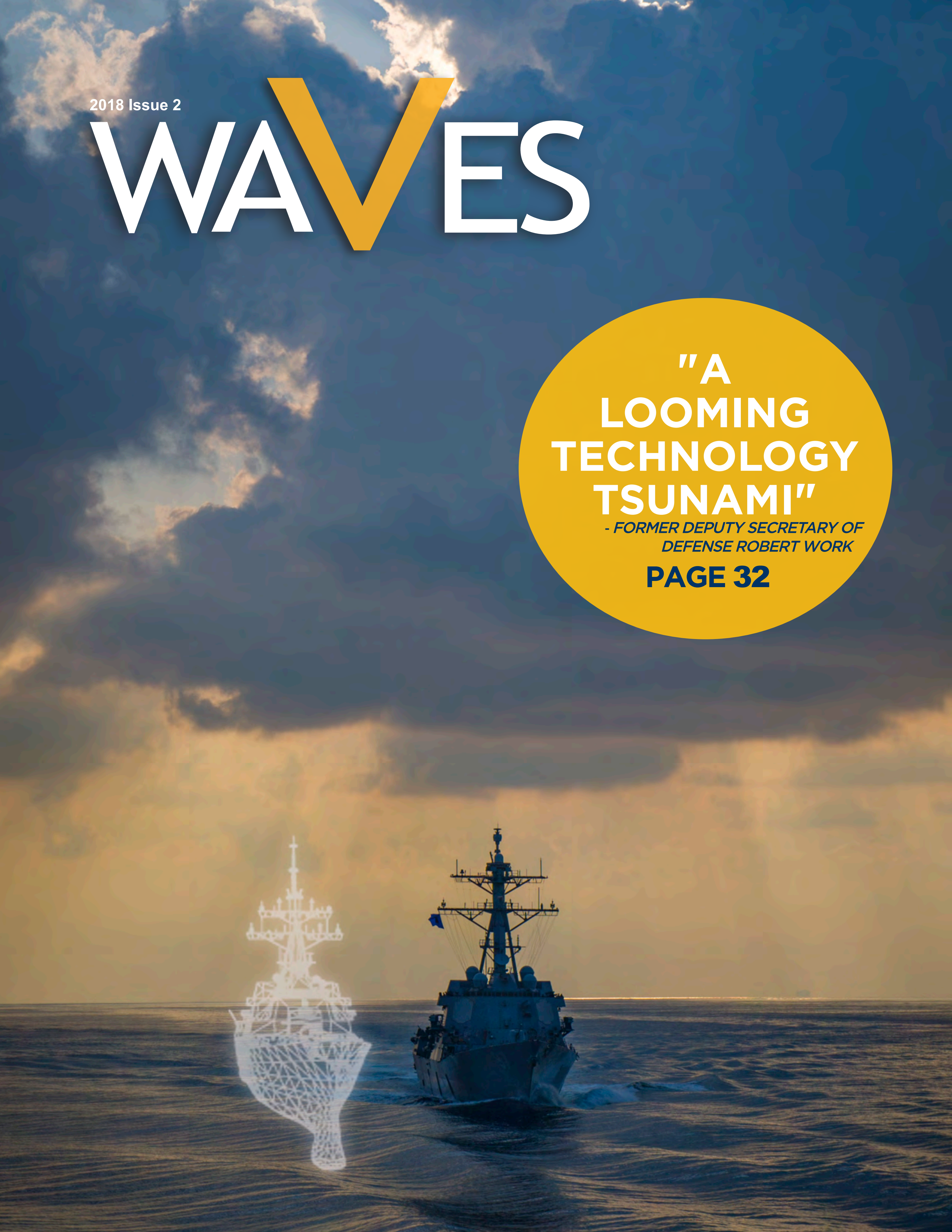
2018 Issue 2

WAVES



"A LOOMING TECHNOLOGY TSUNAMI"

- FORMER DEPUTY SECRETARY OF DEFENSE ROBERT WORK

PAGE 32

Contents

In this issue

The world of ever-evolving science and technology continues to change and emerge at a geometric rate. In a relatively short amount of time, we have found ourselves standing at the brink of a tsunami, a whole new revolution in harnessing the power of big data and artificial intelligence.

The significant advances in amassing and using big data will take the Navy to new frontiers that cannot yet even be imagined. Carderock's role in the development of advanced platforms and systems, enhanced naval performance, integrated new technologies and reduced operating costs, is a natural role for us in shaping big data to build Navy Digital Twin-Platforms.

History has taught us that future wars will be waged in far different ways than any we've fought before. For sure, we can no longer afford to be complacent and we don't want to get caught scrambling to meet new threats. Instead, we need to start now by making quantum-leap changes in the fleet to meet future challenges. New engineers coming out of universities today, with their new ways of thinking as a result of a lifetime of digital media immersion, should be given prominent places at the research table.

Industry is already using and developing digital twins, but not on the vast scale that the Navy needs. If we want to continue to expand the advantage given to our warfighters, we can waste no time. We must move out with a sense of urgency to take advantage of this new revolution coming upon us.

We've dedicated an entire section of this issue to the world of big-data analytics and digital twin. Carderock has started a data-analytics community of practice in order to network ideas, tools and solutions for managing the large amounts of data we collect through research, design and evaluation. Digital twin, while not a new concept, is going to take the Navy and Carderock to a whole new level of operating, managing maintenance and planning missions in a smarter way.

We need to change attitudes to encourage sharing information with other tech codes and warfare centers and use communication tools that allow for greater sharing and crowd-sourcing ideas. You will also see highlighted in this issue information about the Rear Adm. David Taylor Naval Architecture Series, and new Education Partnership Agreements. But our bread and butter is in our technical excellence, so we wanted to showcase that by adding a new spotlight section on people, patents and technical posters, as well as a new section in the magazine for recently cleared technical papers authored by Carderock engineers and scientists and their research partners.

All the best, and enjoy Waves,

Dr. Paul Shang
Acting Technical Director
Head, Signatures Department

Cover

A digital twin is a virtual representation of a platform where scenarios can be preformed before being tested on the actual platform. (Graphic illustration by Bob Kurhajetz/Released)

Original photo: The Arleigh Burke-class guided-missle destroyer USS Haley (DDG 97) transits the Indian Ocean on March 28, 2018. (U.S. Navy photo by Mass Communications Specialist 3rd Class Morgan K. Nall/Released)

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Spotlight
our people & work

People: Joe Venne, Program manager, Underwater Explosives Test and Trials Program Office

By Justin Hodge, Carderock Division Public Affairs

Joe Venne, the program manager for the Underwater Explosives (UNDEX) Test and Trials Program Office, made his way to Naval Surface Warfare Center, Carderock Division in 1999 after more than 20 years working in the fields of acoustics and shock.

Venne started his career in Washington, D.C., as a consultant before going on to work for an Italian shipyard, Intermarine USA, in Savannah, Georgia, where he assisted in the building of its coastal mine hunter (MHC), the first all fiberglass U.S. Navy ship.

While in Savannah, Venne met a few key people that changed the trajectory of his career. During the MHC Full Ship Shock Trials (FSST), he met teams from the Underwater Explosives Research Division (UERD) and Naval Sea Systems Command (NAVSEA) headquarters, with whom he now works.

"We had two years of post-trial design work that established some great relationships, in particular with Fred Costanzo who was branch head for the Underwater Explosives Analysis group," Venne said. "When I came to D.C. to visit in-laws in the summer of 1999, I stopped by Carderock to see the folks and talked to the Division head at the time, Mike Riley, for a while, which resulted in getting a job offer, and I started here that December."

In his first shock trial with the MHC, Venne tested the ship fully powered but not under propulsion in the UNDEX Test Facility at Aberdeen Proving Ground, dubbed "Super Pond." Being a new type of design, the Navy wanted to ensure they were in a controlled environment. Now ships are fully manned and underway during FSSTs, utilizing an operational scenario where one ship tows the charge, while the test ship moves into place alongside the charge.

"My job on the bridge is to control the ship, advise on how to operate the ship and when to detonate the charge," Venne said. "Ensuring the charge goes off at the right time and place can be quite nerve-racking, but it's the challenge that makes the job exciting."

When Venne started at Carderock he was responsible for submarine testing and qualification at Aberdeen and at-sea trials, in part because of his experience from working for a shipyard prior to joining Carderock. In addition, the position he filled was a critical need due to the loss of personnel when UERD moved to Carderock from Chesapeake, Virginia.

In his current role, Venne is responsible for FSSTs and large-vehicle shock testing for submarines and surface ships. He works closely with the various program managers and shipbuilders to support the shock qualification of equipment in accordance with standards to ensure the equipment is rugged enough to survive an underwater explosive attack.

Growing up in Muskegon, Michigan, just north of Grand Rapids on Lake Michigan, Venne received his Bachelor of Science in physics and mathematics at Grand Valley State University, in Allendale, Michigan, and then followed his passion to the Georgia Institute of Technology, where he graduated with a Master of Science in mechanical engineering, with an acoustics engineering certification.

Throughout his time at Grand Valley State University, Venne was heavily into music, where he enjoyed performing and spent a substantial amount of time in the music department. Although he loved playing the trombone, he realized he needed to decide on a career path where he could support himself utilizing his education, but also feed his passion, which led him into the acoustics field.

"It all transitions to what makes me happy, and what I'm good at," Venne said. "Going to sea is the best part of the job. Seeing how the Sailors respond to what we are doing and helping them understand what they might experience if attacked is very rewarding and important. I really love being out there and that's what drives me."

Venne's intense work ethic can be directly attributed to his father, who was an auditor for a manufacturing company.

"My dad went through the Depression and World War II, and through it all was very dedicated to his job," Venne said. "He retired after 40 years without taking a single sick day. Seeing that instilled the same type of work ethic in me. It's important to do a good job and meet responsibilities, and hopefully pass that knowledge along to others."

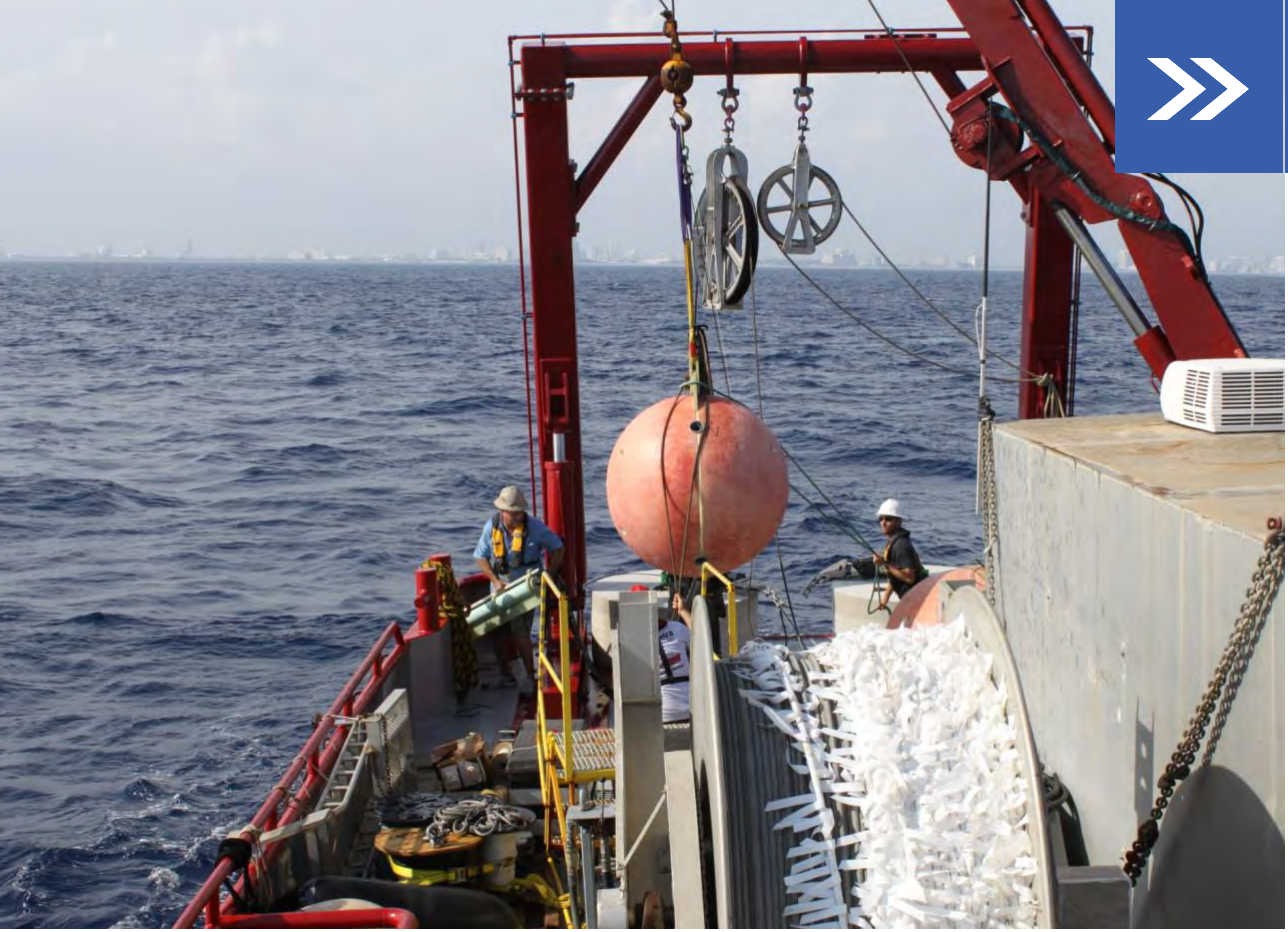
The latest round of back-to-back Littoral Combat Ship shock trials was an intense period for Venne and his team, as two hurricanes that hit Jacksonville, Florida, caused schedule delays and hampered keeping the ships operational and ready for testing. However, Venne said the trials program was extremely successful, providing key ship survivability data for the Navy, and the team was recognized with multiple awards for their work.

"Eight months at the test site and at sea was stressful, but the team was committed and made it a successful two shock trials," Venne said. "Being away from home for that long can put quite a bit of stress on a person, the team has a tough job yet doesn't always have the opportunities to be recognized for the work they do, so I wanted to make sure I worked even harder to submit them for as many awards as possible."

From Venne's efforts, Roy Javier, deputy trials director, won the Platform Integrity Department technical leadership award. Venne's LCS team received the NAVSEA Test and Evaluation Teaming Award, followed by Carderock's "Magnificent Eight" Benjamin Isherwood Award and the Center Collaboration Award.

His dedication to the team did not go unnoticed. During the 2018 command quarterly awards, Venne said he was pleased to receive the Meritorious Civilian Service Award.

He said the next big challenge for his team is preparation for the CVN 78 shock trials in 2020.



Patent: Method and System for Measuring Physical Phenomena in an Open Water Environment

Inventors: Robert Wingo, John Holmes and William Venezia

U.S. Patent no. 9,651,374 – Issue date: May 16, 2017

Abstract:
According to exemplary inventive practice, a deployment line connects a vessel to an anchor, and a tether connects a buoyant electronic unit to the same anchor. The buoyant electronic unit includes a syntactic foam sphere, and a computer and sensors that are housed in the sphere. The anchor and the buoyant electronic unit are discharged from the vessel and sink in the water. The deployment line mechanically detaches from the anchor when the anchor reaches bottom. The buoyant electronic unit stabilizes into an equilibrium position, tethered vertically and tautly to the anchor. Measurements pertaining to phenomena such as underwater electric potential, pressure, magnetic field and acceleration are taken by the corresponding sensors and are processed by the computer. An electrical (e.g., acoustical) signal is transmitted to detach the tether from the anchor, whereupon the buoyant electronic unit rises to a retrievable position on the surface of the water.

Background:
The present invention relates to sensing and measurement of physical phenomena in a marine environment, more particularly to methods and systems for sensing or measuring underwater physical characteristics (e.g., electromagnetic, acoustic, pressure, velocity/acceleration, vibrational, temperature, gravitational, etc.) such as pertaining to signatures of marine vessels.

Measurements of open ocean underwater electromagnetic fields serve many purposes, such as environmental modeling of earth's fields and ocean currents, which can be used for signal-processing noises for cancellation. Existing systems to measure underwater electromagnetic (UEM) signatures require extensive underwater electronics; these electronics can only be serviced by expensive dynamic positioning boats that are difficult to schedule. Systems costs are driven by costs of hardware, deployment/recovery, and life cycle repairs. Even if hardware costs are kept to a minimum, the costs of the deployment scheme may be driven by the costs of the deployment vessels.

The present invention, as frequently embodied, represents a unique multi-influence electromagnetic field measurement system. The present invention provides an ultra-stable subsurface platform for integrated multi-sensory underwater electromagnetic and oceanographic physical measurements.

An exemplary inventive system includes a complex sensor system housed inside an extremely motion-stable platform, which defines a substantially spherical shape. In-water column measurements are performed using a number of physical influence sensors, including electric and magnetic field sensors. Moreover, an exemplary inventive system carries out a novel deployment and recovery method and uses novel hardware and software. An easily deployable tethered ball of multi-influence sensors is implemented to measure UEM signatures in open ocean environments.

According to exemplary inventive practice, an underwater electromagnetic measurement system includes a spherical buoyant electronic device, an anchor, and a tether connecting the buoyant electronic device and the anchor. The buoyant electronic device is deployed from a marine vessel situated on the water surface, using a mooring-like deployment line (e.g., cable) that connects the vessel to the anchor. The anchor is dropped from the vessel into the water and is slowly lowered (e.g., using a boat crane or ship crane) via the deployment line, until the anchor sinks to the bottom of the water body (e.g., seafloor or ocean floor). When the anchor is positioned at the bottom, the deployment line is disconnected from the anchor.

According to exemplary inventive practice, a complex sensor system is housed inside an extremely motion-stable platform to enable in-water column measurements using a number of physical influence sensors including electric and magnetic field sensors. The present invention features, inter alia, an integration of electrical apparatus including electromagnetic sensor, acoustic sensor, pressure sensor, accelerometer, data acquisition electronics, and power electronics. Situated inside a fiberglass housing, the electrical apparatus encounters a minimal amount of adverse radiated signal interference. The inventive spherical buoyant electronic device is mechanically mounted in an inventively deployed, non-conductive tethered, ultra-stable mooring system.

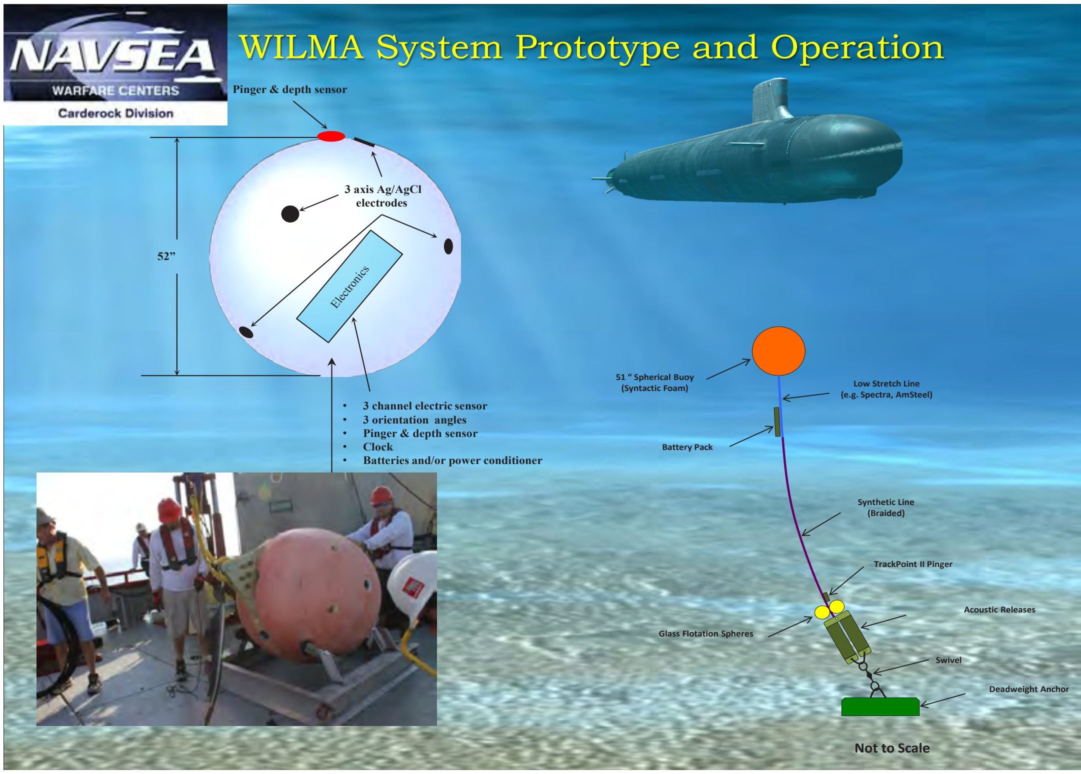
The buoyant electronic device remains submerged and tethered to the anchor, which is situated on the bottom surface. The buoyant electronic device reaches a submerged equilibrium position in the water, distanced above the anchor in an approximately vertical direction. Stably positioned underwater, the buoyant electronic device is implemented to sense or measure any of various physical phenomena. Subsequent to its implementation, the buoyant electronic device is recovered by the vessel by sending a signal (e.g., acoustic signal) that releases the tether from the anchor. The buoyant electronic device rises to and floats on the surface, where it may be captured by the vessel.

Inventive practice can satisfy all stated parameters of a mission in a cost-effective manner. The present invention's deployment methodology can afford lower deployment costs and greater deployment scheduling flexibility. Generally speaking, the nature of underwater electromagnetic (UEM) measurement is such that deployment should not be restricted to a specific water depth; exemplary practice of the present invention satisfies this requirement.

As frequently embodied the present invention is self-contained; this is advantageous insofar as eliminating costly underwater infrastructure. Furthermore, the present invention can meet challenges of data integration, analysis, and security. Exemplary inventive practice features, inter alia, a stealthy fully integrated sensor suite including an electronics can, a unique configuration of electrode sensors in an ultra-stable glass bead flotation ball, and a deployment rig.

Exemplary inventive practice implements a non-conductive sphere and mounts electric sensors thereon, thereby obtaining a 1.54 gain factor. In addition, exemplary inventive practice provides orthogonal sensor axes rotated 45 degrees. Diametrically opposite sensor pairings are placed on the non-conductive sphere at 45 degree rotations relative to spatial horizontality-verticality, thereby facilitating tethering from the bottom of the non-conductive sphere.

See full patent here: http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO1&Sect2=HITOFF&d=PALL&p=1&u=%2Fnetahtml%2FPTO%2Fsrchnum.htm&r=1&f=G&l=50&s1=9651374.PN.&OS=PN/9651374&RS=PN/9651374



Patent: Lightweight Armor with Slide Region for Slidably Redirecting Projectiles

Inventors: Philip Dudt and Alyssa Littlestone

U.S. Patent no. 9,459,079 – Issue date: Oct. 4, 2016

Abstract:
A lightweight armor for resisting penetration by both fragments and high-velocity sharply pointed projectiles. The lightweight armor includes a slide region and a receiving region, with the slide region having a backing material coated with polyurea to slidably redirect projectiles towards the receiving region, which may include high strength thickened projectile stopping materials.

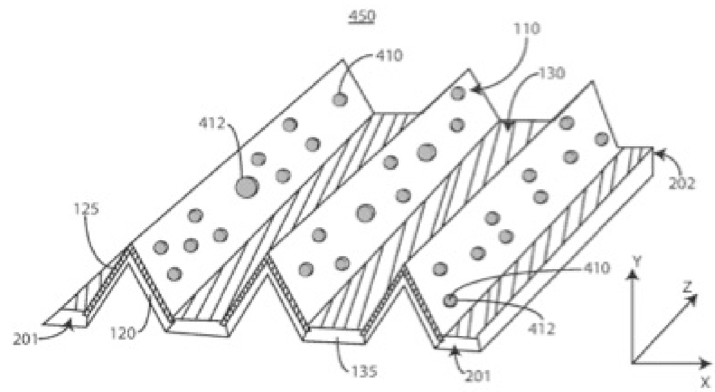


Figure 4B

This figure is an exemplary illustration of a lightweight corrugated plate armor assembly for resisting penetration by both fragments and high-velocity, sharply pointed projectiles, according to an embodiment of the invention.

Background:
Military vehicles are subject to attack from high-velocity projectiles, including sharply pointed bullets and fragments. The projectiles can penetrate vehicles and cause serious injury or death to the occupants thereof. Thus, these vehicles require armor to protect against these types of attacks. In addition to military vehicles, other vehicles which require armor protection include, for example, limousines, commercial armored cars and other non-military vehicles used for transporting people or high-value cargo.

Over the years, various forms of armor have been developed to provide protection to both the vehicles and the occupants. When developing a specific armor, consideration must be given to the type or types of projectile and energetic force against which the armor must provide protection. Consideration must also be given to the effectiveness of the overall armor system in protecting against multiple threats. Further consideration must be given to the weight of the armor system and to the practicality of use of the armor in view of its weight. To this end, consideration must also be given to the material that is used for the armor.

Currently, armor piercing and other high-velocity rounds are defeated by thick, high-strength steel armor, with or without angled perforations, ceramics, high strength fabrics or combinations of the same. A new component has been added more recently, i.e., highly rated sensitive polymers. This material has been of interest in resisting penetration by fragments, but is not very effective against sharply pointed bullets that tend to pierce through it. It is desired to have an armor system that is lightweight, that protects against multiple threats such as fragments and sharply pointed bullets.

In one aspect, this invention is a lightweight armor assembly for resisting penetration by both fragments and high velocity sharply pointed projectiles. In this aspect, the lightweight armor assembly includes a structure having a substantially sinusoidal profile in an X-Y coordinate reference system. The substantially sinusoidal profile has a plurality of slide regions for slidably redirecting high-velocity projectiles. Each slide region has a substantially V-shaped protrusion elongated in the Y-direction, having an apex and a base. According to the invention, each substantially V-shaped protrusion includes, a backing material having a thickness t, and a polyurea coating over the light-weight material. The polyurea coating has a thickness t.sub.c, with the polyurea coating being converted to a lubricated slide surface when contacted by said high-velocity projectiles. The substantially sinusoidal profile also has a plurality of receiving regions for receiving and stopping high-velocity projectiles, either redirected from the sliding region or emanating from another source. Each receiving region has a substantially flat lateral section, having a thickness T, thicker than the backing material thickness t, the substantially flat lateral section extending in the X-direction between the substantially V-Shaped protrusions and contacting each substantially V-shaped protrusion at a respective base.

