shared the projects they've been collaborating on at the mid-Atlantic meeting of the Naval Engineering Education Consortium (NEEC), hosted by Naval Surface Warfare Center (NSWC), Carderock Division on April 11 in West Bethesda, Maryland.

"I think the opportunity for you to work with us and be part of the Warfare Centers construct here in terms of supporting us gives you a really good feel for the things we do for the Navy and the greater nation as a whole," said Larry Tarasek, deputy technical director at NSWC Carderock, when welcoming the nearly 150 attendees.

NEEC is a program under the Naval Sea Systems Command (NAVSEA) Warfare Centers. In addition to NSWC Carderock, other mid-Atlantic Warfare Centers represented at the event were NSWC Dahlgren Division, NSWC Indian Head Explosive Ordnance Disposal Technology Division and NSWC Philadelphia Division.

"The intent of NEEC is for the Warfare Centers to work with students at research universities so they know about the extent of Navy problems and also about the opportunities to join our technical workforce," said Kirk Jenne, director of the NEEC. "I'm impressed with the breadth of research represented at this event."

The program provides funding for relevant research at selected academic research institutions, in addition to opportunities for students to participate in hands-on research during the academic year to develop their technical skills.

"We know universities are doing cutting-edge research. We want to get the best and brightest minds to help us solve Navy problems, and you're part of that," said Don McCormack, director for NSWC and Naval Undersea Warfare Center (NUWC).

Dr. Stephanie TerMaath, a professor at the University of Tennessee, Knoxville, whose team is working with NSWC Carderock, presented her team's research at the NEEC meeting. In basic terms, her team wants to better understand how printing parameters, such as nozzle temperature, cooling, sample size and print time, affect the mechanical properties of the material, with the ultimate goal of qualifying components made from these materials for use in shipboard applications. This could have immediate benefit to the Navy as the results get published, by sharing the data with other researchers, as well as establishing a quicker process for Sailors to use qualified and certified material to print parts.

"We are also looking at building our own customized materials for a particular application and we are specifically interested in recycling," TerMaath said. "So, if you're out on a ship and you want to build a part, can you just grind up what you have and reprint it but still maintain your structural properties? And how many times can you recycle it?"

Dr. Alan Brown, a professor from Virginia Tech, has students working with NSWC Philadelphia Division to address issues related to affordability for ship systems as the combat systems and other systems on a ship require more and more power in different ways.

Zeenat Kukoyi, an industrial engineering student at Morgan State University in Baltimore, is working with NSWC Indian Head. Their NEEC project is the "Effects of Copper Thickness on Electrical Conductivity of Carbon Nanotubes and Carbon Black Electrodes."

"Working with NEEC has brought me closer to what I want to do outside of college and making me appreciate lab work 10 times more than what I originally did," Kukoyi said. "A lot of people don't understand the basic strengths of lab work in the process and how experiments, data collection, data analysis helps with a lot of stuff on a day-to-day basis."

Data analytics was a common theme among all of the speakers, specifically how to process the amount of data being collected through research so that it's useful to future generations. Brown, who has been working with NEEC for nine years, said they are looking at data in the design process, adding that they have to find new approaches to cut down the costs, not just in the details for the technologies, but in their integration.

"Data, data, data – I hear data all the time; data from prior designs; data that you generate from your models from future designs," Brown said. "And using all of that data to come up with knowledge to make early-stage decisions is a very important part of what we are trying to do."

A panel of young professionals representing each of the Warfare Centers offered advice to the up-and-coming job

Chief of Naval Research Rear Adm. David Hahn (right) speaks with student researchers from Virginia Tech during the meeting of the Naval Engineering Education Consortium for the mid-Atlantic region on April 11, 2018, at Naval Surface Warfare Center, Carderock Division in West Bethesda, Md. (U.S. Navy photo/Released)

hunters, touting continuing education as a benefit.

"There are rotational opportunities within the division," said Chelsea Graham, an electrical engineer at NSWC Indian Head Division. But she said new employees should build the craft they were initially hired for and then seek the other opportunities that help further their career.

Several senior employees imparted their wisdom to the students attending, hoping to encourage them to work for the Navy.

Dr. John Seel from NSWC Dahlgren Division talked about his experience installing lasers on ships, and testing rail guns by blowing stuff up, all things he thought every college-aged student might be interested in. He went on to say that the scope of work done there spans from basic science to applied engineering, computer science to rocket science, and unmanned systems to laser systems.

Steve Greineder, the senior technologist for acoustic signal processing at NUWC Newport Division, reiterated the scope of the work that is being done and therefore, the people who are needed to do that work.

"What do the Warfare Centers want from you? It's very simple: To do what you were put on this earth to do. What is your gift? We need it," Greineder said, describing the breadth of talent required to do the work the Navy needs. "Where do you see yourself? We need people that can sit down and do the theory. We need people that can take the theory and make it work in reality. We need good acquisition people — all to support the fleet."

Continuing on the theme of encouraging students to work for the Navy, specifically a Navy Warfare Center or Naval Research Lab, keynote speaker Rear Adm. David Hahn, chief of naval research, said the technological talent this next generation brings to the table will be important to the Navy's mission.

"Our job is to provide to the warfighter the necessary advantage to stop the adversary from moving ahead," Hahn said, adding his thanks for what they do today, "what you're going to do tomorrow, and tomorrow's tomorrow, to make sure that we, as America's Navy, never let our Sailors enter into a fair fight."

To learn more about NEEC, visit http://www.navsea.navy.mil/Home/Warfare-Centers/Partnerships/NEEC/

Tennessee students help Navy research 3-D print materials' properties

By Kelley Stirling, Carderock Division Public Affairs

University of Tennessee, Knoxville (UTK) students have partnered with Naval Surface Warfare Center, Carderock Division to study the material side of additive manufacturing (AM).

Specifically, the team wants to better understand how printing parameters such as nozzle temperature, cooling, sample size and print time affects the mechanical properties of the material, with the ultimate goal of qualifying components made from these materials for use in shipboard applications.

The project is part of the Naval Engineering Education Consortium (NEEC), which is a program that provides research funding for relevant research at academic institutions and provides opportunities for students to participate in hands-on research during the academic year to develop their technical skills.

Dr. Stephanie TerMaath, a professor at UTK, and doctoral student William Ferrell presented their NEEC project March 13 at Carderock's West Bethesda, Maryland, headquarters. They stayed for the week to print additional test coupons to further understand the variability of printing on one model of a machine to another in the Manufacturing, Knowledge and Education (MAKE) Lab. In addition, they also were able to use some Carderock facilities to perform thermal and mechanical testing on polymer AM materials that they had printed at UTK.

The UTK students weren't the only ones gaining knowledge during the visit to Carderock. Ferrell said he was also able to help employees in Carderock's Advanced Materials and Structures Branch fabricate a composite laminate in the Integrated Manufacturing and Project Management Office's Composites Lab using the vacuum-assisted resin transfer molding (VARTM) process.

TerMaath said the technical objective of

Johnny Ruffa, from the Ship Structures Branch at Naval Surface Warfare Center, Carderock Division; Will Ferrell, a doctoral student at University of Tennessee, Knoxville; and Dan Hart, an aerospace engineer from Carderock's Advanced Materials and Structures Branch discuss the vacuum-assisted resin transfer molding (VARTM) process for additive manufacturing in the Composites Lab on March 15, 2018, at Carderock's West Bethesda, Md., headquarters. (U.S. Navy photo by Devin Pisner/Released)

this NEEC project, which is in its second year, is to explore and demonstrate the potential of an integrated experimental and computational approach to the qualification process of composite parts fabricated with embedded fibers.

"Can we take the current building-block approach to material qualification and part certification and supplement that with computational simulation to explore customized materials prior to comprehensive testing, especially when inserting emerging materials," TerMaath said. "We are starting to build our own materials for additive manufacturing, actually making our own custom filaments. So, as you do that, we don't necessarily want to do a full building-block test program for every potential design, so can we take validated computational models, use them to explore the whole design space and then do the building-block approach and the comprehensive testing on the most promising designs."

Dr. Maureen Foley, a materials engineer in Carderock's Integrated Manufacturing and Project Management Office, is Carderock's program manager for the NEEC with UTK.

"The research we are doing with the University of Tennessee is extremely relevant to our needs for the Navy," Foley said. "As additive manufacturing becomes more mainstream, we absolutely need to find ways to better understand how the various materials are affected by the printing parameters that can be changed by the user of the 3-D printers in order to qualify components for use in shipboard applications safely and quickly. The whole point of AM is to provide an option to print a part to maintain mission readiness. If we don't understand the variability of the 3-D printing process, it will be difficult to understand the risk of transitioning more critical polymer AM parts in the long run. These students are working through ways that we might be able to better understand the variability of the materials and printers and developing computational tools that can be used to perform simulations to be able to predict crack behavior. And when they graduate, hopefully they will come work with us."

Ferrell, who is working on his Ph.D. in materials science engineering, is one of the primary researchers for this particular NEEC project. During this second year the students are performing comprehensive testing to investigate crack growth with the goal of developing multi-scaled computational models that capture the resulting observations.

Ferrell said the focus of the previous year was in material characterization and establishing test programs and performing the mechanical testing of the materials and the parts to understand why the material was behaving in a specific manner.

"We want to be more predictive and be able to have more efficient qualification of future materials under marine conditions. If we put an AM part on a ship, we need to be able to predict what's going to happen in order to design against failure from it being hot, wet and salty," Ferrell said.

For year three, Ferrell said the goal is to do a concept demonstration. Through the work they are currently doing, they want to be able to create a demonstration part, test it, and then predict and model the crack behavior at a stress concentration such as a corner.

"The idea is once we have a part, we're still using that building-block approach, supplemented with knowledge on the uncertainty in material behavior due to print process variables. And at this point, we will be able to say, because of all these steps that we have taken over the past two years to quantify atomistically, molecular dynamically, all the way through structural analysis validated by the testing, that we understand variability in structural performance," Ferrell said. "We're moving towards repeatability — that way, our defense, our Sailors, our workers can all rely on the parts that are being printed in the future."

While they are working toward that technical goal, the students involved are preparing themselves for a potential career with a Navy lab. TerMaath said the students have been very interactive with her and with Carderock, especially Foley.

"I can't thank Dr. Foley enough, she emails, she helps them with resumes, she gives them advice, talks to them on the phone," TerMaath said. "She's been phenomenal. We couldn't ask for a better program manager."

According to the Naval Sea Systems Command (NAVSEA) Warfare Centers NEEC information website, the program offers students who may be interested in pursuing civilian science and engineering careers with the Navy the opportunity to investigate real Navy challenges while working hand-in-hand with university faculty and Navy mentors.

Garth Jensen, Carderock's director of innovation and NEEC program manager, said Carderock currently has three NEEC projects going on.

"As Carderock's NEEC program manager, I have been privileged to witness firsthand the profound impact this program is having on recruiting this nation's next generation of Navy scientists and engineers," Jensen said.

Carderock hosted the mid-Atlantic NEEC annual conference April 11, where the UTK project, as well as projects from other Warfare Centers, were highlighted. The meeting included representatives from NSWC Dahlgren Division, NSWC Indian Head Explosives Ordnance Technology Division, and NSWC Philadelphia Division.

Local students compete in ninth annual Carderock Math Contest

By Justin Hodge, Carderock Division Public Affairs

More than 220 students from over 30 regional schools participated in the ninth annual Carderock Math Contest (CMC) on April 13 at Naval Surface in Naval Surface Warfare Center, Carderock Division in West Bethesda, Maryland.

The contest, part of Carderock's science, technology, engineering and math (STEM) outreach efforts, is an opportunity for students to showcase their mathematical talents in a series of individual and team competitions in MATHCOUNTS-style tests.

Capt. Mark Vandroff, Carderock's commanding officer, kicked off the event with a brief speech to the elementary and middle school children.

"Carderock is a place where math and science come together to aid in the defense of our country," Vandroff said. "We are very proud of what we do here and hope to encourage individuals in our community, and students at all levels, of the power of math."

The morning, written-test portion of the event consisted of sprint and target rounds

Students work to solve timed math problems during the countdown round portion of the Carderock Math Contest on April 13, 2018, at Naval Surface Warfare Center, Carderock Division in West Bethesda, Md. (U.S. Navy photo by Jake Cirksena/Released)

and concluded with a team round. The top scorers in the morning competitions moved on to the main event, the oral countdown round, answering advanced math questions for speed in a bracket-style tournament.

Naama Ende, vice president of the parent-teacher organization at Gesher Jewish Day School in Fairfax, Virginia, said she was excited to be at Carderock, but even more excited to see the children interacting with their peers and the staff.

"Many of these children have never been on a Navy base, so it's enjoyable to see them being able to meet with the commanding officer," Ende said. "It means a lot to me to see them engaged with the math contest and funny jokes on the walls, and just being able to see how much math affects their world. My children still talk about the camaraderie and fun they had when they were here years ago, because to them math is really cool."

Students also toured various facilities across Carderock to gain a better understanding of what the engineers and scientists do there every day. The David Taylor Model Basin; the Manufacturing, Knowledge and Education (MAKE) Lab; and the Subsonic Wind Tunnel were a few of the highlight tours, in addition to other hands-on engineering-based activities focused on ship design.

Carderock scientists and engineers helped proctor and score the tests, lead tours and speak with the students about their careers.

In his fifth year on the CMC committee, Dr. Charles Fisher, a materials engineer with Carderock's Welding, Processing and Nondestructive Evaluation Branch, led the team of 13 volunteers who he said worked tirelessly throughout the year to ensure the event was as successful and engaging as possible.

"We want to encourage students to see how they can use the skills here at the math contest to become engineers, naval architects or ship designers," Fisher said, adding that he was very proud to be part of this event. "When I was their age I had help, and I want to pass that along so they aren't discouraged about their future. So it's not solely about the math contest, we want to keep them excited and engaged about how this can help guide their career path."

