FY20

Science & Technology

RESEARCH OVERVIEW

NAVSEA
WARFARE CENTERS
Carderock

Contents

Executive Summary

The In-house Laboratory Independent Research (ILIR) program is the premier Science and Technology (S&T) program supporting scientists and engineers of Naval Surface Warfare Center (NSWC) Carderock Division conducting Basic Research. NSWC Carderock Division uses this program to focus on stimulating new ideas and stewarding foundational knowledge through advanced degree research, internships, visiting researchers, and technical mentoring. In particular, ILIR investigators are encouraged to concentrate on high-risk innovative research in emerging technical needs not addressed in other sponsor-driven programs. In addition, ILIR is the major investment supporting recruitment, retention, and professional development of scientists and engineers researching problems facing the future fleet. The Carderock Division Office of Technology & Innovation executes this program together with the Naval Innovative Science & Engineering (NISE) program. NSWC Carderock Division receives the resources to conduct the ILIR program from the Office of Naval Research (ONR) under Program Element 0601152N (ILIR). Along with ONR funded ILIR and the internally funded NISE programs, the Division's knowledge base gains support from other projects funded by ONR, the Defense Advanced Research Projects Agency (DARPA) and other agencies amounting to nearly eight percent of the total business base.

The NSWC Carderock FY20 ILIR program leveraged the innovation of a "Bottom-Up" idea generation process with a "Top-Down" alignment and prioritization assessment. The proposals are evaluated and ranked according to specific criteria: Basic Research Merit, Technical Background, Technical Approach & Risk Evaluation, Impact to Technical Discipline, Naval and Division Relevance, Potential for Future Applications or Transitions, and Technical Knowledge Management (Mentoring). All projects are encouraged to leverage NSWC Carderock Division Post-Doctoral Fellowships, ONR Summer and Visiting Faculty, as well as interns from programs such as Science & Engineering Apprenticeship Program (SEAP), Science Mathematics and Research for Transformation (SMART) and Naval Research Enterprise Internship Program (NREIP) to maximize collaboration with universities and to expand recruitment pools of talented scientists and engineers. Besides supporting traditional research areas of Platforms, Materials, and Power & Energy, Carderock continued looking into "non-traditional" areas. With an eye toward the future, the Division invested in several scoping projects to examine new areas or supporting those needing a broader foundation: Complexity & Emergent Behaviors, Submarine Hydrodynamic Resistance, Machine Learning for Damage Assessment, Advanced Hull Form Design, Underwater Electromagnetics, as well as Modeling and Simulation of Corrosion. This shift to add small projects will continue as Carderock positions itself to address future technology requirements and funding constraints.

FY20 HIGHLIGHTS	ILIR
Projects - New Starts	11
Projects - Continuing	4
Projects - Completed	6
Transitions (to higher level S&T or program of record)	16
Participating Junior Investigators/Engineer Scientist Development Program (ESDP)	11
Doctoral Candidates Supported	6
Doctoral Degrees Awarded	1
Masters Students Supported	4
Masters Degrees Awarded	0
STEM INITIATIVES	**ILIR**
SMART Interns	1
NREIP Interns	4
SEAP Interns	1
Summer Faculty	7
Sabbatical Leave Professors	1

Program Highlights & Bibliometrics

Program Highlights

NSWC Carderock Division uses the ILIR program to focus on stimulating new ideas and stewarding foundational knowledge through advanced degree research, internships, visiting researchers, and technical mentoring.

Out of the 21-ILIR projects: four individuals were supported in master's research and six individuals were supported in their doctoral research, with one being awarded; seven interns were mentored in technologies key to the Division's future needs, and one project was supported by an ASEE Post-Doctoral Research Fellow. Collaborations with university faculty form a major emphasis of stewarding core technologies. Last summer NSWC Carderock Division hosted 17 faculty researchers (16 DoN/ONR SFRP and one by a separate contract). Of these, seven were from Historically Black Colleges or Universities, Hispanic Serving, or Minority Institutions (HBCU/HSI/MI). Four Summer Faculty directly supported ILIR projects, and one project benefited by a Sabbatical Leave professor. 10 supported NISE projects, 12 supported direct funded (ONR, DARPA, or NAVSEA) projects, and 1 supported the Center for Innovation in Ship Design (CISD). A Sabbatical Leave professor supported Gordon Waller.

Bibliometrics

In an international pandemic constrained environment coupled with continued emphasis on documentation, the Division struggled with reporting appropriate metrics for tracking knowledge advancement. Many meetings and professional society conferences were either canceled or shifted to virtual participation limiting knowledge sharing. Having restrictions on in-person attendance in Division laboratories hampered projects requiring experimentation for validation of theoretical or M&S predictions. Overall though, NSWC Carderock ILIR researchers published four refereed journal articles, one un-refereed paper, three (archived) NSWC Carderock technical reports, and seven un-archived reports, with thirteen papers in draft form for submission or accepted to journals. One patent was awarded, with four others filed with the United States Patent and Trademark Office (USPTO) and another nine invention disclosures were filed with the Carderock Patent Counsel Office. Despite travel restrictions, NSWC Carderock continued to support Colloquia and professional societies with 25 various presentations to academia, government, and professional societies. Six researchers served their respective professional society conferences as panel and session chairs. The NSWC Command also bestowed the Senior Technical Excellence Award to Alexey Titovich.

BIBLIOMETRICS	ILIR
Refereed Papers Published	4
Non-refereed Papers Published	1
Books/Chapters Published	0
Manuscripts in Prop or Accepted	13
Government Reports Published (Archived)	3
Government Reports Published (Non-archived)	7
Masters Theses Completed	0
Doctoral Theses Completed	1
Patent Disclosures	9
Professional Society/External Presentation	16
Government Colloquium	6
Academic/Industrial Colloquium	3
Panel Participation	6
National/SYSCOM/Division Awards	0
Award/Honor	1
Editorial Review	1

ILIR Project Summaries

Naval Surface Warfare Center, Carderock Division uses ILIR to address high-risk innovative research focusing on future and emerging technical needs that are not addressed in other sponsor-driven programs. In addition, these major investments support the recruitment, retention, and professional development of scientists and engineers researching problems facing the future fleet. The FY20 ILIR selection process leverages the innovation of bottom-up proposal generation with top-down technical alignment and prioritization. Projects must show excellence in describing Research Merit, Technical Background, Technical Approach with Risk Evaluation, Advancement of Technical Discipline, Impact to Warfighter, Knowledge Management (including Mentoring), and Potential for Future Applications (Transitions). Outlined in this section are overviews of the projects with short biographical summaries of investigators.

Director of Research, NSWC Carderock

Jack Price, Ph.D.


Jack Price

Dr. Price is the Director of Research for the NSWC Carderock Division. He provides vision for the role of Science and Technology (S&T) in developing future Maritime needs. He is the Division's lead for the oversight, planning, and execution of the internal directed research program and the Division Technical POC for S&T funding agencies (ONR, DARPA, etc.). In addition, he is responsible for overall S&T strategic planning. Dr. Price is a 1976 cum laude graduate from Norwich University with BS degrees in Physics and Mathematics. In 1978, he earned a MS degree in Space-Plasma Physics from the University of Kansas (KU), and in 1986 he earned a PhD from the University of North Texas specializing in Atomic Collision Physics. Dr. Price was Adjunct Faculty at Montgomery College, Germantown, MD for 20 years and an Adjunct Professor at the American University Physics Department, Washington, DC. He has served on doctoral review panels for students at George Washington University and the Catholic University of America.

Science & Technology Coordinator

Judy Conley, D.Sc.


Judy Conley

Dr. Conley is the Science & Technology (S&T) coordinator for the Platform Integrity Department, and assists the Director of Research to guide his Laboratory Directed Research and Development (LDRD) portfolio. In addition, she also assists the Director of Innovation, in facilitating a culture of innovation via guiding the Technical Director Innovation Challenge (TDIC) effort and Human Centered Design (HCD) practices, as well as the Director of the Disruptive Technologies Laboratory (DTL) in exploration of non-traditional product areas through assembly of ad-hoc interdisciplinary teams to explore the technical potential and naval relevance of new technology.

Dr. Conley received a Doctorate of Science and Masters of Science in Structural Engineering each from The George Washington University in 1997 and 1985, respectively. Her Bachelors of Science degree in Civil Engineering (Structures) is from Michigan State University in 1982. Dr. Conley has been employed by NSWC Carderock Division from 1982 until the present.

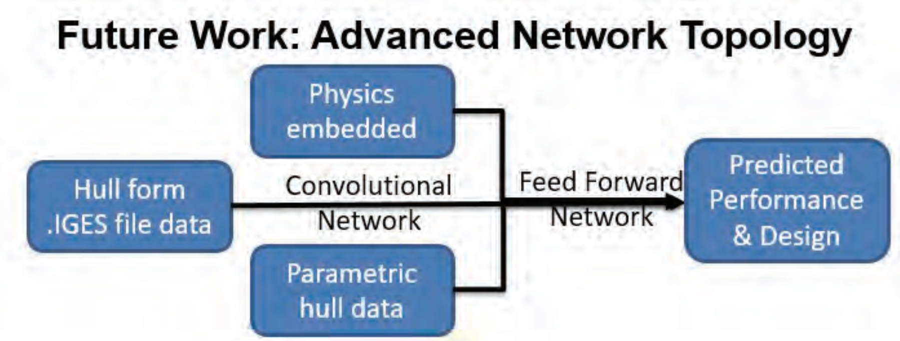
Application of Machine Learning to Early Stage Hull Form Design ILIR, Year 1/1

Principal Investigator

Austin Shaeffer

Austin Shaeffer

Mr. Austin K. Shaeffer graduated from Stevens Institute of Technology in 2016 with a Bachelors of Engineering in Naval Engineering and Masters of Engineering in Ocean Engineering. His Master's thesis worked with comparing RANS based CFD to potential flow methods for use in identifying the optimum placement of sidehulls for a trimaran. In addition, he worked with a number of research projects in the field of fluid flow and hydrodynamics including three years of experience working with model tests in the Davidson Lab tow tank. He started at Carderock in the summer of 2016 and started at GMU working towards his PhD in Physics with a concentration in Engineering in August of 2017. He currently works in the Future Ship and Submarine Design Tools branch (823) working primarily with the hydrostatic and hydrodynamic programs such as SHCP-L and IHDE.