See full patent here: http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO1&Sect2=HITOFF&d=PALL&p=1&u=%2Fnetahtml%2FPTO%2Fsrchnum.htm&r=1&f=G&l=50&s1=9459079.PN.&OS=PN/9459079&RS=PN/9459079

Hydrodynamic Modeling of Biofouling Roughness and Drag

Objective

- Develop computational approaches for predicting performance penalties associated with ship hull biofouling.
- Transition computational approach to a tool or metric that provides a hydrodynamic basis for making hull maintenance decisions in real time.
- Transition computational approach to a tool or metric that provides a hydrodynamic basis for evaluating efficacy of existing or novel biofouling control processes or technologies.

Background

The Chief of Naval Operations has set a goal for a 15% reduction in fuel use during vessel operations by 2020. A significant proportion of this reduction could potentially be achieved through improved control of biofouling roughness on ship hulls. Due to the relatively poor understanding of the actual extent of biofouling on ship hulls, and of the hydrodynamic consequences of that biofouling, the exact proportion of savings that could be achieved is unknown. An improved understanding of the nature and hydrodynamic impact of biofouling roughness found on the hulls of Navy vessels is required to make the decisions necessary to reach the targeted reduction. A deeper knowledge of the relationship between hull biofouling, drag, and ship performance, will improve our ability to evaluate the costs and benefits of biofouling control systems, coatings and maintenance processes. Our work aims to develop the capability to quantify this relationship through modeling.

Approach and Results

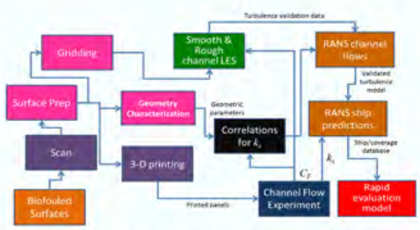


Fig. 1. Structure of the project, showing interactions among components, and data flow.

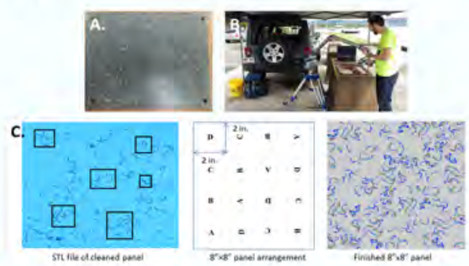
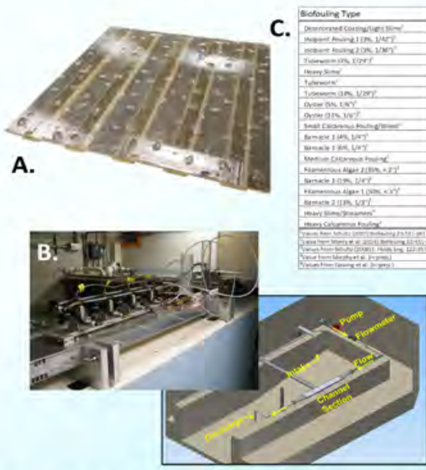


Fig. 2. Capture and processing of biofouling configurations for evaluation for roughness and drag. **A.** Biofouled panel. **B.** Scanning biofouled panel in the field. **C.** Process for constructing a biofouling configuration for printing and testing.



C.

Biofouling Type	k_s (µm)
Deteriorated Coating/Light Slime	100
Hydroid Fouling 1 (3%, 1/42")	150
Hydroid Fouling 2 (3%, 1/38")	200
Tubeworm (3%, 1/29")	250
Heavy Slime	300
Tubeworm	325
Tubeworm (18%, 1/29")	560
Oyster (5%, 1/6")	570
Oyster (11%, 1/6")	770
Small Calcareous Fouling/Weed	1000
Barnacle 1 (4%, 1/4")	1090
Barnacle 1 (8%, 1/4")	1710
Medium Calcareous Fouling	3000
Filamentous Algae 2 (33%, > 2")	3300
Barnacle 1 (19%, 1/4")	4490
Filamentous Algae 1 (50%, < 1")	4600
Barnacle 2 (13%, 1/3")	5080
Heavy Slime/Streamers	6800
Heavy Calcareous Fouling	10000

[illegible]

Fig. 3. Testing of printed biofouling configurations for hydrodynamic characteristics. **A.** Printed panel (oyster biofouling). **B.** Channel flow facility for testing printed configurations. **C.** Hydrodynamic roughness (k_s) for biofouling configurations, relative to previously published values.

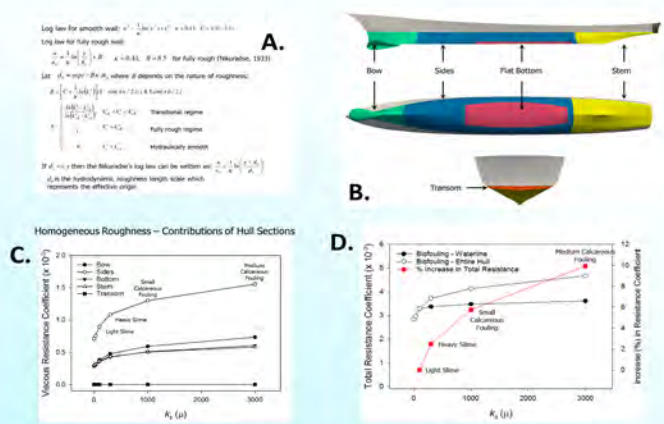


Fig. 4. RANS modeling of resistance of biofouled ships. **A.** Reparameterized wall model incorporating biofouling roughness. **B.** Division of hull into sections corresponding to those used by divers in hull condition inspections. **C.** Impact of biofouling on viscous resistance for each hull section. **D.** Prediction of impact of biofouling on waterline on ship total resistance.

NSWCCD POCs: Eric Holm, Peter Chang, Christina Dehn, Scott Gowing, Scott Storms, Abel Vargas, Wesley Wilson
This work was sponsored by the Carderock Division under the Naval Innovative Science and Engineering (NISE) program, managed by the NSWC Carderock Division Director of Research.

NR&DE

MAKE LAB STEWARDSHIP

NAVSEA WARFARE CENTERS Carderock

Background

Digital modeling and fabrication is becoming a key enabling component across multiple disciplines. Accelerated adaptation of digital modeling and additive manufacturing (AM) at NSWC Carderock necessitates that engineers have access to modeling software packages, high power computing, and cutting-edge design tools.

This project seeks to develop digital modeling and fabrication skillsets through the continuation of the Manufacturing Knowledge and Education (MAKE) Lab and new Digital Design Lab.

Containing capabilities tailored to the needs of our workforce and sponsors, both labs will be test beds for investigations in cybersecurity, reach-back support for the fleet, and compliment existing digital design projects at Carderock. These labs will improve the communication of new concepts and reduce the time to develop demonstrations.

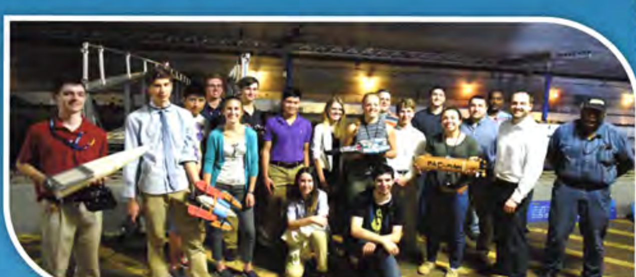
In the past 2 years, the MAKE Lab has trained almost 200 people in the use of additive manufacturing systems and techniques, and done so in a way that encourages community engagement and cohesion. The reservation system helps put faces to names of other users, and allows different codes to interact and exchange ideas. Feedback from users is encouraged to allow the MAKE Lab to rapidly adapt to an ever-changing industry.

Objective

- **Provide** workforce development training and support Carderock's core capabilities with skill development in the MAKE Lab.
- **Establish** an open access computer lab equipped with software packages that will augment the capabilities of the MAKE Lab to enable our scientists and engineers to better solve our sponsor's problems.
- **Reinforce** the "One NAVSEA" mentality by encouraging community engagement.
- **Support** Carderock's STEM outreach presence
- **Gather** user feedback and adapt the MAKE Lab as necessary to adapt to changes in mission or need.

Demonstration Plan

- **FY18**: Coordinate digital design training for Carderock employees and demonstrate reverse engineering capabilities to support fleet
- **FY19**: Demonstrate the ability to perform networked digital manufacturing and monitoring of additive manufacturing
- **FY20**: Demonstrate use of the digital design lab as an innovation space and continue workforce development through training



Impact

This effort will improve the speed and efficiency with which systems and solutions are able to be developed and deployed to support the warfighter, as follows:

- Improved agility of workforce.
- allowing workforce to rapidly address warfighter's needs and have the most up-to-date software packages and tools.
- Centralize software access to reduce support cost by requiring fewer overall software licenses
- Enhance Carderock's hands-on STEM efforts.

This work was sponsored by the Carderock Division under the Naval Innovative Science and Engineering (NISE) program, managed by the NSWC Carderock Division Director of Research.

NSWCCD POCs: Jonathan Hopkins, Scott Ziv, Matthew Jeffries

Design Qualification Process Utilizing Polymer Based Additive Manufacturing Materials for Shipboard Use

Objective

Qualification of polymer additive manufacturing (AM) fabricated, functional components for shipboard use will require a traceable link from AM process parameters and the resulting as-built material properties, to design calculations and functional qualification testing. The goal of this project is the demonstration of the process for developing a shipboard qualified polymer AM fabricated component.

Justification

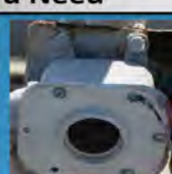
Polymer AM has the potential to enable the Regional Maintenance Centers (RMC) and the fleet to fabricate small non-critical replacement parts on demand. The project is looking to develop the process by which these components are qualified.

Technical Approach

1. Leverage work being performed under Cross Platform System Development (CPSD), Naval Engineering Education Consortium (NEEC) and FAA/America Makes funding
   a. Ultem 9085 and Polycarbonate (CPSD)
   b. Print parameters and effect on material properties. (NEEC)
   c. Materials allowables for Ultem 9085 being developed.(FAA/America Makes)
2. Engage the fleet to identify components that can be manufactured using polymer AM that meet a fleet need for replacement parts.
3. Design and fabricate components based on identified polymer AM build parameters.
4. Subject components to defined qualification testing (e.g. load/deflection, shock, impact, …)
5. Install component for shipboard demonstration and develop transition strategy assuming favorable demonstration.

Examples of Shipboard Need

Sound Powered Phone Jack Boxes
Symbol 2843 Symbol 2842



Electrical Receptacle
Symbol 1099.1

3D Printed Knobs for Equipment

Ships have identified missing or broken knobs as a maintenance problems. Reverse engineered knobs (white) .

3D Printed Caps for Enclosures

Successfully reverse engineered caps for the electrical receptacle (left) and sound powered phone jackbox (right).

Qualification Path Forward

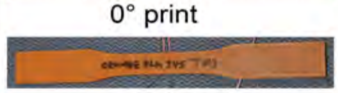
NSWCCD will be working closely with the technical warrant holders (TWH) that have cognizance over the knobs and the caps to qualify the parts in FY18. This will include the following TWH: Non-metallic materials, additive manufacturing, electrical, sound powered phone and communication systems.

Material Allowables Development

1. This project was able to print and test parts with unique print directions to evaluate the elastic properties of the material.
   a. Samples in the 0, 90, ±45 and default print directions were printed and tested.
   b. FY18 will use standard composite lamination theory to determine if we can predict the elastic properties of 3D printed parts.

0° print

90° print



±45° print

default print

NSWCCD POCs: Dr. Maureen E. Foley and Grant Honnecker NSWCCD Code 6102

This work was sponsored by the Carderock Division under the Naval Innovative Science and Engineering (NISE) program, managed by the NSWC Carderock Division Director of Research.

Additive Manufacturing Digital Transition Framework

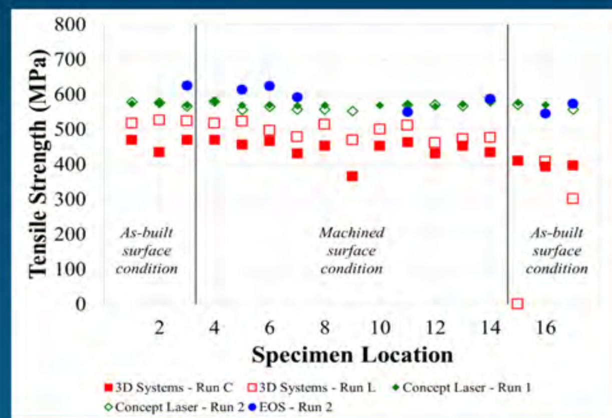
Background

Additive Manufacturing (AM), as a digital technology, offers the ability to fabricate parts on-demand, at the point of need, helping to address ongoing readiness challenges due to part obsolescence and enabling the ability to rapidly obtain parts in forward deployed and afloat environments.

It is critical to ensure that quality AM parts can be consistently reproduced when printed across a range of systems in these varying environments. This project helped to establish and demonstrate AM-specific guidelines for Technical Data Packages (TDPs) to enable consistency in geometric and material properties.

Objective

- Demonstrate an additive manufacturing digital transition framework through the use of a technical data package that produces consistent parts across multiple sources for both polymer and metal constructs
- Leveraged DLA and Task Force Innovation projects that collaborated with NSWC Indian Head and NSWC Dahlgren for the part demonstration
- Use results to inform collaborative approach to TDP between NAVSEA, NAVAIR and USMC



Results of tensile strength testing vs specimen location on the build plate for three different powder feedstock run on three separate powder bed fusion additive manufacturing machines

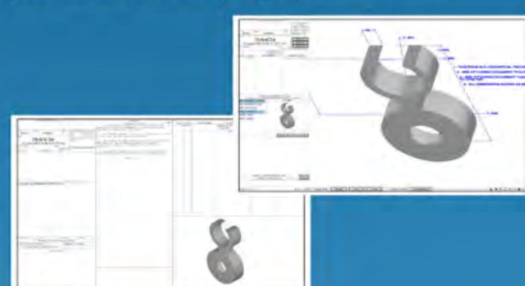
Approach

Metal

- Fabricate metal Tomahawk Fastener using three different powder bed fusion systems at three different sites with three different powder feedstocks
- Use base processing parameters for each printer while using the same build plate layout to quantify differences in tensile, fatigue, corrosion and microstructural properties

Polymer

- Quantify geometric, tensile, and flexural fatigue differences between two prints on the same additive manufacturing polymer fused filament fabrication printer while demonstrating the build of a springboard latch handle spring clip



Impact

A common framework that adequately addresses all of the appropriate build parameter requirements helps to ensure repeatability across locations and systems and reduces build failures.

Resulted in the demonstration of a common framework, with DLA input, that can be used for transitioning AM parts to the supply system through the establishment of guidelines and data item descriptions for AM.

NSWCCD POCs: Nathan Desloover

This work was sponsored by the Carderock Division under the Naval Innovative Science and Engineering (NISE) program, managed by the NSWC Carderock Division Director of Research.
Distribution Statement A: Approved for public release; distribution is unlimited.

Paramagnetic Nanoparticles: Formation and Seeding During Electrocoagulation

Motivation

- Electrocoagulation (EC) is an effective solution when optimized for a specific influent; however, bilgewater is a highly variable influent
- Byproducts, some of which are magnetic, are formed as a result of non-optimized wastewater treatment

Objective

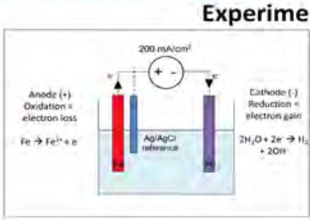
Leverage iron oxide (FeOx) nanoparticles formed from electrocoagulation as a method for magnetically removing oil-in-water emulsions with the expectation that:

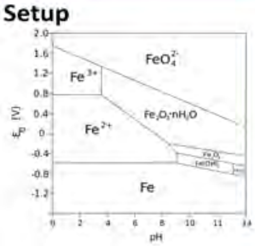
1. High fidelity magnetic iron oxide compounds can be produced via EC
2. The same adsorption principles of iron oxide particles apply to solid and liquid colloidal systems

Technical Approach

- Electrochemical oxidation of sacrificial Fe electrode used for *in situ* production of emulsion-breaking cations through **electrocoagulation**
- Magnetic FeO_x nanoparticles form as a byproduct of the electrocoagulation process and can be removed by magnetic separation
- FeOx product characterized by SEM/EDS, XRD, and magnetometer
- Wastewater treatment efficacy determined by turbidity measurements

Experimental Setup

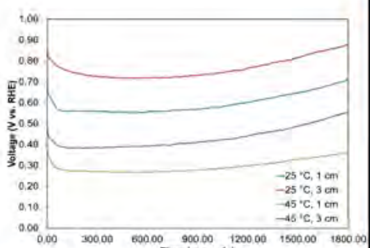




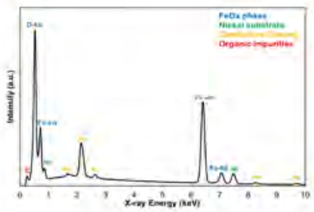
$Fe^{2+} \rightarrow Fe^{3+} + e^-$

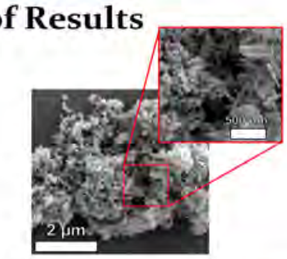
$Fe^{3+} + OH^- \rightarrow FeO(OH) \bullet H_2O$

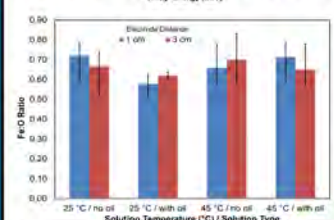
- 3-electrode configuration
- Solutions of salt and surfactant investigated with and without oil
- Testing conditions included ambient (25°C) and elevated (45°C) temperatures

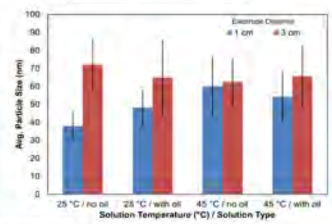


Summary of Results

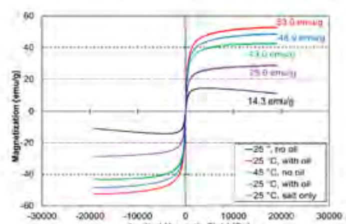




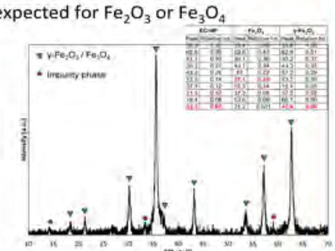




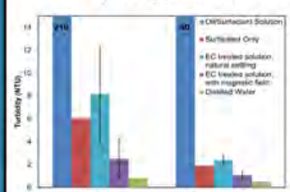
- SEM analysis shows a mixture of aggregated spherical particles with occasional clumps of needle/plate like morphologies
- EDS shows no trace of Cl (rinsed samples), indicating all phases are variants of FeO_x
- Fe:O ratio was between 0.66 and 0.75 expected for Fe_2O_3 or Fe_3O_4



Magnetic analysis is consistent with ferri/ferro-magnetism, though exact phase(s) is inconclusive



XRD analysis found an average crystallite size of 25 nm, with all peaks consistent with either Fe_3O_4 or γ-Fe_2O_3



Turbidity of EC-treated solutions is dramatically reduced relative to prepared emulsion without treatment

Conclusions

- Probable mixture of Fe-oxides produced by electrochemical process
- Efficiency of production is influenced by synthesis parameters, while final product/effectiveness for EC are not
- Optimization of parameters might lead to better magnetic properties

NSWCCD POCs: Ms. Danielle M. Paynter (633); Dr. Gordon H. Waller (636); Dr. Nicholas Jones (612); Mr. Curtis Martin (617)

This work was sponsored by the Carderock Division under the Naval Innovative Science and Engineering (NISE) program, managed by the NSWC Carderock Division Director of Research.

Submarines flying at Carderock? It could happen

From Carderock Division Public Affairs

In a cross-command collaboration effort, Dr. Dan Edwards, an aerospace engineer with the Vehicle Research Section of the U.S. Naval Research Laboratory (NRL), presented his flying submarine research at Naval Surface Warfare Center, Carderock Division, on Dec. 4 with the intention of finding further possibilities for the unmanned vehicle.

"NRL and the Navy's Warfare Centers are being encouraged to collaborate more closely," Edwards said. "And we see the Warfare Centers as a potential collaborator or transition outlets for our research."

Edwards' team has designed a few configurations for an unmanned undersea vehicle to fly over the water's surface for rapid emplacement. The most recent design, named the Flying Sea Glider, is an underwater glider with a relatively wide wingspan, which allows the vessel to fly over the water at about 100 knots for 100 nautical miles on a battery-electric motor. A custom-designed buoyancy engine enables glide speeds around 1 knot to a maximum depth of 600 feet. Edwards said the advantage of keeping the wings in the water after splashdown is ability to do shallow glides.

"Our group specializes in unmanned aircraft vehicle design and usually odd-looking, folding configurations, such as airplanes that come out of tubes, rocket-launched helicopters and these flying submarines," Edwards said.

Edwards said the key element of the Flying Sea Glider program is to combine airplane and underwater gliding modes into a single vehicle. The research project investigates potential benefits from integrating an air-delivery method and an underwater glider with the aim being fast and long-range deployment with long-term underwater loiters.

The Flying Sea Glider vehicle glides underwater in the Naval Research Lab's Laboratory for Autonomous Systems during testing in October 2017. The glider's large wings and lung volume enable very shallow glide angles at reasonable speeds. The tank's 5-foot depth and 35-foot length is sufficient for one short glide cycle at approximately 1 knot. (Photo provided by NRL/Released)

Carderock employees were keenly interested in the actual design of the glider. Bringing aero and hydrodynamics together initiated questions about the overlap between unmanned electric aircraft and underwater gliders which use buoyancy for motion, especially since the two mediums have very different densities.

Edwards said some of possible applications for these flying submarines include: rapid reaction measurements of oil spills and environmental disasters; emplacement into a storm while maintaining safe stand-off distances; search and rescue; and bypassing areas with high underwater currents.

NRL's vehicle research section is ultimately seeking industry partners who are interested in cooperative research or commercializing the Flying Sea Glider or other unmanned aerial-undersea glider technology.

"I wanted to show some of our hardware and share our research goals," Edwards said, explaining why he came to Carderock. "Perhaps there is some interest in further development. I am also interested in learning what tank facilities are available at Carderock and hopefully setting up some testing in your unique testing environments."

Naval Meteorology and Oceanography Command collaborates with Carderock for remote autonomous demonstration

By Dustin Q. Diaz,
Carderock Division Public Affairs

Engineers at the Naval Oceanographic Office (NAVOCEANO) at John C. Stennis Space Center, Mississippi, remotely collaborated with their counterparts from Naval Surface Warfare Center, Carderock Division on a joint autonomous vehicle demonstration in Brookeville, Maryland, Sept. 25-29.

This integrated unmanned demonstration involved NAVOCEANO's parent command, the Naval Meteorological and Oceanography Command (NMOC), and Carderock collaborating on autonomous bathymetry through missions run by NAVOCEANO from Mississippi and supervised by Carderock's Autonomous Vehicle and Instrumentation Group on station in the Triadelphia Reservoir near Maryland's Brighton Dam.

According to Jim Rice, the group leader, they teamed with NMOC to develop the capability of communicating with an unmanned underwater vehicle (UUV) during submerged operation from a shore station using an unmanned surface vehicle (USV) as a communications relay. The two parties signed a memorandum of understanding (MOU) in August planning this collaborative autonomous demonstration using a kayak catamaran USV developed by the Autonomous Vehicle and Instrumentation Group and a Remus 100 UUV with side-scan sonar capability provided by NMOC, with the USV and remote shore station in Mississippi linked via satellite connection.

"The purpose of this project is to demonstrate the capability of getting data status updates and mission re-direct commands between a submerged UUV and a remote shore station using a USV relay," Rice said. "What we are offering them now is a more continuous communication path and ability to control and change the UUV's mission via the USV, or have more constant updates of where the UUV is, what it's doing and what its condition is."

The demonstration was carried out via preprogrammed missions in the reservoir, with the UUV running east to west and back taking oceanographic measurements in the reservoir for about a half hour while being autonomously trailed at a safe distance by the USV. The two vehicles communicated regularly via acoustic modem, with the USV providing guidance updates to the UUV and relaying UUV sensor data via satellite link to NMOC.

Matt Greytak, a control systems engineer assigned to Carderock's Ship Control Branch, developed the USV autonomy algorithm used in the demonstration. After having worked on them for several years, he said these algorithms are advanced enough to support the USV autonomously with little to no human intervention, allowing the parties to achieve one of the MOU's objectives of exploring the capabilities offered by employing a more maneuverable USV as support to the UUV, compared to using a slower USV in the past that couldn't keep up with the UUV.

Group member Ben Gordon said that while Carderock engineers supervised

A kayak catamaran unmanned surface vehicle follows an unmanned underwater vehicle in Triadelphia Reservoir in Brookevile, Md., Sept. 28, 2017, during a joint integrated autonomous demonstration with engineers from the Naval Oceanographic Office in John C. Stennis Space Center, Miss., controlling the test with supervision and assistance from colleagues on station from Naval Surface Warfare Center, Carderock Division's Autonomous Vehicle and Instrumentation Group. (U.S. Navy photo by Ryan Hanyok/Released)

the demonstration for safety, the success of the demonstration proves this may not be necessary for future tests.