Nelson Dellis, a four-time USA Memory Champion and one of the leading memory experts in the world, was the guest speaker for the event and gave a few examples of how anyone can train their brain.

Traveling the world as a competitive memory athlete, memory consultant, mountaineer and Alzheimer's disease activist, Dellis preaches a lifestyle that combines fitness, both mental and physical, with proper diet and social involvement.

Dellis said that he was born with an average memory, but the passing of his grandmother from Alzheimer's disease in 2009 inspired him to start training his memory so that he could keep his mind strong and healthy throughout his lifespan.

"You might think I was born with this skill, but I had an average memory until about seven years ago," Dellis said. "Through techniques and practice any one of you can do what I and other competitors do at memory competitions. Even things that seem impossible can be accomplished by anyone with a little bit of guidance."

Nelson is the founder of Climb for Memory, a non-profit charity that aims to raise awareness and funds for Alzheimer's disease research through mountain climbs all around the world, and has climbed numerous peaks for this cause, including Mount Everest three times.

The event made a big impact on attendees both young and old.

Brian Heller, chaperone with the team from Joyce Kilmore Middle School in Vienna, Virginia, said the Carderock Math Contest continues to be a great experience for him and his team, and he hopes to continue coming back each year.

"This is kind of a well-kept secret," Heller said. "We didn't know this contest existed until last year, but I am glad we came again this year because it continues to be a well-organized event for the children.

Experimental and computational fluid-structure interaction studies of a semi-planing hull

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ABSTRACT

Current structural design methods for high speed naval craft (HSNC) rely heavily on empiricism. These structural design methods saw reliable employment for a number of years but an unknown level of conservatism exists in the prediction of wave impact loads and structural responses. An improved physical understanding of the HSNC dynamic responses in waves allows for improved structural optimization and understanding of structural failure risks.

Naval Surface Warfare Center Carderock Division performed a secondary loads test with Model 5365 of the *R/V Athena* in October 2017 Testing conducted in the semi-planing regime involved panels and transducers to measure pressure loads, and involved two different stiffened grillage panels to measure strain responses. The test conditions included regular and irregular head waves.

The October 2017 test results are compared with computational fluid dynamics and computational structural dynamics simulations of fluid-structure interaction. These simulations perfomred by CFDShip-Iowa V4.5 employ a tightly coupled, one-way and two-way fluid-structure interaction between secondary pressure loads and stiffened grillage panel. Comparisons between test results and CFDShip-Iowa V4.5 predictions are limited in this paper to regular wave conditions. Comparisons in irregular wave conditions are planned for future studies.

Motions and forces from the October 2017 secondary loads test compared well with the JUL15 test results, particularly for pitch and vertical accelerations. The agreement between these two tests demonstrated reproducibility, which allowed the CFD grids validated with JUL15 test results to be applied for additional secondary loads simulations in regular waves.

The absolute errors for regular wave results are normalized on the October 2017 data range (*DR*) (i.e. %|*E*|/*DR*) to avoid dividing by small, or zero, values. The averaged errors from the mean, RMS, and mean peak absolute errors are used as a generalized comparison with CFDShip-Iowa V4.5 simulations. The average absolute errors are 6.2%*DR* and 4.7%*DR* for resistance and motions (combined heave, pitch, and vertical accelerations) respectively. Simulations of hull bottom pressure and side panel (grillage) pressure have average absolute errors of 2.7%*DR* and 14.3%*DR* respectively. The average absolute errors for grillage pressure and grillage strain are 14.3%*DR* and 18.6%*DR* respectively. However, the mean peak error for grillage pressure and grillage strain are 29.9%*DR* and 43.5%*DR* respectively. These large grillage pressure and strain errors are attributed to small pressure loads from the spray sheet along the side of the hull.

INTRODUCTION

The Office of Naval Research (ONR) Ship Systems and Engineering Research Division currently supports a small craft science and technology (S&T) program for investigation of hydrodynamics and structural optimization related to high speed naval craft (HSNC). This program seeks an improved physical understanding of the HSNC dynamic responses from high fidelity experimental fluid dynamics (EFD). Comparisons of high fidelity EFD test results and complimentary computational fluid dynamics (CFD) and computational structural dynamics (CSD) simulations allow for the future evaluation of HSNC design methods. In particular, the design methods of interest are described in Allen *et al.* (1978) and the American Bureau of Shipping (ABS) rules for HSNC (2017).

The secondary loads test in October 2017 (OCT17) includes similar test conditions to prior model tests in November 2014 (NOV14) and July 2015 (JUL15), with the additional collection of secondary structural loads (i.e. panel pressures and grillage panel strains). The October 2017 (OCT17) secondary structural loads test objectives were;

(1) establish a calm water baseline for comparison with the July 2015 test,
(2) evaluate conservativism in design pressure load methods,
(3) evaluate conservatism in the design area factor applied to empirical methods, and
(4) comparisons of grillage panel stain measurements with fluid-structure interaction (FSI) simulations.

Model 5365 is a λ=8.25 scale model of the *R/V Athena (ex-USS Chehalis)*. The *R/V Athena* is a converted *PG-84 Asheville-Class* patrol gunboat. The *R/V Athena* and Model 5365 are depicted in Figure 1 and Figure 2. The OCT17 test is a captive test with a tow post at the longitudinal center of gravity (LCG) and grasshopper fixture allowing pitch and heave motions, and conducted from Carriage 2 in the Naval Surface Warfare Center Carderock Division (NSWCCD) deep water basin. The model mass properties are nominally the same as the JUL15 test configuration. The OCT17 vertical center of gravity (VCG) is lower than the JUL15 VCG to better align with the gimbal pitch axis.

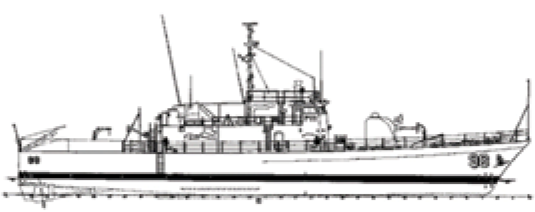


Figure 1. Full Scale *R/V Athena*

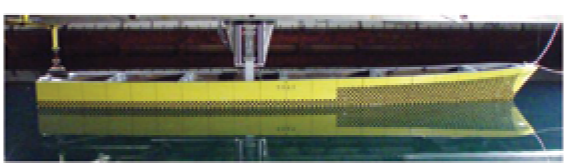


Figure 2. Model 5365 Floating Static Condition

The OCT17 test matrix is a reduced set of test conditions from the JUL15 test with a focus on high speeds and high sea states. This focus allows for development of extreme value distributions for acceleration, pressure, and strain at a representative safe operating envelope limit. The OCT17 test matrix consists of a low speed (Froude number *Fr*=0.432), a high speed (Froude number *Fr*=0.617), one regular wave condition at the high speed, and two irregular wave conditions at both the low and high speeds. The two irregular wave conditions represent a full-scale sea state 3 (SS3) condition and a full-scale sea state 4 (SS4) condition as defined in North Atlantic Treaty Organization Standardization Agreement (NATO STNAG) 4194. The NSWCCD wavemaker calibrations nominally produced Bretschneider spectrums for the SS3 and SS4 irregular wave conditions. The regular wave condition represents the irregular waves following the method applied to the JUL15 test results and described in Diez *et al.* (2013). The regular wave height has the same energy (i.e. same wave elevation standard deviation) as the SS4 wave condition, and the regular wave period is the same as the peak period of SS3 wave condition.

The data acquisition system (DAS) and sensor arrangements are similar to the prior tests in 2014 and 2015. Sensors installed for the OCT17 secondary loads test include;

(1) vertical accelerometers,
(2) pressure transducers,
(3) pressure panels nominally representing full-scale hull panels,
(4) a grillage panel nominally representing full-scale stiffened panel (i.e. GP-B configuration), and
(5) a grillage panel with reduced structural stiffness to produce greater strain responses (i.e. GP-A configuration).

Installation locations for pressure transducers and pressure panels are based on prior CFDShip-Iowa predictions of areas with high pressure loading. Accelerometers, pressure transducers, and pressure panels are co-located on the model hull to provide complementary data sets to characterize dynamic responses and support comparison with simulations.

The pressure transducers are located on the opposite side of the hull from the pressure panels and are aligned with the panel centers. These mirrored locations provide measurement redundancy and allow correlation between these two different pressure measurements. The pressure transducers have small sensing areas that provide high-resolution measurements of peak pressures. The pressure panel measurements provide an equivalent uniform static pressure that represents the non-uniform pressure distribution on the panel. The relationship between a non-steady pressure pulse and an equivalent uniform static pressure is described in Allen *et al.* (1978).

The comparisons between test results and FSI simulations from CFDShip-Iowa in this paper focus on one pressure panel location (out of six panel locations) and the corresponding grillage panel location. Comparison data from the pressure panel location includes co-located measurements and simulations of panel pressure, transducer pressure, and vertical acceleration. Comparison data for evaluation of strain predictions focus on the low stiffness grillage configuration (GP-A) that has a smaller stiffener height than the high stiffness configuration (GP-B). The low stiffness GP-A grillage configuration produces larger strain responses than the GP-B configuration, which allows for better discrimination of grillage strain responses. The grillage panels have nine strain gages along the top surface of the stiffeners (interior facing), and are oriented longitudinally. The strain gage at center of the GP-A middle stiffener (i.e. grillage panel center) is the focus of test result comparisons with FSI simulations from CFDShip-Iowa. Additional comparison data includes transducer pressures, vertical accelerations, and panel pressure at the center of the grillage panel.

EXPERIMENTAL APPROACH

The OCT17 test has a calm water phase and a regular wave phase to support program and test objectives. The data uncertainty analysis follows the methods established in Coleman and Steele (2009), and methods applied in the prior JUL15 and NOV14 tests, which are described in Lee *et al.* (2016). The uncertainty analysis method consists of general terminology for statistical variables such as the data value (D), simulation value (S), bias uncertainty for systematic effects (B), precision uncertainty for random effects (P), and total uncertainty of the combined bias and precision uncertainties (U). The data reduction equations (DREs) for total resistance pitch are the same as the DREs developed for the JUL15 test. These DREs are not presented again here for brevity. No DRE is applicable to sinkage (heave) since that is measured directly. The accelerations, transducer pressures, panel pressures, grillage pressure, and grillage strain are direct measurements from calibrated sensors that do not require DREs to characterize bias uncertainty.

A matrix of test conditions including run durations and wave encounters are provided in Table 1. These test conditions are a sub-set of test conditions conducted with Model 5365 in July 2015 (JUL15), and described in Lee *et al.* (2016) and presented at the 31st Symposium on Naval Hydrodynamics. CFD/CSD FSI simulations in irregular waves are ongoing and are not presented in this paper.

Baseline Calm Water Performance

The first test phase establishes a calm water (CW) performance baseline at the same conditions as the JUL15 test. Comparisons of OCT17 and JUL15 calm water performance ensures that model modifications and test procedures are consistent with the JUL15 test. The calm water baseline data includes total resistance, sinkage (heave), and pitch angle. The tow post, fixtures, and instrument configurations are similar to the JUL15 test, with the tow post and gimbal located at the target LCG and VCG positions. To conduct the test efficiently, the number of calm water runs performed are less than the number of runs performed for the JUL15 test. However, the reduced number of runs are conducted over a longer total duration. This longer run duration mitigates the difference in statistical degrees of freedom between the OCT17 and JUL15 calm water runs. The statistical variables used for comparison are mean values for:

(1) total resistance (X),
(2) sinkage at CG (z_{CG}), and
(3) pitch angle (θ).

Baseline Dynamic Responses in Regular Waves

The second phase of the OCT17 test establishes a baseline of dynamic responses in regular waves (RW) at the same conditions as the JUL15 test. This baseline data includes vertical accelerations and transducer pressures for comparison. Additional baseline data includes panel pressure, grillage panel pressures, and grillage panel strains. JUL15 test results do not include panel pressure and grillage strain. In the future, the regular wave baseline responses will be compared with the dynamic responses from operation in irregular wave (IW) conditions. At least 100 regular wave encounters (for each grillage configuration) are considered sufficient to give statistically reliable mean and root mean square (RMS) values. This number of wave encounters corresponds to 1.74 minutes at model scale, and 5.00 minutes at full scale.

The regular wave condition represents an irregular wave condition following approach in the JUL15 test, and described in Diez *et al.* (2013). The regular wave condition was derived from a SS4 wave height and a SS3 peak period to represent a single, severe operating condition for comparison with simulations. The regular wave height (H_{RW}) has an equivalent energy to the SS4 irregular wave condition (i.e. $H_{\mathbf{RW}} = 2\sqrt{2}(\sigma_\zeta) = 2\sqrt{2}\,(H_S/4)$). The regular wave period (T_{RW}) is equivalent to the SS3 wave peak period (T_P) from the period spectrum ($S^+(T)$). The spectral relationship between the period spectrum ($S^+(T)$) peak period and the frequency spectrum ($S^+(f)$) modal frequency ($f_o=1/T_o$) is based on the Bretschneider spectrum as described in Michel (1999), and summarized as: $T_{\mathbf{RW}} = T_{\mathbf{P}} = (3/5)^{1/4}T_o$.

Six pressure panels for the secondary loads test represent non-stiffened panels of *R/V Athena* full-scale scantlings. These panels measure pressure over the area inside their panel boundary, providing an equivalent uniform static pressure (p_{avg}) representation of the complex impact pressure distributions. The maximum pressure (p_{max}) within a panel (or transducer) exposure area is more detectable as the exposure area decreases since a larger sensor area smooths (or averages) the complex pressure distribution. This attenuates the localized maximum pressures that may be detected within a pressure sensor's exposure area. The relationships between maximum impact pressure, equivalent uniform static pressure, exposure area, and bottom slamming design pressure are described in Hoggard and Jones (1980), Allen *et al.* (1978), and ABS Rules for HSNC (2017).