External Collaboration

Professor Chi Yang at George Mason University

S&T Products:

SNAME SMC Presentation and Publication, NSWCCD Code 82 Lunch & Learn, GMU PHD Proposal

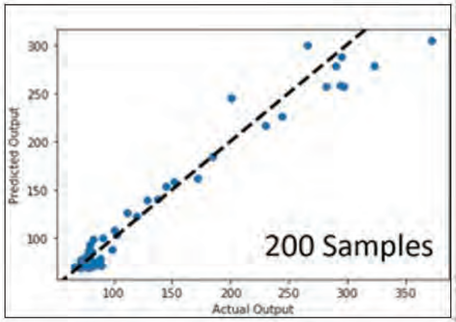
Workforce Development:

Doctoral Degree in Progress: Austin Shaeffer, PhD in Physics with Concentration in Engineering from George Mason University (GMU)

Results/Achievements/Future Work/Recommendations

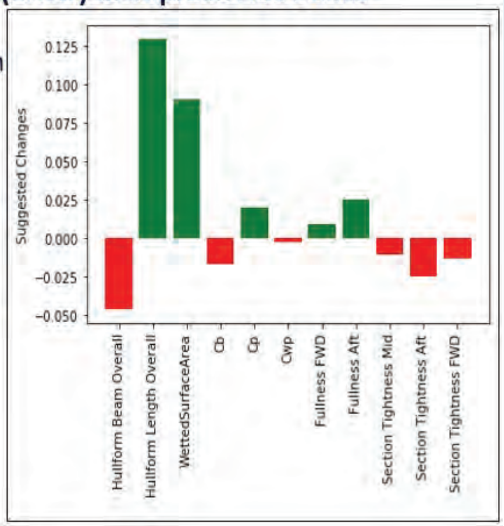
Proof-of-Concept

- Average Abs. Error~ 10%
- Optimal Abs. Error~ 6%
- Error within expectations
  - TSD introduces error
  - Geometry VS 12 Design variables



Using Artificial Neural Networks (ANNs) to Improve Hull Forms

- Partial derivatives of design variables to objective function variables calculated using backpropagation
  - Direct search direction
  - Improved computational expense from other derivative calculation
  - Surrogate SME input for hull form design improvement



Motivation and Objective

Utilize the recent advances in physics embedded neural networks to improve the current hull form design methodology in early-stage ship design. Provide a surrogate for both experienced hull form designers and CFD. Also, derive a more direct search algorithm based on the neural network in order to reduce risk and improve efficiency of hull form design, both automated and manually.

Background

The drive within the naval architecture community over the last couple of decades towards set-based design and design space exploration has resulted in increasingly large and more readily obtainable sets of ship design data. This research focuses on coupling the state-of-the-art in machine learning techniques with the increasingly available ship design data in order to improve the hull form design process. The application of artificial neural networks (ANNs) within the ship design community has thus far been limited to providing surrogates for predictive models. The focus of this study goes beyond using ANNs to predict performance, investigating the application of ANNs to predict design. Proof-of-concept has been achieved for using ANNs to predict design improvements based upon very simple hull form design data.

Procedure, Set-Up and Approach

- Use HPCMP CREATE™-Ships Rapid Ship Design Environment (RSDE) & Integrated Hydrodynamics Design Environment (IHDE) to create hull form design datasets
- Create and train an ANN with large datasets of hull form design variables and hull form performance variables
- Test the robustness and effectiveness of the ANN

Applications and Pay-off

- Advance the technical knowledge in the state-of-the-art fields of machine learning and data clustering
- Develop expertise and technologies in hydrodynamics and hull form design
- Improve the effectiveness and usability of hull form optimization and design tools
- Increased range, improve speed, and lower power requirements for surface ships to improve mission capability

Future Customer/ Transition

- HPCMP CREATE™-Ships Rapid Ship Design Environment (RSDE) & Integrated Hydrodynamics Design Environment (IHDE)
- NISE 219 Data Analytics Tasks
- SimDShip Hull Optimization funding

Automated Damage Detection Using Machine Learning

ILIR, Year 1/1

Principal Investigator

Nicholas A. Reynolds


Nicholas A. Reynolds

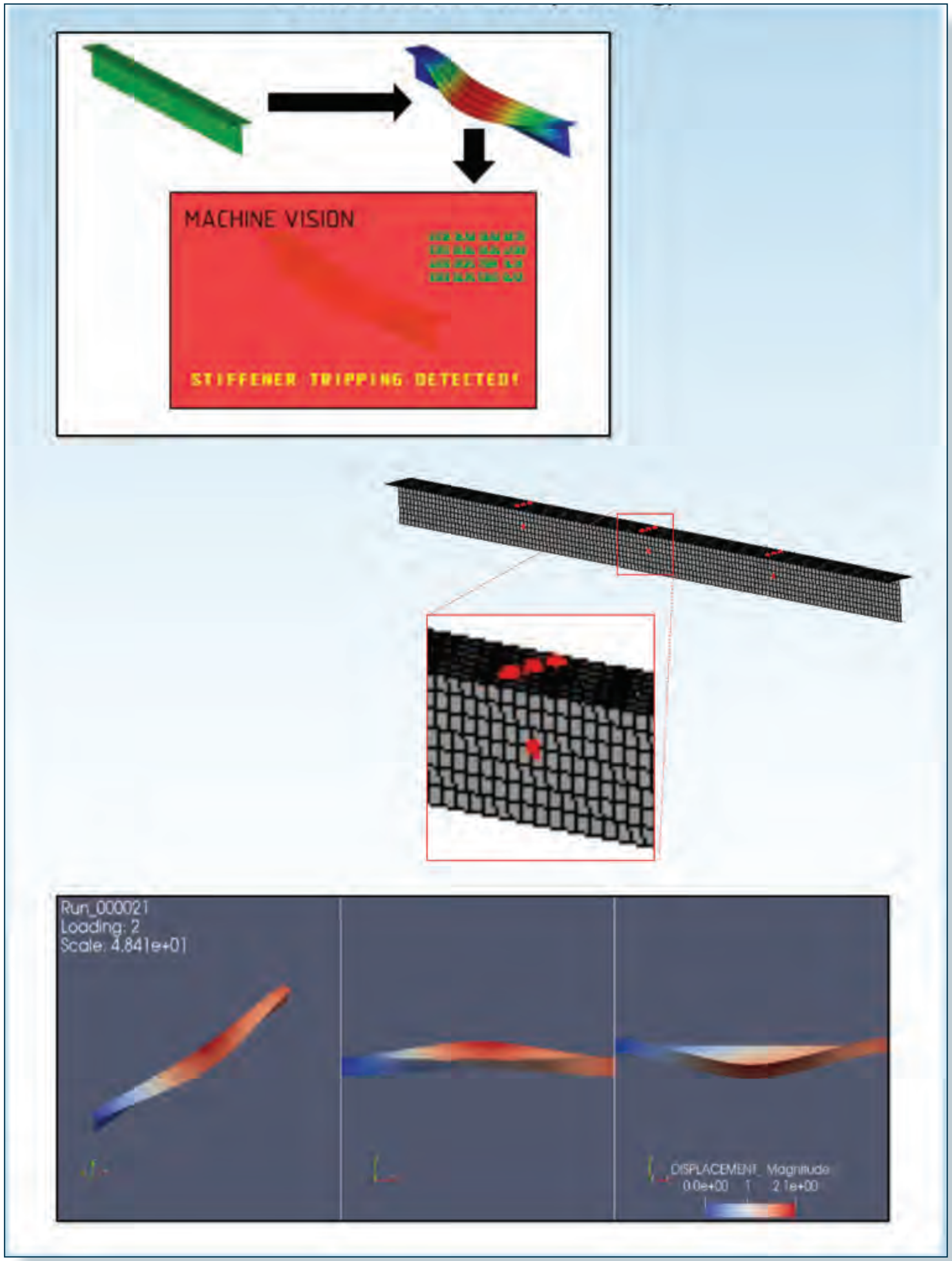
Dr. Nicholas A. Reynolds is an engineer in the Hull Response and Protection Branch (Code 6640). He has supported the ONR Ship Reliability Program and presently works as a developer for the Navy Enhanced Sierra Mechanic's Program for CREATE Ships as part of the DoD High Performance Computing Modernization Program. He holds a doctorate and master's degree in civil engineering from the Georgia Institute of Technology and a bachelor's degree in civil engineering from Vanderbilt University. He has also worked as a stress analyst with NASA's Marshall Space Flight Center in Huntsville, AL.

Future Customer/Transition

Navy-Enhanced Sierra Mechanics (CREATE-SHIPS Shock/Damage Product)

Achievements

- Developed analysis infrastructure (e.g. scripts) to parametrically generate models, submit analyses, and post-process results.
- Populated a database of 345,000 entries that can be used in further development of MLAs
- Developed a Random Forest classifying algorithm with 98.5% accuracy.
- Advanced the state of practice in modeling and simulation by demonstrated that MLAs are a viable technology to be used in damage assessment in finite element models.
- Developed a framework for populating future datasets for training MLAs for damage detection.
- The experimental results will provide starting point for further exploration of MLAs for damage detection to identify suitable algorithms for this problem space.
- Future work includes exploring effectiveness of other MLAs (e.g. nonlinear Support Vector Machines); training MLA for other structural components; aggregating component level MLAs to detect system level damage



Motivation and Objective

- Acquisition and decision making involving Navy ships and submarines relies on finite element analysis (FEA)
- Post-processing FEA requires a human-in-the-loop, thereby reducing efficiency and increasing likelihood of error
- Machine learning algorithms (MLAs) that could detect and categorize structural damage (e.g. in T-stiffeners) would reduce analysis turnaround and increase accuracy
- Goal is to establish a framework that can be applied to the development of future MLAs to assess damage in more complex structural components and systems; demonstrate efficacy by developing an algorithm for T-stiffeners

Background

- Damage assessment in real-world structures falls under structural health monitoring, and is detected using changes in sensor readings
- State-of-art damage assessment for numerical models is rendering images to screen, relying on human judgment to interpret results.
- Compared to typical component-level FEA, damage assessments for ships/ submarines are becoming increasingly large and complex making rendering and navigating the model during post-processing more challenging.
- Nodal displacement field data computed as part of FEA provides much of the information that sensors would otherwise provide in detecting the onset of damage and is readily accessible through the EXODUS data format

Approach

- Conduct an extensive parametric study of T-section dimensions, lengths, material properties, and loading conditions.
- Perform FEA and extract results from the nodal displacement fields.
- Generate and categorize screenshots of deformed shape.
- Train/test MLA to categorize deformed shape using nodal displacement data and FEA input parameters

Applications

- Structural Health Monitoring of critical infrastructure when using scanning technology (e.g. laser scanning or photogrammetry)
- Ship/submarine damage assessment/prediction as part of acquisition or operational decision-making

Ceramic Electrolytes for Beyond Li- Ion Batteries

ILIR, Year 1/3

Principal Investigator

Jim Zaykoski, Ph.D.

Jim Zaykoski

Dr. James A. Zaykoski: B.S. Materials Engineering (1985), Wilkes College, M.S.(1988) and Ph.D.(1994), University of Maryland, employed NSWC White Oak (1985-1995), NSWCCD (1995-present) as Materials Engineer, 34 years of experience synthesizing and characterizing ceramic materials for high temperature applications, oxidation protection, IR transparency, high dielectric constant, adhesive characteristics, photo-catalytic capability, dopant control of phase transformation, porosity and crystalline morphology control for particulate filtering. Dr. Zaykoski has been developing ceramics and carbon/carbon composites for the Navy since 1985.

Associate Investigators

Patricia Smith, Ph.D.