"We're here to coordinate missions and make sure the commands they (NMOC) send to the kayak are getting through, but once both parties have more experience with this system, it will almost be unnecessary for us to be here," said Gordon, an electrical engineer in Carderock's Hydrodynamics and Maneuvering Testing Branch. "As it is, they're starting the kayak, they're sending and receiving data and everything is working the way we were hoping. And they're doing all that from Mississippi."

According to Gordon, Carderock engineers developed the USV for a project for the Office of Naval Research for the purpose of tracking a submersible with a surface vehicle, as it is doing here. This demonstration added a direct acoustic link between the two vehicles and a satellite connection between the USV and shore station to previous methods, as well as the ability to send simple redirect instructions to the USV during the mission.

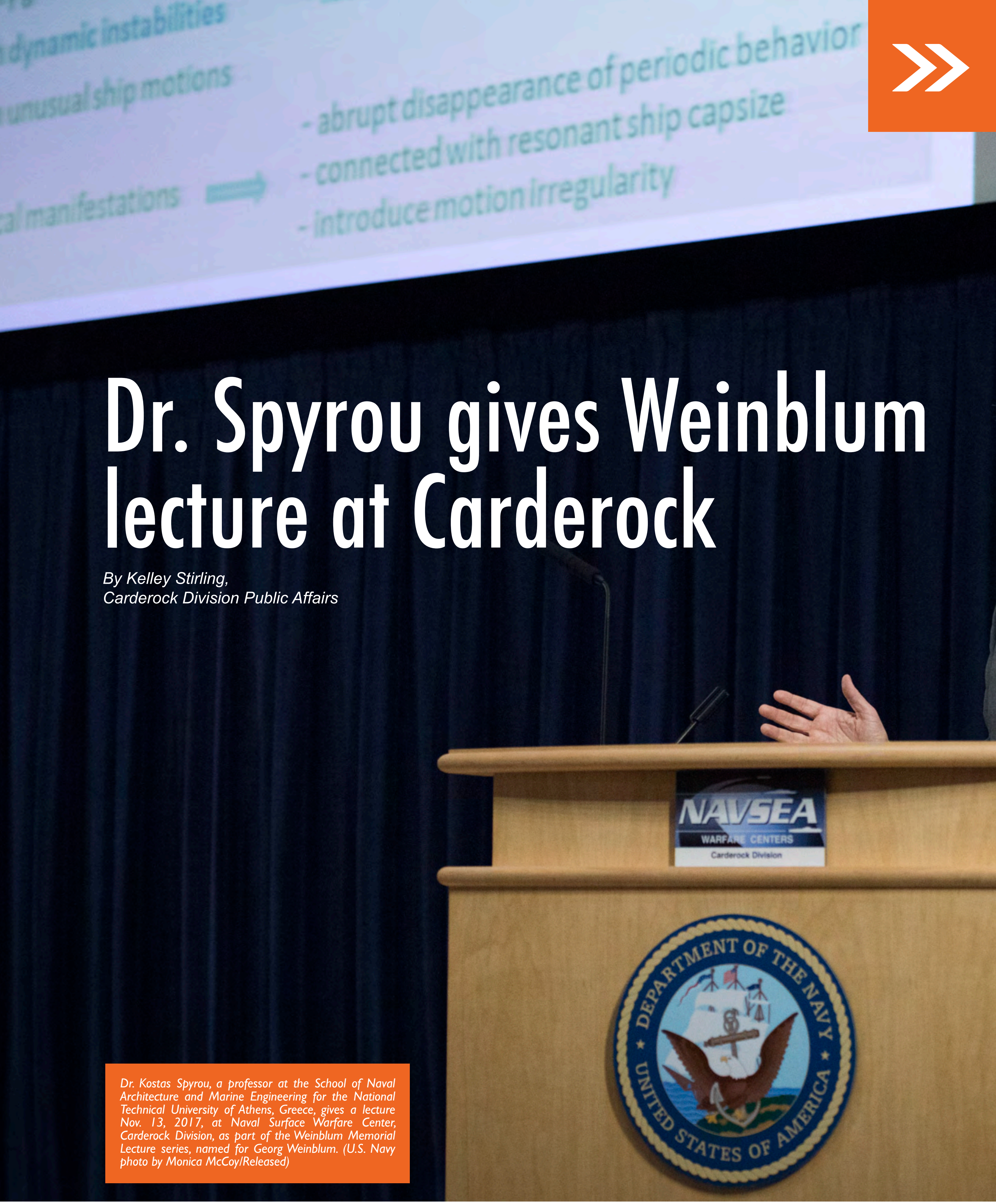
Rice added the collaboration demonstrated a relatively mature UUV/USV system that can be fielded without significant additional investment, achieving another goal of the MOU.

"Using the satellite connection, this can be controlled basically anywhere in the world," Rice said. "The mission is not dependent on that connection; this particular UUV will run with a preloaded mission. But the test demonstrates that you can have a UUV doing an oceanographic survey anywhere in the world with someone controlling it remotely."

Rice said this was Carderock's first collaboration with NMOC. He believes both parties are happy with the results and looks forward to working with them again. Other Carderock engineers participating in the demonstration included Judah Milgram from Carderock's Sea-based Aviation and Aeromechanics Branch and Woody Pfitsch, Alex Punzi and Kyle Corfman from the Hydrodynamics and Maneuvering Testing Branch.

NAVOCEANO is responsible for providing oceanographic products and services to all elements of the Department of Defense and maximizes sea power by applying relevant oceanographic knowledge in support of U.S. National Security. For more information on NAVOCEANO, visit www.usno.navy.mil/NAVO.www.navy.mil/local/navo/.

NMOC provides information on the physical environment – including wind, weather, wave height, currents, temperature and precise time – that is required by Navy ships, submarines, aircraft and special forces to operate and navigate safely and effectively. Located at John C. Stennis Space Center, Mississippi, NMOC headquarters directs and oversees 2,500 globally-distributed military and civilian personnel who collect, process and exploit information to assist fleet and joint commanders around the world in all warfare areas to make better decisions faster than the adversary.



Dr. Spyrou gives Weinblum lecture at Carderock

By Kelley Stirling,
Carderock Division Public Affairs

Dr. Kostas Spyrou, a professor at the School of Naval Architecture and Marine Engineering for the National Technical University of Athens, Greece, gives a lecture Nov. 13, 2017, at Naval Surface Warfare Center, Carderock Division, as part of the Weinblum Memorial Lecture series, named for Georg Weinblum. (U.S. Navy photo by Monica McCoy/Released)

The 39th Weinblum Memorial Lecture was given by Dr. Kostas Spyrou at Naval Surface Warfare Center, Carderock Division in West Bethesda, Maryland, on Nov. 13. Spyrou is a professor at the School of Naval Architecture and Marine Engineering for the National Technical University of Athens in Greece.

This lecture series was established in 1978 by colleagues of Georg Weinblum, a German engineer who studied ship hydrodynamics and had major contributions to aspects such as wave-resistance theory, maneuvering, ship motions and hydrofoils. Weinblum also worked at Carderock from 1948-1952, then known as the David Taylor Model Basin. The lecture series honors a person each year who exemplifies the ideals of Weinblum.

Spyrou's lecture, "Homoclinic Phenomena in Ship Motions," was given first in Hamburg, Germany, about a year ago and then at Carderock, which is normal for the lectures.

"The title homoclinic is strange for most people, but it is not strange to me as it is a Greek word and I'm a Greek person, so I understand the deeper meaning of the word," Spyrou said, describing homoclinic as one special class of non-linear phenomena that can affect ship systems that are dynamic, such as a giant wave that would be very rare.

Spyrou has been working with Dr. Vadim Belenky, a naval architect with Carderock's Simulations and Analysis Branch, over the past nine years in a collaborative effort to study these rare events and looking into extreme values, into the extremes in ship motion, such as capsizing.

Specifically, the objective of Spyrou's lecture was to identify the cases of strange behavior that might happen to a ship and may affect the safety of the system in a critical mode as something that happens very suddenly. Once identified, Spyrou said it's possible to approach the problem with a rational scientific approach, and engineers or Sailors may be able to predict the phenomena, and therefore see ways to avoid the phenomena.

"I have tried to identify all the cases we know about such phenomenon, which are relevant to ship motions, from the studies that have taken place in the past," Spyrou said. "It's not the kind of work that many people are actually doing right now because it's about something that's very rare. You don't expect a ship to capsize in its lifetime, but you know that this is something you need to avoid at any cost."

Spyrou said it is essential to put some effort in this area of study. With more knowledge, there may be a way to prevent a disaster with simple design changes. But there may be operational strategies, as well, by avoiding getting the ship into trouble in the first place.

"One of the conclusions was that we need to do more to educate naval architects to understand the phenomenon," Spyrou said, adding that the math used to describe homoclinic phenomena needs to be included in the naval architect curriculum.

Combatant Craft Division celebrates 50 years

By Kelley Stirling
Carderock Division Public Affairs

Sailors temporarily assigned to the amphibious transport dock ship USS Mesa Verde (LPD 19) conduct rigid-inflatable boat (RIB) training off the coast of Haiti on Oct. 12, 2016. (U.S. Navy photo by Petty Officer 2nd Class Shamira Purifoy/Released)

The Combatant Craft Division (CCD) of Naval Surface Warfare Center, Carderock Division marked its 50 years with an anniversary celebration picnic Oct. 14 at Joint Expeditionary Base Little Creek-Fort Story, Virginia, a day after the U.S. Navy celebrated 242 years.

CCD develops, designs, tests and supports combatant craft and boats for the nation's defense.

Boats have always been part of the U.S. Navy at some level, but their importance changed with the onset of the Vietnam War and the criticality of riverine operations. Driven by this need, in August 1967 the Navy established authority for combatant-craft design and testing in Norfolk, giving the boat technical community a dedicated organization with this new boat engineering center.

"The military was buying boats like crazy from commercial industry and adapting commercial products, with mixed results. There weren't a lot of technical processes and methodologies to predicting boat performance," said Mack Whitford, a retired naval architect from CCD who said he had to watch a video about Vietnam patrol boats and swift boats titled, "The Small Boat Navy," narrated by Raymond Burr, when he first started working at CCD in 1986.

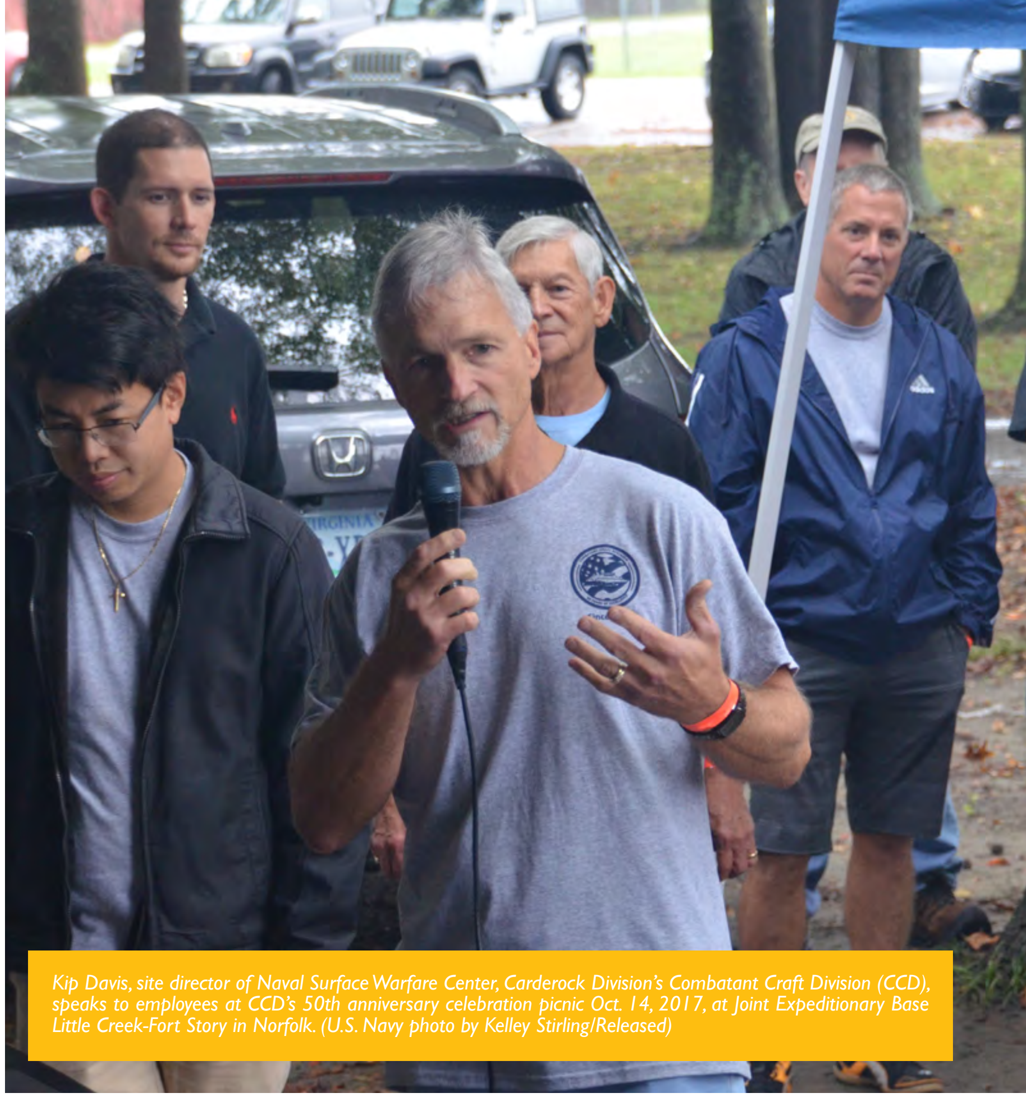
Part of CCD's full life-cycle portfolio is the 7-meter rigid-inflatable boat (RIB), a small, high-performance boat every Navy ship carries. The RIB replaced the long-used 26-foot motor whaleboats in the 1980s. For about 40 years starting in the early 1950s, more than 1,500 whaleboats were built and used aboard nearly every Navy ship as the ship's lifeboat and, in some cases, as a liberty, cargo, mail and work boat. Jack Mathias, who started working at CCD in 1974 and is still there managing the inventory for more than 3,600 boats and craft for the entire Navy, said bringing the RIB in was a huge undertaking and initially there was resistance since it was inflatable.

Mathias said he used to walk by the office of the engineer who was really pushing for the RIB saying, "psssssssssssssssssss," jokingly referring to air being let out of the boat. Whitford said that the justification for replacing the motor whaleboats with the RIB was the top-side weight on the new DDG class (Arleigh Burke) decreased because they could use a lighter davit to lower and raise the small boat into the water.

The RIB, which was initially developed by the Royal Naval Lifeboat Institute as combination lifeboat and surf-and-rescue boat, has expanded its role in the Navy over the years, especially after the October 2000 bombing of USS Cole (DDG 67) by a small boat driving into the side of the ship with explosives. After the Cole incident, Combatant Craft Division supported increased acquisitions of the RIB, as well as providing a modification to the security package, which became even more important after 9/11.

Some of the updates to the RIB at that time included adding a machine gun foundation, security strobe lights, a siren, VHF radio and spotlights. The boat itself is not only the ship's ready service lifeboat, but also is used for maritime interdiction operations, vessel boarding search and seizure, anti-terrorism and force protection, and law enforcement operations.

Over its 50 years, CCD has had many homes and several name changes since the Navy's decision that testing and evaluating small boats was work much better suited in the Norfolk area than in Washington, D.C. Originally under the Naval Ship Engineering Center, Norfolk Division on Little Creek Amphibious Base, the division moved to the Glopar Building in Norfolk in 1969 as a component of the Naval Sea Combat Systems Engineering Station. It became part of Carderock Division in 1992 and relocated to Suffolk, Virginia, and then moved back to Little Creek, Virginia, in 2002, where most of its 180 personnel work to this day. The division also maintains a waterfront test and evaluation facility at Naval Station Norfolk, which was moved there from nearby Fort Monroe in 2009.



Kip Davis, site director of Naval Surface Warfare Center, Carderock Division's Combatant Craft Division (CCD), speaks to employees at CCD's 50th anniversary celebration picnic Oct. 14, 2017, at Joint Expeditionary Base Little Creek-Fort Story in Norfolk. (U.S. Navy photo by Kelley Stirling/Released)

"When I first got here, Jack had 12-foot drawing boards. We were still doing drafting, serious drafting," Whitford said. "To me, it was like, 'This is a real naval architecture place.' In school, you had the big drawing room with a wooden drawing board and so it was like, 'this is home.'"

The differences between boats and ships are a big distinction for Combatant Craft Division, as they provide the support only for boats and craft, with the exception of the patrol coastal ship, the single U.S. Navy commissioned ship under Combatant Craft Division's purview. As characterized by Combatant Craft Division Head Kip Davis, the differences are not necessarily about the size. Boats are designed to operate in multiple environments and may have a requirement for multiple operational modes, meaning displacement, semi-displacement or planing. Boats have to be able to come from an ocean environment into regions and shallow waters where only boats can get to. Boats are generally carried to operating theaters by other vehicles, such as ships or aircraft.

"Small boats, like the motor whaleboat and the RIB, because they are small, but they still have diesel engine and all the associated systems and you have to have room for certain number of personnel – they are really harder to design than a larger boat because everything has to fit and be efficient and have adequate accessibility for maintenance, etc. – so they are more of a challenge," CCD Engineer Lori Fanney said.

Over the last 50 years, CCD has had a hand in the testing or development of some interesting things, like the "flopper stopper," a device that helps to keep boats from capsizing when they are top-heavy; the "lead sled," which was like a disposable landing craft; or the "sea pringle," a not-so-successful wave strider with a pringle-shaped hull.

Some of the special projects that have been quite successful out of CCD were the Integrated Bridge Systems, which is standard today, and the Stiletto Maritime Demonstration Program.

Most recently, the division provided full-spectrum support for the Coastal Riverine Force Mark VI Patrol Boat and the Naval Special Warfare Combatant Craft Medium. CCD is currently working the redesign of the landing craft utility (LCU) 1600 class, expected to hit the fleet in about five years. The division is also at the forefront of development of unmanned surface vessels.

"There is no other organization in the U.S. that has the capabilities we have at Combatant Craft Division for the development, design, testing and support of the Navy's combatant craft and boats," Davis said. "These are world-class capabilities, and to my knowledge, are unmatched worldwide."

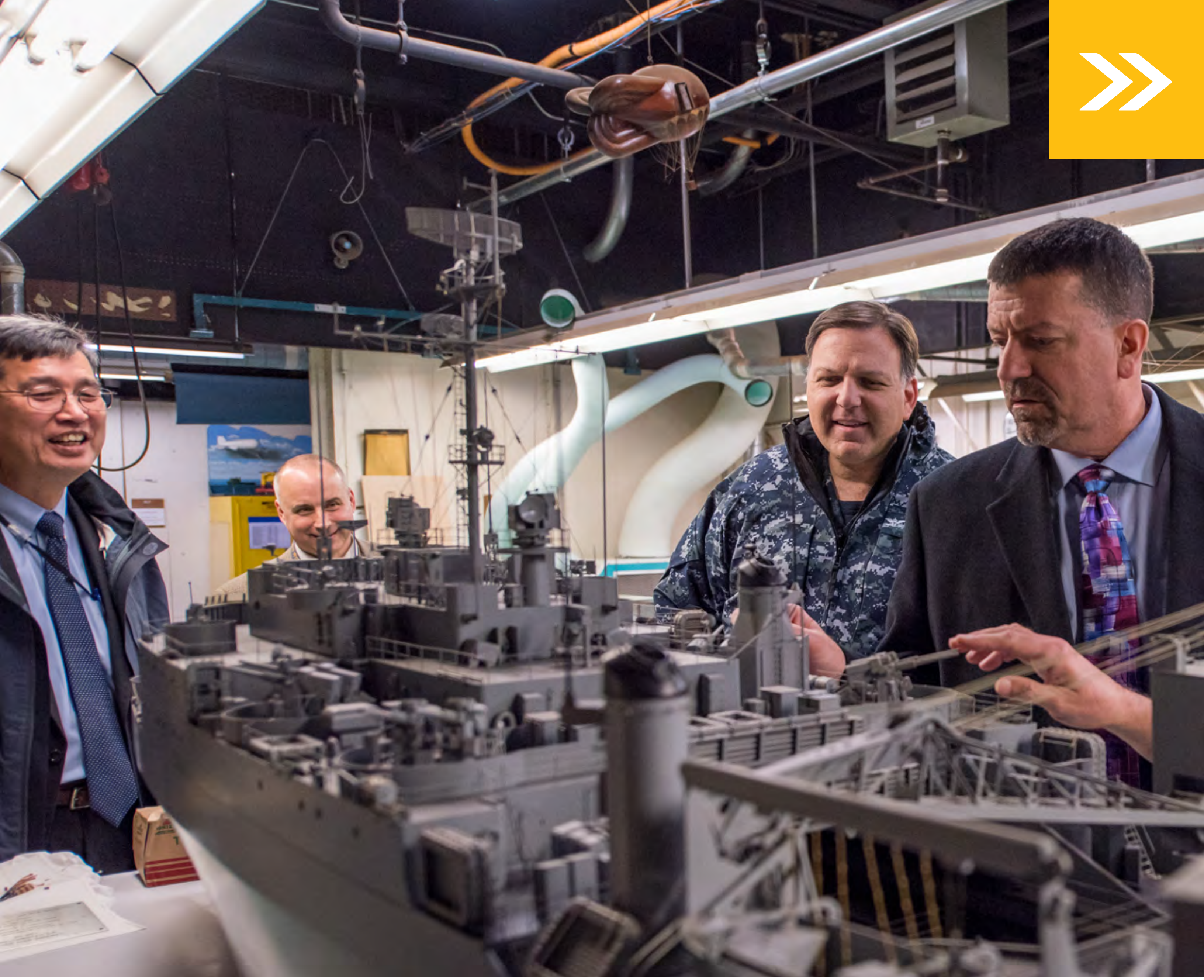
At the ceremony, Davis reminded employees of his credo.

"The mothers and fathers of the sons and daughters who joined the Navy expect that their children will operate in the very best marine vehicles, systems and craft in the world. For boats and combatant craft, it is CCD's mission to satisfy this expectation. This is our common goal. Give your very best every day so the Sailors who depend on our product and services can accomplish their mission any day," Davis said. "Face each day thankful for the opportunity to serve. Congratulations to all of you and your families, on the accomplishments of CCD, for making CCD the best job in the Navy."


DO NOT PAINT

Carderock's Business Operations Team visits Norfolk

The Business Operations Team of Naval Surface Warfare Center, Carderock Division visits USS Mahan (DDG 72) in Norfolk on Oct. 26, 2017, as part of an off-site meeting to develop fiscal 2018 goals, objectives and team vision. From left to right: Alex Shoulders, Buddy Beavers, Vernon Daley, Deanna Boyd, Bob Simpson, Addist Bennett III, Wesley Hill, Karen Musselman, Christine Rustad, Suzanne Donohue, Anne Grandi, Charlotte Reines and Cheryl Burris. (U.S. Navy photo by Petty Officer 3rd Class Armour/Released)



NAVSEA executive director visits Carderock

By Bill Putnam, Carderock Division Public Affairs

At any given point during the year, Naval Sea Systems Command (NAVSEA) has 40 percent of the capital fleet under its control, said James Smerchansky during an all-hands call at Naval Surface Warfare Center, Carderock Division in West Bethesda, Maryland, Jan. 17.

Smerchansky, NAVSEA's executive director, visited Carderock to learn more about the Warfare Center's capabilities, tour facilities around the base and hold the all-hands to update staff on the NAVSEA "Campaign Plan to Expand the Advantage."

NAVSEA Commander Vice Adm. Thomas Moore laid out the campaign plan in 2016 to help move the command into the future. The campaign has three mission priorities: "On-time Delivery of Ships and Submarines," "Culture of Affordability" and "Cybersecurity," which are supported and enabled through two foundational lines of effort, "Design for Talented People" and "High-Velocity Learning."

"Mission priority number one – if we don't make on-time delivery of ships and submarines, then the Navy suffers," Smerchansky said.

Ships are needed to be ready for deployment because if they're not, there could be a gap in service or a deployment may have to be extended, he explained.

"On-time delivery of ships and submarines makes the top priority for the commander," Smerchansky said. "And there are a lot of pieces that make that up."

Building a culture of affordability drives right into what the Warfare Centers do. New technology is needed to keep pace with threats, Smerchansky said.

James Smerchansky (center), executive director for Naval Sea Systems Command, listens as the Navy's curator of ship models, Dana Wagner (right), explains the models being worked on in his shop at Naval Surface Warfare Center, Carderock Division in West Bethesda, Md., Jan 17, 2018. From left: Dr. Paul Shang, acting technical director; Larry Tarasek, deputy technical director; Capt. Mark Vandroff, commanding officer; Smerchansky; and Wegner. (U.S. Navy photo by Jake Cirksena/ Released)

"But we have found ourselves at many points in time in the history of the Navy not being able to deliver those capabilities because we made it unaffordable," he said, adding that the culture of affordability is about making the right decision with the money appropriated and making sure requirements are right as development begins.

Cybersecurity is important now because systems are more interconnected than they were in the past and more digital than in the past, he said.

"Just think about what would happen with connected warships if we had a cybersecurity incident," Smerchansky said.
The command wants to highlight it so cybersecurity becomes built into how things are done because of its importance, he said. His goal with cybersecurity is to get it to a point where it's treated like a "-ability" like "availability" and "reliability."

"But for now, it is treated like its own separate area because it requires focus," he explained.

Smerchansky also spoke about his career and how he arrived at his current position. He started with NAVSEA in 1985 as an engineer two weeks after graduating from college. Then he worked as a sonar project manager for the Virginia-class submarine. In 2002, he served as a science advisor to the commander, U.S. Pacific Fleet in Hawaii.

The position, sponsored by the Office of Naval Research, was a good one for him and his family, he said. Staying on as a NAVSEA employee, he was sent to Hawaii to translate operational requirements for what's now the Naval Research and Development Establishment.

"It truly was a bridge to what's happening now and what's happening in the future," Smerchansky said of his time at Pacific Fleet.

He entered the Senior Executive Service in 2006 where he was the director for the Above Water Sensors program at Program Executive Office-Integrated Warfare Systems. In 2009 he was selected as the chief engineer for Marine Corps Systems Command, and in 2014 he was named that command's executive director.