The comparison variables for the regular wave baseline include the mean, RMS, and mean peak values for,

(1) total resistance (X),
(2) heave at CG (z_{CG}),
(3) pitch (θ),
(4) vertical acceleration at CG ($\ddot{z}_{CG}$),
(5) vertical acceleration at pressure panel 5 ($\ddot{z}_{PP5}$),
(6) transducer pressures (*PT*),
(7) panel pressures (*PP*),
(8) grillage panel pressures (*GP*), and
(9) grillage panel strains (*GS*).

EXPERIMENT SETUP

Model and Instrument Configuration

Model 5365 was constructed in 1979 with plywood web frames, wooden longitudinal stiffeners along the deck-sheer edge, and a fiberglass-resin composite single skin hull. A 2017 scan along selected feature lines, station lines, and waterlines verified the 2002 model surface measurements. The 2017 verification scan also identified a 0.2° trim angle discrepancy between the waterlines marked on the physical hull and the digital geometry model. This discrepancy prevents the use of model hull markings for verification of loading in a floating static condition.

NSWCCD Carriage 2 tows the bare hull model at the center of gravity and is free to pitch and heave. The physical model is rigged onto the carriage such that the digital model centerline is aligned with the direction of travel.

Table 2 provides a summary of model hydrostatics, mass properties, particulars, and associated uncertainty intervals as configured for this secondary loads test. The as-tested mass properties are generally less than 1% difference from the JUL15 target values. The OCT17 VCG is 17% lower than the JUL15 VCG, since the ballast weights are lower to better align the center of gravity with the gimbal pitch axis.

All instruments were calibrated prior to testing to determine voltage scale factors and bias uncertainties. These pre-test calibrations are traceable to National Institute of Standards and Technology (NIST) calibration documents. Pre-test calibrations are perfomed in an end-to-end procedure that includes the as-tested cables, data acquisition hardware, and data acquisition software.

String potentiometers mounted between the model and the underside of the carriage measure sinkage (heave) at selected locations. These locations include the bow, stern, and the tow post aligned with LCG. Running pitch angle calculations with the bow and stern heave measurements gives an angle relative to the floating static condition. The floating static trim angle adds onto the running pitch angle to give a total pitch angle relative to the earth horizontal. The tow post mounted string potentiometer gives a direct measurement to sinkage (heave) at the model's LCG. Figure 3 illustrates the arrangement of these string potentiometers. The string potentiometers are

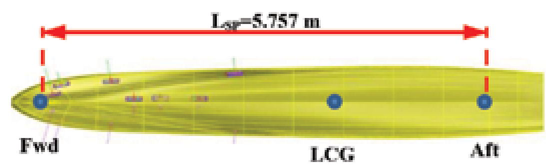


Figure 3: String Potentiometer Arrangement

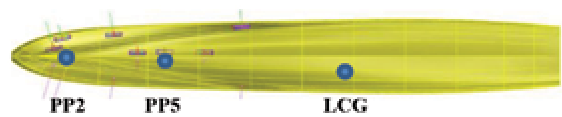


Figure 4: Accelerometer Arrangement

Table 1. Test Matrix

Fr	Grillage	Wave Type	Wave Height, *H* (m)	Enc. Wave Period, T_{enc} (s)	No. Runs	No. Wave Encounters	Duration (min)
0.432	GP-A	CW	-	-	3	-	4.25
0.617	GP-A	CW	-	-	2	-	1.73
				Total=	5	-	5.98
0.617	GP-A	RW	0.157	1.002	2	100	4.25
0.617	GP-B	RW	0.157	1.002	2	110	1.73
				Total=	4	210	5.98
0.432	GP-A	SS3	0.117	1.038	3	177	3.78
0.432	GP-B	SS3	0.117	1.038	3	171	4.75
				Total=	6	348	8.53
0.617	GP-A	SS3	0.116	0.894	6	219	5.50
0.617	GP-B	SS3	0.116	0.894	6	218	5.50
				Total=	12	437	11.00
0.432	GP-A	SS4	0.216	1.259	8	391	12.14
0.432	GP-B	SS4	0.216	1.259	8	390	12.67
				Total=	16	781	24.81
0.617	GP-A	SS4	0.215	1.047	13	418	11.42
0.617	GP-B	SS4	0.215	1.047	18	610	16.50
				Total=	31	1028	27.92

UniMeasure model number PA-50-004 with an average bias uncertainty of 1.3 mm.

Installed accelerometers are aligned with pressure panel two (*PP2*), with pressure panel five (*PP5*), and with the LCG. These aligned accelerometer locations, illustrated in Figure 4, allow for correlation of pressure and vertical acceleration measurements. These accelerometers are Silicon Designs model number 2260-025 with an average bias uncertainty of 0.030 (g).

The model's pressure and grillage panels are located in areas of high loading as indicated by prior testing and CFD predications. These panel locations are limited to local areas of hull flatness where the panel frames do not protrude more than 2.54 mm from the hull surface. This constraint minimizes disturbance to the boundary layer flow. A set of pressure transducers are installed on the opposite side of the hull from the panel centers. Figure 5 illustrates the arrangement of the panels and transducers.

Seven pressure transducers (identified as *PT1* through *PT7* in Figure 5) mount to the starboard side of the model at mirror image locations from the panel centers. These pressure transducers measurements are relative to the ambient atmospheric conditions. The installed pressure transducers are Honeywell 19 mm Series model number 19C005PG2K with an average bias uncertainty of 0.27 kPa. These pressure transducers have a range of 0 to 34.5 kPa and are configured for temperature compensation between 0°C and 82°C.

Six pressure panels are distributed on the model to measure wave impact secondary loads (identified as *PP1* through *PP6* in Figure 5). The scaled non-stiffened pressure panel design represents the full-scale scantlings of *R/V Athena*. The pressure panels consist of Type 1 PVC plate membranes with a modulus of elasticity (E_{PVC}) of 2.83 (GPa), an approximate Poisson's ratio of 0.4, and an approximate density of 1.38 g/cm^3. The panel support frames are made of EvoLVe128 stereo lithography material (SLA) and installed in the fiberglass hull with epoxy bedding. The SLA frames and epoxy bedding are considered sufficiently stiff and act as a completely rigid support along the panel boundary. Figure 6 details the pressure panel dimensions (147.6 x 36.3 mm) and strain gage configuration. The panel strain gages (Micro Measurements model number ED-DY-125PC-10C/E) are calibrated in air to give pressure measurements relative to atmosphere. The pressure panels have an average bias uncertainty of 0.090 kPa. The pressure panel strain gages are in a differential configuration that only provides pressure measurements.

The grillage panel plate and stiffener elements are the same Type 1 PVC material as the pressure panels. The grillage frame has the same SLA material and epoxy bedding as the pressure panels. The configuration of the grillage panel structural elements and their dimensions (147.3 x 146.8 mm) are illustrated in Figure 7. The GP-A low stiffness grillage configuration has stiffener dimensions of L x W x H = 147.3 x 11.4 x 5.8 mm. The GP-B high stiffness configuration has larger stiffeners with dimensions of L x W x H = 147.3 x 11.4 x 13.0 mm. The three stiffeners in each grillage panel have the same location

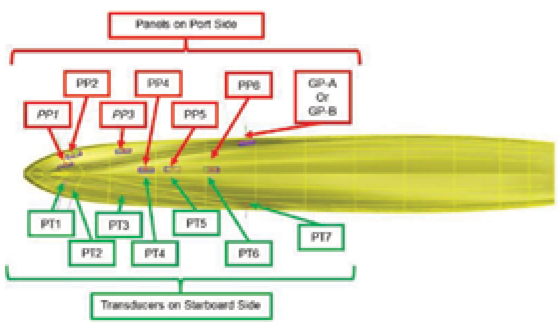


Figure 5. Arrangement of Panels and Transducers

Table 2. Model 5365 Particulars and Test Configuration

Parameter	Units	OCT17 Mean (*D*)	Total Uncertainty (U)	*U*%*D*	JUL15 Mean (D_{JUL15})	Diff %D_{JUL15}
Scale ratio, λ	-	8.25	-	-	8.25	-
Motion Degrees of Freedom	-	Heave, Pitch	-	-	Heave, Pitch	-
Length Between Particulars, LBP	m	5.68960	0.00092	0.016%	5.68960	-
Displaced Mass, Δ_m	kg	389.73	0.65	0.167%	389.18	0.139%
Basin Density at 23.00±0.14°C, ρ	kg/m^3	996.890	0.046	0.005%	996.820	0.007%
Basin Kinematic Viscosity, ν	m^2/s	1.0837E-04	4.9E-07	0.450%	1.0757E-04	0.751%
Longitudinal Center of Gravity, LCG	m +AFP	3.2497	0.0057	0.174%	3.2506	-0.028%
Vertical Center of Gravity, VCG	m +ABL	0.2047	0.0027	1.31%	0.2461	-16.8%
Longitudinal Center of Tow Point, LTP	m +AFP	3.2497	0.0057	0.174%	3.2161	1.04%
Vertical Center of Tow Point, VTP	m +ABL	0.1954	0.0042	2.15%	0.1953	0.027%
Pitch Mass Moment of Inertia about CG, I_y	kg-m^2	758	12	1.64%	781	-2.91%
Pitch Radius of Gyration about CG, k_y	m	1.395	0.012	0.825%	1.417	-1.53%
Draft at CG Above Baseline, T_{CG}	m	0.1860	0.0012	0.624%	0.1868	-0.462%
Static Trim Angle from Baseline, Θ_D	deg. +bow ↑	0.113	0.060	52.7%	0.119	-4.86%
+AFP = positive values aft of the forward perpendicular, +ABL = positive values above the baseline						

within the GP-A and GP-B assemblies. The plate thickness for both GP-A and GP-B is 2.29 mm.

The grillage panel has 14 strain gages that output raw voltages from differential strain gages and from single strain gages. The five differential strain gages, circled in red on Figure 7, only give panel pressure measurements (GP01 to GP05). The remaining single strain gages, circled in green on Figure 7, give both pressure (*GP06* to *GP14*) and strain measurements (*GS06* to *GS14*). The grillage pressure channels have an average bias uncertainty of 0.48 kPa. The strain channels have an average bias uncertainty is 2.2 μ-ε for GP-A and 23.0 μ-ε for GP-B. All strain measurements are oriented longitudinally with the grillage stiffeners. Positive strain values correspond to stiffeners bending inward, and negative strain corresponds to stiffeners bending outward.

Facility Description

Testing was conducted in the NSWCCD deep-water basin from Carriage 2. The deep basin is approximately 575 m long, 15.5 m wide, with a maximum depth of 6.71 m. Carriage 2 has a maximum towing speed of 10.3 m/s. Test speeds for all conditions have a total uncertainty (U) less than 0.05% and differ from the JUL15 test by less than 0.07%. All test runs are towards the wavemaker, which gives head sea encounters into the uni-directional wave fronts.

Wavemaker settings for generating regular waves are a blower speed of 310 rpm and a plenum valve frequency of 0.435 Hz. These regular wave settings are unchanged from the JUL15 test.

A set of three wave sensors are arrayed about the model to capture the encountered wave. These acoustic wave sensors (Senix model number TSPC-15S-23) have an estimated bias uncertainty of 2.79 mm. One wave sensor is mounted on the carriage forward of the bow. The other two wave sensors are mounted on the carriage on the port side of the model, outboard of the LCG and *PP5*. These two wave sensors are located outside of the model's wake. This wave sensor set is depicted in Figure 8, facilitates measurement of the wave surface. The wave sensor mounted forward of the bow gives the most representative measurement of the undisturbed wave surface. This forward sensor provides the reported wave parameters in this paper.

The water depth during the test is 6.31 m for calm water runs and 5.95 m when operating in waves. At the highest test speeds, these basin water levels give depth (h) Froude numbers of F_{rh}=0.571 and F_{rh}=0.570 respectively. The lowest basin cross section blockage coefficient occurs with the basin water depth lowered to 5.95 m when testing in waves. This gives a cross section blockage coefficient of A_{basin}/A_x=845, which is much greater than a minimum value of 200 typically used at NSWCCD.

EXPERIMENTAL RESULTS

Measurements from the secondary loads test include 27 pressure channels from the panels and transducers; 9 strain channels; 12 force and moment channels from two block gages; 9 channels for motions; and 3 channels from wave sensors. The analysis presented in this paper focuses on areas with highest secondary structure loading and on tensile strain measurements at the center of the GP-A grillage configuration.

Pressure transducer five (*PT5*) measures the largest pressures, which is co-located with pressure panel five (*PP5*) and a vertical accelerometer. The high loading in this area would control the full-scale design of a secondary structure. Pressure transducer seven (*PT7*) and grillage panel pressure four (*GP04*) are co-located with their sensor centers aligned on opposite sides of the hull. These two pressure sensors provide comparable measurements with different sensitivities to peak pressure loads. GP-A grillage

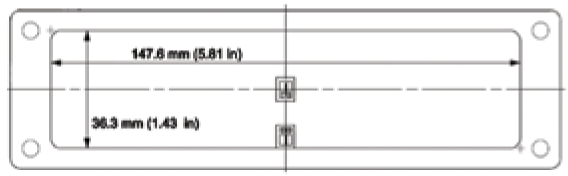


Figure 6. Pressure Panel Dimensions and Strain Gage Arrangement

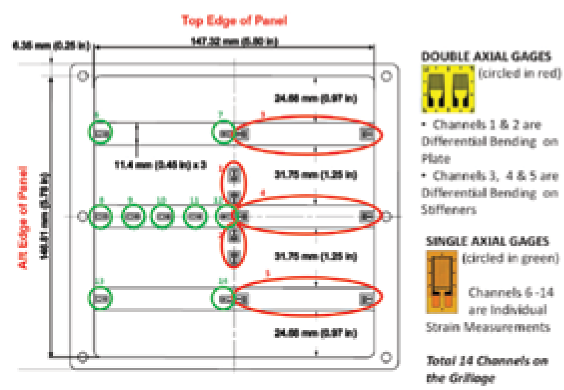


Figure 7. Grillage Panel Dimensions and Strain Gage Arrangement

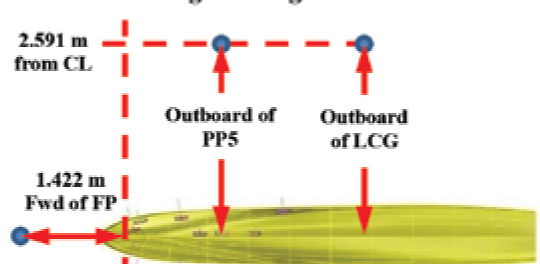


Figure 8. Wave Sensor Arrangement

pressures *GP01*, *GP02*, and *GP09* have calibration anomalies attributed to their locations on structural curvature inflection points and are ignored for analysis. These grillage pressure channels exhibited no calibration anomalies with the GP-B grillage configuration.