Patricia Smith

Dr. Patricia H. (Tricia) Smith has over 35 years' experience in planning and executing research and development strategies to bring innovative power source technologies to the Navy and Marine Corps. Her areas of expertise encompass electrochemical double layer capacitors, asymmetric capacitors, lithium ion rechargeable batteries and lithium metal rechargeable batteries. She is presently on a detailed assignment to the Vehicle Technologies Office at the Department of Energy. There she helps DOE manage more than 63 projects in the Advanced Battery Materials Program and the Battery500 Program. She is presently the Co-PI of the Beyond Li-Ion Battery-Capacitor Hybrid Power Source project for the Office of Naval Research. She routinely collaborates with university researchers and industry engineers and is a conduit to system developers. Together the team identifies and nurtures new technology from a concept to a demonstrated prototype for a specific Navy or Marine Corps application. Dr. Smith obtained her Ph.D. in Chemistry from the University of Maryland.

Kimberly Garvin

Ms. Kimberly Garvin started this past fall as a Materials Engineer at Naval Surface Warfare Center Carderock Division performing under Code 615, Advanced Materials for Sensors and Systems. Kimberly earned her Bachelor of Science degree in Materials Science and Engineering from Clemson University in 2019. Her undergraduate research focused on tailoring properties of silicon based polymer derived ceramics and processing them at intermediate temperatures. Now, Kimberly has been working on the electrochemical interests with the use in ceramics along with other technologies using ultra-high temperature materials.

Kimberly Garvin

Curtis Martin

Mr. Curtis A. Martin has been developing Randome materials and other ceramics for the Navy since 1985. Curtis is a DoD Subject Matter Expert for high-temperature RF transparent materials, for Radomes and RF windows as well as in conformal antennas on supersonic and hypersonic missiles. He has experience with fabrication and testing of all types of structural ceramics. He supports a number of missile programs for Navy and the rest of DoD and DARPA. Curtis has BS and MS degrees in Materials Engineering from Virginia Tech in 1979 and 1982 respectively. Prior to joining NSWC, he worked in the refractories and fiber optic cable industries.

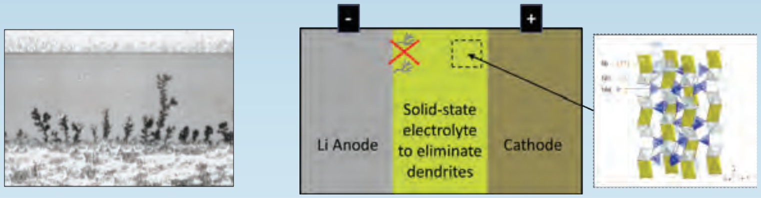
Curtis Martin

Jaime Santiago

Mr. Jaime R. Santiago is a Materials Engineer at the Naval Surface Warfare Center Carderock Division and has a B.S. degree in Chemical Engineering from the University of Delaware. He has 4 years' experience in research, development, testing, and evaluation of materials including polymers, ceramics, metals, and electrochemistry for various Navy applications. Mr. Santiago has expertise in computer programming languages such as MATLAB, Simulink, Visual Basic, C++, and HT Basic. He has served as Principal Investigator for electro-spun nano-fiber processing and as an Associate Investigator for research and development in supramolecular polymers for applications in electrolyte, composite, and acoustic materials. Mr. Santiago participates in testing and evaluation of Navy and Marine Corps power sources including lithium ion batteries, capacitors, and electrolytes.

Jaime Santiago

Concept

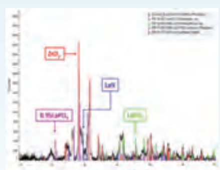


Left: Lithium dendrites formed in organic liquid electrolytes. Center: Elimination of dendrites with high-modulus solid-state electrolytes. Right: Schematic of hexagonal NASICON crystal structure.

Results

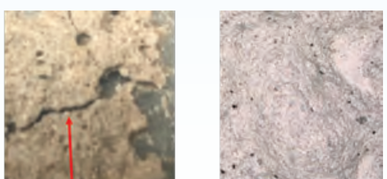
Several Li containing NASICON-structured ceramics with the general formula of $LiM_2(PO)_4$ and a skeleton consisting of MO_6 octahedral and PO_4 tetrahedral sharing oxygen atoms were synthesized at ambient temperature using a variety of transition metals. The reactions did not go to completion and the coatings exhibited significant mud- cracking indicating either the need for higher temperature synthesis or the use of a sintering agent.

Photograph of the mud-cracking typically observed with ceramic products synthesized at ambient temperature.



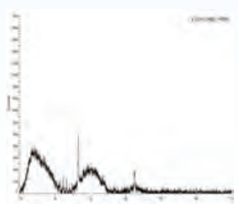
X-ray diffraction of a material showing precursor materials and a small amount of a highly crystalline NASICON-type material.

Addition of boron-containing additives appeared to improve synthesis completion and formation of thin, crack-free, low porosity electrolyte coatings.



Specimen cracked intentionally

Photographs of ceramic electrolytes synthesized with a boron-containing reactant. Materials do not display mud-cracking. The specimen on the left was intentionally cracked to determine hardness.



X-ray diffraction of a highly amorphous NASICON-type material synthesized using a boron precursor. There was minimal evidence of precursor material.

Objectives

Lithium (Li) metal has a higher theoretical capacity (3,862 mAh/g) than traditional Li-ion battery carbon anodes (LiC_6, 370 mAh/g). As a consequence, batteries utilizing Li anodes are expected to deliver 3-5X the energy density of today's Li-ion batteries containing liquid organic electrolytes. Unfortunately, Li metal does not plate uniformly in liquid electrolytes. It forms dendrites and rechargeability is greatly diminished.

ionically-conductive ceramic (> 1 mS cm-[1]) allowing the implementation of Li metal anodes for high energy density electrochemistries [e.g. Li-S (650 Wh/Kg), Li-air (900 Wh/Kg) vs 250 Wh/Kg for Li-ion].

Background

Theoretically, the electrolyte shear modulus should be approximately twice that of Li metal to suppress dendrite growth. (solid polymer/Li, Monroe, Newman, JECS, 152, A396, 2005). Li metal shear modulus is ~ 4 x 109 Pa at room temperature.

Various ceramic materials have high elastic modulus and are ionically conductive. Several challenges must be overcome before they can be utilized in practical cells. These include high interfacial resistance between particles, thick film processing creating Ohmic loss, and high temperature synthesis that degrades cathode materials.

Approach

Investigate Li-containing NASICON-type phosphate ceramics. Identify dopants enabling low-temperature synthesis (<500oC) and thin-layer processing. Explore pure ceramic and ceramic-polymer blends as a means of preventing Li dendrite formation.

Characterize materials using X-ray diffraction, scanning electron microscopy, electrochemical impedance spectroscopy, and dynamic mechanical analyzer. Fabricate/test half and full cells.

Pay-off

A fundamental understanding of the basic mechanical and electrochemical properties of ceramic electrolytes and their influence on Li dendrite formation and suppression. Ability to develop a high energy battery utilizing a naturally abundant cathode (sulfur, air).

Safer, longer lasting and more affordable power source for the warfighter.

- Eliminate the threat of fire caused by over-heated liquid electrolyte
- Avoidance of expensive, foreign-sourced, critical materials (cobalt).

S&T Products

ILIR Mid-year and End-Year Reports and presentations.

Workforce Development

Kimberly Garvin, Jr. Investigator; Jaime Santiago, M.S. degree

Combining the Electrochemical and Mechanical Regimes

ILIR, Year 1/1

Principal Investigator

Jacob Steiner, Ph.D.

Jake Steiner

Dr. Steiner, Ph.D., is a materials engineer in the Corrosion and Coatings Engineering Branch (Code 613), where he covers projects focused on the research and development of corrosion prevention technologies as well as the advancement of computational materials science of complex corrosion phenomena.

He holds a B.S. degree and a Ph.D. in Materials Science and Engineering from the University of Maryland, College Park. He has one year of experience with the US Navy. He has authored two technical papers from his graduate work on the phase transformation behavior of ferromagnetic shape memory alloys.

Since joining the Navy, he has prepared and delivered briefs on topics such as conversion coating of aluminum alloys for maritime environments and novel chemistries to reduce passivation time of CuNi alloys. Technology from his work on the latter topic is currently under review for filing a patent.

Associate Investigators

Elissa Trueman, Ph.D. , PE

Elissa Trueman

Dr. Trueman, is a materials engineer for the Corrosion and Coatings Engineering Branch (Code 613), where she is the corrosion science subject matter expert and is focused on research and development, failure analyses, acquisition support, and in-service engineering for corrosion prevention and control of structures and machinery systems for the Navy.

She holds B.S. and M.S. degrees in Mechanical Engineering from Florida Atlantic University and the University of Maryland, College Park, respectively, and a Ph.D. in Materials Science and Engineering from the University of Virginia. She is a licensed professional engineer in the Commonwealth of Virginia and the State of Florida.

She has 16 years of experience in corrosion prevention and control with the Navy. She is an active member of NACE International, the Electrochemical Society, and ASM International. She currently serves as an adjunct professor at Virginia Polytechnic Institute and State University. She has authored numerous technical papers and has one patent.

Transition:

Short term:

- Continuing development and implementation of model under seedling status in FY21

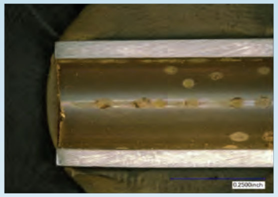
Long Term:

- Present findings to Technical Warrant Holder for Heat Exchangers, Condensers, and Air Ejectors, NAVSEA 05Z25 to establish a list of objective quality evidence to be developed in follow-on research and development programs
- Establish potential collaborative partners with respect to fluid-flow simulations beyond laminar regime

Collaboration:

Dr. Jason Howison, School of Engineering,
The Citadel, Charleston, SC

Results: Phase-field equations governing flow-assisted corrosion



Thermodynamic forces:

$$\mathcal{F} = \int_{\Omega} [f_{chem}(\boldsymbol{c},\xi) + f_{int}(\xi) + f_{elec}(\boldsymbol{c},\phi) + f_{mech}(\boldsymbol{u},\xi)] d\Omega$$

$$f_{chem} = Wg(\xi) + RT \textstyle\sum_i^n c_i \ln c_i + \sum_i^n c_i \mu_i^{\ominus}$$

$$f_{int} = \frac{\kappa(\xi)}{2} \sum (\nabla \xi)^2$$

$$f_{elec} = F \textstyle\sum_i^n z_i c_i \phi$$

$$f_{mech} = \frac{h(\xi)}{2} \left(\varepsilon(\boldsymbol{u})^T \cdot \left(\boldsymbol{D} \varepsilon(\boldsymbol{u}) \right) \right) + \frac{\rho(\xi)}{2} |\boldsymbol{u}^2|$$

Constraints:

$$\sum_i^n z_i c_i = 0$$

$$\nabla \cdot (\sigma(\xi) \nabla \phi - i_{net}) = 0$$

$$\nabla \cdot \boldsymbol{u} = 0$$

$$\nabla \cdot \left(\frac{h(\xi)}{2} \left(\boldsymbol{D} \varepsilon(\boldsymbol{u}) \right) \right) = 0$$