"That was just a wonderful opportunity," he said.

It's important to take on new challenges and different opportunities throughout a career, Smerchansky said.

"People say you learn from mistakes, you learn from different experiences. I can absolutely vouch for that because in several of those jobs I had my fair share of mistakes that were made over my career," Smerchansky said.

He felt suited and even a bit intimidated to become NAVSEA's executive director after working there for 24 years and seven years with the Marines.

"If you're looking for challenges, there is something for everybody within this whole enterprise of NAVSEA," Smerchansky said.

James Smerchansky (center), executive director for Naval Sea Systems Command, listens to a presentation by Seth Lambert, during a visit to Naval Surface Warfare Center, Carderock Division's Acoustic Research Detachment (ARD) in Bayview, Idaho, on Feb. 28, 2018. (U.S. Navy photo by Keith Thomas/ Released)

LEEP opportunity with Smerchansky helps expand NAVSEA view for Carderock detachment employee

By Katie Ellis-Warfield, Carderock Division Public Affairs

River Clemens, a radiated noise analyst at Naval Surface Warfare Center, Carderock Division's Acoustic Research Detachment (ARD), got to see how she contributes to Naval Sea System Command's goals by participating in Executive Director James Smerchansky's visit to Bayview, Idaho, Feb. 28.

Clemens' participation in Smerchansky's visit was part of NAVSEA's Leadership and Enterprise Exposure Program (LEEP). This program offers employees the opportunity to meet and interact with NAVSEA leadership during site visits in order to gain a better understanding of the enterprise and how their organizations contribute to the mission.

Prior to his visit, Smerchansky's office requested that an employee from the Carderock Division detachment be offered the opportunity to participate in the visit as part of LEEP.

Clemens saw an opportunity to better understand the organization and decided to submit her application. "I love meeting new people and knew I would enjoy helping to make Mr. Smerchansky feel welcome at ARD," she said.

"I thought this was a good opportunity to get some context, not just in terms of technical knowledge, but to understand how the organization works, to understand the language that is spoken and how that translates into what we are trying to do," Clemens said.

"River (Clemens) contributed significantly to the overall visit," said ARD's Site Director Alan Griffitts. "She represented ARD extremely well and provided great context from a relatively new employee perspective."

"I didn't really know what to expect so I was trying to play it by ear, but I think overall it was really good," Clemens said. "My job was to listen and absorb as much as possible and I thought, 'Well, that doesn't sound too hard,' but I actually ended up with a lot to process."

Clemens said that while participating in this visit she not only learned more about NAVSEA, but she also learned a lot about ARD. "I have been here nine months and have heard a lot about the

James Smerchansky (left), executive director for Naval Sea Systems Command, visits Naval Surface Warfare Center, Carderock Division's Acoustic Research Detachment (ARD) in Bayview, Idaho, on Feb. 28, 2018. Also pictured from left after Smerchansky is River Clemens, a radiated noise analyst; Lou Carl, Carderock's chief engineer; and Alan Griffitts, ARD site director. (U.S. Navy photo by Keith Thomas/Released)

different things that we do, but seeing the top-level presentations gave me a much better understanding of what it is we do here. I was pretty impressed," she said.

During his visit, Smerchansky held an all-hands meeting with the ARD employees highlighting the NAVSEA campaign plan, strategic framework, knowledge transfer and high-velocity learning.

Griffitts said the ARD team enjoyed the inspiring nature of Smerchansky's all-hands call. "Mr. Smerchansky encouraged and answered several questions from the staff. We all left this meeting with increased motivation, and even felt entertained," Griffitts said.

"In the all-hands meeting you could tell he cares about people at ARD's experience with NAVSEA," Clemens said. "He put a lot of effort into answering questions and explaining things."

Afterwards Smerchansky was briefed by ARD subject-matter experts and toured the major facilities and ranges located on Lake Pend Oreille, an 1,150-foot-deep lake where the Navy tests ship and submarine acoustics. Smerchansky also saw several of the large-scale models that are housed at this detachment.

"He was asking good questions that showed he had an in-depth knowledge of this stuff," Clemens said. "You could tell he was engaged, and I admired that."

Griffitts said he was pleased with how Smerchansky's visit went. "Mr. Smerchansky expressed a genuine interest in the testing being conducted and, most importantly, in the personnel who support the ARD mission," he said.

Clemens is fairly new to ARD, having started in May 2017. Prior to this position, she was an equipment programmer for an industrial measurement company.

She is a native of Portland, Oregon, and has a bachelor's degree in physics from Harvey Mudd College in Claremont, California, and a master's degree in physics from Montana State University in Bozeman, Montana.
Clemens is currently assisting with the validation of the newly installed acoustic arrays on the Large Scale Vehicle range.

"There is just so much to learn, so many opportunities to learn, both technical and administrative." Clemens said. "The more I learn, the more there is to learn."

Carderock CO speaks at SNA symposium

By Bill Putnam, Carderock Division Public Affairs

One word is what Capt. Mark Vandroff wanted audience members to concentrate on during a panel discussion: flexibility.

Flexibility in shipbuilding and fielding is what makes a ship relevant in the future, said Vandroff, commanding officer of Naval Surface Warfare Center (NSWC), Carderock Division, during a panel discussion on integrating ship design at the Surface Navy Association's annual national symposium in Crystal City, Virginia, Jan. 10.

The panel, moderated by Rear Adm. Tom Druggan, commander of NSWC, was on a continuum of ship design, from ship design to combat-system design to ship integration to fleet introduction.

"Flexibility is a requirement, it is a capability, it is what we desire," Vandroff said.

Carderock's piece in shipbuilding and design is well known in Navy circles for naval architecture and hydrodynamics because of the David Taylor Model Basin and the Maneuvering and Seakeeping Basin, Vandroff said. But the center has facilities to test for vulnerability and survivability. All of those facilities play a part in a bigger question in shipbuilding and ultimate fielding: "What is it that we need to win?"

A combat system isn't fully effective unless it is fully integrated across the system, said Capt. Godfrey Weeks, commanding officer for NSWC Dahlgren Division.

"That is easier said than done," he said.

The operating environment for Navy ships is unforgiving, Weeks said. A ship and its combat systems are affected by things like sea spray, humidity and how

Naval Surface Warfare Center, Carderock Division Commanding Officer Capt. Mark Vandroff (center) speaks at the Surface Navy Association's 30th National Symposium on Jan. 10, 2017, in Crystal City, Va. From left: Rear Adm. Tom Druggan, NSWC commander; Vandroff; and Capt. Godfrey "Gus" Weekes, NSWC Dahlgren Division commanding officer. (U.S. Navy photo by Bill Putnam/Released)

the ship maneuvers through waves.

"We have to build the systems to survive that," Weeks said.

Then there are man-made effects on platforms from gun and missile shots. The gases from missile shots are corrosive to a ship's hull, while guns will produce a sonic shock to the hull.

Weeks said the idea is the Navy has plenty of space to put new systems on a ship, but what can be forgotten is the crew. Their berthing and operating spaces take up room with explosives, fuel and sensors.

"So it's not a trivial matter to shoehorn, especially afterwards, on to these platforms," Weeks said. "Doing it with modularity and flexibility up front will allow our nation to bring future capabilities to the forefront much easier."

"It is not getting simpler out there. The threat is growing, and it's becoming more complex," Weeks said.

Future integration and rapid fielding will be done through big data, analytics and constant software updates, said Dr. Megan Fillinich, chief technology officer for NSWC. All of this will be built around a data "library" and sensor network that will identify gaps and new tactics, Fillinich said.

These updates can be pushed to legacy and future systems, she said.

"This integrated sensor network ultimately provides the ability to build maneuver space in contested and congested environments," Fillinich said.

Capt. Steve Murray, former commanding officer of NSWC Corona Division, opened his portion of the panel by saying the work the other panelists produce isn't beneficial if Sailors don't understand the capability they have and how that capability is integrated in a way that allows them to fight and win.

To reach that understanding, the Navy is moving to a live-virtual constructive (LVC) training environment method. LVCs will allow the Navy to train as it builds weapons and tactics that exceed the capabilities of live ranges. The Navy will have the space in those environments to train their Sailors.

Another benefit of LVC training is unlimited resources. The Navy only has a limited amount of ordnance, targets and ships to use as opposing force (OPFOR), Murray said.

"When ships are playing OPFOR they're not preparing themselves for the fight," he said. "And we need all the ships we can."

But in LVC there are unlimited amounts to learn and build training on.

The Navy is also challenged with operational security because future adversaries can see what the Navy is doing and any developed advantage will disappear, Murray said.

"We have to maintain that advantage always," he said.

It's a good thing that when someone thinks about a Navy ship and modularity they may think about the Littoral Combat Ship (LCS) mission, Vandroff said.

"But modularity exists on a continuum," he said.

Modularity has been a part of the Navy since the 1920s, Vandroff said. The Navy's first aircraft carrier was a modular ship. In the aftermath of World War I, the Navy was limited in the types of ships it could have, Vandroff said. A battle cruiser, USS Lexington, was partly built. Too light to be a battleship, the Navy converted it to a new type of ship at the time – the aircraft carrier.

"That was our first modular ship," Vandroff said. "We just didn't know it at the time."

Carderock engineers train 3-D printing at ONR

By Alisha Tyer, Carderock Division

The role of additive manufacturing (AM) within the Department of Defense (DOD), particularly within the Navy and Marine Corps, has seen exponential growth in recent years. Current naval efforts focus on providing AM capabilities to the fleet by methods of innovation initiatives, the establishment of fabrication laboratories (fab labs) such as the Naval Surface Warfare Center, Carderock Division's (NSWCCD) Manufacturing, Knowledge and Education (MAKE) Lab and by providing hands-on training to the warfighter. Nonetheless, the request for training in on-demand AM technologies has not ended with the warfighter, it now extends to program officers and key stakeholders in naval technology development.

The NSWCCD Additive Manufacturing Project Office (AMPO), which manages the MAKE Lab (established in 2016), offers training to anyone interested in learning about AM technology. Predictably, many of the trainees have been technical personnel interested in learning how to apply AM in support of their programs, enabling production to run more efficiently. However, future projections of AM integration include all aspects of naval operations from research and development to lifecycle maintenance support, not just production and manufacturing. As such, the AMPO team has been hard at work delivering AM training outside of the Warfare Center, encouraging a broad spectrum of support and involvement from key stakeholders within each step of the capabilities development process.

Samuel Pratt (left), an engineer with the Additive Manufacturing Project Office at Naval Surface Warfare Center, Carderock Division, teaches Office of Naval Research program managers (from left after Pratt) Dr. Jennifer Wolk, Stephen Glotzhober, Dr. Airan Perez and Dr. David Drumheller how to use a recently installed 3-D printer Oct. 19, 2017, in Arlington, Va. (U.S. Navy photo by Eric Anderson/Released)

The observable benefits of on-demand AM technology for the Navy are its quickness, efficiency and ultimately, the enhancement of warfighter capabilities. But the technology also provides significant overall cost savings when compared with more traditional forms of manufacturing. The program office's interest in as-needed AM printing capabilities centers on research and development competence, as well as the ability to rapidly prototype designs developed by field activities prior to costly full-scale production and manufacturing.

On Oct. 17 and Oct. 19, with the support of Dr. Jennifer Wolk, a program officer from the Office of Naval Research, Carderock engineers Samuel Pratt and Bryan Kessel provided hands-on training to ONR program managers in Arlington, Virginia, on their recently installed 3-D printing machine, the Stratasys uPrint SE Plus. The well-attended training included participants primarily from ONR's Sea Warfare Weapons Office and across a wide range of research areas within the department. Wolk expressed to the attendees that on-demand printing is valuable to the program office as it allows for visualization of the concepts and models the field activity is intending to produce, and affords the ability to recommend or make suggestions to work prior to incurring excessive manufacturing costs.

The three-hour training began with a basic overview of AM processes and current technologies. The Carderock engineers then demonstrated proper use, protection and troubleshooting for the uPrint SE Plus. Prior to training, each attendee was tasked with providing their own 3-D CAD designs, which they would print at the end of the training. Many of the attendees had no direct experience with additive manufacturing or 3-D printing machines prior to participating in the training event, but were able to use readily downloadable CAD files from online sources or those developed by their sponsored field activities.

Dr. Michele Anderson, program manager for Electrochemical Materials at ONR, who attended the training without prior experience in 3-D printing or CAD drawing, expressed great enthusiasm for the ability to personally additively manufacture parts and designs as needed and discussed the utility of AM to the program offices.

"ONR has significant investments in fuel cell systems for unmanned undersea (UUV) and air vehicle (UAV) propulsion, and we have started to apply additive manufacturing methods to develop more capable systems. The Naval Research Laboratory flew a fuel cell stack that incorporated bipolar plates developed using additive manufacturing in the Ion Tiger UAV last year in an ONR-funded program," Anderson said. "Additive manufacturing was an invaluable tool for the rapid prototyping and development of the bipolar plates, which could not have been developed and implemented as quickly using the standard approach."

So, what does the future of AM look like within the Navy? Wolk predicts that due to the rapid growth of the technology, the next generation of manufacturing platforms will all include AM. Current work across the naval enterprise, DOD, standard development organizations and public private partnerships like America Makes – National Additive Manufacturing Innovation Institute seek to develop, expand and enable integration of additive manufacturing processes and materials for critical applications.

"AM is a developing technology and there is not always exposure to its strengths and limitations, but as our engineering and manufacturing costs become more constrained, additive offers an opportunity to reduce development and lifecycle costs," Pratt said. "It is important to expose program offices to additive to help them understand how it can be used to reduce system development and lifecycle costs and, ultimately, next generation naval capabilities."

Naval innovators prepare for the coming Singularity with post-MMOWGLI workshop

From Carderock Division Public Affairs

Innovators at Naval Surface Warfare Center, Carderock Division; Space and Naval Warfare Systems Command, Atlantic; and Naval Postgraduate School (NPS) have spent the last several months curating the output from a massive multiplayer online wargame leveraging the Internet (MMOWGLI) to examine how the Navy might address the emergence of greater-than-human intelligence from technological means, otherwise known as "the Singularity."

The "Design for Maritime Singularity MMOWGLI" took place in the spring and asked players to collaborate on responses to two distinct, yet complementary questions: "What concepts for human-machine teaming might we develop as we approach the Singularity?" and, "As complexity rises all around us, what new organizational constructs should we consider?"

According to Carderock's Director for Innovation Garth Jensen, who designed the game, the impetus for the Singularity MMOWGLI rose from a growing concern that the Singularity represents "a tidal wave of change approaching the Navy. This wave presents us with a binary choice. If we recognize this wave in time, we can ride it and harness its energy. But if we ignore this wave, or try to resist it, we will get washed up on the shoals of history. There's really no middle ground. We either ride the wave or get crushed by the pace of change."

Garth Jensen, director for innovation at Naval Surface Warfare Center, Carderock Division, briefs the Singularity massive multiplayer online wargame leveraging the Internet (MMOWGLI) workshop Aug. 15, 2017, on the results from the MMOWGLI game at the Naval Postgraduate School in Monterey, Calif. (U.S. Navy photo Javier B. Chagoya/Released)

The game was hosted on NPS's MMOWGLI platform and was playable on any web browser or mobile device. Jensen said the audience response to this game was among MMOWGLI's most vibrant ever, with more than 21,000 YouTube views, 4,000 signups, 1,250 active players, 9,000 idea cards played and 45 action plans developed by participants.

Following the game, Jensen, teaming up with Dr. Matt Largent of Space and Naval Warfare Systems Command, combed through all 9,000 idea cards and 45 action plans, using "hermeneutics," a process more often associated with theology and the liberal arts than with standard engineering practice.

"We had to treat the MMOWGLI output as a form of literary text, reading it several times through, highlighting major themes and significant outliers, sometimes stitching disjointed threads together to form a completely new idea," Jensen said. "Our goal was to uncover those ideas that warranted further detailed development."

From there, Jensen and Largent enlisted the services of Lyla Englehorn, from NPS, to plan and conduct a workshop at NPS in Monterey, California. Englehorn, who Jensen called "a world-class design thinker and practitioner," put together a three-day workshop using design thinking principles, drawing participants from across the Naval Research and Development Enterprise (NRDE). Using Jensen and Largent's curated MMOWGLI output as her "Design Challenge," Englehorn divided her workshop into three smaller teams, each focused on a different aspect of the Singularity and each one challenged to come up with an actionable, fully formed idea by the end of the workshop.

Jensen said the workshop was a success, and the teams presented their results at the end of the workshop to an audience including the sponsor, as well as leadership from NPS and the NRDE.

You can read more about MMOWGLI in Carderock's previous article at http://www.navy.mil/submit/display.asp?story_id=99069.

Analytics Community of Practice launches at Carderock

By Kelley Stirling, Carderock Division Public Affairs

Naval Surface Warfare Center, Carderock Division has launched a new community of practice (COP) for data analytics and data science, with aerospace engineer Trisha Shields leading the effort. The first meeting of the Analytics COP was held Nov. 15 with about 75 people in attendance, quickly overflowing the meeting room.

Shields explained the reason she felt this Analytics COP was important stems from what she does in her own job within Carderock's Sea-Based Aviation and Aeromechanics Branch, which includes analytics on individual aircraft and across the fleet of aircraft for a type-model series.

"Over the past seven years of working in this field, it has been continuously emphasized that the realm of data science and analytics has not been covered by my engineering background and that I needed to increase my skill sets to include stats, machine learning, training in new tools, understanding computational limitations and the list goes on and on," Shields said.

Some degree fields, such as computer science or statistics, are better suited for data analytics and data science. But Shields said everyone could benefit from learning some of the basics about data exploration and this led her to want to create the community of practice.

"My assumption is that there are others at Carderock who have at least dabbled in areas, techniques and methods that can help me do my job," Shields said, explaining that knowing who these people are would prevent her from starting from scratch. "My other assumption is that there are other people like me at Carderock who are in the same position."

Shields laid out two main goals for the Analytics COP moving forward. The first goal is to develop, encourage and grow a sustained fundamental competency in the areas of data science and analytics within the workforce. The second goal is to help Carderock as an organization maintain stewardship and technical proficiency of the past, present and future state of data science and analytics at Carderock and its direct and abstract application to Navy ships and ships' systems.

"I see this as kind of our mission statement for the community of practice," Shields said. "As experts in the Navy, it's going to fall on us to at least have a reasonable awareness of the current state of where these methods and techniques are."

Shields listed several ways for the Analytics COP to realize the goals, including knowledge management, information sharing, problem identification, training requirements and networking across Naval Sea Systems Command (NAVSEA) and the Department of the Defense as necessary. Some other objectives include establishing a steering committee of four or five people to help her lead the Analytics COP to success; developing a charter to lay out exactly how the Analytics COP will operate; setting up an active community to start information sharing of best practices and techniques; identifying training for the skill gaps; and establishing a regular drumbeat of meetings.

“I see this community of practice as aligning and both feeding into and drawing from the various other data-related efforts going on in the organization and at NAVSEA,” Shields said. “Data is a pretty hot topic right now at headquarters and a lot of other efforts are capitalizing on terms like big data, digital twin and predictive analytics. The main thing to understand and communicate to everyone is that the focus of this community of practice is to develop the fundamental skill sets that are pieces and enablers of these broader efforts.”

Shields opened the floor to suggestions for the Analytics COP by providing a few examples of what topics might be important to the group, such as how to deal with dirty data, sparse data, missing data and low-veracity data; applying machine learning methods to time-series data; best practices for Python; best libraries to accomplish X, Y or Z; and considerations for computational limitations. She also recognized that there are information technology (IT) and cyber security issues that may prevent or limit success, but that as a group, members may have more leverage to push past some of these issues.

Some suggestions from attendees included specific training on different software already available, like MATLAB, GitLab, TensorFlow and Spork. There was also a desire to learn how to register newly developed code through DADMS, which is the Navy’s system for application and database management.

“Based on what I’ve seen, there are a lot of experts already here at Carderock,” said Brian Fuller, an aerospace engineer who works with Shields. “And what I’d like to see is some portion of our regular meetings set up like a seminar provided by our in-house expert.”

Jonathan Hopkins, head of Carderock’s Additive Manufacturing Project Office, said his knowledge and background in data analytics is fairly limited, so he is excited about the establishment of a community of practice.

“It is an excellent forum to bring ideas together from all departments to shape Carderock's future in data science and digital design efforts,” Hopkins said.

Hopkins has been detailed one day a week to headquarters where he says they are looking to understand what work each Warfare Center is doing in this area and leverage that across the enterprise.

"Carderock is very committed to helping this community grow and helping us gain the skill sets and move forward on the digital front as best we can," Hopkins said, adding that he is helping to set up a new digital design lab that will be focused on training. Called the Innovation, Design, Engineering and Analysis (IDEA) Lab, Hopkins envisions this to be a space that employees could use to learn more about certain data science software. He plans to send out an announcement as the IDEA Lab takes shape.

Shields said she wants to have participants from across the command in the Analytics COP, and that it’s not limited to the technical codes. Analytics can be used to improve human resources, finance and business offices.

Data definitions (Taken from online sources)

Machine-learning: is a field of computer science that gives computers the ability to learn without being explicitly programmed.

GitLab: is a web-based Git repository manager with wiki and issue tracking features, using an open source license, developed by GitLab Inc.

Apache: is a permissive free software license written by the Apache Software Foundation (ASF). The Apache License, Version 2.0 requires preservation of the copyright notice and disclaimer. Like other free software licenses, the license allows the user of the software the freedom to use the software for any purpose, to distribute it, to modify it, and to distribute modified versions of the software, under the terms of the license, without concern for royalties.

TensorFlow: is an open-source software library for dataflow programming across a range of tasks. It is a symbolic math library, and also used for machine learning applications such as neural networks.

MATLAB: (matrix laboratory) is a multi-paradigm numerical computing environment. A proprietary programming language developed by MathWorks, MATLAB allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages, including C, C++, C#, Java, Fortran and Python.

Python: is a widely used high-level programming language for general-purpose programming. An interpreted language, Python has a design philosophy that emphasizes code readability (notably using whitespace indentation to delimit code blocks rather than curly brackets or keywords), and a syntax that allows programmers to express concepts in fewer lines of code than might be used in languages such as C++ or Java. It provides constructs that enable clear programming on both small and large scales.

Data, data and more data: What do we do with it?

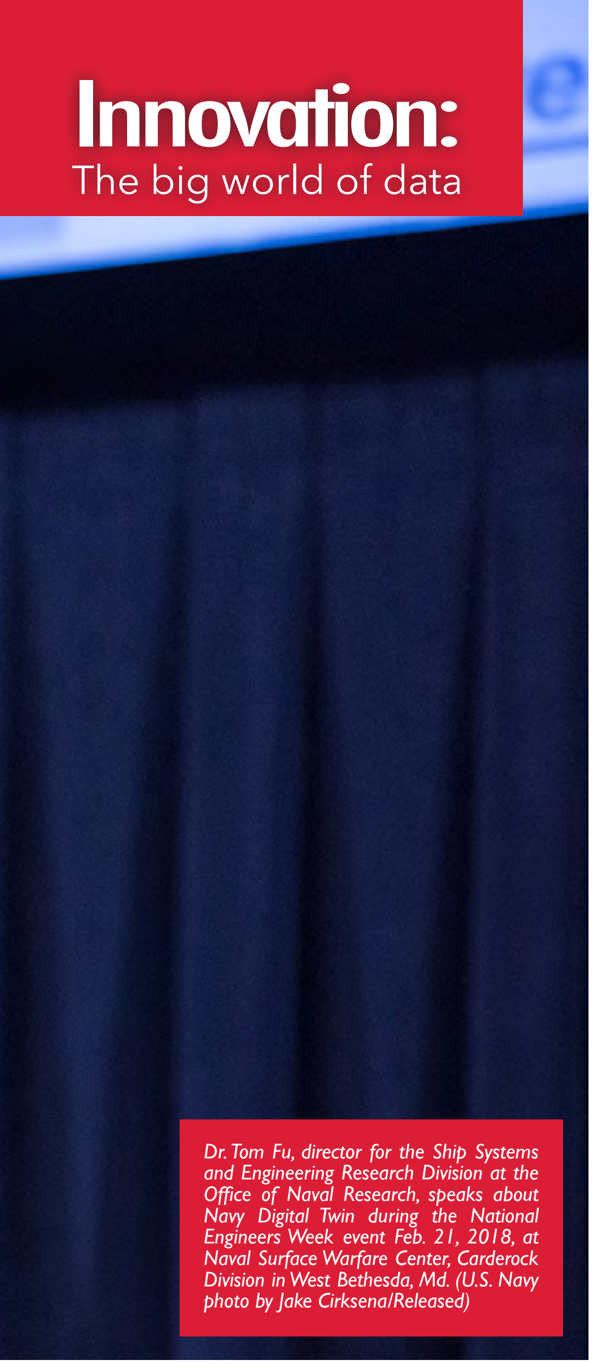
By Kelley Stirling, Carderock Division Public Affairs

Data science, data analytics and Navy Digital Twin (NDT) were the topics for the National Engineers Week event Feb. 21 at Naval Surface Warfare Center, Carderock Division, in West Bethesda, Maryland.

“We recognize the contributions of our 1,500 world-class scientists and engineers here at Carderock,” said Larry Tarasek, Carderock’s deputy technical director, adding that he is proud of his engineering degree and the work he has done at Carderock as an engineer, specifically early in his career in the experimentation for the Seawolf program. “We have 60 years of acoustic trials; we have massive amounts of data through large-scale model testing. How are we going to do data analytics, how are we going to do machine learning going forward in the future?”

The event featured Trisha Shields, lead of the aviation data analytics projects for Carderock’s Sea-Based Aviation and Aeromechanics Branch, and keynote speaker Dr. Tom Fu, director for the Ship Systems and Engineering Research Division at the Office of Naval Research.

Shields talked about the new Data Analytics Community of Practice (COP) she is leading for Carderock. She said that generating actionable information from data processing is one of the key underlying concepts that drives the community of practice, and it is the core to the Navy Digital Twin effort, which was the focus of Fu’s presentation.