A majority of the grillage strain measurements are collected along the middle stiffener (i.e. channels *GS08* to *GS12*). This middle stiffener also has a larger strain response than the other stiffeners in the grillage panel. The prominence of these strain responses provide the best set of data for comparison with FSI simulations.

The regular wave height and period for OCT17 test RUN#15 are 0.157 m and 1.001 s respectively. The regular wave height and period for JUL15 test RUN#179 are 0.157 m and 1.002 s respectively. The regular wave condition between RUN#15 and RUN#179 are effectively the same and verify consistency between the OCT17 and JUL15 regular wave results.

The following test results also include an uncertainty analysis with estimated bias (systematic) and experimental precision (random) components. The bias uncertainty values come from instrument calibrations for direct measurements, or from data reduction equations (DREs) that combine multiple sources of uncertainty.

For calm water analysis, the total uncertainty values are derived from the experimental precision and estimated bias uncertainties following the Coleman and Steele approach with the degrees of freedom as described in Coleman and Steele (2009). The degrees of freedom (ν) in this approach is taken as one less than the number of independent test runs (i.e. $\nu = N_{runs}-1$).

For regular wave analysis, the mean, root mean squared (RMS), and mean peak values are determined via a block bootstrap method, with 10 regular wave cycles as the block length. This bootstrap method samples within the single test run (i.e. RUN#15 and RUN#179) to estimate both the statistical values and their associated precision uncertainties. The sensor calibration data provides the bias uncertainties.

The uncertainties are estimated at a 95% confidence level, giving a 95% probability that the true mean value lies within the reported confidence interval (i.e. $\mu_{true} = D \pm U$). All results are unfiltered except for accelerations. Acceleration data are filtered with a 6th order Butterworth, zero phase delay, low pass filter at a 100 (Hz) cutoff frequency. The digital filtering parameters are the same as the JUL15 filtering parameters for acceleration data. Acceleration peak identification follows the procedures described in Riley and Coats (2012).

Calm Water

Calm water baseline data includes total resistance (X), sinkage at CG (x_{CG}), and trim (steady) angle (θ). This baseline is compared with JUL15 test results to verify reproducibility as summarized in Table 3 and Figure 9. Total resistance is determined from two separate dynamometers. The primary forward dynamometer is located between the tow post and gimbal, and the other dynamometer is located aft between a grasshopper fixture and the transom. The aft dynamometer forces are measured in a body fixed reference frame that are transformed to an earth fixed resistance component, consistent with the forward dynamometer.

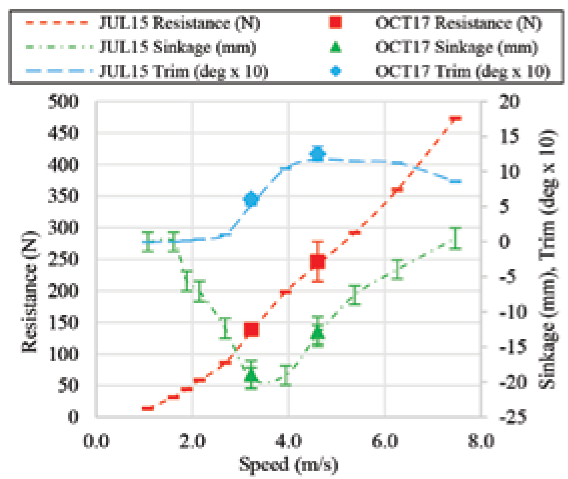


Figure 9. Comparison of Calm Water Results

Table 3. Test Results in Calm Water

Speed (m/s)	Fr	ν	Mean Resistance, X (N)								
			P	B	U	D	%P²/U²	%B²/U²	%U/D	D_{JUL15}	Diff. D (%D_{JUL15})
3.228	0.432	2	5.5	5.5	7.8	138.5	49.9%	50.1%	5.6%	135.0	2.5%
4.610	0.617	1	23.3	21.3	31.6	246.2	54.5%	45.5%	12.8%	241.8	1.8%
Speed (m/s)	**Fr**	**ν**	**Mean Sinkage at CG, z_{CG} (mm +up)**								
			P	B	U	D	%P²/U²	%B²/U²	%U/D	D_{JUL15}	Diff. D (%D_{JUL15})
3.228	0.432	2	1.9	0.5	1.9	-18.9	93.0%	7.0%	-10.3%	-19.5	-2.7%
4.610	0.617	1	2.1	0.5	2.1	-12.8	94.2%	5.8%	-16.6%	-13.2	-3.1%
Speed (m/s)	**Fr**	**ν**	**Mean Trim Angle, θ (deg +bow up)**								
			P	B	U	D	%P²/U²	%B²/U²	%U/D	D_{JUL15}	Diff. D (%D_{JUL15})
3.228	0.432	2	0.005	0.060	0.060	0.607	0.8%	99.2%	9.86%	0.521	16.5%
4.610	0.617	1	0.085	0.060	0.104	1.256	66.8%	33.2%	8.25%	1.173	7.1%

Trim angle is calculated from the floating static trim angle (θ_o), the forward string potentiometer (σ_{FSP}), and the aft string potentiometers (σ_{ASP}). Derivation of the resistance and pitch angle data DREs are described in Lee *et al.* (2016). The running pitch angle for NOV14 and JUL15 calm water runs are reported in Lee *et al.* (2016) and Fullerton *et al.* (2017).

Regular Waves

The regular waves test-phase consists of two runs with the GP-A grillage configuration (RUN#15 and 18), and two runs with the GP-B grillage configuration (RUN#76 and 78). The first regular wave runs of the day (RUN#15 and RUN#76) are closest to the overall mean and have the lowest standard deviation. This regularity is attributed to the glassy water surface and lack of basin seiching at the start of a test day. The first runs of the day are RUN#15 and #76 corresponding to GP-A and GP-B grillage configurations respectively. The presented regular wave results are limited to RUN#15 with the GP-A configuration since that low stiffness grillage panel has the largest strain response.

RMS pressure from *PT5* and *PP5* are generally small but appreciably larger than the uncertainty intervals. The RMS pressures for *PT7* and *GP04* are very small, which is attributed to minimal immersion and emergence of the grillage panel in regular waves. The grillage panel is generally exposed to an intermittent spray sheet that partially runs along the hull surface during an impact event. This intermittent wetting produces low pressure loads with air entrained in the spray sheet. This intermittent sheet wetting and entrained air may contribute to the high frequency content in *PT7*.

The grillage pressure is ideally measured with differential strain gages oriented transversely on the panel plate. This transverse gage orientation decouples the in-plane hull girder stains from the out-of-plane pressure loading on the panel surface. These ideal grillage pressure channels are GP01 and GP02 are not available for the GP-A configuration due to calibration anomalies. *GP04* is the next best grillage pressure channel for GP-A. However, the *GP04* strain gages are oriented longitudinally and measures in-plane stain as out-of-plane panel pressure.

The pressure impact events measured by panel channels *PP5* and *GP04* exhibit a negative dip in pressure approximately 0.18 seconds before these panels make contact with the spray sheet. This behavior is attributed to the hull girder structure in a momentary sag condition that induces an in-plane compression on the panels. The in-plane compression occurs as the tolerance between the panel edges and panel fame are clamped together in a binding contact. In-plane tension on the *GP04* occurs when the hull is in a hogging conditions, but the four machine screws that fasten the panels into the panel frame transfer less stretching force than the clamping force exerted on the panel edges during hull sagging.

The estimated location of the hull girder elastic neutral axis is below the middle stiffener as indicated in Figure 10. The grillage strain gage calibrations give positive pressure values when the exterior surfaces is exposed to out-of-plane loading. When the grillage panel experiences in-plane compression, these panel pressure channels give generally small negative values. This in-plane compression effect is minimal on *PP1* through *PP6* since their differential strain gage arrangements is oriented perpendicular to longitudinal hull strains.

The grillage pressure and strain impacts are identified as magnitudes over the impact rise time to capture the out-of-plane panel loading, and mitigate the effects of in-plane compression. Figure 11 shows the effects in-plane compression on the GP-A grillage

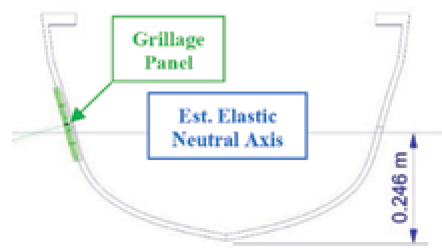


Figure 10. Estimated Location of Elastic Neutral Axis at Grillage Panel

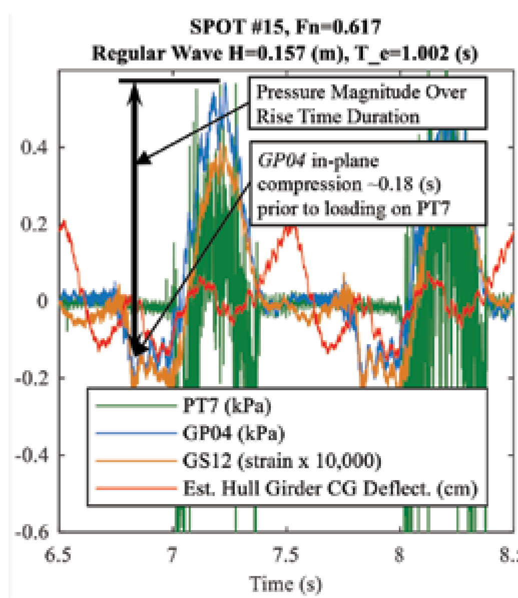


Figure 11. Grillage Pressure and Strain Impacts

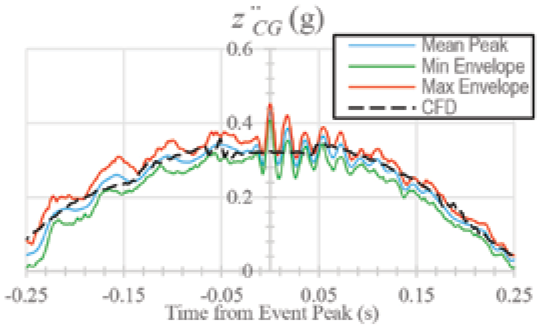


Figure 12. $\ddot{z}_{CG}$ Aggregate Acceleration Peak

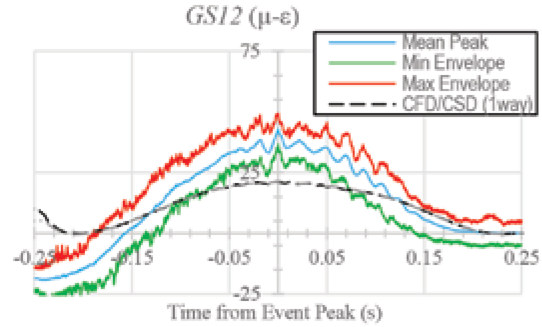


Figure 15. *GS12* Aggregate Tensile Strain Peak

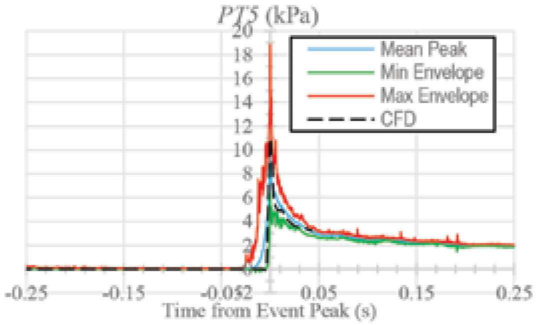


Figure 13. *PT5* Aggregate Pressure Peak

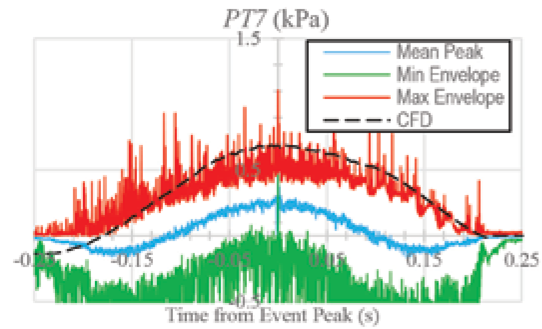


Figure 16. *PT7* Aggregate Pressure Peak

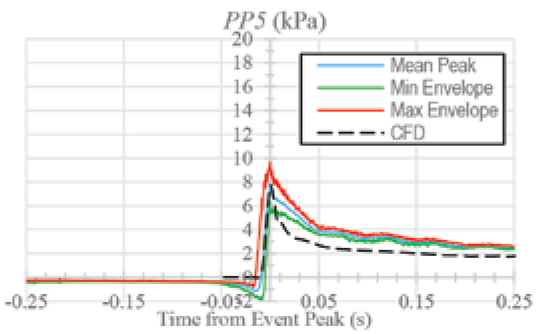


Figure 14. *PP5* Aggregate Pressure Peak

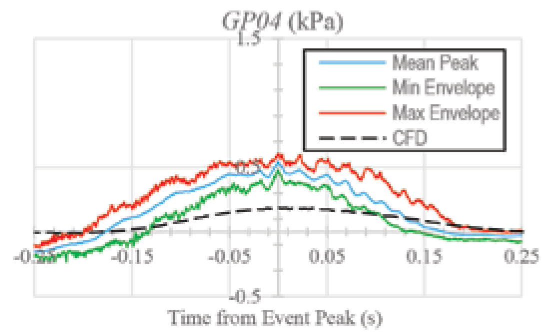


Figure 17. *GP04* Aggregate Pressure Peak

pressure and strain, and illustrates the magnitude over rise time from a negative initial value to positive peak. Table 4 provides a summary of test results for the OCT17 test RUN#15 with comparisons of results from JUL15 test RUN#179. Figure 12 through Figure 17 display the aggregated events peaks for the comparison variables given in Table 4. These aggregated peaks are determined by averaging each sample over at ±0.25 s interval about the RUN#15 peak events. These figures also include the corresponding aggregate peaks from the CFDShip-Iowa simulations.