From *The Guardian*, 22NOV2016

Kinetics:

$$\frac{\partial \xi}{\partial t} = \nabla \cdot M(\xi) \nabla \frac{\delta F}{\delta \xi}$$

$$\frac{\partial c_i}{\partial t} = \nabla \cdot (D(\xi) \nabla c_i) + \nabla \cdot \left(\frac{D(\xi) c_i}{RT} z_i F \nabla \phi \right) - \boldsymbol{u} c_i + r_i$$

$$r_{net} = k_0 \left(\exp \left(\frac{\alpha}{RT} [zF\eta + \boldsymbol{D}\varepsilon(\boldsymbol{u}) V_m] \right) - \exp \left(\frac{1-\alpha}{RT} zF\eta \right) \right)$$

$$i_{net} = \frac{zF r_{net}}{m_w}$$

$$\rho_i \left(\frac{\partial \boldsymbol{u}_i}{\partial t} + \boldsymbol{u}_i \cdot \nabla \mathbf{u}_i \right) = -\nabla p_i + \nabla \cdot [\eta_i (\nabla \boldsymbol{u}_i + \nabla \boldsymbol{u}_i^T)] + \rho_i \boldsymbol{g}$$

Objective

- Copper-nickel tubing used throughout the Navy may be susceptible to flow assisted corrosion
- Fundamental models of flow-assisted corrosion are lacking due to complex coupling of electrochemical and mechanical forces
- The objective is to investigate state-of-the-art physics-based simulation to establish a fundamental model to simulate this phenomenon
- Part of larger effort to advance computational tools the Navy can use to prevent and mitigate corrosion

Background

- Fundamental model for flow-assisted corrosion is lacking in literature
- Flow-assisted corrosion involves interplay of:
  - stress imposed on a material in an environment of flowing fluid
  - chemical potential gradients promoting diffusion of aqueous species
  - electrochemical forces which drive oxidation/reduction reactions of the corrosion process
- Past decade has seen significant advancement in computational modeling due to:
  - Integration of Arbitrary Lagrangian-Eulerian meshing techniques into commercial software
  - Developments in applying phase-field methodology to simulate localized corrosion
- To date, this methodology has not been tested to describe flow-assisted corrosion, but a general description for the approach was consolidated based on the literature

Applications/Pay-off

- Advance the computational tools the Navy's to predict and mitigate corrosion of critical systems from these complex failure modes
- Maintain the Navy's technological edge over its adversaries by remaining at the forefront of materials computational science
- Development of physics-based models of corrosion part of Code 613's effort to support the Integrated Computational
- Materials Engineering program headed by Dr. Charles Fisher within Department 60, Platform Integrity Department

Convolutional Neural Networks for Analysis of Hull Condition Imagery ILIR, Year 2/3

Principal Investigator

Vincent Franke

Mr. Vincent Franke studied Electrical Engineering at Frostburg State University and has years of experience with python programming, data analysis, and object detection and tracking via OpenCV from previous positions in the private industry.

Associate Investigators

Eric Giesberg, M.S.

Mr. Giesberg is a Naval Architect for the Full Scale Trials Branch (Code 853), where he covers projects focused on applying non-standard algorithms and machine learning to hydrodynamic problems for the Navy.

He holds a B.E. degree and M.S. degree in Naval Architecture from Stevens Institute of Technology. He has 9 years of Hydrodynamic testing experience, seven with Carderock.

He has published multiple papers for the Chesapeake Power Boat Symposium, Hull Performance Insight Conference, and American Towing Tank Conference. Additionally he has authored ten internal technical reports. Before working at Carderock, he was a member of the student steering committee of the Society of Naval Architects and Marine Engineers; he has continued to support the organization receiving awards for his support.

Eric Holm, Ph.D.

Eric Holm

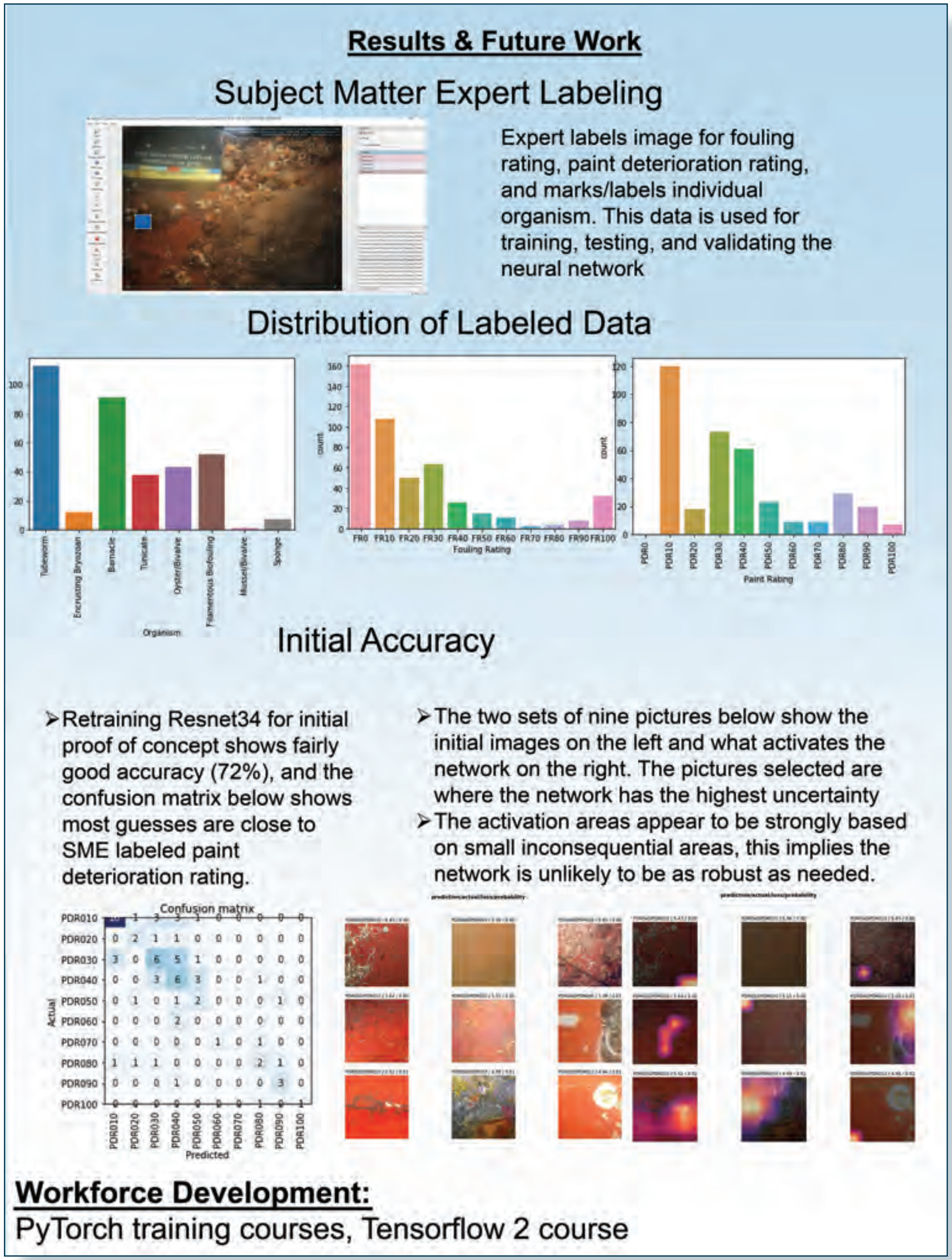
Dr. Holm is an ecologist in the Corrosion and Coatings Engineering Branch (Code 613), where he works on projects focused on biofouling of ship hulls and propellers by organisms such as barnacles and tubeworms, and the mitigation of that biofouling by coatings and cleaning technologies.

He holds a Ph.D. in Zoology from Duke University, where his research examined the ecology and genetics of settlement site choice of barnacles.

Dr. Holm has over 30 years of experience working with invertebrate biofouling organisms and evaluating control technologies. He has been an author or co-author on more than 30 peer-reviewed publications, and more than 20 technical reports.

Science and Technology Payoffs

- Development of Artificial Neural Network capable of analyzing and segmenting noisy underwater photos
- Automated processing of visual data(still photography or video) would support automated collection of inspection data by unmanned or autonomous vehicles, further reducing manpower requirements and sustainment/lifecycle costs:
- ROV/AUV inspections of ship hulls and propellers
- ROV inspection of tanks and voids without requiring draining/ evacuating –ballast tanks, fuel tanks, shoreside fuel storage
- ROV/AUV inspection of immersed infrastructure –pilings, seawalls
- Habitat assessment by ROV/AUV/drone–marine, aquatic, terrestrial
- Increase the amount of data available for predictive maintenance algorithmsetc.
- Use for fouling model development indigital twin



Motivation

Many of the Navy's and Marine Corps' important maintenance inspection processes (e.g. assessment of underwater hull and propeller condition; inspection of tanks, voids, topside surfaces, and vehicles for corrosion) entail manual collection and evaluation of visual data.

Automated processing of visual data, from still photography or video, would ultimately support automated collection of that data using unmanned or autonomous vehicles, further reducing manpower requirements and sustainment and lifecycle costs.

Hull-condition imagery creates various challenges

- low visibility
- crowding/stacking of bio-organisms
- encode the instinct of experts on the condition.
- Simple filters and object detection algorithms are developed for using on static objects in ideal conditions are not designed for this suboptimal environment.

Background

2004 –SPAWAR -Automated Image Processing/Image Understanding Coupled with an Artificial Neural Network Classifier for Quantifying Biological Fouling on Ship Hulls

- Need for pre-processing/ filtering images (images not done in studio conditions)
- Complex Fouling 'This layering of fouling organisms on top of fouling organism will make it extremely difficult or impossible for automated methods (or even human observers) to correctly identify individual organisms'.

1998-2004 First Convolutional Neural Networks(CNNs) Produced

Not popular until GPUs (Graphics Processing Units) applied to training in 2010

- CPUs (Central Processing Units) are great at fast sequential operations
- GPUs are capable of performing highly parallel simple operations
- Thousands of cores versus just a few

Huge leaps and bounds in previous few years in object identification and semantic segmentation

Coral reef studies are a parallel effort

Approach

Year 1

- Labeling
- Initial approach with common networks

Year 2

- Modification and customization of networks for domain

Year 3

- Video analysis

Drag Production and Structural Response of Compliant Streamers in Flow ILIR, Year 1/3

Principal Investigator

Joel Hartenberger, Ph.D.

Joel Hartenberger

Joel Hartenberger is an expert in lab-scale fluid mechanics experiments with 13 years of experience working on a variety of projects in multiphase flow and wall-bounded turbulence. He earned his Ph.D. in Naval Architecture and Marine Engineering at the University of Michigan working under the direction of Prof. Mar Perlin and Prof. Steven Ceccio. Joel began work at NSWCCD in February 2019 as part of a SMART scholarship agreement. He has conducted lab-scale fluid mechanics experiments throughout his time as an intern at Sandia National Laboratories, a graduate student at the University of Michigan, and as an engineer at NSWCCD. His work includes lab-scale experiments investigating selective withdrawal of stratified fluids, single bubble cavitation, roughness effects on near-wall turbulence, and drag production mechanisms of compliant roughness through experimental trials of living biofilm. Joel is a member of the American Physical Society (APS) and American Society of Mechanical Engineers (ASME). He has presented his work at the Symposium on Naval Hydrodynamics, the Annual APS Division of Fluid Dynamics Meeting, and the ASME International Mechanical Engineering Congress and Exposition (where he submitted, presented, and won best paper in the Fluids Engineer Division's Young Investigator Paper contest).