Dr. Tom Fu, director for the Ship Systems and Engineering Research Division at the Office of Naval Research, speaks about Navy Digital Twin during the National Engineers Week event Feb. 21, 2018, at Naval Surface Warfare Center, Carderock Division in West Bethesda, Md. (U.S. Navy photo by Jake Cirksena/Released)

"It's the organization, structuring, contextualization and analysis of data to produce actionable information and to help us make decisions," Shields said. "Right now, we are at a point where the generation of data is so easy and so cheap that it would be foolish of us not to take advantage of it."

The main objective of the COP is to "maintain stewardship and technical proficiency of the past, present and future state of data analytics/science at Carderock, as well as their application to the Navy's ships and ship systems." Shields said in basic terms this means to establish and empower a fundamental competency within the workforce.

With the Department of Defense and the Navy's unique problem space, Shields said that the workforce needs to keep in mind the methods and techniques being developed in industry.

"They (industry) don't necessarily take into account our mission requirements and our operating environments," she said. "We need to work with industry and academia to take what they are doing and adapt it to our unique problem space. That's where the community of practice comes in."

The mission of the community of practice is to build a sustained and strong community of practitioners that help Carderock, and Shields laid out four key actions that the COP will focus on:

- Identify and leverage existing experience and expertise
- Network with others and share knowledge
- Develop and support analytics best practices
- Train and develop skills in the workforce

Shields said she intends to hold a monthly meeting of the COP, featuring short seminars on a data analytics tool, method, technique, workshop or conference.

Fu, a member of the Senior Executive Service, is a former Carderock engineer who eventually became the deputy department head at Carderock for what is now the Naval Architecture and Engineering Department. During his talk about Navy Digital Twin, he linked the Navy's overall vision to what the Naval Sea Systems Command (NAVSEA) provides.

When working as an engineer, Fu said he was very focused on his particular contribution. In his current position at ONR, he said he thinks about the bigger picture all the time, how NAVSEA provides maritime dominance.

"I think it's a message that does get lost. You guys need to think about it also," Fu said. "It is not a trivial vision; it's not a trivial mission. It's a very hard thing to execute."

Fu used a definition by Srivathsan Govindarajan, the vice president of SAP Digital Twin, to describe digital twin as "a dynamic digital representation of a live physical object," and that it will "dynamically change in near real-time as the state of the physical object changes." For the Navy, the physical object can be a full platform, a ship or ship systems, with Sailors actively working.

"We have the history of that object; we have the current state; and we will have what happens in predicting what's going forward," Fu said. "I have an infinity of futures that I can project into and say, 'What do I want that future of this platform to be?'"

Fu talked about not only the speed of technology improvements, but also the speed of technology adoption. He said from the onset of electricity in the late 19th century it was 46 years before a quarter of the population had adopted electricity. By the time the Internet came along, that adoption rate dropped to seven years.

"The speed of innovation and adoption continues to increase," Fu said. "To maintain the competitive advantage, we will need to move faster to capture those opportunities."

With the speed of technology advancements, Fu said the Navy has to be able to look into the future to support ships and submarines, which can have a 30-50 year lifetime.

"Maritime superiority starts here and the future is now," Fu said, adding that maritime superiority is a hard problem. "It's prompt and sustained combat; it's sea floor to space, from deep water to littorals, information and cyber; it's to conduct decisive combat operations. These are not trivial things, there are millions of things that go into each one of those and how does it all roll together."

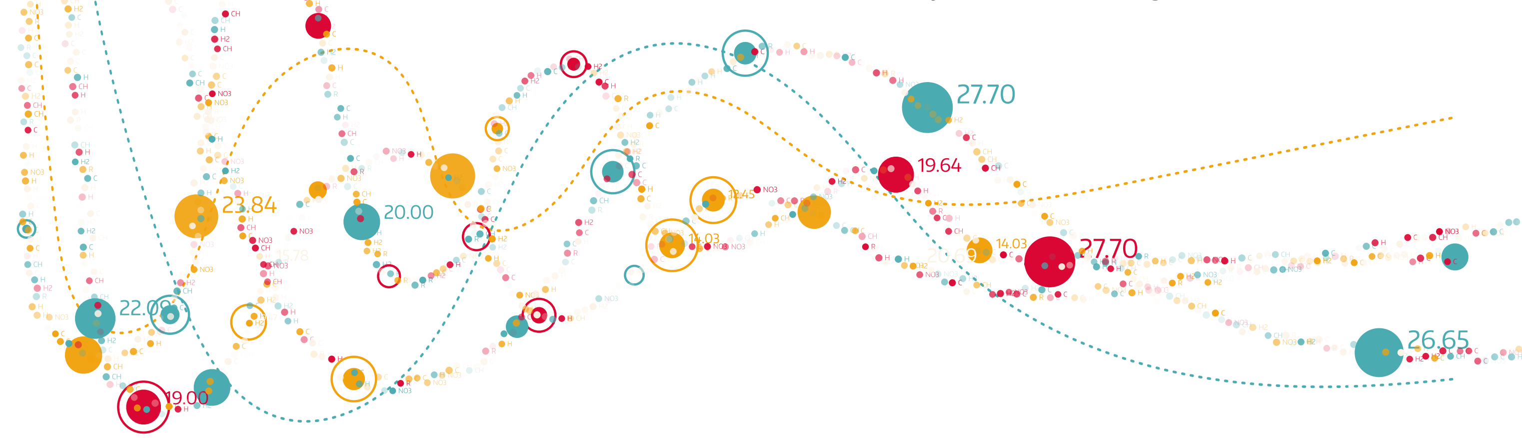
He said digital twin can support the quest for maintaining maritime superiority, but digital twin needs its own set of support.

"All the things that Trisha talked about for the community of practice, you're going to need those skills. We're going to need that capability," Fu said. "This is the challenge. You're going to have to figure out how to do it."

Fu ended by thanking the engineers for being engineers, recognizing that from his position, he can speak for the Navy in saying that everything the engineers do that supports the Navy is appreciated by leadership and the rest of the Navy.

Warfare Centers use data analytics to speed, enhance capabilities

By NAVSEA Warfare Centers – as printed in the February issue of Soundings



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

By better instituting agility and flexibility across the enterprise – and by harnessing the power of new technologies – building a truly "Digital Navy" and digital workforce is rapidly being realized.

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

For example, the continual monitoring and capturing of data across multiple frequencies can better enable the electromagnetic warfare (EMW) Command and Control (C2) necessary to respond to changes in the electromagnetic environment and warfighter requirements across Command, Control, Communications, Computers and Intelligence (C4I) and combat systems.

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

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

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

"The Warfare Centers are researching and developing analysis and engineering capabilities that will enable a 'digital twin' of engineering systems and businesses processes by coupling modeling and simulation output with decision aids made possible by data analytics," said Nathan Hagan, NSWC Carderock Division naval architect and NSWC Headquarters Digital Strategy Lead. In this role, Hagan coordinates efforts across NAVSEA and is building a community of practice across the Warfare Centers geared toward disciplines of big data analytics, digital twin modeling and simulation, model based simulation engineering and digital manufacturing and production, including additive manufacturing.

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

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

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

Innovation:
The big world of data

(Graphic illustration by Kristin Behrle/Released)

Digital twin submarine hull, mechanical and electrical condition-based maintenance

NSWC Carderock Division is developing and exercising a framework for applying distributed analytics to predict the contribution of Hull, Mechanical and Electrical (HM&E) components to a ship's acoustic signature through an fiscal 2018 Naval Innovative Science and Engineering (NISE)/Section 219 project. The Office of Naval Research (ONR) is developing Navy Digital Twin technology to support signature management. This NISE/219 effort seeks to leverage that investment by investigating potential HM&E inputs such as sensors and data, communication channels and data display concepts capable of supporting and exploiting distributed analytics. This will support workforce development as well as lay the foundation for the essential parts on the submarine Navy Digital Twin research. "A key component of signature management is Navy Digital Twin and the robustness of the Navy Digital Twin products depend on the information provided by shipboard sensors and historical data," said Richard Loeffler, NSWC Carderock Division engineering program manager. "Additionally, rapid transition requires easy integration into NAVSEA's Acoustics Rapid COTS Insertion (ARCI) build process. This task supports both of these key components, enabling ONR to focus on the science and NSWC Carderock Division to build the workforce to develop and apply Navy Digital Twin."

Digital twin large scale vehicle demonstration

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

Community of Practice/ Community of Interest

A Data Analytics Community of Practice (COP) and Community of Interest (COI) was established in November 2017 to network NSWC and NUWC employees and support workforce development and knowledge transfer.

The Data Analytics COP and COI team has several objectives to employ a digital strategy across the enterprise.

The first objective is to implement acquisition and sustainment management practices, which will improve the Warfare Centers' ability

Innovation:
The big world of data

LSV 2 Cutthroat, the world's largest unmanned autonomous submarine, has been operating at Carderock Division's Acoustic Research Detachment in Bayview, Idaho, since its delivery in 2001. (U.S. Navy photo/Released)

to meet fleet capability and availability requirements for NAVSEA platforms and combat systems. These practices will improve warfighting, operational and interoperability effects in manned and unmanned systems, and the timely modernization and maintenance of in-service ships and submarines.

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

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

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

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

"We provided teams' publicly releasable maintenance and operational data of three Navy platforms with known maintenance failures and challenged teams to develop data analytics tools which could successfully identify and predict the system mechanical failures," Hagan said. "Based on the success of the HACKtheMACHINE event, the Warfare Center Data Analytics team will be planning and coordinating another data analytics challenge on collision-avoidance in summer 2018 sponsored by Program Executive Office Integrated Warfare Systems 6 (Command and Control)."

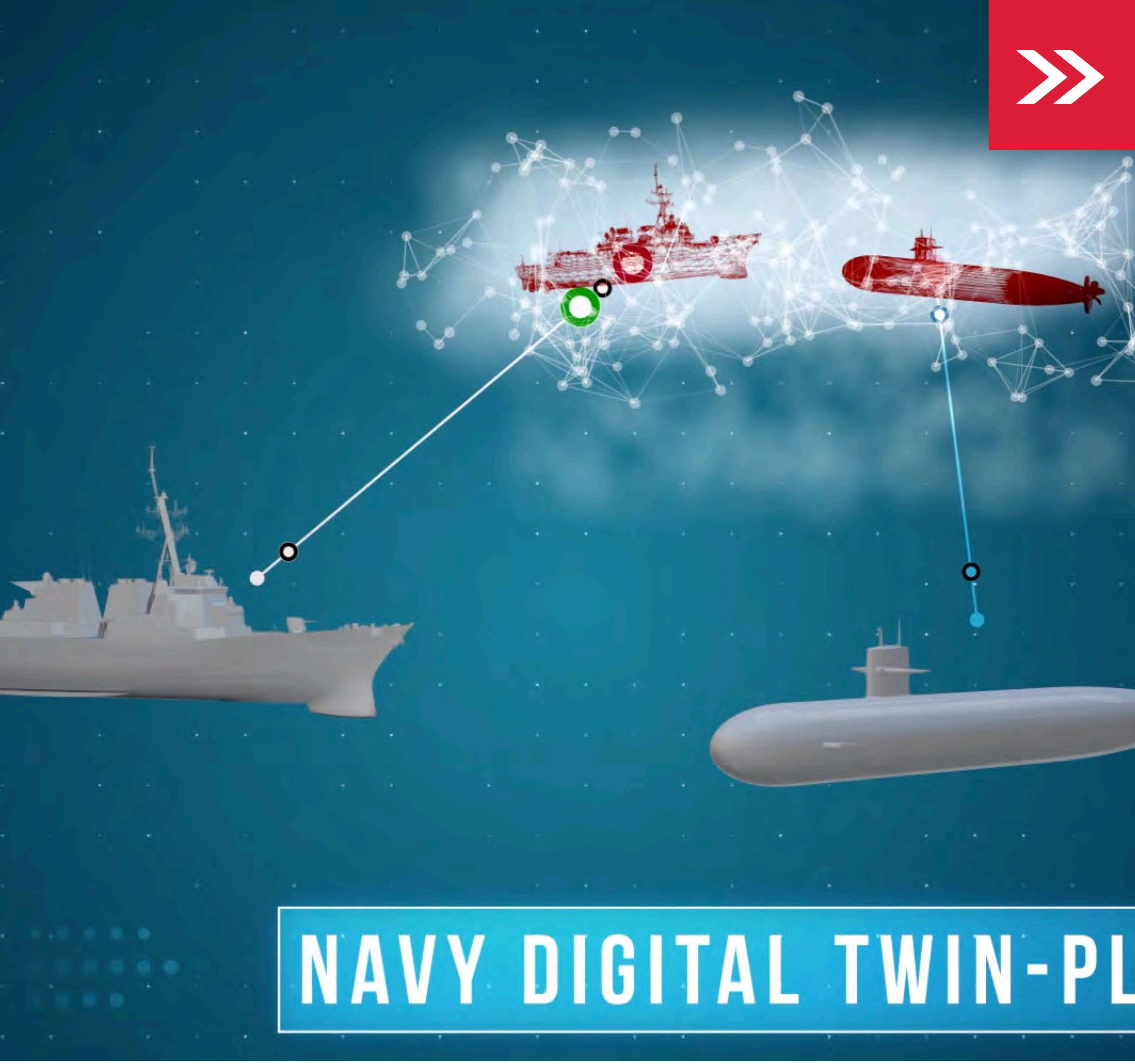
Digital focus areas

The Warfare Centers are continuing to invest in the development of technical capabilities and engineering tools aligning those projects to demonstrations that fit into the following focus areas: Digital Human Resources and Business; Digital Acquisition; Digital Test and Certification; Digital Life-Cycle Maintenance; and Digital Shipyard.

The Warfare Centers' digital transformation will encompass technical areas of opportunity for artificial intelligence, such as EMW, to leverage data-driven decision making, modeling and simulation capabilities and computational and technical resources across NAVSEA.

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

"The development and maintenance of an EMW Digital Twin is a key component of an overall future architecture that can leverage emerging AI technologies and optimize frequency utilization within a dynamic EW context," she said. "Dynamic control of the electromagnetic spectrum is a critical part of architecting a Force Level Design to enable Distributed Maritime Operations."



Digital Universe Workshop

By Roxie Merritt, Carderock Division Public Affairs

"The digital universe is here!" said Dr. Tom Fu at the Digital Universe Workshop held at Naval Surface Warfare Center (NSWC) Carderock on Feb. 6. "There can be no turning back or we are going to get left behind in this era of big data."

According to Fu, if the Navy wants to keep expanding its technological edge, everyone needs to be using big data to make faster decisions similar to the way Amazon and Google leverage data, but in a much more robust and much more sophisticated way. The future of artificial intelligence (AI) is every

bit as revolutionary as the Internet itself. The data explosion presents both opportunity and peril. Harness it and gain a real competitive advantage; fail and be quickly swamped. The pace of technological growth is occurring on a geometric scale and consumers of that technology are keeping pace, meaning they are ready for this next revolution in artificial intelligence.

Using real current data blended with developmental information and using physical modeling to fill in the holes is the first step in realizing a revolutionary approach to the Navy’s operating, managing maintenance and influencing planning missions on an individual scale, and eventually, at the fleet scale.

Companies like Amazon are very data driven. They target users with individualized advertising based on the websites that are clicked on and even for what is searched. Indeed, digital solutions promise significant value for an organization, a value that could never have been realized prior to the advent of connected smart technologies.

“We are now entering a fourth technical revolution driven by artificial intelligence,” Fu said. “The ever-increasing speed of innovation and people’s acceptance of new technology is driving the revolution.”

The Navy, as in most of government, is not a fast adaptor and Fu is concerned about the current pace of development of the Navy digital strategy.

“How do we really accelerate and speed the growth of big ideas and use of big data?” he said. The progress of computing power, development of faster algorithms and use of quantum physics will eventually lead to more artificial intelligence in the world than there is human intelligence in the world.

A relatively new concept related to digital warfare is the Navy Digital Twin (NDT). Carderock’s part in the implementation of the Digital Twin is focused on platforms. Additionally, Carderock, whose slogan is “America's Fleet Starts Here,” is leading an effort, by partnering with its sister Navy labs, to create the framework that will define how this technology is applied on Navy ships and submarines. This framework is the baseline of Navy Digital Twin.

Since the NDT is inherently a governmental activity, commercial entities will not be able to build the framework and the cloud needed to develop the NDT, which means the Navy needs to invest heavily in server farms and banks of search engines.

Data is useless unless you use it. “Start small and build a tactical decision aid, but start it now,” Fu said. “Even if it is just lab-based, just pick something that if you had it, would make your job easier. You need to make it part of your lexicon.”

Fu said the world is asking more and more from its Navy fleet and ship lifetimes need to be extended from the “get go.” The Navy needs to use platforms in the most effective way in order to stretch its investment. “You should be putting your data in the cloud even if it is just maintenance records,” Fu said. Minimally manned ships are here to stay so how are they going to handle repairs and maintenance? How will fleet asset management be handled? Speaking to engineers at Carderock, Fu said the Warfare Centers’ analytics and data will eventually be used by everybody. He emphasized, “There is a lot going on with big data but we also need to get focused.”

Advances are happening now that need other technologies to be developed in order to use them. This is technology building on technology, and hard decisions are being made on funding. The Navy needs an acquisition strategy,as well as technical models and better, smarter buying.

“We should be building a Digital Twin version of every Navy platform,” Fu said. “NDT is a continuous analytical fusion of data, physics-based models and machine learning to prescribe multiple future instantiations of the ship and its environment, which enables the user to readily identify optimum choices.”

The objective of NDT is to move all levels of Navy platform command and logistics from heuristic decision-making to data driven and ultimately, multivariable optimization where digital tools are used to conduct quantitative trade-offs beyond the capabilities of the operator.

“Its artificial superintelligence will trigger runaway technological growth, resulting in unfathomable changes to human civilization,” Fu said. “We need to start now if the United States wants to maintain maritime superiority. Navy leaders are counting on us, the engineers and scientists, to come up with the strategy to turn big data into actionable data.”

“You guys need to hurry up,” Fu said after describing how the Navy is falling behind both China and Russia in the AI race. Bottom line, NDT needs a coherent approach and Fu made it very clear to all the Warfare Center representatives at the Digital Universe Workshop that they needed to get started right away if we want to stay ahead.

Carderock CO kicks off first of naval architecture series

By Kelley Stirling, Carderock Division Public Affairs

A new series of lectures with an emphasis on preserving knowledge and lessons learned of naval architecture began Feb. 15 at Naval Surface Warfare Center, Carderock Division in West Bethesda, Maryland.

Capt. Mark Vandroff, Carderock's commanding officer, kicked the series off talking about his experience as the major program manager for the Arleigh Burke-class destroyer (DDG 51) program.

The Rear Adm. David W. Taylor Naval Architecture Lecture Series was standing room only for the first event.

"There will be no Reynolds numbers, there will be no Froude numbers," Vandroff said, referring to specific calculations used in naval architecture. "It's not really a naval architecture brief because I'm not sure I'm entirely qualified to give such a brief."

Vandroff said he intended to communicate to the audience lessons learned from his time as a program manager of the DDG 51 program, a ship that has been part of his life for the majority of his naval career, which spanned 27 years before he arrived at Carderock in September 2016.

"Twenty-three of those 27 years I spent in the DDG 51 program in one way or another, either as part of the wardroom on one of the destroyers, or at a Supervisor of Shipbuilding where those ships were being built, or in a program office where the ships were being managed, or in the Pentagon as an action officer where that program was in my portfolio," Vandroff said.

The first DDG 51 was funded by Congress in 1985. Vandroff noted that about half the audience wasn't even born before then and a handful of the audience actually was part of the early design efforts of DDG 51.

"I know of no program in the history of the Navy that benefited more from solid up-front systems engineering than the DDG 51 program," Vandroff said, adding that this was an emotional statement without factual basis. "Its longevity is a testament to that systems engineering."

Vandroff said the ship benefited from great systems engineering and great design, down to the way the berthing was designed in order to be more survivable and to be more redundant, to the overall survivability, reliability and ease of maintenance, to the hull form and to the propulsion system.

"It was a disciplined process and most importantly, it had, throughout its lifetime, good engineering, good systems engineering, disciplined approach to design, disciplined approach to change, that served the program well," Vandroff said.

Vandroff described the acquisition process of the DDG 51 and how the acquisition strategy changed over time as the quantity, the industrial base and the requirements changed. He also talked about the cost of the ship itself and how over the history of the ship, once the cost of initial design came down, there has been a fairly steady cost, which is also a testament to good systems engineering.

"It means you have to be disciplined in your change-management processes," Vandroff said. "And you can't be disciplined in your change-management process if you don't have engineers that understand the systems engineering behind the systems that you change or upgrade."

Vandroff said total ownership cost (TOC) has to be taken into consideration in systems engineering, adding that if something is very expensive to operate, even if it's free at the front end, it's no good to the customer.

"So, balancing what you pay up front versus what you pay downstream to operate whatever thing you're creating has always been a part of systems engineering," Vandroff said, comparing TOC to baseball. "It's a game of a lot of singles, I would urge you, don't look for the one big solution, the home run, it doesn't exist. You try to work it down one at a time, a little bit at a time and you never stop. The way you get the win is not with any one breakthrough. It's dedicated teams of engineers working those singles throughout the entire production run of an acquisition program."

Vandroff also used the teachings of Aristotle when talking about building ships. In Aristotle's Ethics, he said that virtue existed at the midpoint between two different vices. Vandroff used courage as an example.

"Too little courage and you're a coward, too much and you're a lunatic," Vandroff said. "True courage is the middle point where you're willing to take risks when

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Capt. Mark Vandroff answers a question during the first presentation of the Rear Adm. David W. Taylor Naval Architecture Lecture Series, held Feb. 15, 2018, at the West Bethesda, Md., headquarters of Naval Surface Warfare Center, Carderock Division. (U.S. Navy photo by Monica McCoy/Released)

it's prudent, when it means something, when there's some possible return for the risk."

Vandroff said he thinks that when designing ships, a good ship is a mean point between two extremes. A ship that's reconfigurable is a balance between it being overly malleable and overly survivable, and the balance between cost and performance is affordability.

He also said the longevity of the DDG program, which will probably span 40 years from funding the first ship in 1985 to funding perhaps the 90th ship in 2025, is pretty remarkable, adding that systems engineers should make that the standard.

"I want to design a ship that will be affordable today and then perhaps 40 years from now, people can still be buying some version of that and have it still be relevant and have it still be something that the warfighter needs," Vandroff said.

In response to a question about the ship requirements and engineering not necessarily going hand-in-hand, Vandroff said Rear Adm. Tom Druggan, commander, Naval Surface Warfare Center, is trying to drive that awareness across the Navy, trying to make systems engineering part of the requirements generation.

"I think that set-based design offers us a unique tool to help inform the requirements process," Vandroff said. "And I think we are starting to see that."

Members of the Naval Surface Warfare Center, Carderock Division fiscal 2018 Leadership Education and Development (LEAD) Program listen as some of Carderock's senior leaders talk about their career experiences during a mentor-matching session on Nov. 15, 2017, at the West Bethesda, Md., headquarters. (U.S. Navy photo by Monica McCoy/Released)

Fiscal 2018 LEAD cohort mentor match-up

By Ryan Hanyok, Carderock Division Corporate Communications

Great leaders often have great mentors. Yet even star employees can have difficulty finding a good mentor, especially one with similar early career experiences. To jump start the mentor search, the fiscal 2018 Leadership Education and Development (LEAD) program held a mentor-matching session with senior leaders at Naval Surface Warfare Center, Carderock Division in West Bethesda, Maryland, on Nov. 15.

"Hearing different perspectives and learning how people got to where they are now is why these sessions are valuable," said Mike Brown, head of the Naval Architecture and Engineering Department. "I really enjoyed the recommendations my fellow department heads had to offer."

In a casual, round-table discussion, LEAD members heard tales of key decisions, major milestones and life lessons from the storied careers of Carderock's senior leaders, whose experiences were as unique as the individuals.

"I grew up on a hog farm in Nebraska. After college I chose to join Carderock to work on full-scale acoustics. It was the best decision I ever made," said Paul Luehr, deputy head of the Ship Signatures Department. "I've had several mentors, including Paul Shang, and I learned that becoming a mentor is as valuable for them as it is for you."

Jeff Mercier, head of the Platform Integrity Department, spent eight years in the Coast Guard, worked at White Oak Laboratory, in the private industry and in several Carderock branches. He suggested LEAD members "find a good sounding board wherever you are."

"The relationships you build are as important for you as they are for those around you," said Kathy Stanley, chief of staff. "Embrace your weaknesses, play on your strengths and utilize your relationships to enhance both."

As the event progressed, LEAD members quickly realized that there is no single path to leadership or universal qualities defining good leadership. Some senior leaders charted career paths with specific goals in mind, while others took risks as new opportunities arose. All nine senior leaders in attendance agreed: hard work,

honesty and integrity matter to gain the trust of subordinates, peers and leaders.

"I learned a lot about the choices that our senior leaders made through their careers and what role mentoring played - and still plays - in their development," said Eric Silberg, LEAD chair and aerospace engineer in Carderock's Sea-Based Aviation and Aeromechanics Branch.

"It was nice to hear all of our Carderock leaders have the same issues we all have, just at a different level," said Lauren Hanyok, an aerospace engineer in Carderock's Seakeeping Test Branch. "After listening to their careers and advice, I think I have two potential mentors."

"The meeting showed me the abundance of opportunities I have available to me. It was very encouraging," said Ben Testerman, a naval architect in Carderock's Research and Development Programs Branch.

As the discussions drew to a close, LEAD members were heartened to find potential mentors with a variety of career paths and personalities to match with their own. Eric Stone, Carderock's comptroller, offered these parting words: "Getting to know yourself and what works best for you is important to advancing your career. The LEAD program is a great start."

The year-long LEAD program provides high-performing journey-level employees at Carderock an opportunity to improve their personal strengths, management and leadership skills. This is the fourth LEAD cohort since the program's inception in 2014. Fiscal 2018 members are Eric Silberg (LEAD chair), Manik Anand, Michael Britt-Crane, Lauren Hanyok, Matthew Jefferies and Benjamin Testerman.