CFDSHIP-IOWA SIMULATIONS: BACKGROUND, OBJECTIVE, APPROACH, AND NUMERICAL RESULTS

CFD has shown the capability of predicting motions and primary/secondary loads for semi-planing and planing hulls in calm water and waves, including the assessment of motions and loads during slamming. Early CFDShip-Iowa studies for the Delft catamaran slamming in regular and irregular waves were presented by He *et al.* (2013), where no experimental data was available. Later, Mousaviraad *et al.* (2015) presented regular and irregular wave slamming of the Fridsma hull with comparison to EFD, whereas Fu *et al.* (2014) described CFD and EFD studies of the United States Naval Academy (USNA) model

Table 4. Test Results in Regular Waves: OCT17 RUN#15 & JUL15 RUN#179

OCT17 Regular Waves Results: RUN #15, V=4.61 m/s Fr=0.617, H_{RW}=0.157 m, $T_{enc,r}$=1.002 s, GP-A Grillage Configuration															
Comparison Variables	Units	v	Data Range DR	D_{OCT17}			$U_{OCT17}\%DR$			D_{JUL15}			$(D_{OCT17}-D_{JUL15})\%D_{JUL15}$		
				Mean	RMS	Mean Peak	Mean	RMS	Mean Peak	Mean	RMS	Mean Peak	Mean	RMS	Mean Peak
X	N	40	653.8	291.9	331.0	548.8	0.4%	0.4%	1.3%	293.00	325.89	482.00	-0.4%	1.6%	13.9%
z_{CG}	mm	40	202.2	-3.16	67.48	95.26	0.4%	0.3%	0.7%	-3.42	71.32	101.35	-7.6%	-5.4%	-6.0%
θ	deg	40	6.0	1.574	2.511	4.334	1.0%	1.0%	1.2%	1.6094	2.5013	4.3100	-2.2%	0.4%	0.6%
$\ddot{z}_{CG}$	g	40	0.9	0	0.279	0.432	3.2%	3.2%	3.2%	0	0.295	0.431	-	-5.4%	0.3%
$\ddot{z}_{PP5}$	g	40	1.5	0	0.489	0.649	1.9%	1.9%	2.0%	-	-	-	-	-	-
PT5	kPa	40	19.0	1.57	1.99	10.44	0.6%	0.6%	3.3%	-	-	-	-	-	-
PP5	kPa	40	11.6	1.68	2.36	8.41	1.2%	1.2%	2.7%	-	-	-	-	-	-
PT7	kPa	40	2.8	0.01	0.14	0.88	3.4%	3.4%	3.7%	-	-	-	-	-	-
GP04	kPa	40	0.9	0.06	0.21	0.72	16.4%	16.4%	16.4%	-	-	-	-	-	-
GS12	μ-ε	40	78.3	3.3	17.0	61.7	6.3%	6.3%	6.3%	-	-	-	-	-	-

slamming in regular and irregular waves. This USNA model is cited in prior papers and reports as the General Prismatic Planing Hull (*GPPH*). More recently, Lee *et al.* (2016) and Fullerton *et al.* (2017) presented CFD and EFD studies of the model in calm water. CFDShip-Iowa studies of the model in regular waves were performed by Mousaviraad and Stern (2017). Lee *et al.* (2017) presented benchmark testing of the *GPPH* model for validation of CFD tools in calm water.

In addition to CFD, FSI simulations predicted secondary loads and structural deformation and strain of high-speed planing hulls, including applications to real world problems. Volpi *et al.* (2017) presented one- and two-way CFD/CSD FSI simulations from Lehigh University's high-speed slamming load test facility (*SLTF*) including full-scale validation of slamming responses of composite bottom panels during sea trials.

Simulations were able to correctly identify pressure and strain trends and predict the effects of different composite layouts. On average, both CFD and CFD/CSD FSI studies of primary/secondary loads for laboratory and sea conditions provide quite large validation errors and uncertainties. Table 5 provides a summary of validation errors (E) and uncertainties (U) for input wave, force, and motions from earlier CFD/EFD studies (using D as notation for data values). The input wave height presents an average 12% error compared to theoretical values with a 6% uncertainty. Force and motions have an average error of 9% and 25%, with uncertainties smaller than 2%.

Table 6 provides a summary of validation errors and uncertainties for pressure and strain from earlier slamming studies. Re-entering and emerging pressure peaks errors (24.6% and 27.5% respectively) have an average 26.1% error with an average 9.2% uncertainty. The re-entering strain peak have a 28.8% error with 16.0% uncertainty. Remarkably, laboratory tests and sea trials present similar errors and uncertainties indicating the need for larger sets of experimental data and finer grid simulations to reduce validation errors and uncertainties.

Table 5. Summary of Errors and Validation Uncertainties for Input Wave, Force, Motions from Earlier Regular/Irregular Wave Studies

Value	Wave height[1]		Force[2]		Motions[3]	
	$E\%I^4$	$U\%I^4$	$E\%D$	$U\%D$	$E\%D$	$U\%D$
Ave	11.85	5.94	9.30	1.24	24.99	1.45
Min	2.49	0.74	0.11	0.68	0.34	0.56
Max	49.04	21.13	26.83	1.53	238.30	4.30

[1]EFD values for EV and SD of regular (*GPPH*, Model 5365) and irregular wave studies (Fridsma, *GPPH*, Delft Cat., 5415M)
[2]Average/Min/Max values based on 0^{th} and 1^{st} harmonics for regular waves (Model 5365) and EV and SD for irregular waves (Fridsma and Delft Cat.)
[3]Average/Min/Max values based on heave, pitch, acceleration 0^{th} and 1^{st} harmonics for regular waves (Fridsma, *GPPH*, Model 5365) and EV and SD for irregular waves (Fridsma, *GPPH*, Delft Cat., 5415M)
[4]I represent the desired ideal value

The objective of the present research is to perform high fidelity CFD/CSD FSI of grillage panel slamming on the model under regular wave conditions, reducing validation errors and uncertainties compared to earlier studies. A collaborative effort between University of Iowa and NSWCCD teams comparing simulations with experimental results achieved these objectives.

Preliminary blind simulations were performed under regular wave conditions from JUL15 experiments (namely RUN #179). A new set of experiments was collected (OCT17) and the associated wave conditions (RUNs #15 and #76) were found equivalent to those of the earlier experiments, as differences in mean encounter period and wave height are small and within the uncertainty intervals. Earlier CFDShip-Iowa (V4.5) studies for RUN #179 were conducted by Mousaviraad and Stern (2017) applying both regular wave and wave group approaches. Three grids were developed with systematic refinement and size ranging from 11 to 46 million grid points. Average errors of zero-th to third harmonics amplitude and phase for *X* force, heave and pitch motions, acceleration at CG and bow, and pressure at a specified location (namely probe *P11*) were found equal to 6.86% (regular wave) and 6.51%*DR* (wave group), where *DR* is the data range. For the same variables, the simulation numerical uncertainty ranged from 8% to 35%*S*, where *S* is the simulation value on the finest grid.

Herein, the simulation approach includes partitioned solvers for fluid and structure: CFDShip-Iowa V4.5 and ANSYS Mechanical V14.5. The fluid dynamics is studied by unsteady Reynolds-averaged Navier-Stokes (URANS) equation with a single-phase level-set method, integrated with a six degree of freedom (6DOF) solver for the rigid-body motions (Huang *et al.* 2008). Compared to earlier RUN #179 studies, the medium grid (27 million points) has a smaller tolerance for the turbulence, level set, momentum solvers, and the velocity-pressure coupling. Pressure probes (panels and transducers) are investigated at new locations, based on OCT17 experiments. The structural dynamics are modeled through modal expansion. FSI is evaluated by one- and two-way coupling of hydrodynamic loads and structural deformations. Two-way coupling is achieved tightly within each time step. The study presents modal analysis and CFD/CSD FSI results of two grillage panel designs (GP-A and GP-B, having different stiffener thickness) mounted at two different locations (one at the actual experimental location, one at the hull bottom). The experimental location is on the hull side and in an area of minimum curvature, unfortunately it demonstrates small hydrodynamic loads. Therefore, a virtual location at the bottom (overlapping with *PP5*) was selected for assessing the effects of larger loads as those studied in earlier research for *SLTF*. The panels are flat in the CSD domain, whereas in the CFD domain they follow the hull curvature. Effects of the curvature might be significant and will be studied in future research.

Computational Methods

The solution of the FSI problem is achieved over the separate fluid, structure, and dynamic mesh partitions, in a sequential or iterative fashion. Although generally this approach conserves momentum and energy only in an asymptotic sense, the approach offers several appealing features, including the ability to use available high-fidelity tools specifically designed for complex industrial problems, with well-established discretization and solution methods within each discipline, and preservation of software modularity. Accuracy and robustness of partitioned methods depends on both the conservation properties at the interface and the convergence properties of the non-linear iterations. Convergence of ship hydrodynamics inner iterations is also a critical issue for rigid structures, as CFD usually couples with the ship rigid-body equation of motion.

The two-way coupling of partitioned solvers can be loose or tight. In a loose coupling (also referred to as weak, staggered, or explicit) the structural deformation feeds back into the CFD only at the beginning of the time step. In a tight coupling, also referred to as strong or implicit, fluid and structure solvers exchange load and deformation in an iterative manner using non-linear inner iterations (such as predictor/corrector steps) until convergence within each time step.

<u>Computational Fluid Dynamics (CFD) and rigid body motions</u>

Continuity and URANS equations model the hydrodynamics and compute the hydrodynamic loads *f*. Turbulence is modeled by isotropic Menter's blended *k-ω/k-ε* model. A single-phase level-set method is used for the free surface. Finite difference schemes are used on body-fitted curvilinear grids to discretize the continuum equations with second order implicit Euler backward difference time integration. The convective velocities are linearized when solving the momentum equations, but are changed within the

Table 6. Summary of Errors and Validation Uncertainties for Pressure and Strain from Earlier and Current Regular and Irregular Wave Studies

Value	Pressure						Strain[4]			
	Re-entering slam peak[1]		Emerging slam peak[2]		Duration[3]		Re-entering slam peak		Duration	
	E%D	U_V*%D*	*E%D*	U_V*%D*	*E%D*	U_V*%D*	*E%D*[7]	U_V*%D*[8]	*E%D*[7]	U_V*%D*[8]
Average	24.6	10.7	27.5	7.7	23.4	12.0	28.8	16.0	21.0	14.7
Min	6.1	4.1	6.6	4.7	0.2	6.0	-	-	-	-
Max	48.6	15.5	75.5	12.8	56.3	24.8	-	-	-	-

[1]Average/Min/Max values based on *GPPH* 4ft and 8ft, and Model 5365 regular wave; *GPPH* 4ft and 8ft irregular wave towing tank data; and *SLTF* sea trials (average *H*p and *H*a is shown). Positive peak is shown.

[2]Average/Min/Max values based on *GPPH* 4ft and 8ft regular wave; *GPPH* 4ft and 8ft irregular wave towing tank data. Positive peak is shown.

[3]Average/Min/Max values based on *GPPH* 4ft and 8ft regular wave; *GPPH* 4ft and 8ft irregular wave towing tank data; and *SLTF* sea trials (average *H*p and *H*a is shown)

[4]Only *SLTF* sea trials available (average *Hp* and *H*a is shown). Tensile peak is shown.

nonlinear iteration loop to account for nonlinearities from turbulence equations, nonlinear momentum transport, etc. The spatial discretization of the convection terms uses a second-order upwind approach. The diffusion and pressure terms in the momentum equations are discretized using a second order central scheme. The temporal and spatial discretizations for the *k-ω/k-ε* equations are consistent with the momentum equations. The projection algorithm or the pressure implicit with splitting operator (PISO) method couples the momentum and continuity equations. Finally, a fully implicit predictor-corrector method determines the 6DOF motions. Details of equations and numerical methods can be found in Huang et al (2008).