Future Customer/Transition

- ONR Code 32, 33
- PEO USC

External Collaboration

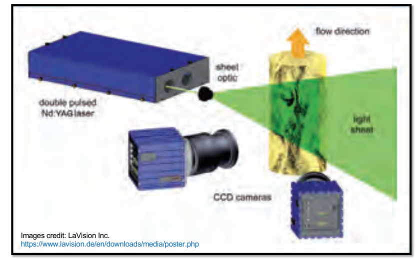
- NUWC Newport Division *Dr. Christin Murphy*
- NSWC Philadelphia Division *Philip Greiner, Brennan Appleman*

Newport

Philadelphia

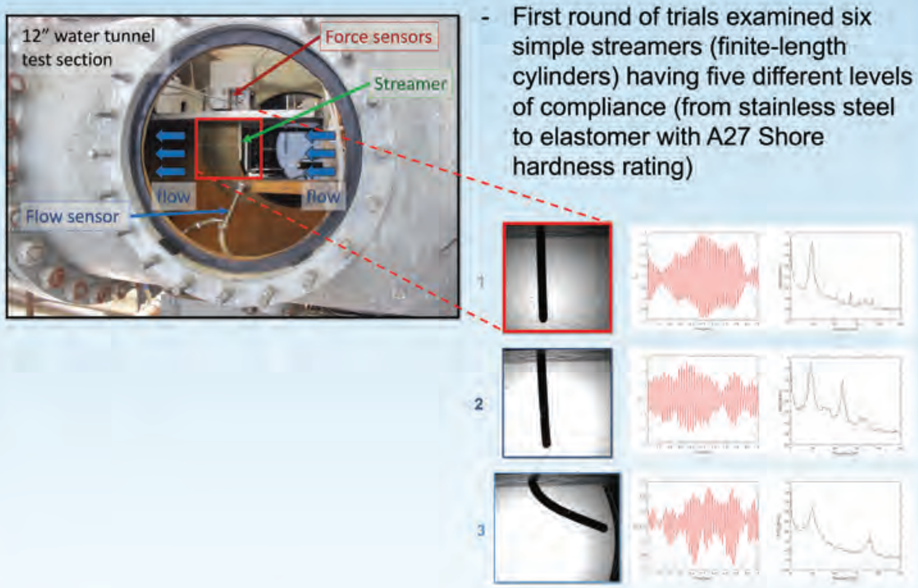
Future Work

- Evaluate existing FSI models
- Trials of complex streamers with advanced geometry (synthetic seal whiskers)
- Implement Particle Image Velocimetry (PIV) to capture flow field around streamers, couple structural response to fluid features

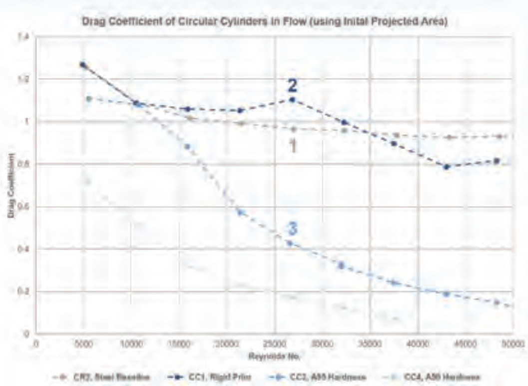


Scientific Understanding & Applications

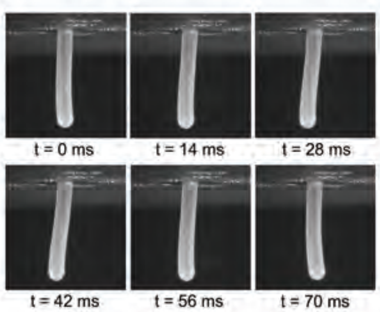
- Systematic development of FSI understanding for a wide range of compliant materials
- Inform development of novel sensors for tracking underwater bodies based on seal whiskers
- Provide further insight into how filamentous biofilms produce 'outsized' drag
- Demonstrated capability to inexpensively perform time-resolved, high-speed measurements of vibrating/fluttering structures



- First round of trials examined six simple streamers (finite-length cylinders) having five different levels of compliance (from stainless steel to elastomer with A27 Shore hardness rating)

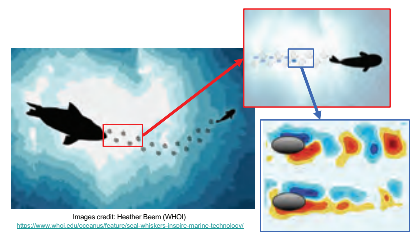


- Time series of images shows simple streamer deflections
- Streamwise, spanwise (shown) deflection along length from image processing algorithm



Motivation and Objective

- Biomimetic systems used by the Navy reproduce advantages observed in marine life forms
- Adaptations in material compliance, streamlined geometry lead to drag reduction, novel methods of tracking submerged bodies
- Prior studies of compliant streamers focus on specific applications, have narrow range of performance; **wide-ranging, systematic studies are needed to complete current understanding and improve design tools**



Harbor seals track fish using specially adapted whiskers

Approach

- Additive Manufacturing used to fabricate streamers with range of material properties

- Hydrodynamic testing of streamers performed in historic 12" water tunnel at NSWCCD
- Time-resolved measurements of drag and side force are coupled with high-speed video capturing streamwise, spanwise motions of the streamers
- Results used to evaluate Fluid-Structure Interaction (FSI) models of streamer drag, structural response

S&T Products:

- On the Dynamics of Finite-Length Compliant Cylinders in Cross-Flow (in preparation)

Workforce Development:

- PI trained to use historic 12" water tunnel for hydrodynamics studies

Initial Findings:

- Instantaneous drag, side force vary substantially
- Distribution of spectral energy changes with material compliance
- Case 1: simple streamer baseline drag
- Case 2: drag increase—streamwise-to-spanwise deflections small
- Case 3: drag decrease—streamwise-to-spanwise deflections large

Systematic Investigation of Enhancements and Limitations of Ship Motion Forecasting Using System Identification ILIR, Year 3/3

Principal Investigator

John Vorwald, M.S.

John Vorwald

Mr. Vorwald is an aerospace engineer in the Sea-Based Aviation and Aeromechanics Branch (Code 882), where he covers projects focused on the analysis of aircraft and rotorcraft flight dynamics.

He holds a B.S. degree in Aerospace Engineering from Iowa State University and an M.S. degree in Aerospace Engineering from the University of Maryland, College Park.

He has 33 years of experience with the Navy, is the author of 12 technical papers, has filed one patent, and has received 17 awards. He is a member of the Vertical Flight Society (VFS), where he is the Director of the International Investigation of Helicopter Dynamic Loads in the VFS Dynamic Committee.

Prior Year Results

- FY-18: Simplified nonlinear ship motion with frequency shifting forcing was forecasted for 120 seconds.
- 2016: Near Term Ship Motion Forecasting From Prior Motion
- 2018: Forecasting Optimal Time-of-Arrival for Carrier Landings Using Prior Ship Motion

Associate Investigators

Christopher Kent, Ph.D.

Christopher Kent

Dr. Kent is the Chief Engineer and Director of Science and Technology for the Naval Architecture and Engineering Department (Code 80), where he covers a range of projects related to naval architecture and hydrodynamics.

He holds a Ph.D. in Naval Architecture and Marine Engineering from the University of Michigan, and has 14 years of experience in naval architecture and hydrodynamics.

He has authored 13 technical conference and journal papers and has filed for a single patent. He is also a member of the Society of Naval Architects and Marine Engineers (SNAME) and an associate editor of the Journal of Ship Research.

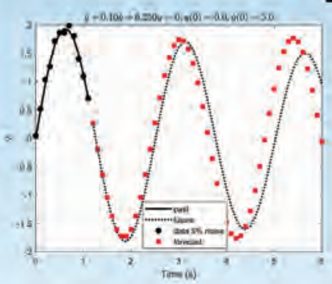
External Collaboration

UCLASS Landings in High Sea States

NAVFAC Enhanced Performance of Wave Energy Converters

Naval Research & Development Establishment, Data Science Workshop Poster Presentation

Forecasting Illustrated



time	y
0	0.05
0.1	0.52
0.2	1.04
0.3	1.27
0.4	1.72
0.5	1.86
0.6	1.86
0.7	1.99
0.8	1.81
0.9	1.41
1	1.10
1.1	0.71

$$y_t = a_1 y_{t-1} + a_2 y_{t-2} + a_3 y_{t-3} = [a_1 \quad a_2 \quad a_3]\begin{bmatrix} y_{t-1} \\ y_{t-2} \\ y_{t-3} \end{bmatrix}$$

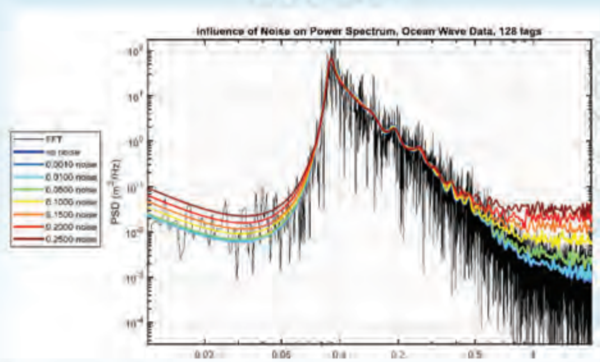
$$[y_4 \quad y_5 \quad \cdots] = [a_1 \quad a_2 \quad a_3]\begin{bmatrix} y_3 & y_4 & \cdots \\ y_2 & y_3 & \cdots \\ y_1 & y_2 & \cdots \end{bmatrix}$$

$$Y_L = AY_R$$

Minimize error in single step forecast

$$A \approx Y_L (Y_R Y_R^T)(Y_R Y_R^T)^{-1} = [1.59 \quad -0.340 \quad -0.343]$$

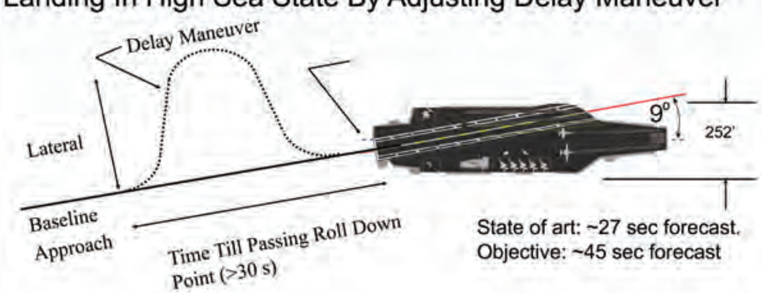
Observation



Results indicate forecasts with noise do not asymptotically approach noise free forecast. This phenomenon is indicated by the power spectrum showing models with noise are unable to resolve lower power regions of the spectrum. A proper filter may mitigate the information loss.