(editor's note: Ryan Hanyok is a photographer in Carderock's Corporate Communications Division. He was a member of the fiscal year 2017 LEAD cohort.)

Members of the Naval Surface Warfare Center, Carderock Division fiscal 2018 Leadership Education and Development (LEAD) Program take notes during a mentor-matching session on Nov. 15, 2017, at the West Bethesda, Md., headquarters. (U.S. Navy photo by Monica McCoy/Released)

Carderock, University of Iowa sign education partnership

By Kelley Stirling, Carderock Division Public Affairs

Capt. Mark Vandroff, commanding officer of Naval Surface Warfare Center, Carderock Division, signed an Education Partnership Agreement (EPA) with the University of Iowa on Feb. 26 at Carderock's West Bethesda, Maryland, headquarters.

"The idea is to get students interested in hydrodynamics," said Dr. Thad Michael, a naval architect with Carderock's Propulsors Branch and the partnership program manager for the EPA. Michael received his doctorate in computational hydrodynamics from the university.

He said the partnership started with the naval hydrodynamic certificate program for undergraduates, which is intended to provide students with a solid technical and leadership background that will help graduates to thrive in civilian careers in Navy science and technology positions,

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Naval Surface Warfare Center, Carderock Division Commanding Officer Capt. Mark Vandroff (left) signs an Education Partnership Agreement with the University of Iowa on Feb. 26, 2018. Seated next to Vandroff is Dr. Paul Shang, acting technical director for Carderock. Back row, from left is Dave Ghatt, a patent attorney in Carderock's Office of Counsel; Dr.Thad Michael, a naval architect with Carderock's Propulsors Branch; and Dr. John Barkyoumb, Carderock's director of strategic relations. (U.S. Navy photo by Monica McCoy/Released)

and in supporting industry, according to the university website.

Even before this EPA was formalized, Michael said Carderock has had a partnership with the University of Iowa, and he and other Carderock employees have advised student projects, via Skype or teleconference, at the university. He said their partnership has been funded by the Office of Naval Research, which provided the school with a small tow tank that the students can operate themselves.

Dr. John Barkyoumb, director of strategic relations, heads Carderock's EPA programs. The program is geared toward public school systems and colleges that want to partner with the Navy to increase awareness for students in science, technology, engineering and math (STEM) career paths, potentially leading them to a career in a Navy lab.

The University of Iowa is the 15th EPA that Carderock currently has with schools and colleges. Located in Iowa City, Iowa, the university has one of the nation's oldest fluids laboratories within their IIHR-Hydroscience and Engineering Center. The IIHR used to be the Iowa Institute of Hydraulic Research, and although the name has changed, Iowa's college of engineering maintained the acronym for historical reasons. With labs situated alongside the Iowa and Mississippi rivers, IIHR focuses on hydraulic engineering and fluid mechanics, including basic fluid mechanics, laboratory experimentation and computational approaches, something Carderock can lend expertise to.

"There is a long history of hydrodynamics with Iowa," Barkyoumb said. "It's not something many people think about in terms of Iowa, but with the Mississippi River there, there are a lot of hydrodynamics to think about, such as navigation, flood control and power."

Barkyoumb said EPA partnerships allow schools to tap into the vast resources at Carderock, such as the engineers and scientists and their expertise pertaining to naval warfare science and technology; the base's world-class facilities and equipment; and computer software and analytics.

Carderock has several employees who are University of Iowa graduates, working on projects like the Very Large Test Apparatus being tested at Carderock's Large Cavitation Channel in Memphis, Tennessee.

And former employees have gone on to teach at the University of Iowa, like Louis Landweber, once the head of the Hydrodynamics Division at Carderock. Long before Landweber passed away in 1998, he had initiated Iowa's major ship hydrodynamics research program, which continues under Professor Fred Stern.

"Whenever I talk to new employees at Carderock, I always impress upon them that all business is a people business, because it is people who accomplish missions of the organization," Vandroff said. "Partnerships like this are a way to help us attract great people and maintain a top-notch workforce and tap into the expertise at these schools, too."

Carderock engineer judges science and engineering fair in Fairfax County

Dr. Maureen Foley (left), a materials engineer at Naval Surface Warfare Center, Carderock Division, issues a prize on behalf of the Office of Naval Research Naval Science Awards Program during the awards ceremony for the 63rd Annual Fairfax County Regional Science and Engineering Fair held on March 18, 2018, at Robinson Secondary School in Fairfax, Virginia. The recipient is Isabella Salinas (middle), a high-schools student from Robinson, for her project, "Modeling the Effect of an Artificial Pancreas on Blood Sugar Control." With Salinas is Travis Hess, an assistant principal at Robinson. (Courtesy photo provided by Fairfax County Public Schools)


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Naval Academy midshipmen visit Carderock

Dr. Steve Potashnik, head of Carderock's Underwater Electromagnetic Sensors and Technology Branch, shows midshipmen from the Naval Academy the magnetometer array that is used to assess the magnetic signature of Navy ship models during a tour Oct. 18, 2017, in West Bethesda, Md. (U.S. Navy photo by Jacob Cirksena/Released)

Hydrogen Powered Ultra Green Ship (HUGS):

A systems engineering-based design space exploration of a 'green' research vessel

By Austin Shaeffer, Andrew Weinstein and Dr. Kieran Rutherford, Carderock Division

ABSTRACT

This report describes the concept design of a Hydrogen-powered Ultra Green Ship (HUGS) that has minimal impact on the environment with emphasis on emissions, underwater noise generation, and marine life interaction. This vessel's requirements are based on National Oceanic and Atmospheric Administration (NOAA) missions and the study was performed by Naval Surface Warfare Centre Carderock's Center for Innovation in Ship Design. This project focused on integrating environmentally-conscious, current technologies into the design of a 'green' research vessel.

This project utilized a novel systems engineering based approach for design space exploration without the use of existing vessel data. The systems engineering approach enabled the team to consider a wide design space and quickly justify equipment selections. This approach parameterizes each system based on independent system data and iterates through a 'design spiral-like' process to rapidly create large numbers of possible designs. The feasibility and sensitivity of this new design process are discussed as well as the benefits over conventional design methods.

The final design concept is a 20,820 kg (45,900 lbs), 15.85 m (52 ft), titanium catamaran with a range of 240 nautical miles. It is powered by hydrogen fuel cells stored in composite pressure vessels within the demi-hulls, resulting in reduced machinery noise and zero harmful emissions. The ship is propelled by electrical rim driven propulsors to reduce mammal strikes, and utilizes integrated electric infrastructure to reduce mechanical noise.

INTRODUCTION

NOAA is responsible for the enforcement of sanctuary regulations and the monitoring of natural and cultural resources in United States National Marine Sanctuaries. They achieve this with a fleet of small research vessels carrying out specialized missions. With governments worldwide striving for cleaner, 'greener' technologies to reduce the environmental impact from man-made activity, this market provides an ideal opportunity to introduce a new 'ultra-green' ship concept. NOAA has partnered with the Center for Innovation in Ship Design (CISD) to design a concept boat with as little environmental impact as possible.

The concept set out to combine currently available technologies that are readily available, in a ship concept that effectively reduces its impact on the environment with greatly reduced harmful air and water emissions, reduced marine mammal strike risk, minimal wake, and significant reductions in the radiated noise that affects marine life. This study used a systems engineering based approach to determine the feasible design-space and make design decisions. This systems engineering-based approach is a novel way of performing early stage concept design and allows for the generation of a design space incorporating new and uncommon technologies. This design space was then used to make design decisions and perform decision trade off analysis.

DESIGN SPACE TOOL CREATION

The systems engineering-based approach for creating the design space required breaking out individual systems and parameters that are the primary design drivers. Each system of the design was modelled independently and then integrated within an iterative design spiral to determine the feasibility of a design. The automated output created a representation of the design space that can be analyzed to determine Pareto lines and optimal design choices.

Area and Volume

Area and volume requirements for the vessel are the first of the primary drivers of ship size and the only system that was modelled based primarily on mission requirements. Due to the infinite options for space and volume arrangements, this is a challenging design space for a human engineer. The design space tool aided by speeding through many iterations and creating a "True or False" check to determine if the ship design being considered provided enough space to fit the sum of all required areas and volumes. Due to these complexities of modeling area and volume, the user was given the ability to override this check, allowing ship designs that pass some but not all of the checks to be saved as viable.

To assess the area analysis of the ship only mission requirements were considered due to the complexity of multi-level general arrangements. Area requirements were assigned areas in ft2 based either on design requirements or predicted area sizes for required spaces. For example, 150 ft2 of lab space was given in the mission requirements and used for the modelling. Whereas, a head with a shower was a requirement but no area was given, so 12 ft2 was used based upon regression from other vessels. More complex area requirements, such as area for walkways, were based on a formula derived from assumptions about the general arrangements. The sum of all required spaces was checked against a suggested possible area that could be fit on the ship based on the ship's length and beam.

Volume modeling of the ship was more complex due to the increased dimension but also need to consider more onboard systems. Volume requirements were in part derived from the area analysis, multiplying the areas by a height of 7 ft to account for headroom. Volumes for equipment, machinery, and tankage were derived from other systems' models within the tool. Other volumes derived margins or constants from mission requirements (e.g. potable water tanks). Multiple internal checks were done when modelling volume as it was found that volume was still sensitive to variables that were initially assumed to have relatively small impact on overall design, such as freeboard.

These checks included a below deck volume check, determining if there was space within the hulls (determined to be the volume below the waterline) to fit all equipment and/or tanks. In addition, there was a total sum volume check, assuming an available total volume to be related to the length, beam, and displacement of the vessel. This total check was the only check that the tool required be passed and was meant to exclude designs in which available volume was likely to not be sufficient. The other checks allowed the iterations to continue, but were flagged as possibly infeasible.

Weights

The weight of the vessel is the other primary driver for ship size, and is largely modelled from given mission requirements. The tool is structured to accept the Ship Weight Breakdown Structure standards of the navy. This is organized into numerical categories to represent: Structures, Propulsion, Electric power, Command and control, Auxiliary systems, Outfit and furnishings and Armament.

The weight of the structures section was parameterized from other vessels, but is the main weight component. The power plant weight was determined by the propulsor section of the tool.

The other areas were determined from parametric values, or specific values from identified technologies or systems. For example the weight of the Rigid Hulled Inflatable Boat was estimated based off boats available in the market.

Propulsor

Different types of propulsors are considered in the tool: contra-rotating propellers, conventional propellers, azimuthing pods, advanced water jets, vertical axis thrusters, and rim drives.

Many of these have large amounts of data published and a parametric estimate of the weight and volume based on anticipated power curves can be found.

In addition to this, each propulsor was assigned an efficiency related to how much energy was lost from delivered power to thrust power based upon averaged research data. This efficiency percentage was input into the power generation model.

Power Generation

Inputs to the power generation model were the resistance the ship has to overcome at the sustained speed and the propulsive efficiency of the candidate propulsor. This, along with other efficiency losses assumed from power transmission, transform the resistance into the required effective power. From the effective power, a 100 % Maximum Continuous Rating is found and this becomes the installed power required.

Parametric equations relate this installed power to volume and weight of the prime mover(s) and then the required fuel tank (except for batteries) to meet the range requirements. The weights and volumes of the fuel tank and prime mover were the primary outputs of this system module.

The design tool had to generate an approximate volume for both diesel and hydrogen fuel. This meant estimating a storage volumetric efficiency and a hydrogen storage pressure.

Hydrostatics and Hydrodynamics

Hydrostatics and hydrodynamic are highly dependent on the hull form selection so a model was developed for each hull form type. Hydrostatic assessment addressed buoyancy and a first estimate of stability then the hydrodynamic assessment considered resistance.

Within each hull form, the principal characteristics (length (L), beam (B), draft (T), hull separation, etc…) were predetermined for the design iteration. The block coefficient (CB) was varied within a user defined range to ensure the buoyant force of the vessel equaled the weight modelled. The stability was measured by calculating metacentric height, GM, which was done by calculating metacentric radius from the transverse moment of inertia and then approximating centers of volume and gravity. The moment of inertia is approximated by using rough geometric shapes to represent the water plane area.

For all hull forms the wetted area of the hull was approximated using representative geometric shapes to represent the hull and then using the principal characteristics and governing surface area equations. The frictional drag coefficient was calculated using the ITTC '57 equation. The residual drag (CR) was found in a variety of ways depending upon what data was available. In the instance of the planing monohull there was very good series data available with textbook formulas available for varying L/B ratios and CB. In other instances, like the SWATH, very little data was available, so a CR was chosen based on previous Navy SWATH experimental data. For other hull forms, smaller series tests were available and so a correction factor based upon CB or L/B ratios was used to make appropriate changes for those design features.

System Integration

Each of these systems was kept independent and the overarching tool integrated the information from each in a way that allowed design spiral iteration to occur until a feasible design was found or the design was deemed infeasible.

The design spiral was initialized by an estimation of installed power, allowing for the approximation of system weights and volumes. This then fed into an approximation of the hydrodynamic resistance and hydrostatic analysis, focusing primarily on buoyancy and resistance. If the ship was able to support the weight, otherwise be buoyant, then the resistance approximation would calculate a required installed power to meet the design speed requirements. This process was repeated until the required installed power is within tolerance of the assumed installed power; or the design was deemed unreasonable either from being too heavy or not having enough volume.

This iteration process provides the ground work for generating a feasible design from whatever design variables have been modeled. In order to achieve a full design space, the tool was automated to perform this iteration for the range of design variable combinations. This automation involved cycling through the four discrete design variables: hull form, propulsor, power source, and hull material. In addition, the automation stepped through the range of possible dimensions for hullform in defined step sizes determined to generate a number of designs within each hullform's design space. In each design cycle, the feasible ships were determined and the main characteristics were saved. (Figure 1).

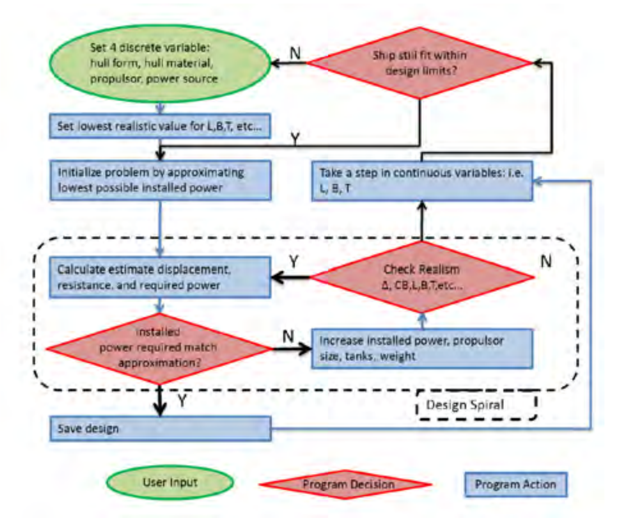

Figure 1. Iterative design tool logic flow.

ANALYSIS

The design space tool generated hundreds of thousands of feasible designs that provided the team with a large amount of data that was used in making design decisions. The design space generated for this project was so large that a first pass filter from common data analysis tools such as Python and Excel was needed to be able to handle the data. Then the systems and design decisions were manually down-selected to reflect other design drivers and to determine the optimum combination of variables.

In addition this design space was used to demonstrate the trade-off effect of certain design variables and enable understanding the whole system impact of selecting one variable over another.

Filtering Data

In order to filter the data into small enough quantities, the team decided to filter out the worst designs first. Designs were deemed worse by one of three measurable categories that are thought to be key to the ships overall effectiveness and aptitude to fitting the specified mission requirements:

- Installed Power (kW)
- Displacement (lb)
- Metacentric height (ft)

It was thought that lower installed power requirements would lead to a more efficient ship requiring less fuel and a smaller power source which would likely reduce life cycle costs and increase the "greenness" of the vessel. Smaller displacements were thought to be correlated to lower lifecycle costs. A median metacentic height was thought to be a good sign of a more stable vessel and better seakeeping , without being too stiff, but this remained an engineering judgement.

In order to filter the data in a way that did not exclude important trends, the top performing designs for the three variables mentioned were chosen for groupings of the design. For example, the top 100 for each of the three criteria were taken for each hullform type. This enabled data analysis to occur quicker but still maintain the important information about trade-offs between systems and design variables.

Down Selecting Systems

Graphical representations of the data were used to understand trends, Pareto fronts, and design variable sensitivity 2-D and 3-D graphs were generated, plotting different variables in order to understand their relationships. For example, Figure 2 shows the relationship of length of the vessel to installed power for each type of hull form. The unfiltered data is typically continuous, all the data points seen as one single cluster across the graph. However, filtering gave multiple clusters and through comparison, led to understanding the combinations of technology common in one cluster compared to another.

Figure 2 clearly shows SWATHs to be the least efficient hullform for reducing installed power of the hull form types. In addition, monohulls are much less feasible if the goal is to reduce the length. Also, a Pareto front can be identified for each of the hull form type, giving the naval architects an idea of the limits of design. For example, it is clear that there is a Pareto front for the SWATH starting at (30 ft, 600 kW) and continuing to (52 ft, 900 kW). Pareto fronts can be very helpful to the naval architect in understanding intrinsic limits to certain design variables and can hasten more detailed design by providing a better starting point. Design conclusions made from this are that trimarans and the two types of catamarans are preferred if reducing the installed power requirement is a major goal of the design.

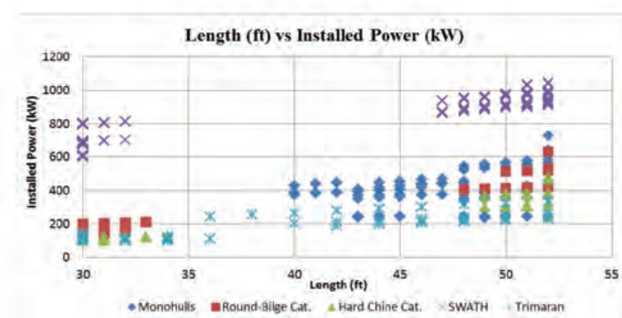

Figure 2. Correlation of length and installed power.

Design Decisions

Ultimately design decisions were made using Pugh matrices with weighted scales for evaluating different characteristics of each variable. There were additional mission requirements (e.g. acoustics and 'green') that could not be quantified into the automated design tool. The Pugh matrices were used in concert with the design space analysis to determine which design decisions would be preferred. A discussion of the decision made for each design aspect is presented in this section, with further discussion on the details of the power source, due to its novelty in the ship design community.

Hull Form

The design space exploration showed the trimarans and the two types of catamarans as the most efficient hull form types in terms of requiring the least amount of power for equivalent sizes. The Pugh matrix analysis looked to consider other aspects of the different hull forms such as manufacturability and familiarity to NOAA, both expressed to be important by the stakeholder. The Pugh matrix also evaluated quantifiable characteristics that weren't included in the analysis were stability and seakeeping characteristics.

Each hullform received a score between 1 and 10 for each of the characteristics and multiplied by weighting values and then summed. The Pugh matrix for the hull forms is in Figure 3 showing the hard chine catamaran as having the best score, due to anticipated stability and NOAA's familiarity with the hullform. In addition to this, the team decided to pull hydrofoil assistance from another NOAA operated research vessel in order to further improve the design. This hard-chine catamaran with hydrofoil assistance is based on current vessels and available research on this type of vessel.

	Seakeeping	Efficiency	Stability	Producability	Familiarity	Total Score
Weighting	0.35	0.3	0.15	0.15	0.05	
Monohull	2	6	3	10	10	4.95
Trimaran	8	8	7	4	1	6.9
Round Bilge Catamaran	7	9	10	7	8	8.1
Hard Chine Catamaran	7	9	10	7	9	8.15
SWATH	10	1	7	2	1	5.2

Figure 3. Pugh Matrix for hullform selection.

Hull Material

Different materials were considered for the structure material of HUGS including various types of aluminum, titanium and composites. Criteria for these materials consisted of structure weight, 'green' potential, maintenance requirements, availability, and manufacturability. Titanium was selected for the hull and superstructure due to its superior characteristics that give it more favorable environmental properties and reduced maintenance requirements.

Titanium provides 'green' aspects as it is chemically inert and does not require harmful chemical coatings to prevent biofouling. Since it doesn't corrode, it does not release particulates into the water and needs no protective painting which could also flake off. These properties also decrease the need for maintenance on the hull itself and increase the hull's lifespan.

When compared to aluminum, which is a more standard building material for NOAA, titanium is stronger, tougher and denser, but the overall vessel structural weight should be similar. Titanium is significantly more expensive upfront both for material and labor costs but the life cycle cost is expected to be similar to aluminum when considering maintenance and resale value.

Power Source

Proton Exchange Membrane (PEM) fuel cells were selected for the HUGS design. The design tool indicated that there were a wide range of feasible solutions for both diesels and fuel cells.

Compared with alternative fuel cell options, such as solid oxide, phosphoric acid, or alkaline fuel cells, PEM fuel cells operate at lower temperatures. This results in the cells warming up to full operating conditions quicker. PEM fuel cells typically take less than 60 seconds to warm up to generate full operating capacity so start up times for the vessel will be suitable. Figure 4 characterizes the mass vs. power of commercially available fuel cells.

The total maximum power demand of the HUGS is 320 kW. As a result, the HUGS fuel cell plant is estimated to require a volume of 65.6 ft3 and weigh 2,470 lbs. The fuel cell plant was split into four smaller equally sized fuel cell stacks to build redundancy into the system and utilize fuel cells similar in size to currently available market options. Each stack in the HUGS design is rated at 80 kW and produces 600 V DC current which can be converted to alternating current power to support necessary hotel loads.

PEM fuel cells have no moving parts; therefore no lubricants, coolants, or protective fluids are required. The lack of moving parts means components will not mechanically wear or degrade resulting in less frequent component replacement compared to a reciprocating engine.

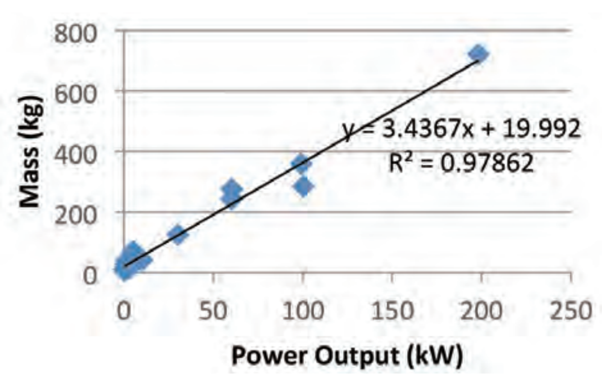

Figure 4. Parametric Power Output to Mass.

The fuel cell stacks can be arranged in series or as a parallel circuit. While the total power output of the cells is not affected, the voltage and current produced will be affected by the choice of circuit. However, failure of a single stack in a series circuit would result in total loss of power. The same casualty in a parallel circuit would reduce power available, but preserve power from the unaffected stacks. Four fuel cell stacks are located in the powering compartment behind the collision bulkhead within the cross-structure. HUGS utilizes an integrated electric architecture that allows for power to be transmitted across cable systems that run through the vessel's structure. Placing the fuel cells and hydrogen tanks in the same compartment reduces the complexity of the ventilation systems needed to prevent hydrogen accumulation within the hull structure.

Fuel Selection

Hydrogen was selected to fuel HUGS because of its minimal environmental impact. Hydrogen is not a common marine fuel source, but it has a market in civil static power generation, testing in land vehicles and even in space exploration. These industries have started mitigating risk hydrogen fuel with improving developments to safety, infrastructure, storage, transfer and production of hydrogen.

Hydrogen has much greater energy content per unit mass compared to other viable fuel sources such as petroleum fuels, alcohol fuels, natural gases, and batteries. However, it has far less energy content per unit volume. To feasibly achieve sufficient hydrogen storage, it has to be compressed or liquefied to reduce the required storage tank volume. HUGS uses pressurized hydrogen at 350 bar requiring a volume of 251 ft3 for 483 lbs of hydrogen gas. This gives sufficient to achieve the mission required range. Considering the cost of additional pressurization and pressure vessel cost compared with the space saving gained by reducing the fuel volume, it was decided that not enough of an advantage was gained by increasing pressure to 700 bar. The external volume of the tanks decreases by around a third while doubling the wall thickness and increasing tank weight and cost.

Fuel Tanks

Pressurized fuel tanks for the storage of hydrogen are available across the energy industry. They are generally made in prescribed shapes and materials. HUGS utilizes a non-standard shape and is made out of carbon fiber composite.

The semi-conformal fuel tank shape (Figure 5) makes the best use of the available volume in the demi-hull and is a good compromise in structural integrity for a high-pressure application.

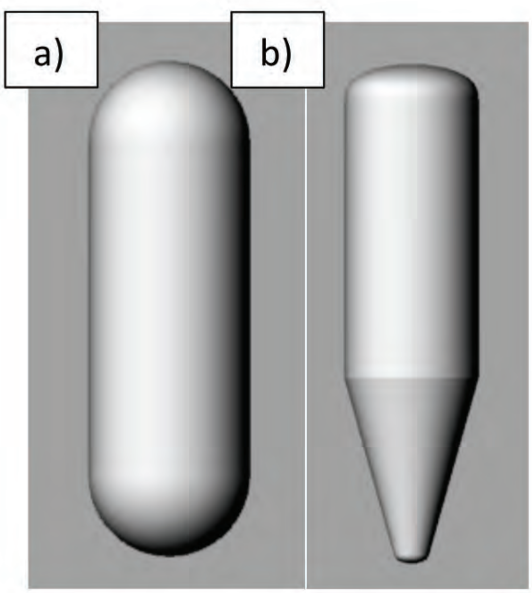

Figure 5. a) Pill-Shape and b) Semi-conformal tank configuration

Due to the changing beam of the demi-hull through the compartment in which the tanks were placed, two different sizes of tanks were proposed, with four of each size to be used to make best use of the available volume. High Modulus Carbon-Fiber was selected as the material for the tanks due to its good strength to weight properties and had some precedent in automobile testing [6].

Propulsion

The design tool considered multiple options including waterjets, contra-rotating propellers (CRP), rim drives, and traditional screw propellers. Concepts with waterjets were discounted as they had too much installed power, implying increased fuel costs. Contra-rotating propellers and screw propellers appeared in many lower power concepts, and rim drives had multiple feasible options in the same design space.