Computational Structural Dynamics (CSD)

ANSYS finite element method (FEM) predicts the discretized modes $\boldsymbol{\varphi}_i$ and frequencies ω_i of the grillage panel. Under the small deformation assumption, the discretized displacement vector is defined as $\boldsymbol{\delta}(\boldsymbol{x},t) = \sum_{i=1}^{\infty} q_i(t)\, \boldsymbol{\varphi}_i(\boldsymbol{x})$ where q_i are solutions of $\ddot{q}_i(t) + 2\omega_i\xi_i\dot{q}_i(t) + q_i(t)\omega_i^2 = f_i(t)$ and f_i are projections of the discretized load $\boldsymbol{f}$ on the structural modes as per $f_i(t) = \int \boldsymbol{f}(\boldsymbol{x},t) \cdot \boldsymbol{\varphi}_i(\boldsymbol{x})\, d\boldsymbol{x}$. The damping ratio ξ_i is assumed proportional to the system mass and stiffness according to the Rayleigh model. The Rayleigh damping expresses the damping ratio ξ_i as $\xi_i = \alpha \frac{1}{2\omega_i} + \beta \frac{\omega_i}{2}$ where α and β are mass- and stiffness damping coefficients. A general Newmark's integration method integrates the structural dynamics. A quasi-steady approximation is applied when the simulation time step does not satisfy Shannon's theorem for the mode and frequency under investigation. The effect of boundary conditions and damping is usually significant. A parametric analysis of boundary conditions and damping coefficients may be required to optimize the structural model and achieve agreement with experimental data.

CFD/CSD Fluid Structure Interaction (FSI)

A mapping between fluid and structural nodes is used along with Gauss integration to compute $\boldsymbol{f}$ on the structural nodes. The method conserves momentum and energy asymptotically (when the discretization dimension tends to zero). Nevertheless, the grid size is deemed sufficiently small to have overall small effects on the results. Within a one-way FSI approach the structural elastic displacements are not fed back into the fluid solver. Non-linear iterations compute the rigid body motion using a predictor/corrector step. The one-way analysis may or may not account for the effects of fluid added mass by using wet or dry modes in the modal expansion. Wet modes are computed by FEM embedding the structure in a fluid domain modeled by acoustic elements. In a tightly coupled two-way approach, fluid and structural solvers exchange both hydrodynamic loads $\boldsymbol{f}$ and structural displacement $\boldsymbol{\delta}$ and velocities $\dot{\boldsymbol{\delta}}$ at each non-linear iteration, cycled within each time step. Such coupled analysis automatically accounts for the added mass effects. With the interpolation of $\boldsymbol{f}$ onto the structure grid, the two-way approach also requires the deformation of the fluid grid according to the structural displacement, within each time step.

In the following, ten dry modes are applied to both one- and two-way CFD/CSD FSI.

Numerical Results

Regular Wave Conditions

A comparison of regular wave conditions for the JUL15 and OCT17 tests presented in Table 7, demonstrates a substantial equivalence of test conditions. Specifically, differences in mean wave height and encounter period are very small and always within the associated standard deviation. For current CFD and FSI results, the conditions associated with JUL15 RUN #179 utilized for both GP-A and GP-B simulations. Simulations of OCT17 RUNs #15 and #76 will be planned and performed with finer grids and finer time steps after additional OCT17 test results are released. All simulations are performed at *Fr*=0.617. Simulation values are reported for the eight encounter period (8*T_e), which is consistent with the most representative block of waves from the test.

CSD Modal Analysis

The structural model for both modal analysis and FSI studies is composed by shell (bottom plate) and brick (grillage stiffeners) elements, as illustrated in Figure 18. Clamped boundary conditions are applied to all edges. These assumptions might be too rigid; therefore, softer conditions will be tested in the future. The total number of structural grid nodes in the simulation equals 94k. Table 8 provides the first ten dry modal frequencies evaluated by ANSYS and

Table 7. Regular wave conditions: OCT17 and JUL15 Test Results

		Wave Elevation (mm)		Mean Up-crossing Wave					
	# Enc.	EV		Enc. Period (s)		Height (mm)		*λ/L*	1/(*H*/*λ*)
RUN #	Waves	(mean)	SD	EV	SD%EV	EV	SD%EV	EV	EV
179 (JUL15)	53	-4.1E-16	56.13	1.002	3.89	156.7	11.05	1.442	52
15 (OCT7)	50	-4.6E-08	55.40	1.001	1.90	156.7	2.819	1.441	52
18 (OCT17)	50	2.4E-08	55.14	1.000	2.89	155.4	8.024	1.439	53
76 (OCT17)	55	2.7E-09	55.80	1.004	1.63	157.6	5.554	1.446	52
78 (OCT17)	55	3.6E-08	56.21	1.006	2.49	158.6	7.737	1.449	52

highest peak, larger than 10 kPa. *PT/PP 2*, *3*, and *PT7/GP04* have the lowest peaks, specifically smaller than 1 kPa. A comparison with experimental data is provided in in Table 10, as well as Figure 13, Figure 14, Figure 16, and Figure 17 for *PT5*, *PP5*, *PT7*, and *GP04* respectively. Peak pressure values for PPs and *GP04* are identified as magnitudes, as per Figure 11. Pressure errors are reasonable (less than 5.2%*DR*) for all variables but *GP04* (almost 60%*DR* for peak value). All errors fall within the data range.

<u>One- and Two-Way Coupling CFD/CSD FSI</u>

Figure 18 illustrates the location of simulation strain probes. Probes lay on the top surface of the stiffener (*GS12*, longitudinal strain measured and simulated, transverse simulated only) and plate (*GS15*, longitudinal and transverse strain simulated only). Longitudinal strains are evaluated parallel to the stiffeners, while transverse strains are evaluated perpendicular to the stiffeners. For comparison to experimental data, strain impacts are identified as magnitudes, following Figure 11.

Figure 26 (a) plots longitudinal and transverse strain at *GS12* and *GS15* for GP-A at the actual experimental locations. One- and two-way coupling have similar results. The maximum strain is found for probe *GS12* (longitudinal) with a tensile strain of 21 micro-strain μ-ε. A comparison to EFD/ESD data is included in Table 10 and is also plotted in Figure 15. Longitudinal strain peak at *GS12* is underpredicted by nearly 40%*DR*.

Figure 26 (b) plots longitudinal and transverse strains at *GS12* and *GS15* for GP-B at the as-tested location. One- and two-way coupling have similar results. The maximum strain simulated at *GS15* (transverse) and is one order of magnitude smaller than found for GP-A. The corresponding tensile strain equals 2.7 micro-strain μ-ε. Measurements for GP-B in regular waves (RUN#76) includes longitudinal strain measurements at *GS12*. These *GS12* measurements were skewed by four extreme strain events occurring in the middle of the run, and are not shown in in Figure 26 (b).

Figure 26 (c) plots longitudinal and transverse strains at *GS12* and *GS15* for GP-A virtually mounted at the *PP5* location. One- and two-way coupling have similar results. The maximum strain found for GP-A under *PP5* loads is one order of magnitude larger than experienced by the same grillage at GP location, and two orders of magnitude larger than GP-B at the GP location. The maximum strain is found for *GS12*, longitudinal, with a tensile strain of 133 micro-strain μ-ε.

The modal participation during slamming is presented in Figure 27 for: (a) GP-B at GP location,

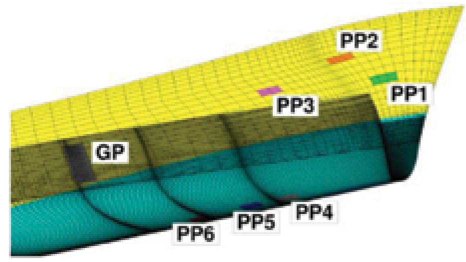
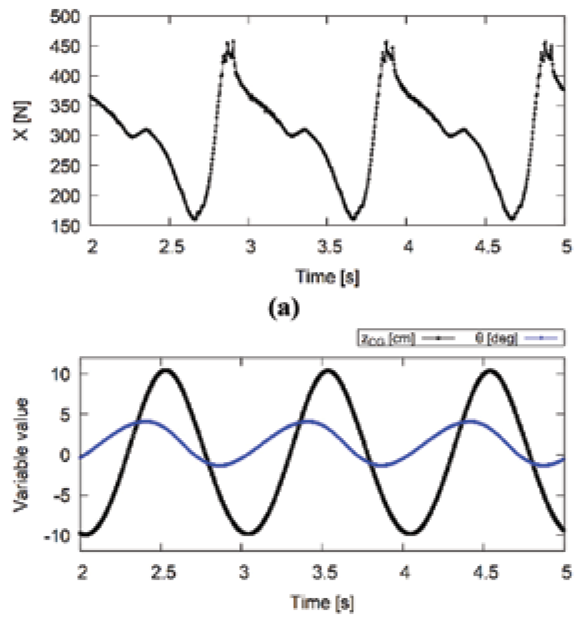


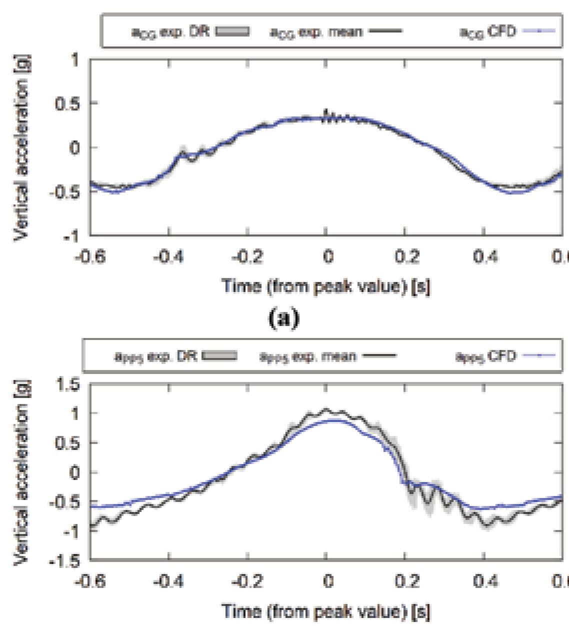
Figure 21. Detail of the CFD Body-Surface Grid



(a)

(b)

Figure 22. *X* Force (a) and Motions (b) by CFD



(a)

(b)

Figure 23. Vertical Accelerations of CG (a) and

highest peak, larger than 10 kPa. *PT/PP 2*, *3*, and *PT7/GP04* have the lowest peaks, specifically smaller than 1 kPa. A comparison with experimental data is provided in in Table 10, as well as Figure 13, Figure 14, Figure 16, and Figure 17 for *PT5*, *PP5*, *PT7*, and *GP04* respectively. Peak pressure values for PPs and *GP04* are identified as magnitudes, as per Figure 11. Pressure errors are reasonable (less than 5.2%*DR*) for all variables but *GP04* (almost 60%*DR* for peak value). All errors fall within the data range.

<u>One- and Two-Way Coupling CFD/CSD FSI</u>
Figure 18 illustrates the location of simulation strain probes. Probes lay on the top surface of the stiffener (*GS12*, longitudinal strain measured and simulated, transverse simulated only) and plate (*GS15*, longitudinal and transverse strain simulated only). Longitudinal strains are evaluated parallel to the stiffeners, while transverse strains are evaluated perpendicular to the stiffeners. For comparison to experimental data, strain impacts are identified as magnitudes, following Figure 11.

Figure 26 (a) plots longitudinal and transverse strain at *GS12* and *GS15* for GP-A at the actual experimental locations. One- and two-way coupling have similar results. The maximum strain is found for probe *GS12* (longitudinal) with a tensile strain of 21 micro-strain μ-ε. A comparison to EFD/ESD data is included in Table 10 and is also plotted in Figure 15. Longitudinal strain peak at *GS12* is underpredicted by nearly 40%*DR*.

Figure 26 (b) plots longitudinal and transverse strains at *GS12* and *GS15* for GP-B at the as-tested location. One- and two-way coupling have similar results. The maximum strain simulated at *GS15* (transverse) and is one order of magnitude smaller than found for GP-A. The corresponding tensile strain equals 2.7 micro-strain μ-ε. Measurements for GP-B in regular waves (RUN#76) includes longitudinal strain measurements at *GS12*. These *GS12* measurements were skewed by four extreme strain events occurring in the middle of the run, and are not shown in in Figure 26 (b).

Figure 26 (c) plots longitudinal and transverse strains at *GS12* and *GS15* for GP-A virtually mounted at the *PP5* location. One- and two-way coupling have similar results. The maximum strain found for GP-A under *PP5* loads is one order of magnitude larger than experienced by the same grillage at GP location, and two orders of magnitude larger than GP-B at the GP location. The maximum strain is found for *GS12*, longitudinal, with a tensile strain of 133 micro-strain μ-ε.

The modal participation during slamming is presented in Figure 27 for: (a) GP-B at GP location, (b) GP-A at GP location, (c) GP-A at *PP5* location.