Application

Landing In High Sea State By Adjusting Delay Maneuver



Purpose, Motivation and Objective

Recent work on Recent Time Forecast Methods (RTFM) identified two complementary areas of research

- Algorithm Enhancements: Increase forecast accuracy and/or horizon, and provide real time estimate of accuracy
- Forecasting Characterization: Understand the characteristics and limitations of RTFM methodologies based on properties of system being forecasted and model being used

These two areas of research support the following hypotheses

- Forecasting accuracy and horizon can be enhanced via modifications to forecasting method
- Observations of capability and limitations of RTFM can be uncovered via systematic investigation of dynamic characteristics relevant to motions in a seaway

Background

System identification methodologies for process control were developed in the 1990s for slow process such as glass plate manufacturing. Faster processes forecasting was enabled by advances in hardware speed, software multi threading, and linear algebra enhancements.

A survey of ship motion forecasting methodologies was performed, 2016. An open loop forecast estimated the time of favorable landing conditions, 2017.

Closed loop wave energy forecasting controller optimizes energy extracted from individual waves, 2018. Simplified nonlinear ship motion forecasted in 2018.

Approach

- Examine classes problems that represent the fundamental physical coupling and nonlinearities
  - Baseline data set of ship motion
  - Pseudo-spectral wave model data with varying levels degrees of nonlinearities
- Evaluate the functional dependency of the error for different forecast horizons
- Modify forecast model to incorporate multiple steps

Technical Payoffs

- Currently no system in the Navy that utilizes forecasted future states in this manner. A wide range of applications are possible, such as improving launch and recovery of surface or air craft,
- Work on wave systems may point to approaches for making hyper-efficient wave models vs the Fourier approach that is the standard.

Fundamental Investigation of Electrode-Electrolyte Interface Using Novel Electrolytes ILIR, Year 1/3

Principal Investigator

Gordon Waller, Ph.D.

Gordon Waller

Dr. Waller is a materials engineer in the Advanced Power and Energy Branch (Code 636), where he covers projects focused on synthesis techniques for oxide materials and nanomaterials, materials characterization (SEM, XRD, XPS and Raman spectroscopy), and electrochemical testing for the Navy.

He holds B.S. and M.S. degrees in Materials Science and Engineering from Virginia Polytechnic Institute and State University, and a Ph.D. from Georgia Institute of Technology in Materials Science and Engineering with an additional coursework minor in electrochemistry. He has over three years of experience with the Navy, and is the author and co-author of 19 technical papers and 10 conference presentations, submitted two patent applications, and mentored two students through the NREIP program

Associate Investigators

Azzam N. Mansour, Ph.D.

Azzam Mansour

Dr. Mansour is a research physicist in the Expeditionary and Developmental Power and Energy Branch (Code 635), where he is the technical area lead for Science & Technology / Research & Development and the subject matter expert on the atomic level characterization of technologically important materials. He covers projects focused on applying synchrotron based X-ray absorption spectroscopy and X-ray photoelectron spectroscopy to investigate the electronic and atomic level structure of materials used in electrochemical power sources, thermoelectrics and catalysis.

He received a Ph.D. in Physics from North Carolina State University and has over 35 years of research experience. He has authored or coauthored over 100 journal articles, over 50 conference proceedings, over 150 technical presentations and 3 patents with over 4400 citations in the literature. He is a member of the Spectroscopy Review Panel of the Advanced Photon Source at Argonne National Laboratory (2015-present). He is the recipient of the 2010 NSWCCD Command Award for Mentoring. He is also a lifetime member of the Electrochemical Society.

Transition

NAVSEA program offices focused on batteries for UUV/submarines would benefit from electrolytes which can improve LIB safety/performance.

- PEO Submarines
- PMS 394 Advanced Undersea Systems
- PEO Unmanned and Small Combatants
- PMS 406 Unmanned Maritime Systems

External Collaboration

Informal collaborations with:

- Sandia National Laboratory
- Florida International University

Sandia National Laboratories

FIU FLORIDA INTERNATIONAL UNIVERSITY

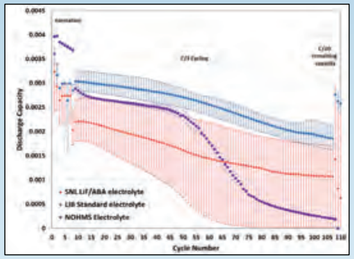
S&T Products

Presented at October 2019 ECS conference and project overview to div. head

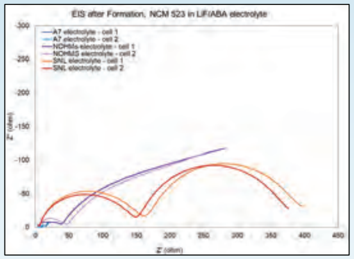
Workforce Development

Collaboration with ONR summer faculty Prof. Chunlei Wang (FIU)

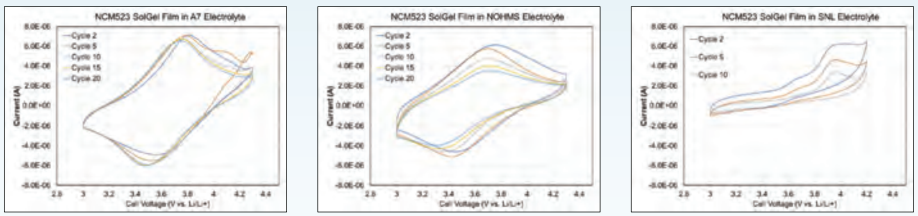
Results to Date



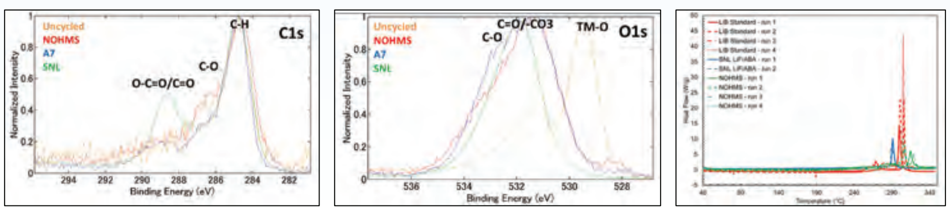
NCM523 half-cells containing a standard electrolyte solution (BASF A7) and two electrolytes reported to enhance battery safety (Sandia National Labs developed LiF/ABA salt in EC:EMC and NOHMs developed electrolyte solution containing an ionic-liquid co-solvent) were cycled to evaluate capacity loss (left). The SNL electrolyte showed consistently lower capacity, while the NOHMS electrolyte showed rapid capacity fade after ~50 cycles. Both the SNL and NOHMs electrolyte had higher impedance (lower left) and lower conductivity (table) than the standard formulation.



Electrolyte Solution	Conductivity (mS/cm)
Standard LIB (1M $LiPF_6$ in 3:7 EC:EMC)	9.03
NOHMS (1M $LiPF_6$ in EC:EMC:Ionic Liquid)	6.18
SNL (1M LiFABA in 3:7 EC:EMC)	3.68



NCM523 thin-film model electrodes were cycled by cyclic voltammetry (above) in the standard electrolyte solution (A7), NOHMs electrolyte, and SNL electrolyte. NOHMs electrolyte and SNL electrolyte indicate instability with NCM523 electrode resulting in decreasing current.



XPS analysis indicates similar C1s containing phases formed on model electrodes cycled in standard electrolyte formulation and NOHMS electrolyte while SNL electrolyte showed significantly more O-C=O/C=O/-CO3 bonding (above left). In the O1s region (above middle) transition metal-oxygen bonding (TM-O) is not visible for the SNL electrolyte cycled electrode indicating a thicker interface layer. DSC analysis of the three electrolytes (above right) shows that both electrolyte reduce exothermic heat flow compared to the standard formulation.

Motivation

Novel electrolyte formulations are critical to enable the use of lithium-ion batteries (LIB) in new arenas, particularly for submarines, however these new formulations must be thoroughly vetted to ensure that performance, lifetime, and safety metrics are met. The electrode-electrolyte interface is a key determinant in all of these metrics but can be difficult to characterize due to the presence of inactive compounds in composite electrodes. Model electrodes containing only active material enable the direct characterization of the interface layer and provide valuable insight into electrolyte design.

Objective

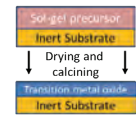
Characterize the electrode-electrolyte interface formed in various electrolytes using model electrodes to develop a fundamental understanding of electrolyte degradation mechanisms.

Background

The electrolyte used in LIB has been continuously optimized over the past three decades of commercialization, however a common aspect has been the use of flammable organic solvents. Careful selection of the solvents, salts, and additives used in LIB electrolytes has enabled continuous improvement in energy density and cycle life while the safety of LIB is still lacking compared to alternative, lower energy-density chemistries. Recently, progress has been made on electrolytes which can enable a safer LIB, specifically by replacing the salts and solvents used in conventional electrolytes with thermally stable alternatives.

Approach

- Thin-film model electrodes are cycled electrochemically using a variety of electrolytes reported to improve LIB performance. In FY20, the emphasis is on enhanced safety.



Production of thin-film electrodes by sol-gel drop coating onto an inert substrate (left).

- Cells are disassembled for analysis by X-ray Photoelectron Spectroscopy (XPS) to determine surface chemistry and thickness of interface layer.
- Physical properties of electrolytes (conductivity, thermal stability) will be measured to support comparison.

Scientific Payoff

Model electrodes provide a straight forward platform to evaluate electrode-electrolyte interfaces. Data generated from this approach will be shared with the research community in the form of peer-reviewed journal publications and conference presentations.

Fundamental Roles of Biostabilized Sediments in Ballast Tanks

ILIR, Year 1/3

Principal Investigator

Rachel Jacobs, M.S.

Rachel Jacobs

Ms. Jacobs is a Chemical Engineer for the Liquid Waste Management Branch where she has been a project engineer for both the Non-oily Wastewater and Ballast Water groups. She received her undergraduate degrees from University of Maryland at College Park. Her graduate degrees are from Johns Hopkins University and George Washington University. She balances time between basic/applied research and general system test and evaluation. Recently, she has focused on integrating ballast water systems onboard U.S. Navy ships as well as in the development of regulations for Armed Forces vessels to manage ballast water and other liquid discharges.

Associate Investigators

Paisan Atsavapranee, Ph.D.

Paisan Atsavapranee

Dr. Atsavapranee is an engineer in the Submarine Maneuvering and Control Division (Code 86), were he covers projects focused on submarine hydrodynamics, surface-ship seakeeping and Navy environmental issues. He received his Ph.D. in experimental fluid mechanics from the University of California at San Diego.

Jared Church , Ph.D.

Jared Church

Dr. Jared K. Church is a Postdoctoral Fellow in the Environmental Engineering, Science and Technology Branch (C/633) where he has been working on projects aimed at understanding and treating oily wastewater. Jared received his undergraduate degree in Biochemistry from the University of South Florida and his Ph.D. in Environmental Engineering from the University of Central Florida. Jared's dissertation research focused on developing electrochemical sensors for understanding biofilm processes in wastewater treatment. This includes more than 5 years of experience in cultivating, characterizing, and modeling biofilm growth and nutrient uptake rates.

Demosthenes George, B.S.

Demosthenes George

Mr. George is a mechanical engineer in the Computation Analysis and Design Branch (Code 871), where he covers projects focused on computational fluid dynamics predictions for submarines and computer-aided design (CAD) modeling for submarines and surface ships. He received his B.S. in Mechanical Engineering from the University of Maryland, College Park.