The design tool gave the team confidence that a feasible solution could be found utilizing rim driven propulsors, through an electrical architecture, powered by fuel cells and still have volume available for the fuel tanks. This would not have been possible having considered each system in isolation.

The design requirements emphasized propulsion which would accommodate a shallow draft, minimize the risk of mammal strikes, and have ease of maintenance with an established infrastructure for easy ordering and replacement of parts, reduced noise, propulsive efficiency, and environmental impact. These requirements could not be quantified and, jointly with the design tool, a qualitative Pugh Matrix enabled selection of rim drives.

Rim drives were selected as the best propulsor due to a number of 'green', acoustic, and technical benefits. First, rim drives are lubricated and cooled by the seawater, eliminating any harmful lubricant leaks from the propulsion system into the environment [7]. Second, rim drives are quieter than other forms of propulsion as they lack a shaft and mechanical gearing which are major sources of noise, and instead utilizes a permanent magnet (PM) synchronous ring motor. The blades of the propeller are attached to an inner ring or stator, which is rotated by the PM synchronous ring motor [7]. Since the PM synchronous motor also reduces the number of moving parts and eliminates any gearing, maintenance is made easier. Third, the duct which covers the blades of the rim drive reduces in the likelihood of a marine mammal strike in an ecologically sensitive area [7]. The design of the shroud enables the unit to achieve a high level of thrust for its weight, which improves efficiency. Lastly, the unit is azimuthing and provides full thrust both forwards and backwards making the unit very capable in dynamic positioning.

Propulsion of the vessel will be provided by two steerable rim drive units located in the aft most section of each demi-hull. Sizing for the rim drives was based on thrust requirements and product availability. Characteristics of the chosen unit are shown in Table 1.

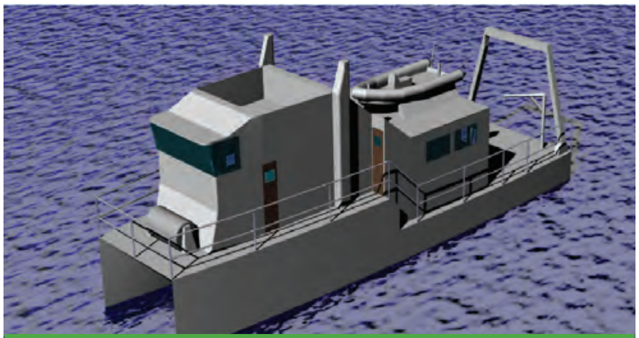

Figure 6 HUGS.

CONCEPT DESIGN

HUGS has several features that allow it to carry out the different NOAA missions. It is equipped with an A-frame and a J-frame on the main deck and a winch rated for 1,600 lbs is located on top of the deckhouse aft. The aft deck is also equipped with a telescoping multi-jointed crane and a grid of tie-downs, spaced 24 inches apart, is included to allow additional equipment to be brought onboard and secured. Foldable diving platforms are provided at the transom. A five passenger Rigid Hull Inflatable Boat (RHIB) is stowed on top of the deckhouse and is launched and recovered using the crane. The wet lab and dry lab are located in the aft section of the deckhouse on the same level as the aft working deck and have direct access to it. There is also room for up to 18 passengers for educational tours, and additional unassigned space with the potential for additional mission packages.

Parameter	Value	Required
Displacement (lb)	45,900	
Length, overall (ft)	52	< 52
Beam, overall (ft)	16	< 16
Draft (ft)	4.3	<5
Total volume (ft^3)	6,384	
Sustained speed (kts)	22	22
Range @ 22kts (nm)	240	200
Delivered power (kW)	300	
Generating capacity (kW)	320	
Endurance (hours)	12	
Wet Lab Area (ft^2)	51	50
Dry Lab Area (ft^2)	100.5	100
Aft Deck Area (ft^2)	208	"large"
Structure material	Titanium	
Power source	Hydrogen fuel cell	
Propulsion system	Steerable rim drive, 150kW, 1.8ft diameter	
Hull shape	Hard chine catamaran	

Table 1 Principle characteristics of HUGS

Ship Weight Breakdown

The weight of the HUGS is summarized in Table 2 broken down into system categories. These weights were initially calculated by the design tool giving confidence as a feasible first pass design. The secondary passes were done to verify and detail the weights.

The weight of the hull is calculated by the design tool and verified as an average density compared with other similar catamarans.

The rim drive system weight was estimated to be 2,400 lbs interpolated from vendor data. The rest of the propulsion plant group weight was due to installations and fittings, exhaust equipment for the hydrogen fuel cells, electronic command and control systems, and fuel supply pipes. The hydrogen fuel cells provide all electricity to the ship, propulsion and hotel loads.

The fuel cells weigh approximately 2,250 lbs with the remaining electric plant weight group coming from the lithium ion batteries, the electrical inverting and converting equipment, and the distribution equipment and cabling. Weights for the remaining groups, were estimated using a similarly sized NOAA research vessel as a guide. HUGS was assumed to incorporate similar equipment to what is currently installed on other research vessels.

The full load weight includes everything not permanently installed onboard. Included in this category are weights for 18 passengers and three crew, research equipment for the different missions, a 500 lb deadweight allowance, various portable winches and cranes, and 483 lbs of hydrogen fuel.

Parameter	Value (lbs)
Hull structure	16,200
Propulsion Plant	2,685
Electric Plant	4,103
Command & Surveillance	628
Auxiliary Systems	4,395
Outfit and Furnishings	3,583
Lightship Weight	34,501
Lightship Weight + 10% margin	37,951
Loads	7,661
Full Load Weight	44,840

Table 2 Ship weight summary

Hydrostatic and Hydrodynamic Analysis

The resistance curve for HUGS was estimated using the program Michlet. Michlet uses thin ship potential flow theory to quickly calculate an estimate of the resistance of the hull form. This program is a CISD-accepted tool used to perform resistance calculations for long slender hulls and multi-hulls. There is a reasonable degree of confidence with HUGS predictions as the power requirements are comparable to similarly sized vessels. Efficiency losses were applied to effective power to determine the required delivered power for HUGS. The resistance reduction from the hydrofoils was determined using an average reduction of 10 % estimated from a previous catamaran study [2] and shown in Figure 9. The maximum delivered power to maintain 22 kts endurance speed was determined to be 300 kW.

The fuel cells have a linear power curve, with no drop off in efficiency. Therefore the sustained speed is almost the maximum

General arrangements

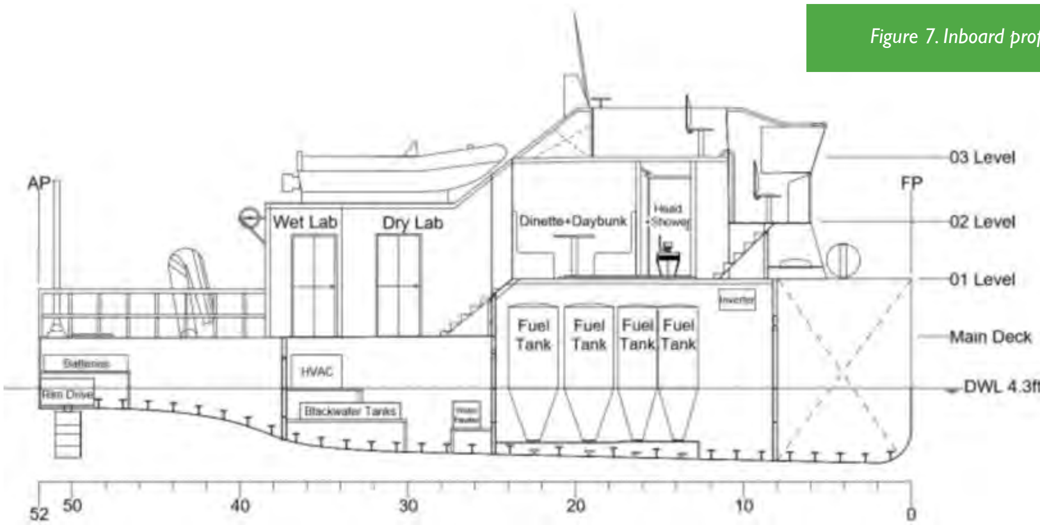

Figure 7. Inboard profile (demi hull)

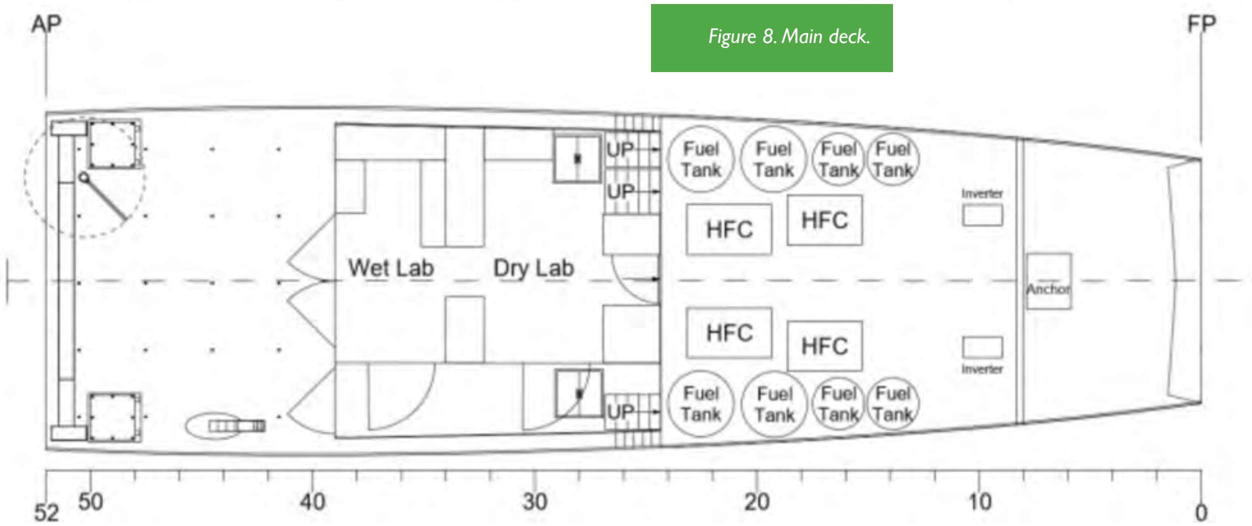

Figure 8. Main deck.

speed of the vessel, with the only other power draw being the other electric systems.

Figure 9. Speed power curve.

Intact stability characteristics of the HUGS design were evaluated against Code of Federal Regulations (CFR) requirements for vessels of unusual form for operation in the open ocean. The characteristics of the righting arm (GZ) curve were evaluated against general criteria, severe weather and rolling criteria, criteria for crowding of passengers to one side, and passenger ship high speed turn criteria. The severe weather assessment used the 80 kt wind speed HUGS requirement rather than the CFR 50 kt wind speed. Heel angle due to passengers crowding to one side was four degrees, well under the ten degree requirement. Heel in a high speed turn at 22 kts was less than two degrees, also well under the 10 degree requirement.

Electric Load Analysis

Results of the electric load analysis are shown in Table 3. The transit condition was identified as the critical load condition and fuel cells were sized to the maximum load required. The main power draw of the vessel is the rim drive propulsion system which required 300 kW at 22 kts. Additional power requirements for hotel loads while transiting resulted in a total power load of 318 kW. After applying design and service life margins, the required power for the vessel is 320 kW. Supplementary batteries were sized to provide maximum transit load for a period of five minutes. These batteries also provide a degree of redundancy in case of fuel cell failure.

Parameter	Transit (kW)	Operations (kW)
Propulsion Plant	300	4
Electric Plant	0.2	26
Command & Surveillance	2.7	2.7
Auxiliary Systems	6.3	15
Outfit & Furnishing	0.6	0.6
Miscellaneous	0	22
Total without margins	318	72.2
Total with margins	320	79

Table 3. Electric load analysis

Safety

Hydrogen is lighter than air and diffuses rapidly, almost four times faster than natural gas. This means that when released in an unconfined space, hydrogen dilutes quickly into a non-flammable concentration. Hydrogen also rises two times faster than helium and six times faster than natural gas. Combined, these characteristics mean that hydrogen will quickly escape a well ventilated area. To become a fire hazard, hydrogen must be confined and allowed to reach a specific concentration. Current industry practice is to install hydrogen sensors in close proximity to the hydrogen equipment. The detection range of the sensors is typically five meters, and so to adequately cover the fuel cell and tank compartments minimal sensors would be required [4]. The design and placement of the hydrogen fuel compartments is to ensure that they are well ventilated without additional fans and exhausts. This might include sloped ceilings to prevent hydrogen from collecting in one space.

CONCLUSION

A design tool has been created that generates thousands of potentially feasible vessel concepts based upon the combined system of systems. Each subsystem was parametrically defined and the whole concept developed through multiple iterations of each. Initial filtering allowed Pareto fronts to be identified and grouped feasible options based on technology. This allowed the engineering team to quickly understand the impacts of each technology on the whole design.

The products generated by the tool gave the team a high level of confidence that a viable solution could be found utilizing rim driven propulsors, an electric drive architecture, and fuel cells with volume in reserve for the fuel tanks. This would not have been possible had each system been considered in isolation, and the system of systems level iteration would have taken much longer.
The tool itself was created in a very short timeframe (several weeks) and takes only minutes to generate thousands of design points. This compares well with the development of larger ship design software, especially at a conceptual level. Further verification and validation for larger and more complex ship concepts should be planned.

HUGS is a conceptual vessel design to support what might be possible for a 'green', quiet future research vessel for NOAA. There are other factors that would need consideration before such a vessel is built (cost of manufacture, hydrogen infrastructure, etc.) but the concept suggests a feasible future ship concept.

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Development of a Galfenol Actuator for Operation Under Tension

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ABSTRACT

A Galfenol-based actuator has been designed to generate output forces while operating under tensile strains, demonstrating successful long term operation with no appreciable change in performance. Two prototype actuators were manufactured and tested under quasi-static and dynamic conditions. Dynamic power requirements included a 15-16 amp DC bias and up to 25-26 amp AC (pk-pk). Two cooling fans were used to provide convection cooling of the drive coils during dynamic operation, allowing for 100% duty cycle at 300 Hz; without the use of cooling fans, 100% duty cycle operation would be limited to frequencies below 150 Hz. In quasi-static displacement mode (0.5 Hz, no applied force), the actuators were capable of outputting between 1300 – 1600 lbf. While the output force decreased with applied tensile stress and operational frequency, significant forces were measured up to 0.14% (0.0014 in/in) applied tensile strain using 300 Hz tones. The magnitude of the measured dynamic force output was limited by the matched stiffness between the MTS 810 load frame (0.8 x 106 lbf/in) and the prototype actuators (0.7 x 106 lbf/in). By connecting to stiffer loads, larger force outputs and higher tensile strains could be applied. Long term testing of the actuator at 63 Hz and alternating tensile loads of 1,000 and 5,000 lbs has continued to over one billion cycles, with no change in actuator performance. Demonstration of the Galfenol technology in this unique tensile application provides a capability that does not exist with current off-the-shelf transducer technologies.

INTRODUCTION

Galfenol (Fe1-xGax, x = 17 – 21) is a smart material that exhibits strain under the application of a magnetic field [1, 2]; this strain is termed magnetostriction. While piezoelectric and magnetostrictive materials often share similar applications, magnetostrictive materials do not breakdown over time and can operate over a large temperature range, making them well suited to long-term, more extreme applications. Many similar, high performance transduction materials are also brittle and cannot operate under tensile stress; in contrast, Galfenol is fairly ductile and machinable, and offers a unique combination of good magnetostrictive and mechanical properties that allows it to survive tensile stresses. Galfenol alloys can also be processed such that an internal compressive stress is built into the material, termed stress annealing. [3] This stress annealing treatment enables Galfenol alloys to perform under tensile loading conditions with minimal loss in performance, typically up to ~50 MPa tension (increasing the tensile load further causes the magnetic moments to align along the active direction, removing the magnetic strain response). In addition to magnetic performance, the ultimate tensile strength (UTS) of Galfenol is 350 MPa [4], which allows it to be used robustly in these applied tensile load applications.

The objective of this work was to design, build, and test a Galfenol actuator capable of outputting force while under a tensile load and operating at frequencies up to 300 Hz. Demonstration of Galfenol in this unique tensile application provides a capability that does not exist with current off-the-shelf transducer technologies. In particular, tensile forces can be useful for long actuators that would buckle under compressive loads, such as interstructural actuators for exciting waves in the structure. Tensile devices can also be used for vibration dampening of hanging machinery. Prior to this test, most applications were under compressive loads or utilized bending beam geometries with minimal load-bearing capability. The cyclic strain under a tensile load also evaluates, for the first time, the magnetic fatigue life of such a tensile actuator.

Actuator Design and Fabrication

Two prototype actuators, utilizing Galfenol as the active material, were designed, built, and tested for operation under tensile loads while providing a force output over a low frequency range up to 300 Hz. Because the actuators are operating under an alternating magnetic field, the active components need to be thin, or laminated, to reduce eddy current losses. To allow them to be pulled under tension, these thin Galfenol laminates had to be welded to stainless steel end- pieces. The stainless steel will handle the applied stress and any stress concentrations due to the actuator design while the Galfenol functions as the active component.

Since welding is an integral part of this actuator design, one concern is that the high temperatures necessary for welding can remove the stress annealing treatment (the maximum allowable temperature is around 150 °C [5]) and can also change the crystallographic texture in the heat affected zone (HAZ). The welding treatment can also introduce residual stresses, which will change the virgin stress state of the material. The best welding process would have minimal residual stresses (especially in the active region) with a small HAZ.

Initially, tungsten inert gas (TIG) welding was investigated as the method to join these active and structural components. However, TIG welds required significant part clean-up after welding, and proved to be inconsistent from weld to weld, leaving weld joints with stress concentrators negatively impacting tensile load capability. In an application-focused tensile test with a strain rate of 0.0001 mm/mm/sec (0.0001 in/in/sec) [6], a large variation in the tensile strength was observed. For reference, directionally solidified meso-crystalline Galfenol has a measured UTS of 350 MPa (55 ksi), although only one out of five laminated stacks achieved close to this value (~317 MPa or 46 ksi). [4]

To further improve on the TIG welded design, electron beam (e-beam) welding was explored as an alternative. E-beam welding is a Computer Numerical Control (CNC) welding technique which provides a more consistent weld through the thickness leading to improved tensile performance; a smaller HAZ was also observed. Appropriate e-beam welding parameters for the Galfenol and stainless steel foot were developed. While some hot cracking was observed, visual inspection was used to determine the optimum samples for the actuator design. Figure 1 shows a cross-section view of the weld quality produced by the e-beam process.

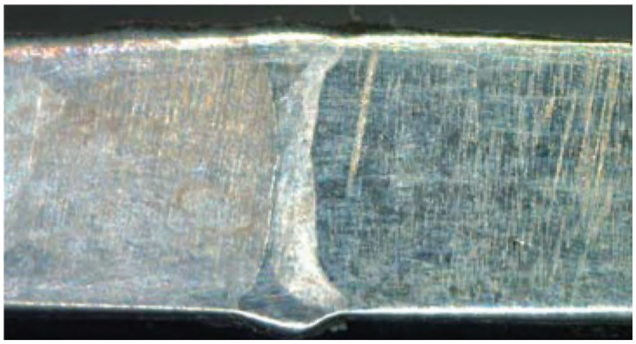

Figure 1. Image of an e-beam cross-section weld of Galfenol (left) to a stainless steel foot (right); thickness is 0.1 inches.

The application-based tensile specimens were pulled to fracture at a strain rate of 0.0001 mm/mm/sec (0.0001 in/in/sec) in an MTS 100 kN (22 kip) hydraulic load frame. Table I provides the tensile test results for the individual e-beam welded samples. Overall, a significant improvement in the tensile performance is noted, compared to the TIG welded assemblies. Of the 13 samples tested, 10 had measured tensile strength values > 275 MPa (40 ksi), with a population average tensile strength of 280 MPa (40.6 ksi). The failure location lies predominately along the weld joint, as can be seen in Fig. 2. This was consistent in the majority of the e-beam welded samples tested. Based on these results, the Galfenol drivers for the actuator prototypes were manufactured from e-beam welded laminates.

Sample ID	Max. Load (lbs)	Tensile Strength (ksi)	Tensile Strength (MPa)
D1-13-13-2A	3014	44.8	309
D1-13-13-2B	2878	41.7	288
D1-13-13-2C	3280	47.5	328
D1-13-13-2D	2087	30.0	207
D1-13-75-3A	3097	45.2	312
D1-13-75-3B	2997	43.1	297
D1-13-75-3C	3458	50.1	345
D1-13-75-3D	3298	47.8	330
D1-13-75-3E	3188	46.2	319
D1-13-75-138A	1880	27.9	192
D1-13-75-138B	3080	45.8	316
D1-13-75-138C	3029	45.0	310
D1-13-75-138D	853	12.4	85
Population Average		40.6	280
Population Standard Deviation		10.7	74

Table I. Tensile test results of 13 e-beam welded Galfenol-stainless steel samples.

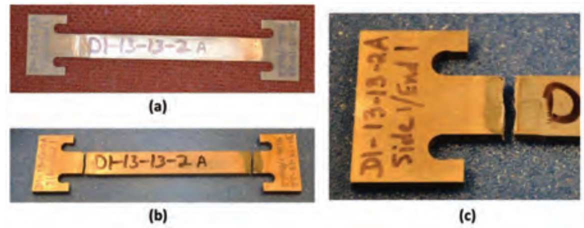

Figure 2. An e-beam welded sample (a) before and (b, c) after tensile testing.

The maximum displacement of the Galfenol Actuator is based on the length of the Galfenol drivers and the magnetostriction (i.e. strain) that they output. For the prototype design a 40 – 50 µm (1.5 – 2 mils) displacement was predicted, with an overall active length of the actuator, from foot-to-foot (i.e., weld-to-weld), of ~25.4 cm (~10 inches). This ratio of output displacement to geometric length made part tolerancing and manufacture critical. Large tolerances would result in a loss of displacement and as a result a reduction in force output.

Based on a tolerance loop analysis, the most critical tolerances were to achieve flatness and parallelism at the interfaces between the welded Galfenol laminates and the actuator structure, with required tolerances of ±0.4 mils. Both Galfenol Actuator prototypes were built with parts that met or exceeded the tolerance requirements.

Each Galfenol Driver consisted of six stress-annealed e-beam welded laminates (see un- machined example in Fig. 3), with drive coils wrapped around the active region (Fig. 4a). Black Delrin covers were machined and used to protect the critical geometry and dimensional tolerance during storage and handling prior to actuator assembly. Strain gages were applied to verify even tensile strain loading across both Galfenol Drivers in each prototype (Fig. 4b).

Figure 3. Stress annealed e-beam welded laminates, prior to machining the final foot geometry.

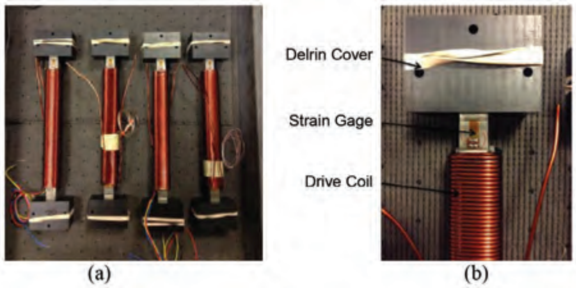

Figure 4. (a) Set of four, finished Galfenol drivers, each consisting of six machined laminates. (b) Close up of the strain gage applied to a Galfenol Driver.

In order to test the drivers in the MTS load frame, a terminal block was installed for the drive coil lead wires and two printed circuit boards (PCBs) were added to improve the robustness of the sensor wire terminations, specifically, the strain gages and Hall sensor. End plates and clamps were also machined (see Fig. 5).

Quasi-static Testing

Quasi-static testing was performed to determine the maximum strain performance of the actuator design. Displacement testing was performed at 0.5 Hz with no tensile load using an AE Techron 7780 linear amplifier to supply the current. A signal generator was used to generate the low frequency sine wave. Displacement was measured using a linear variable differential transducer (LVDT). Figure 6 shows the quasi-static displacement of the pair of legs for one of the prototype actuators, designated "G1". A plate was placed across both drivers with the LVDT positioned on top of the plate in order for the overall displacement to be measured. The largest strain measured was 43 µm, reached at 25 amps of current. The maximum force output capability was calculated to be 1620 lbf, using Eq. 1, where A is the cross-sectional area of the Galfenol drivers (0.85 in2), and E is the modulus of Galfenol (75 GPa or 10,878 ksi). [4, 7, 8]

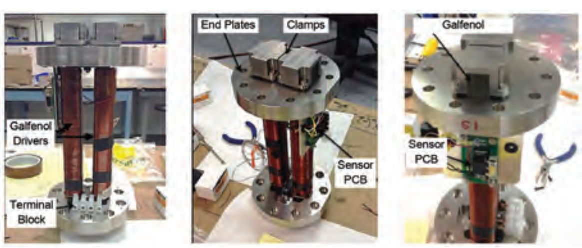

Figure 5. Finished Galfenol actuator prototype.

$$F=AE\varepsilon \quad (1)$$

The second pair of legs, designated "G2", had a similar resultant displacement measured: 36 µm for the same 25 amps of current. For this level of displacement, the maximum force output capability was calculated to be ~1360 lbf.

This quasi-static test was also used to determine the starting DC bias condition for the dynamic tests. It is desirable to operate the actuator in the linear performance region to maximize efficiency and minimize harmonics; if the device is cycled around 0 amps, there is a large amount of oscillating current, with minimal resulting displacement. A DC bias value of 15 amps was chosen for dynamic testing of both prototypes, since this is approximately half-way between the minimum and maximum displacement points for the Galfenol drivers (shown in Fig. 6 by the red dashed line).