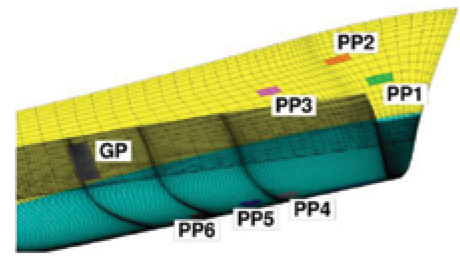


Figure 21. Detail of the CFD Body-Surface Grid

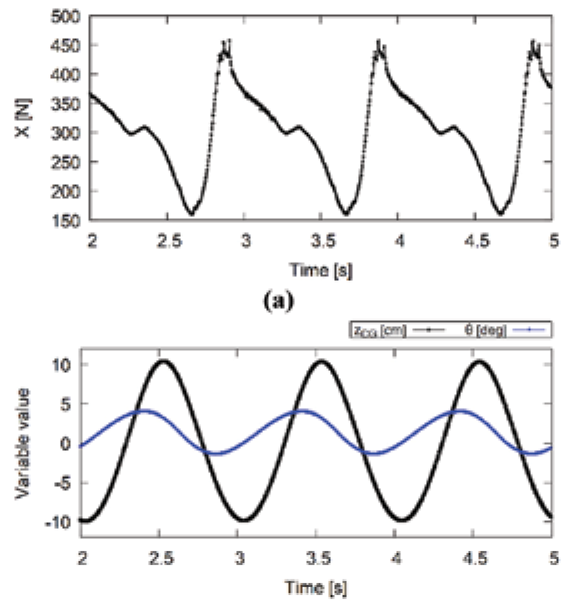


Figure 22. *X* Force (a) and Motions (b) by CFD

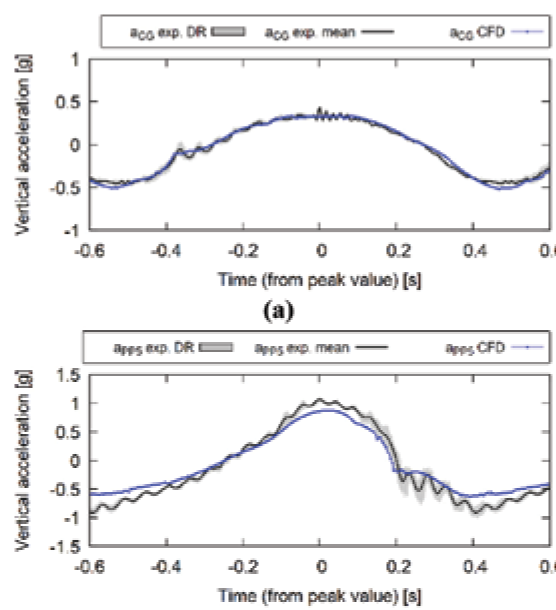
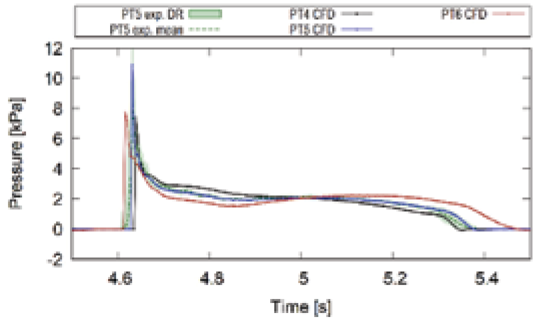
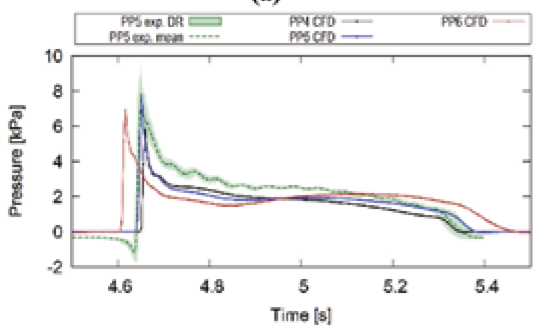


Figure 23. Vertical Accelerations of CG (a) and *PP5* (b) by CFD

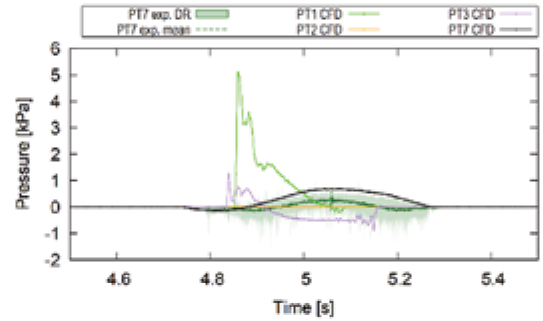


(a)

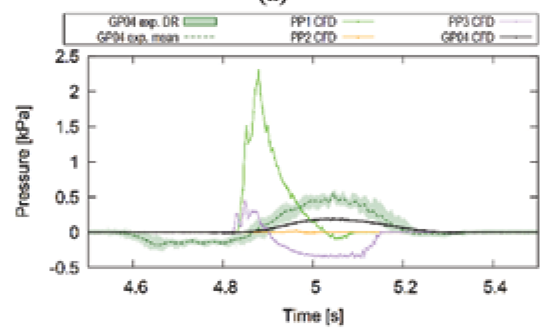


(b)

Figure 24. Local Loads at the Hull Bottom: *PT4*, *PT5*, *PT6* (a) and *PP4*, *PP5*, *PP6* (b)



(a)



(b)

Figure 25. Local Loads at the Hull Side: *PT1*, *PT2*, *PT3*, *PT7* (a) and *PP1*, *PP2*, *PP3*, *GP04* (b)

The first mode is always the most excited. Mode 1, 2, 3 and 6 resolve most of the dynamics for (a), whereas mode 1, 2, and 3 resolve most of the dynamics under conditions (b) and (c).

The effect of the structural damping on the structural displacement is depicted in Figure 28, where Rayleigh damping is applied with $\alpha=0$ and $\beta=0.05$. A very fine time step (sampling frequency equal to 2500 Hz) is applied for studying the damping effects. The maximum structural deformation (displacement) reduces by 29% with a time lag of nearly 0.05 seconds, due to damping. The future final validation needs to include proper quantification of damping from ESD.

Finally, Table 9 provides a summary of current FSI results with comparison to earlier *SLTF* studies (Volpi *et al.* 2017). In summary, differences between one- and two-way coupling FSI are small. Grillage panel GP-A (soft) versus GP-B (rigid) shows one order of magnitude larger strain at GP location (hull side). GP-A at *PP5* location (hull bottom) shows one order of magnitude larger pressure and strain than GP-A at GP location and two orders of magnitude larger strain than GP-B at GP location. GP-A at *PP5* location has nearly half pressure/strain peaks than earlier studies on *SLTF*.

CONCLUSIONS & FUTURE RESEARCH

Experimental Trends and Comparisons with JUL15 Test Results

The calm water baseline (Table 3) compares well with the JUL15 test results as demonstrated in Figure 9. The OCT17 uncertainty intervals overlapped the JUL15 test results, and the percentage differences were about 3.1% or less, except for pitch angle. Trim angle percent differences with JUL15 are 16.5%*D* and 7.1%*D* for 3.23 m/s and 4.61 m/s respectively. A portion of these pitch angle differences are attributed to the different reference surfaces for the JUL15 and OCT17 pitch angle measurements. The JUL15 reference surface is an unfinished section of the gunwale, while the OCT17 reference surface has a smooth sanded finish. The 2017 verification scan measured the OCT17 reference surface relative to the digital Initial Graphics Exchange Specification (IGES) geometry file.

Regular wave test results and simulation results are displayed in Figure 30, Figure 31, and Figure 32 for the mean, RMS, and mean peak comparison variables respectively.
The test result values for these figures are in Table 4, and the simulation results for these figures are summarized in Table 10. Table 10 provides the simulation results with comparisons to the OCT17 test

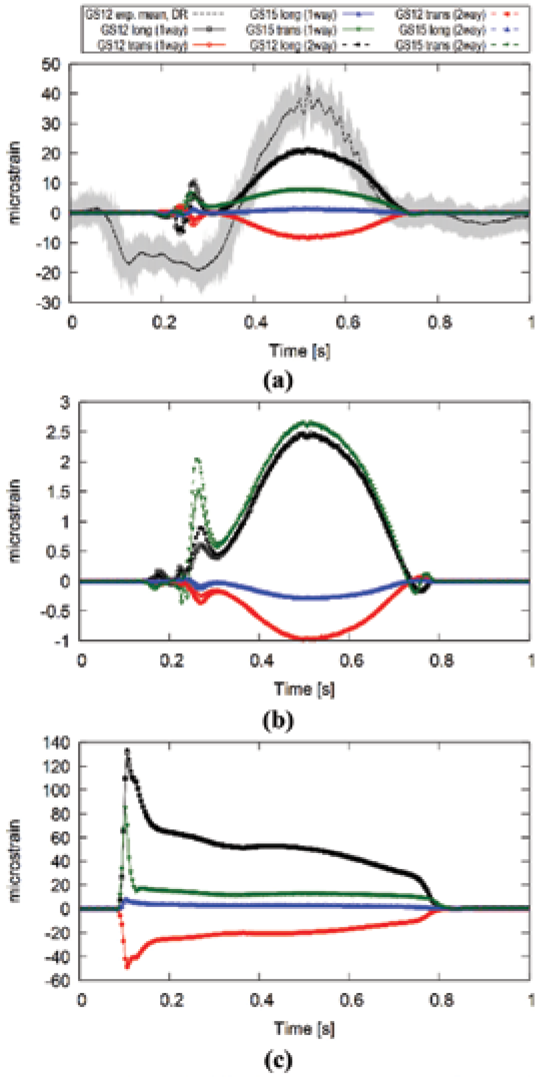


Figure 26. Longitudinal and Transverse Strain by CFD/CSD FSI: (a) GP-A at GP Location, (b) GP-B at GP Location, (c) GP-A at *PP5* Location

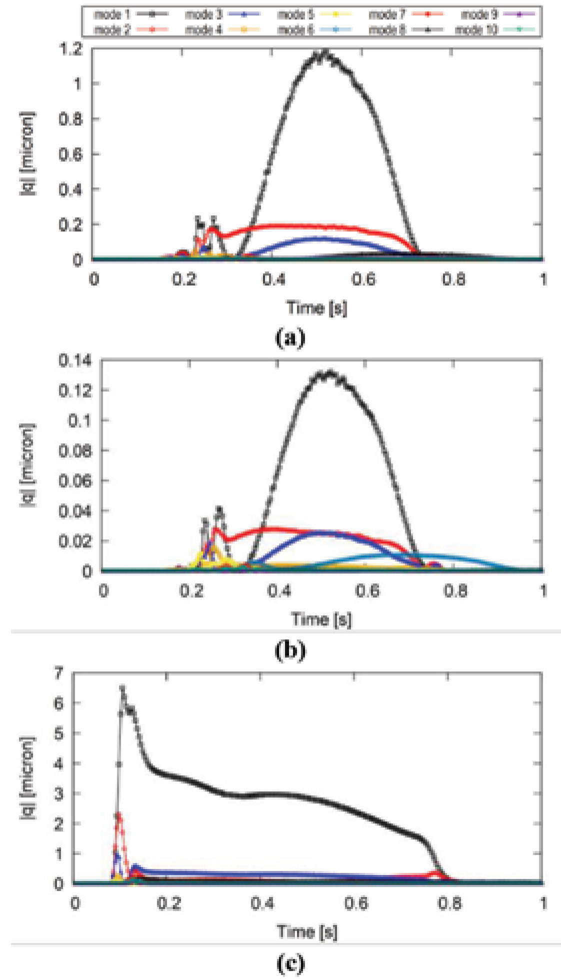


Figure 27. Modal Participation: (a) GP-B at GP Location, (b) GP-A at GP Location, (c) GP-A at *PP5* Location by FEM

results. The simulation results (S), the simulation numerical uncertainty (U_{SN}), the validation uncertainty ($U_V = (U_{SN}^2 + U_D^2)^{0.5}$), and the comparison errors ($|E|=|S-D|$) are all normalized on the data range from the OCT17 test (DR). The level of validation is evaluated via the difference between the validation uncertainty and comparison error ($|E|=|S-D|$).

Figure 30 compares the mean values between the tests and CFDShip-Iowa simulations in regular waves. CFDShip-Iowa simulations are ongoing and only simulation numerical uncertainties are available for resistance (X), Heave (z_{CG}), pitch angle (θ), and vertical acceleration at CG ($\ddot{z}_{CG}$). No mean value results are shown for vertical accelerations since these mean values are subtracted from those channels so that a zero value corresponds to steady vertical heave velocity. The mean values for resistance, heave, and

Table 9. Summary of Current FSI Results with Comparison to Earlier SLTF Studies

Panel	Condition	Location	Coupling	Sampling freq. (Hz)	Pressure		Strain (longitudinal)	
					Peak (positive) (kPa)	Duration (s)	Peak (tensile) (10E-6)	Duration (s)
GP-B	RUN #179	GP	1-Way	255	0.62	0.51	2.5	0.64
GP-B	RUN #179	GP	2-Way	255	0.62	0.51	2.5	0.64
GP-A	RUN #179	GP	1-Way	255	0.62	0.51	21	0.64
GP-A	RUN #179	GP	2-Way	255	0.62	0.51	21	0.64
GP-A	RUN #179	*PP5*	1-Way	255	10.27	0.73	131	0.74
GP-A	RUN #179	*PP5*	2-Way	255	10.89	0.73	133	0.74
SLTF	RW	Bottom	2-Way	616	21.58	0.36	204	0.48

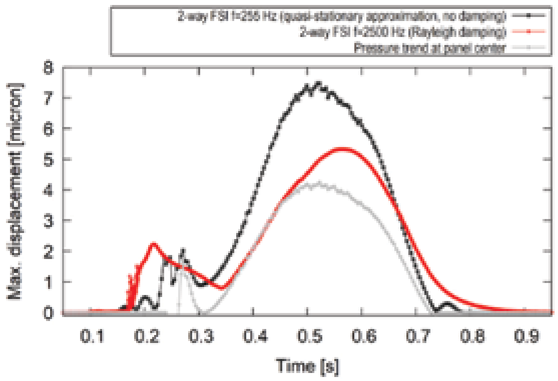


Figure 28. Effect of Structural Damping on Structural Displacement

pitch have a comparison error (|*E*|%*DR*) of 1.6%, 0.6%, and 2.7% respectively. These comparison errors are larger than the corresponding validation uncertainties (U_V%*DR*) of 0.5%, 0.4%, and 1.1%. These validation uncertainties are less than comparison errors (i.e. $U_V<|E|$) and indicates that the CFDShip-Iowa simulations of regular wave mean values do not achieve validation above the comparison error level. This is considered acceptable since the validation uncertainties are very close to the comparison errors, and the RMS and mean peak comparison errors are less than the validation uncertainties (i.e. $|E|<U_V$).