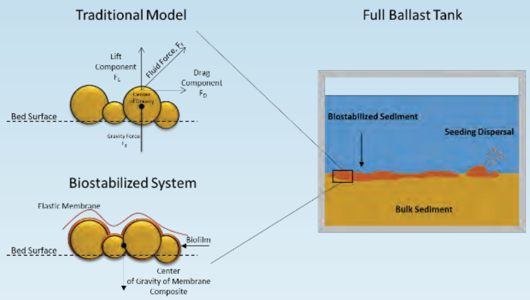
Wesley Wilson, M.S.

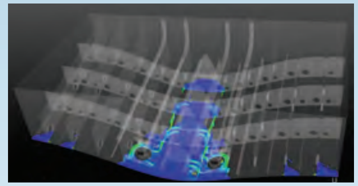
Wesley Wilson

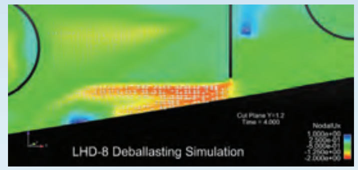
Mr. Wilson is a mechanical engineer in the Computational Analysis and Design Branch. He received a BS from West Virginia Wesleyan College and an MS from West Virginia University, where his research area involved computational fluid dynamics for liquid-liquid flows in support of compensated fuel/ballast systems. His expertise includes computational fluid dynamics predictions for surface ships, submarines, and other marine systems, including environmental quality issues related to ballast water. Mr. Wilson is also the Hydrodynamics Lead for the CREATE-Ships Program, as well as the NSWC Carderock Division Naval Architecture and Engineering Department Hydro colloquium chair.

Results/Achievements/Future Work/Recommendations

Sediment transport models:



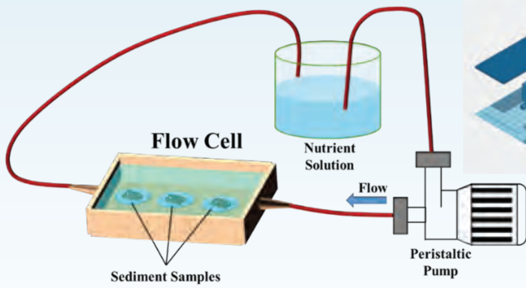


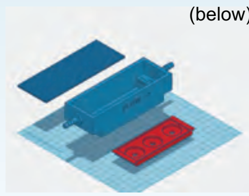


Water entrapment in ballast tanks (above)

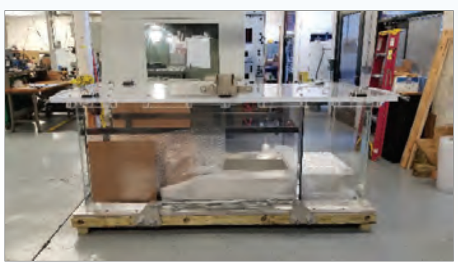
Scouring through ballast tank infrastructure (below)

Bench-scale flow cells for initial biofilm generation





Model tank and baffles at NSWCCD BWRL



Note: Experiments on hold since March 2020 due to COVID-19

Workforce Development:

Master's degree: Systems Engineering University of Maryland (in progress)

Purpose/Motivation/ Objective

Based on NSWCCD foundational knowledge of sediment in shipboard ballast tanks and the role it has in aiding transfer of Aquatic Nuisance Species (ANS) between ballasting locations, it has become apparent that the current simplified assumptions of sediment behavior are insufficient to describe sediment transfer. It is hypothesized that the presence of biofilms on ballast tank sediments changes the hydrodynamic behavior of sediments found within those tanks while also potentially enhancing the release of entrained organisms into the ballast water column. The goal of the project is to generate biofilms and analyze flow pattern changes and bacterial release compared to clean sediments both on a bench-scale and in a ¼-scale model ballast tank to gain a basic understanding of biostabilized sediment.

Background

Sediment movement is typically modeled with the assumption that particles act as perfect spheres. However, this traditional model ignores the importance of biofilms in causing individual sand grains to act as a cohesive unit, a process called biostabilization. Understanding the relationship between biofilms and sediments is particularly important in ballast tanks where organism concentration is regulated to mitigate the spread of ANS. Sediments can protect bacteria from disinfection methods such as ultraviolet radiation, and harbor and support microbial communities within ballast tanks.

Procedure/Set-Up/ Approach

Y1: Establish biofilm growth laboratory and inoculate/cultivate native biofilm. Prepare for scouring experiments in Ballast Water Research Laboratory (BWRL) with both clean and biostabilized sediments

Y2: Continue scouring experiments; perform ballast-deballast tests with variable cycling times and flow rates

Y3: Complete experiments; process and analyze data including transfer for CFD model validation

Applications/Pay-off Technical/Scientific

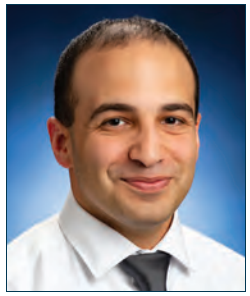
Characterizing, understanding, and modeling the role of biostabilized sediments on the seeding of bacteria into ballast tanks will stand as a major contribution to both the scientific community and the Navy. This basic research project will provide information on the movement of biostabilized sediments that will be used to update and validate a CFD model. The refined CFD model will provide insights into the multi-million dollar design of ballast water treatment solutions into U.S. Navy vessels. Additionally, the project will support the NSWCCD 5-year S&T strategy to develop a targeted approach to ballast water management, design, and technology integration on Navy Ships.

Granular Dynamically Strengthened Pressure Structures

ILIR, Year 2/3

Principal Investigator

H. John Nasrin, M.S.


John Nasrin

Mr. Nasrin is a mechanical engineer in the Submarine Structures and Propulsors Branch (Code 652), where he supports projects focusing on fluid-structure interaction, propeller structures, and collapse analysis of undersea vehicles.

He holds a B.S. degree in Mechanical Engineering from the University of Maryland, College Park and is currently pursuing his master's degree at the same institution.

He has more than eight years experience in structural engineering, has co-authored three technical papers, and is a member of the American Institute of Aeronautics and Astronautics (AIAA).

Accomplishments

- Patent application: "Anti-Magnetic Rheological Fluid Stiffened Structure" Navy case 109,583
- Two reports submitted for Distribution-A approval
- Shear-Thickening Fluid Augmented Structural Strength
- Surveys past and present research regarding shear-thickening fluids and particle packing
- References test results to discuss how they can be used for enhancing the collapse strength of cylindrical shells
- Expanded Particulate-Filled Container Results
- In-depth discussion of test results and the load carrying capability of particulate-filled thin-wall containers.

Technical Payoffs

- Computation capability to assess granular behavior in the presence of non-Newtonian fluids. There are also biological analogues for such a response.
- Define granular-supported structures for dynamic instability and stiffening with shear-thickening and magneto-rheological fluid
- Provide a design point for utilizing such elements in future Naval applications, i. e. structures, sound damping/radiation suppression, thermal and reduced cost construction

Associate Investigators

Hiren Balsara, Ph.D.


Hiren Balsara

Dr. Balsara is a mechanical engineer in the Structural Composites Branch (Code 655), where he covers projects focusing on numerical modeling of composite patch repair, the DDG-1000 Sonar Dome, the Columbia Bow Dome, and the underwater impact of unmanned underwater vehicles (UUV).

He holds an M.S. degree in Mechanical Engineering from the University of Maryland, Baltimore County and is currently pursuing a PhD in Mechanical Engineering at the University of Maryland, College Park.

He has 3 years of experience in mechanical engineering focused on high fidelity numerical modeling. He has authored one technical paper and two Carderock technical reports. He has been a member of the Society of Automotive Engineers (SAE) for over 8 years.

External Collaboration

Lawrence Livermore National Laboratory

Prof. Abram H. Clark, Naval Post Graduate School

Workforce Development

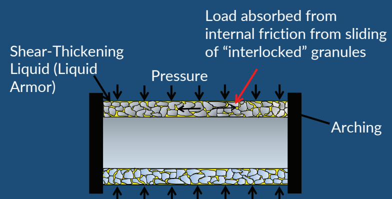
H. John Nasrin, University of Maryland, College Park

Hiren Balsara, University of Maryland, College Park

Potential Sponsor

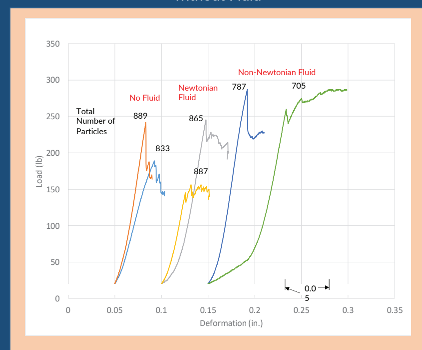
Dr. Roshdy Barsoum (ONR 332)

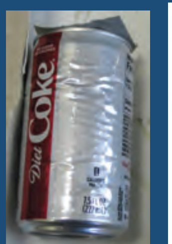
Granular packing with shear thickening fluid develops a passive "smart structure" that dynamically strengthens when under dynamic load



Granular Shell with Shear-Thickening Liquid

Load-Deformation Curves for Equal-Size Containers with and without Fluid



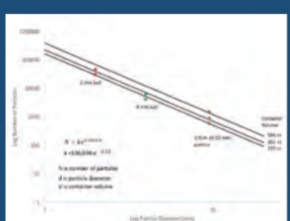


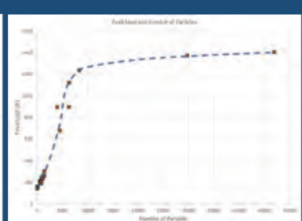
Test Specimen

Finite Element Model (FEM)

FEM Section Cut

Container





Peak Load vs Number of Particles

Motivation

Investigate granular dynamic strengthening of structural materials by use of shear thickening or magneto-rheological fluid to include highly magnetized granules and magnetized shells

Objective

Develop a knowledge base of a novel family of materials: shear thickening (liquid armor) and magneto-rheological fluids, mechanistic behavior and benefits to properties with ultra-strength shells

Approach

- Explore aspects of particle-filled container response
- Initial use of off-the-shelf recyclable beverage containers
- Different particulates along with shear thickening fluid were investigated
- Transition results to thicker-wall design

Results

- Shear thickening fluid increased the threshold for structural buckling
- Role improved structural failure and further use in shock and impact absorbers
- Buckling appears to strongly depend on the number of particles in a container
- Macro-scale physics based model aligns with initial test results

Path Forward

- A unit cell model for the solid particles to focus on granular interactions at the continuum scale
- Develop multi-scale modeling approach to capture granular behavior while suspended in fluid

Risks

- No prior work extended to non-Newtonian particle-fluid interactions
  - Effects of particle packing pursued first, with non-Newtonian fluid analyzed after packing effect on material behavior understood
- Limited work has been pursued in this area
  - Feasible to start with materials that are best characterized in the literature
- No prior work in predicting structures with shear thickening support at the point of instability, requires trial and error effort to establish boundaries and parameters for such structures
  - Simple structures to include cylinders and sandwich configuration for numerical assessments

High Power Laser Phenomena for Underwater Electric Field Measurements ILIR, Year 1/1

Principal Investigator

Henry Elder

Mr. Henry F. Elder received his B.S. degrees in Physics and Aerospace Engineering from the University of Maryland, College Park in 2012. Since then he has been working as a physicist at the Naval Surface Warfare Center, Carderock Division, in the Underwater Electromagnetic Signatures division (Code 75), where he has become an expert on measuring and modeling underwater electromagnetic phenomena. While working at Carderock, Henry completed his M.S. in Applied Physics from Johns Hopkins University and has matriculated at the University of Maryland, College Park for a PhD in Physics.