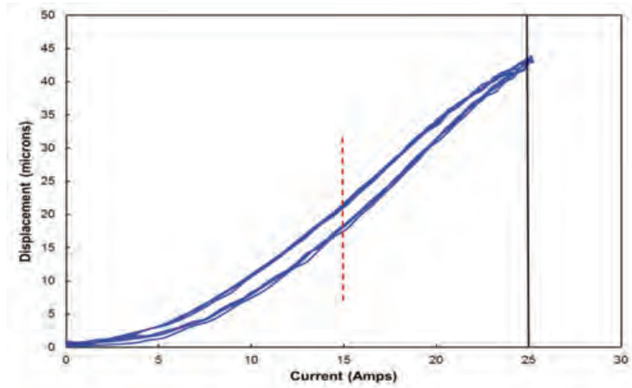

Figure 6. Quasi-static displacement of the pair of G1 Legs, measured at 0.5 Hz with no tensile load applied. The red dashed line indicates the DC bias position selected for dynamic testing.

Dynamic Testing

Dynamic testing was performed to characterize the actuator performance at various frequencies (up to 1 kHz) and tensile loads (up to 0.14% strain), in comparison with the maximum performance described above. The prototype actuators were characterized using an MTS 810 load frame with a Data Acquisition (DAQ) system with multiple channels, including the force transducer connected to the load frame to record the force output. In order to couple the actuators to the load frame, interface plates were designed and manufactured. These parts had precision ground surfaces that mated to the respective end plates of the actuator.

An alignment fixture (Fig. 7), connected to the force transducer, was used to eliminate angular and concentricity misalignment between the top and bottom of the test setup. The ends of the cylinder were precision ground and the circumference had four strain gages applied at a 90° spacing. The alignment cylinder was placed between the interface plates and put under a compressive load. The alignment fixture was adjusted until all four strain gages produced similar readings.

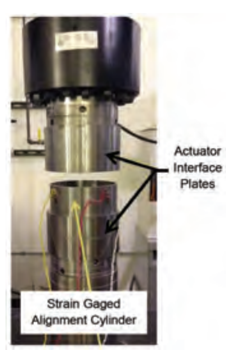

Figure 7. The alignment cylinder situated between the interface plates.

After alignment, the actuator was placed into the MTS load frame and the DC bias current was applied, allowing the system to warm up to an equilibrium temperature; temperature was measured using a sensor inserted between a Galfenol leg and a drive coil. The applied force due to the thermal expansion of the actuator was zeroed. A defined tensile strain was applied to the actuator, and strain gage readings were monitored to ensure no bending or torque was being applied to the Galfenol drivers. A signal generator was used to supply the specified test frequency (either tones or frequency sweeps) and signal voltage to the amplifier. During dynamic testing, it was determined that active cooling would be beneficial and allow full operation at 300 Hz with a stabilized temperature (see below), therefore two 12 V DC fans were positioned to provide cooling across the drive coils during testing.

The first set of tests was performed at 0.5 Hz, similar to the "quasi-static" characterization; with the addition of an applied tensile strain and DC offset. As tensile strain increases, the total change in actuator force output decreases, since the applied tensile strain is in the direction of the applied magnetic field; the tensile strain helps to align the magnetic moments vertically, thus reducing the force output capabilities of the actuator. It is worth noting that as the applied current increases, the force output decreases; since a specific strain level was defined, the extension of the actuator is decreasing the amount of applied force required by the MTS to maintain that strain level; at the lowest strain level (0.01%), the magnetostriction actually forced the MTS to switch into compression mode. It is desirable to avoid this condition in fatigue-related applications. Figure 8 shows the force output of the G1 unit as a function of applied current, for various tensile strains (0.01% – 0.1%). The curves have been shifted so the force output at the maximum current is the same. The maximum force output of ~850 lbf was measured at 0.02% – 0.04% applied tensile strain; even at 0.1% tensile strain, greater than 500 lbf is still being generated by the actuator. While the force output increases with lower applied strains, the minimum strain does not follow the trend. This may be due to the switch between tensile stress and compressive stress (as noted above), and the natural slack in the system configuration when switching modes of force.

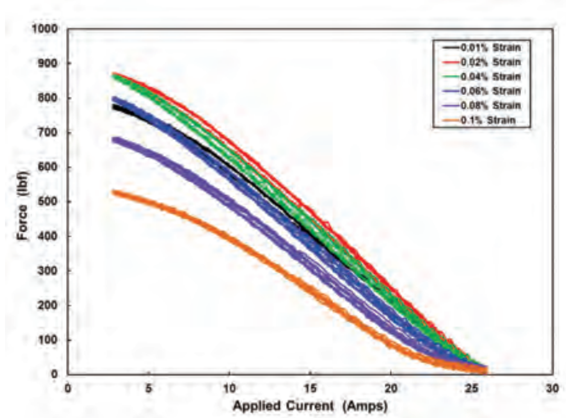

Figure 8. Normalized force output versus current at 0.5 Hz for the G1 unit, with applied tensile strains from 0.01% - 0.1%. (Positive force is tensile force). The force outputs have been shifted so all curves agree at the maximum applied current.

Similar results were obtained for the G2 unit. For this unit at tensile strains up to 0.14%, the actuator was still producing approximately 200 lbf of output. However, a roll off in the force output was observed at this high tensile strain suggesting that further increases in tensile strain could potentially result in saturating the magnetic moments in the Galfenol legs in the tensile direction. The G2 actuator never went into a fully reversible mode of operation as the applied tensile strain was limited to a minimum of 0.02%. The maximum force output for the G2 unit was less than the G1 unit: 700 lbf vs. 850 lbf. This is directly attributed to the lower displacement values from the G2 Legs documented in the quasi-static measurements.

Device performance was also characterized with respect to operational frequencies (between 50 and 300 Hz) at both the full drive level (15 amps DC ± 13 amps AC) and half drive level (15 amps DC ± 6.5 amps AC). In general, force output decreases with increasing frequency (see Fig. 9) which is attributed to the impact of eddy currents decreasing the volume of Galfenol exposed to the magnetic field. However, significant force outputs were measured at the highest frequencies tested (300 Hz) and the highest tensile strains applied (0.14%).

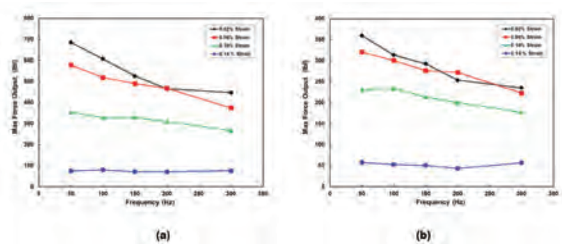

Figure 9. Maximum force output versus frequency for the G1 unit at (a) full drive level (15 amps DC ± 13 amps AC) and (b) half drive level (15 amps DC ± 6.5 amps AC).

The force output measured was approximately 50% of the maximum capability based on the quasi-static displacement results. A complicating factor limiting the magnitude of the observed dynamic force output is the matched stiffness between the MTS 810 load frame (0.8 x 106 lbf/in) and the prototype actuators (0.7 x 106 lbf/in); this will be further expanded in the Discussion section.

The frequency response of the entire system was measured for each actuator up to 1000 Hz under different applied tensile strain conditions (see Figs. 10 and 11). The bias current was ~15 amps DC for all frequency sweeps; but the AC drive current was limited due to voltage limits of the amplifier at the elevated frequencies. The results from the frequency sweeps are good indicators of the resonant characteristics of the system. Little change in the frequency response is observed until 0.10% and 0.14% tensile strains are applied. Resonance frequencies of approximately 350, 400, 600 and 725 Hz were observed; all of these major resonances are above the maximum intended operating frequency (300 Hz) used for the force output testing discussed above.

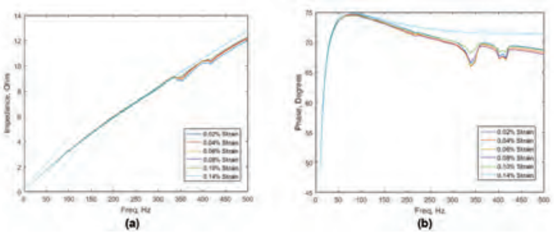

Figure 10. (a) Impedance and (b) phase versus frequency for the G1 unit tested over applied tensile strains from 0.02% - 0.14% up to 500 Hz.

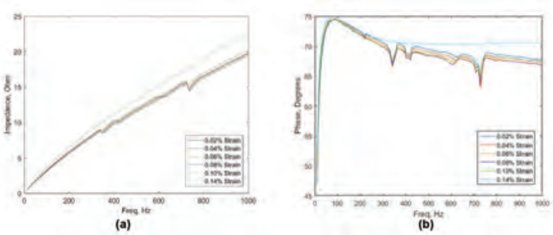

Figure 11. (a) Impedance and (b) phase versus frequency for the G1 unit tested over applied tensile strains from 0.02% - 0.14% up to 1000 Hz, using a lower drive level (15 amps DC ± 6.5 amps AC) than that for the 500 Hz sweeps.

Thermal Stability Testing

During dynamic testing heat was generated as a result of hysteresis and eddy currents in the Galfenol. Heat was also generated from the I2R losses in the coil. Two cooling fans were powered during the dynamic testing to provide convective cooling across the Galfenol legs and drive coils. Additional testing was completed with and without these fans at 150 Hz and 300 Hz for both units. The temperature and force output was recorded as a function of time to determine the impact of the cooling fans.

At the half-drive level, with no cooling fans, the temperature continues to significantly increase after 25 minutes of operation, while the force output continuously decreases due to thermal expansion, even approaching the compression regime. With the cooling fans, however, temperature stabilization can be achieved at full-drive levels at 300 Hz (see Fig. 12).

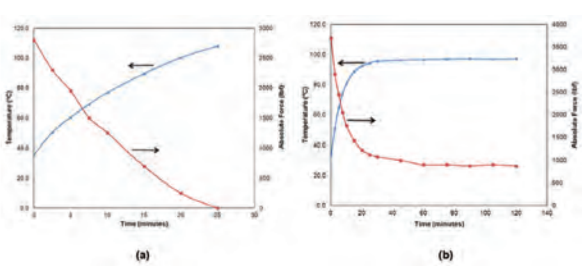

Figure 12. Temperature and force versus time for the G1 unit at (a) half-drive levels and no cooling fans, and (b) full-drive levels and cooling fans; the units were driven at 300 Hz with a 0.09% tensile strain applied.

Similar tests were repeated at 150 Hz where heating should not be as severe (see Fig. 13). Where a half-drive level was applied, the temperature does show signs of stabilizing after 80 minutes of continuous operation, however the force output is near zero. With the cooling fans, the actuator can be operated at 100% duty cycle with full-drive levels applied, with a stabilizing temperature of around 60 °C and a force output of ~2,500 lbf. The G2 unit showed near identical responses when exposed to the same test conditions.

Cooling fans should be used during operation of the prototype actuators if 100% duty cycle is desired at and above frequencies of 150 Hz. Frequencies less than 150 Hz have not been evaluated.

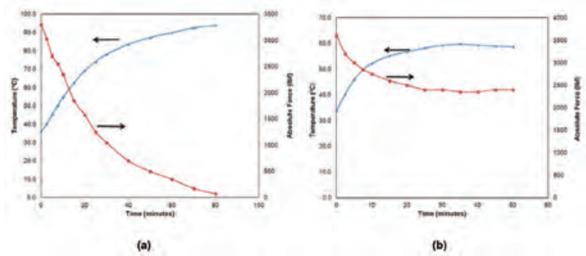

Figure 13. Temperature and force versus time for the G1 unit at (a) half-drive levels with no cooling fans, and (b) full-drive levels with cooling fans; the units were driven at 150 Hz with 0.09% tensile strain applied.

Fatigue Testing

After the above characterization of the prototypes, actuator G2 was subjected to fatigue testing to determine the possible longevity of such an actuator. The actuator was mounted in a 100 kN (22 kip) MTS hydraulic load frame (see Fig. 14), and two tensile fatigue loads were applied: ~ 1,000 lbs cycled with ±400 lbs or ~5,000 lbs cycled with ±300 lbs. In between these fatigue sessions, the load frame was cycled between 1,000 lbs and 5,000 lbs in steps of 500 lbs for a total of four cycles. During the fatigue sessions, the load frame was switched to constant displacement mode, to maintain a constant position for the hydraulic piston. Two AE Techron 7224 amplifiers were connected in parallel through a 0.05 Ω load leveling resistor, and were used to activate the actuator. The applied frequency was 63 Hz, since that was the highest frequency for which the load frame was able to provide reasonable displacement compensation. A DC offset was applied to keep the current through the coil greater than zero. The force versus field curve for the actuator is a parabola; if the drive is allowed to cross zero, the actuator provides a frequency doubled force.

The intent of this fatigue test was to provide the actuator with a "blocked force" condition, similar to that for certain desired applications; however, the compliance of the load frame was such that only a partially blocked force condition was achieved (see Discussion section). Differential thermal expansion between the load frame and actuator also provided some room- temperature dependent force drift, although the difference between the maximum and minimum forces the load frame supplied during a cycle remained relatively constant. The electrical drive characteristics did not change much over the course of the nine months of testing. A summary of the load conditions is given in Table II.

Figure 14. Galfenol actuator mounted in load frame showing cooling fans to the left of the actuator.

Stress Condition	Segments	Start Date	Stop Date	Verified Running Days	Cycles (millions)	Average High Force (lb)	Average Low Force (lb)	Average Midpoint Force (lb)	Average Difference Force (lb)
1 (Low)	3	1/13/15	1/21/15	3.58	19	2210	1310	1760	900
2 (Low)	1	1/22/15	1/26/15	4.17	23	2300	1500	1900	799
3 (High)	1	1/26/15	2/18/15	22.77	124	4500	3780	4140	720
4 (Low)	4	2/18/15	3/16/15	23.08	126	1400	600	1000	783
5 (High)	5	3/16/15	4/15/15	21.38	116	5080	4470	4780	607
6 (Low)	8	4/15/15	5/19/15	21.62	118	1490	670	1080	805
7 (High)	3	5/20/15	6/15/15	22.49	122	5190	4600	4890	596
8 (Low)	9	6/15/15	8/11/15	21.97	120	1450	630	1040	819
9 (High)	2	8/11/15	9/2/15	21.95	119	5130	4540	4840	598
10 (Low)	1	9/2/15	9/23/15	20.92	114	1671	864	1267	807
11 (Low)	2	9/24/15	10/19/15	24.35	133	5111	4525	4848	586
12 (High)	5	10/19/15	12/9/15	41.69	534	1468	662	1065	789
Total				**249.97**	**1,366**				

Table II. Summary of the Results of Galfenol Actuator Fatigue Testing. Each "Stress Condition" marks a change in load frame tension. The "Segments" indicates the number of times the Stress Condition needed to be restarted after power failures, equipment downtime, etc. This is also the reason that "Verified Running Days" is less than the time between the Start and Stop dates.

The cooling fans were very effective in cooling the actuator; in fact it was so effective that if left on when the amplifiers were temporarily turned off, e.g. to reset the load, the fans quickly cooled the actuator to room temperature. This caused the applied force to drift due to differential thermal expansion. When the amplifiers were restarted, the force drift occurred again as the actuator heated back up to equilibrium. In one instance, the fans were inadvertently left off for seven hours, which caused the actuator temperature to reach 68 °C. The temperature returned to equilibrium 30 minutes after the fans were turned on and the actuator showed no adverse effects.

An accelerometer was placed at various locations on the actuator when the actuator was in a high load condition (~5,000 lbs). The accelerometer output was conditioned by a Stanford Research Systems SR560 low-noise preamplifier. Measurements were taken using a National Instruments DAQPad-6052E digital data acquisition system. The accelerometer output and the sync pulse of the function generator were measured; the sync pulse was used to temporally align the accelerometer outputs from the different locations. The accelerometer locations are shown in Fig. 15.

The bottom of the actuator is connected to the hydraulic piston. The constant displacement mode attempts to keep the position constant. The top of the actuator is connected to the crossbar which has no displacement control, as a result, the top vibrates more than the bottom as shown in Fig. 16; this can be confirmed simply by feeling the top and bottom endplates. In the front-to-back direction, the two legs of the actuator were lined up and the actuator was stiffer than in the side- to-side direction where the actuator could flex by bending the legs. This is similar to pushing

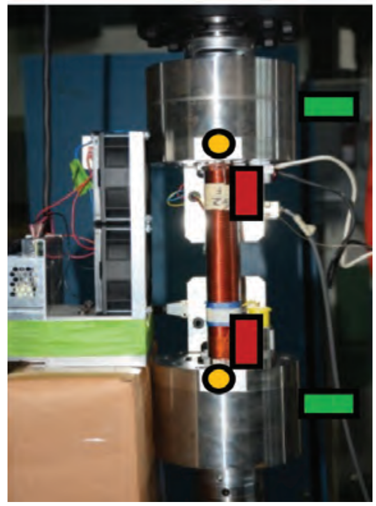

Figure 15. Accelerometer locations: Yellow (top and bottom) measures front to back motion; green (top and bottom) measures side to side motion; red (top and bottom) measures vertical motion.

a person sideways as compared to front and back. This is clearly shown by the acceleration in Figs. 17 and 18 where the side-to-side acceleration is larger than the front to back acceleration.

The magnetostrictive actuator using laminated Galfenol rods accomplished over 1.37 billion cycles with no change in the actuator performance. Results of the fatigue testing are provided in Table II.

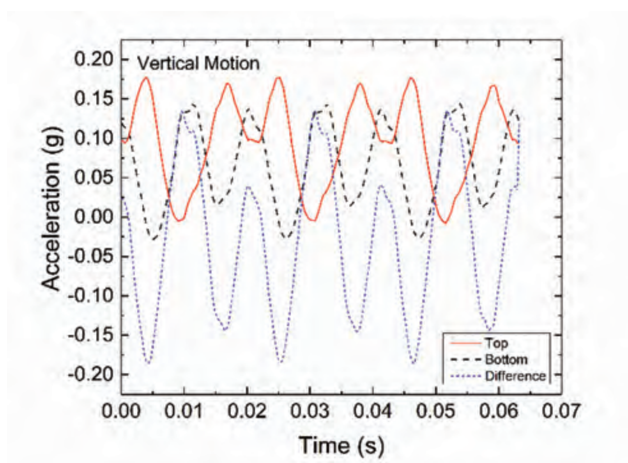

Figure 16. Accelerometer measurements on the top (solid red line) and bottom (dashed black line) of the Galfenol actuator, along with the difference between the two measurements indicated by the short dashed blue line. (Accelerometer locations are indicated by red rectangles in Fig. 15.)

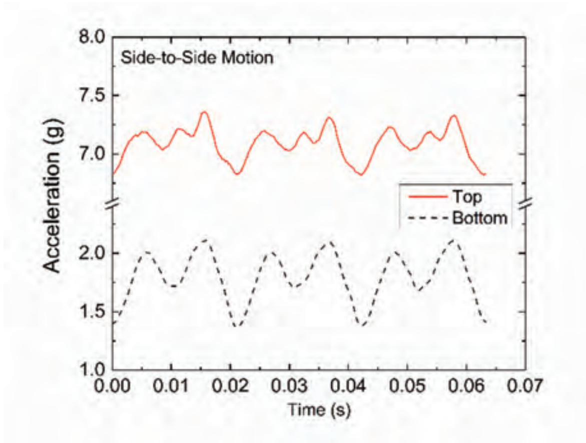

Figure 17. Acceleration measurements on the top side (solid red line) and bottom side (dashed black line) of the Galfenol actuator. The actuator design and mounting direction on the load frame made this direction the most flexible. (Accelerometer locations indicated by green rectangles in Fig. 15.)

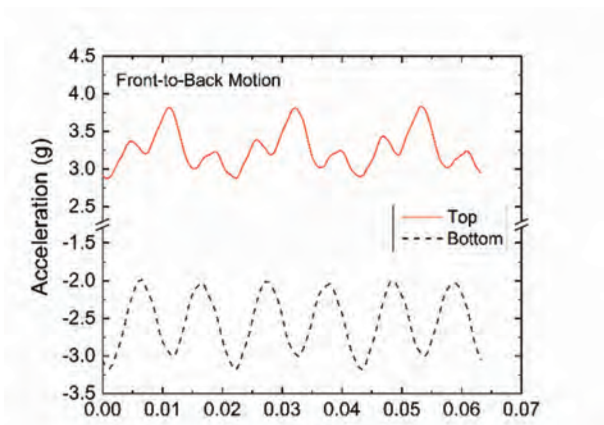

Figure 18. Acceleration measurements on the top front (solid red line) and bottom front (dashed black line) of the Galfenol actuator. (Accelerometer locations indicated by orange circles in Fig. 15.)

Discussion

Optimum test conditions are that the load frame stiffness be at least 10x greater than the actuator stiffness, simulating an infinitely stiff load. If the stiffness of the load frame is of the same order of magnitude as the actuator then a portion of the force output of the actuator will be absorbed by the load frame acting as a spring. The stiffness of the MTS 810 load frame plus the prototype actuator was measured to determine the actual stiffness of the load frame; both the load frame and actuator were of the same order of magnitude. This may explain why the measured maximum dynamic force output of both prototypes falls short of the capability of each unit based on the quasi-static displacement measurements. Dynamic force output was approximately 50% of the maximum capable.

The resulting force versus displacement curves for the test setup with and without a 15 amp DC bias applied can be seen in Fig. 19. Both conditions produced similar system stiffness values of 3.7 x 105 – 3.8 x 105 lbf/inch. The finite element analysis (FEA) for the actuator predicted a stiffness of 0.7 x 106 lbf/inch. By adding the inverses, the stiffness of the MTS load frame is approximately 0.8 x 106 lbf/inch, which is almost equivalent to the actuator. This is an undesirable testing situation for determining the maximum dynamic force output capabilities of the prototypes. A portion of the force output is clearly being lost to absorption in the MTS 810 load frame.

Similar measurements were completed for the G2 prototype. The system stiffness was measured to be 3.8 x 105 – 3.9 x 105 lbf/inch. This resulted in the same condition as the G1 prototype with the load frame absorbing a portion of the force output from the actuator.

An advantage of using the MTS 810 load frame to complete the testing discussed above was the ease in which the applied tensile strain could be adjusted and verified using the displacement sensors on the MTS unit. In application, this convenience will not exist. An alternative method that could be used to infer the applied tensile strain is to measure the overall inductance of the actuator. The actuator would require "calibration" to determine the inductance/strain relationship, but once characterized, inductance measurements could be used to approximate the applied tensile strain, similar to a strain gage. Strain gages, themselves, could be used, however the robustness of the bond and the need for a signal conditioner would add complexity to the overall design.

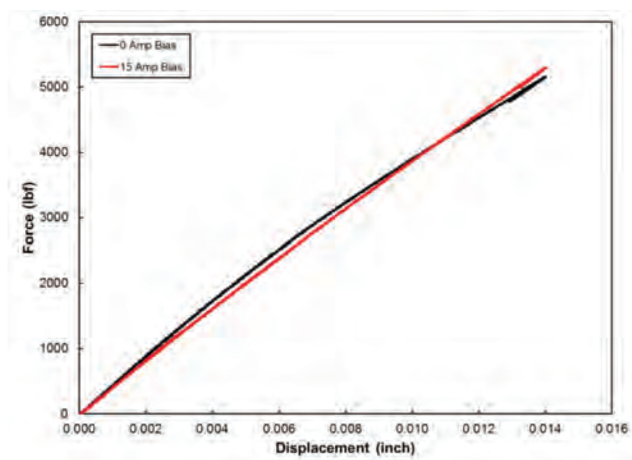

Figure 19. Measurement of the system stiffness for the G1 prototype with and without a 15 amp bias current. The spring constant of the G1/MTS system was observed to be 3.68 x 105 and 3.79 x 105 lbf/inch for 0 amp and 15 amp bias test conditions, respectively.

Figure 20 shows the inductance values versus applied tensile strain for both prototype actuators. Differences in the inductance responses to the applied tensile strain are likely a result of the difference in the built-in compressive stress discussed earlier. Inductance is related to the magnetic permeability which is a stress dependent term. A larger built-in compressive stress would result in a lower magnetic permeability and a lower inductance, which is observed for the G2 prototype unit.

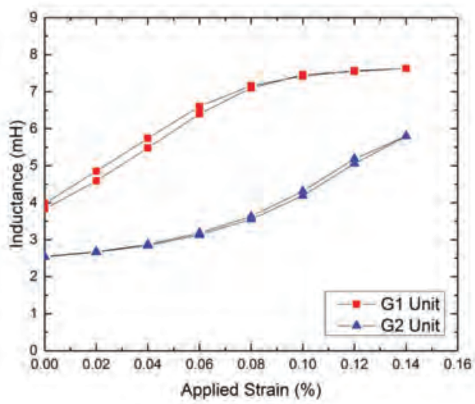

Figure 20. Galfenol actuator inductance versus applied strain for both prototype units. (Inductance and resistance measurements were made using an LCR meter set at 1V and 100 Hz.)

Conclusions

A Galfenol-based actuator was designed that can generate an output force while operating under tensile strains of up to 0.14% (0.0014 mm/mm) at 300 Hz. Manufacturing challenges that were overcome included welding of the foot to the Galfenol lamina and fabricating parts to extremely tight tolerances: ± 0.001" on length and ± 0.0004" on flatness and parallelism held over a 10" length.

Two prototype actuators were manufactured and tested under quasi-static and dynamic conditions. Dynamic power requirements included a 15 – 16 amp DC bias and up to 25 – 26 amp AC (pk-pk). Two cooling fans were used to provide convective cooling of the Galfenol legs and drive coils during dynamic operation.

The actuators were capable of outputting between 1300 – 1600 lbf based on the quasi-static displacement results. The magnitude of dynamic force output was limited by the matched stiffness of the MTS 810 load frame (0.8 x 106 lbf/in) and the prototype actuators (0.7 x 106 lbf/in), however force outputs were observed up to 0.14% applied tensile strain at 300 Hz. It is logical to assume that if the actuator output is connected to stiffer loads, larger force outputs and higher tensile strains could be applied.

Thermal tests showed that operating at 100% duty cycle at 300 Hz is possible if cooling fans are employed. Without the use of cooling fans 100% duty cycle operation would be limited to frequencies below 150 Hz.

Fatigue testing on one actuator achieved over one billion cycles with no observed change in performance.

Demonstration of the Galfenol technology in this unique application provides a capability that does not exist with current off-the-shelf transduction technologies.

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