Figure 31 displays the RMS test results for the GP-A grillage in regular waves. The uncertainty intervals between the OCT17 and JUL15 overlap for pitch and for vertical acceleration at CG. These results do not overlap for resistance and Heave, but their percentage differences with JUL15 are less than 5.4%*D*. Figure 32 displays uncertainty interval trends for mean peak values that are similar to trends for RMS test results. The mean peaks percentage differences with JUL15 are less than 14.1%*D* for resistance and Heave. The OCT17 resistance mean peak value larger than the JUL15 value in regular wave is attributed to minor differences in tow post and grasshopper fixture rigging between the two tests. The RMS and mean peak discrepancies for Heave are likely due to the differences in data collection between the JUL15 and OCT17 tests. The Heave for the JUL15 test is a calculation from the forward and aft heave measurements with a rigid body assumption for hull deflection at CG. The OCT17 test Heave is a direct measurement at the towpost. The three string potentiometer measurements from the OCT17 test give an estimated standard deviation of CG hull deflection of 0.83 mm, or approximately 26% of the mean Heave. This hull deflection estimate assumes 1st bending mode between the forward and aft potentiometers.

The RMS and mean peak uncertainty intervals for grillage pressures in Figure 31 and Figure 32 are a significant portion of their measurements. This finding is attributed to the generally small pressure loading at the grillage panel and the exposure to an intermittent spray sheet with entrained air. Figure 29 illustrates the progression of this spray sheet loading onto the grillage panel. The grillage panel is constrained to this location so that edges of this flat panel do not protrude more than 2.54 mm beyond the curved hull surface.

Transducer pressure *PT7* has a lower mean value than grillage pressure *GP04* even though the grillage has a larger area. This larger grillage area would normally measure a lower equivalent uniform static pressure than the transducer. A *PT7* mean pressure less than the *GP05* mean pressure is attributed to the location of the transducer at the center of the grillage panel. This transducer location generally measures the pressure as the spray sheet propagates across its 16.5 mm diameter, whereas grillage pressure *GP04* would detect the loading of the spray sheet as soon as the spray begins to propagate across the lower edge of the panel. This difference in location and area of measurement produces a longer measurement dwell time for the panel than the transducer, which leads to a higher *GP04* mean value. However, *PT7* does have a larger mean peak value than *GP04* as expected since the smaller transducer area is better able to resolve larger peak pressures once the spray sheet reaches the center of the panel and imparts an impulsive load on the transducer.

CFDShip-Iowa Simulations and Comparisons with OCT17 Test Results

Regular wave conditions from JUL15 (RUN #179) experiments are considered for current study and compared to latest OCT17 experiments (RUN #15). Wave conditions from JUL15 and OCT17 are analyzed and found equivalent, as differences in mean encounter period and wave height are small and within the noise. A summary of current simulations is presented in Table 10, with comparison to the OCT17 experiments. Errors and validation uncertainties are presented as %*DR* to avoid normalizing with very small values such as those associated to pitch and acceleration mean values. Nevertheless, errors and uncertainties of significant variables are provided in the following also as %*D* for comparison to earlier studies.

Average error for the *X* force equals 6.2%*DR* (8.7%*D*), whereas motions (including accelerations) present an average error equal to 2.6%*DR* (12.8%*D*). Prediction of bottom transducer/panel pressure has an average error of 2.7%*DR* (6.0%*D* for peak values), whereas the grillage panel location presents an average error for pressure prediction close to 14.3%*DR* (39.6%*D* for peak values), especially due to *GP04* that is underpredicted. Strain prediction has a consistent trend to *GP04*, with an average error close to 18.6%*DR* (51.8%*D* for peak values).

Validation uncertainties are mainly based on experimental uncertainty since simulation numerical uncertainty information is limited at the current stage of the research. Average validation uncertainties for *X* force and motions are 2.9 and 2.9%*DR* respectively (5.4%*D* and 12.0%*D* respectively). Hull bottom pressure presents an average validation uncertainty of 4.2%*DR* (19.1%*D* for peak values), grillage panel pressure has an average validation uncertainty of 9.9%*DR* (16.3%D for peak values). Finally, strain has an average uncertainty of 6.3%*DR* (8.0%*D* for peak values). The larger average uncertainties (particularly for pressures and strain) illustrate the need for improved (reduced) uncertainty intervals for both simulations and experiments.

Compared to previous RUN #179 CFD studies, current results have similar errors. Comparison to other earlier CFD and CFD/CSD FSI studies (Table 5 and Table 6), force prediction shows very similar errors. Current motion prediction presents half of the error found (on average) in earlier studies. Bottom pressure peak has one third of the average error from earlier studies, whereas no comparison is available for side pressure. Current study presents a 40% error for side-panel strain peak, whereas earlier *SLTF* had a 29% error for bottom-panel strain. Overall, the current study demonstrates advancements for reduced errors. Validation intervals are similar to earlier studies.

The evaluation of the free surface by the current single-phase level set method could be one of the causes for underpredicting *GP04* values. Finer free-surface grid and/or volume of fluid methods

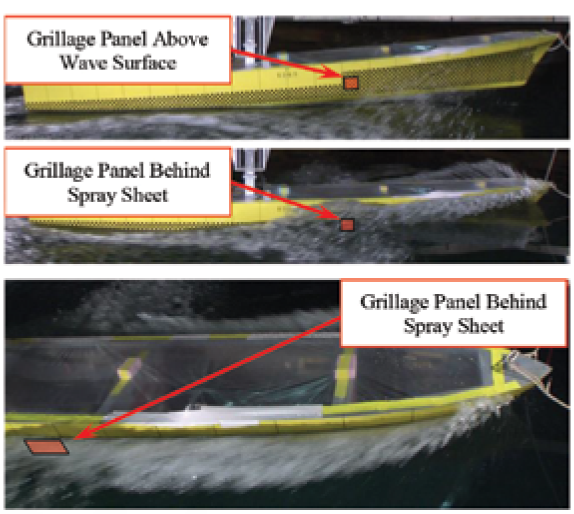


Figure 29. Spray Sheet Loading on Grillage Panel

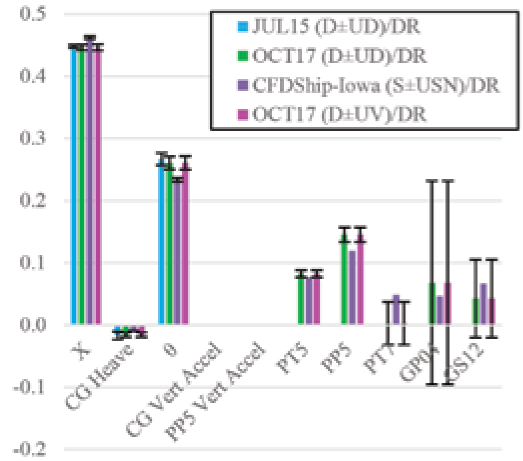


Figure 30. Regular Wave Results: Mean Non-Dimensional on Data Range DR_{OCT17}

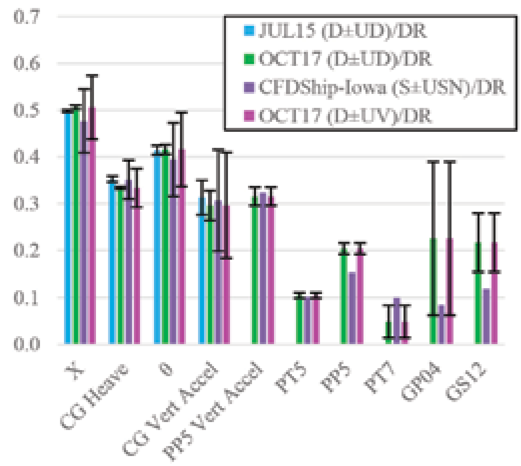


Figure 31. Regular Wave Results: RMS Non-Dimensional on Data Range DR_{OCT17}

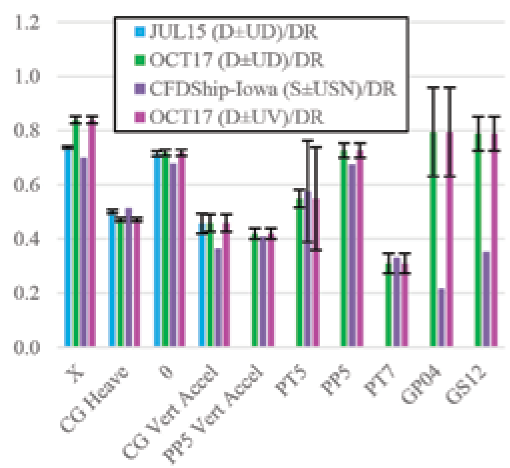


Figure 32. Regular Wave Results: Mean Peak Non-Dimensional on Data Range DR_{OCT17}

Table 10. Comparison of Test Results and FSI Simulations

OCT17 Regular Waves Results: RUN #15, V=4.61 m/s Fr=0.617, H_{RW}=0.157 m, $T_{enc,r}$=1.001 s, GP-A Grillage Configuration
CFDShip-Iowa V4.5 CFD and 2-way coupling CFD/CSD FSI

Comparison Variables	Units	Data Range DR	S (CFDShip-Iowa)			$\%U_{SN}/DR$			$\%U_V/DR=\%(U_D^2+U_{SN}^2)^{0.5}/DR$			$\%\lvert E\rvert/DR=\%\lvert S-D_{OCT17}\rvert/DR$			
			Mean	RMS	Mean Peak	Mean	RMS	Mean Peak	Mean	RMS	Mean Peak	Mean	RMS	Mean Peak	Avg. $\%\lvert E\rvert/DR$
X	N	653.8	302.2	311.7	457.0	0.2%	6.8%	-	0.5%	6.8%	1.3%	1.6%	2.9%	14.1%	6.2%
z_{CG}	mm	202.2	-1.93	71.0	103.8	-0.01%	4.1%	-	0.4%	4.1%	0.7%	0.6%	1.7%	4.2%	2.2%
Θ	deg	6.0	1.409	2.379	4.093	0.3%	7.9%	-	1.1%	7.9%	1.2%	2.7%	2.2%	4.0%	3.0%
$\ddot{z}_{CG}$	g	0.9	0	0.289	0.343	-	10.8%	-	-	11.3%	3.2%	-	1.1%	9.4%	3.5%
$\ddot{z}_{PP5}$	g	1.5	0	0.501	0.633	-		-	-	1.9%	2.0%	-	0.8%	1.0%	0.9%
PT5	kPa	19.0	1.47	1.93	10.95	-	-	18.7%	0.6%	0.6%	19.0%	0.5%	0.3%	2.7%	1.2%
PP5	kPa	11.6	1.38	1.78	7.81	-	-	-	1.2%	1.2%	2.7%	2.6%	5.0%	5.2%	4.3%
PT7	kPa	2.8	0.14	0.28	0.94	-	-	-	3.4%	3.4%	3.7%	4.6%	5.1%	2.1%	3.9%
GP04	kPa	0.9	0.04	0.08	0.20	-	-	-	16.4%	16.4%	16.4%	2.2%	14.1%	57.7%	24.7%
GS12	μ-ε	78.3	5.2	9.3	27.6	-	-	-	6.3%	6.3%	6.3%	2.4%	9.8%	43.5%	18.6%
Average of absolute values	X					0.2%	6.8%	-	0.5%	6.8%	1.3%	1.6%	2.9%	14.1%	6.2%
	Motions (including accelerations)					0.1%	7.6%	-	0.7%	6.3%	1.8%	1.7%	1.4%	4.7%	2.6%
	Pressure at hull bottom (*PT5*, *PP5*)					-	-	18.7%	0.9%	0.9%	10.8%	1.6%	2.7%	3.9%	2.7%
	Pressure at GP location (*PT7*, *GP04*)					-	-	-	9.9%	9.9%	10.0%	3.4%	9.6%	29.9%	14.3%
	Strain (*GS12*)					-	-	-	6.3%	6.3%	6.3%	2.4%	9.8%	43.5%	18.6%

(currently implemented in CFDShip-Iowa V5.5) are planned for future studies.

GS12 values are underpredicted, consistent with *GP04* results. Nevertheless, *PT7* values are slightly overpredicted. This suggests the need for structural model validation versus ESD data (modal frequencies, static/dynamic loading tests, etc.) to assess and tune material properties, boundary conditions and damping before CFD/CSD FSI is performed. The underlying structural model/boundary conditions to *GP04* pressure measurement could also explain differences in pressure magnitude compared to *PT7*. Future studies will address structural model validation via dedicated tests by instrumented shakers.

Differences between one- and two-way coupling FSI are small for all Model 5365 cases (less than 5%), whilst earlier studies for *SLTF* had differences of one- versus two-way coupling FSI larger than 20%. Grillage panel GP-A versus GP-B has one order of magnitude larger strain, evaluated at the actual experimental location (hull side). GP-A virtually mounted at the hull bottom has one order of magnitude larger pressure and strain than GP-A at the actual location and two orders of magnitude larger strain than GP-B at the actual location. GP-A at the bottom location has nearly half pressure/strain peaks than earlier studies on *SLTF*.

Future Work

In the future, Model 5365 CFD/CSD FSI results will be compared to the OCT17 secondary loads test results and new finer grid/time step simulations will be planned and performed for both regular and irregular waves. CFDShip-Iowa V5.5 is planned. Grid studies for CFD/CSD FSI simulations will be carried out with the assessment of momentum and energy conservation on the fluid/structure interface. Softer boundary conditions will be tested for the grillage panel and compared to current results and experiments. Effects of curvature will also be evaluated. Longer simulations will be performed to evaluate all relevant statistics. Validation variables will be mean, standard deviation/RMS, and possibly distributions/ quantiles (Diez *et al.*, 2017).

The location of the grillage panel and relatively small loads and strain make the interpretation of current validation effort difficult, as the significant physical variables are characterized by small values with large ranges/uncertainties. For this reason, CFD/CSD FSI will be applied in 2018 to drive the design of a new *GPPH* experiment, with more suitable flat/replaceable slamming panels mounted at more significant locations, to be performed in 2019, and finally compared to experimental results in 2020. Possibly, CFD/CSD driven structural design optimization studies will be performed on *GPPH* for optimizing structural performance subject to FSI conditions.

ADMINISTRATIVE INFORMATION

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