S&T Products

FY21 ILIR Proposal

Workforce Development

Supporting PhD research of Henry Elder
(Physics, University of Maryland, College Park)

Technical Pay-off

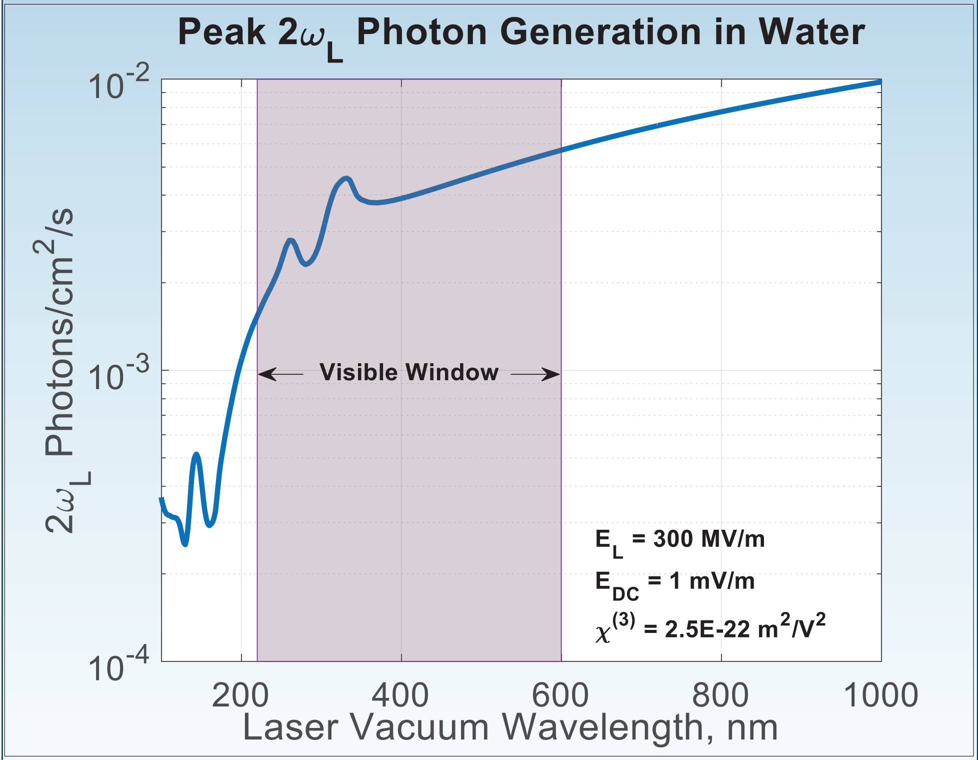
A fundamentally unique UEF sensing scheme would be realized, allowing for more robust signature measurement ranges, cathodic protection systems.

Transition

- OPNAV
- PEO SUBS
- PEO SHIPS

Collaborations

Dr. Phillip Sprangle, Professor of Electrical & Computer Engineering and Physics, University of Maryland, College Park



This work lead to an FY21 ILIR project for the investigation of an underwater electromagnetic tracking algorithm, and a potential FY22 proposal for characterizing the propagation of lasers fields with orbital angular momentum through turbulence and Kerr nonlinear focusing.

Motivation

The current favored method for measuring underwater electric fields (UEF) is by taking a voltage difference across half-cell electrodes. The electrodes operate by chemically interacting with ionized salts in the water; but undesirable compounds – e.g. sulfur – can bind to the cells, degrading or even quenching their measurement ability. An alternate measurement scheme which does not require a chemical interface with the water could prove to be more robust, saving the Navy money and time on sensor replacements.

For this library study, the Kerr effect in the relevant parameter space is investigated for its potential use as an low frequency electric field sensing mechanism.

Background

With a sufficiently intense electric field and/or nonlinear electric susceptibility, wave mixing processes can be generated due to the polarization response of the

$$\frac{1}{\epsilon_o}\vec{P} = \chi^{(1)}\vec{E} + \chi^{(3)}\vec{E}\vec{E}\vec{E} + \cdots$$

Using an intense laser field E_L as a seed, an ambient field level E_{DC} will be mixed in to the second harmonic field. If the second harmonic field is strong enough for the appropriate parameter range, it could be used as a nonchemical sensing scheme.

Approach

The relevant differential field equations are derived from Maxwell's equations, and then solved for the second harmonic component. As an initial feasibility study many simplifying assumptions are made:

- Laser field is a plane wave
- DC field is parallel to laser polarization
- Linear absorption is neglected
- No other nonlinear effects (e.g. ionization)

We then determine the intensity of the second harmonic signal with appropriate parameters for UEF sensing to gauge scheme feasibility.

Results and Future Work

Even with exceptionally generous test parameters (laser field of 300 MV/m ~ 1/100 field ionization for H2O, ambient field of 1 mV/m), Kerr effect mixing generates far too few second harmonic photons to be a useful as a UEF measurement mechanism.

Investigation of Hull Curvature and Stool Height on Control Surface Lift ILIR, Year 1/3

Principal Investigator

Michael Hughes, Ph.D.

Michael Hughes

Dr. Michael J. Hughes received his Ph.D. from MIT in 1993. He is a naval architect at NSWCCD since February 2005, currently working in the Submarine Maneuvering and Control Simulation Branch, Code 862. His work at NSWCCD has focused on the computational methods for predicting the maneuvering, dynamic stability and seakeeping performance of ships and submarines. Prior to coming to NSWCCD, he had worked at Analytical Methods, Inc. and spent a year at the Institut für Schiffbau in Hamburg, Germany with a research fellowship from the Alexander von Humboldt Foundation.

Associate Investigators

Young Shen, Ph.D.

Young Shen

Dr. Young Shen received his Ph.D. from the University of Michigan in 1970. He is currently a senior research scientist at NSWCCD with 46 years of service. His special expertise is in hydrofoil and propeller cavitation, ventilation, and erosion, scale effect on ship resistance, powering, and maneuvering in model tests and full-scale performance prediction. He has published numerous reports and 20 referred journal papers in ship hydrodynamics and he holds 19 US patents.

Pay-off

- Including the influence of hull curvature on control surface lift such as rudders and anti-roll stabilizing fins will lead to improved maneuvering predictions by simulation tools for submarines and surface ships. This will be particularly true in the preliminary design stage, where scale-model test data is not available to correlate with the predicted control surface lift.
- Improved maneuvering predictions in the early stages of design will lead to better maneuvering performance for the final design and the ability to develop new designs more rapidly

Results / Achievements

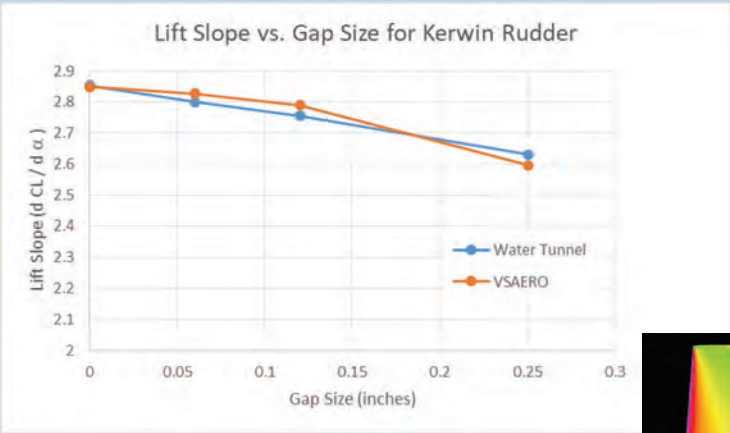
- Collection and analysis of existing experimental data
- VSAERO code modified to account for influence of gap flow
- Correlation of modified VSAERO with water tunnel data for foil with varying gaps size
- Matrix of simulations developed and some simulations performed

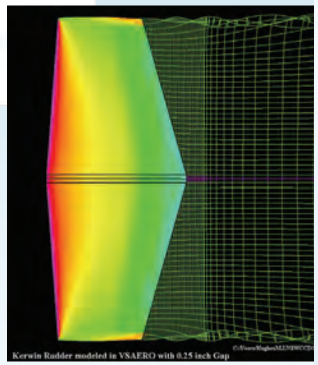
S&T Products:

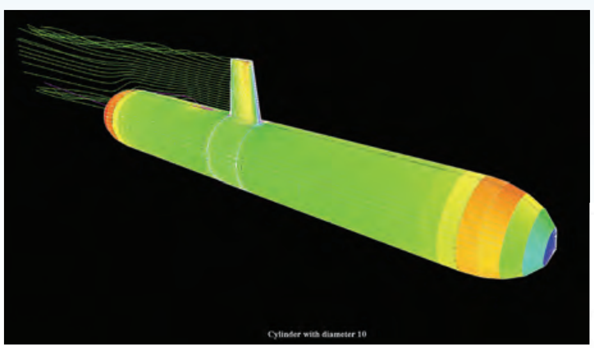
Journal article will be completed and submitted during Year 2.

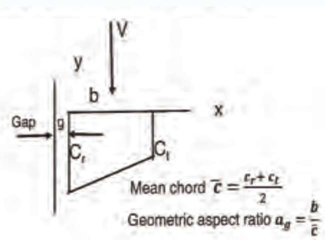
Future Customer/Transition

- Methods will be incorporated in Submarine Maneuvering and Control Simulation (MCSIM, Code 862) and Seakeeping tools such as Tempest used by Code 851









Objective

- Real-time maneuvering tools use simple expressions for lift and drag on rudders and other control surfaces
- Current methods rely on empirical tuning and do not account for:
  - Gap between control surface and hull
  - Hull curvature
  - Stool
- Overall goal is to develop corrections to account for gap size, hull curvature and stool height that can be applied to the simple methods for computing control surface forces in maneuvering codes

Background

- The lift on a rudder or other control surface is influenced by the presence of the hull.
- The "wall effect" can be included using an image or doubling of the effective aspect ratio, but the "wall effect" is reduced by the gap between the hull and the lifting surface and by hull curvature.
- TEMPEST: Dynamic Stability / Maneuvering in Waves
  - Rudder forces computed using low aspect ratio wing theory
  - Computes angle of attack including hull straightening, wave velocities, boundary layer, propeller slipstream, ship motions, etc.
  - User specifies effective aspect ratio to include hull wall effect
- MCSIM: Maneuvering and Control SIMulation for submarines
  - Forces on rudders and planes computed using lifting line theory
  - Image used to include hull wall effect
  - Currently no model for gap between appendage and hull

Approach

- Gather and analyze existing experimental data
- Determine proper normalization of gap size and curvature
- Develop a numerical tool that can perform a large number of simulations on rudders to examine a wide range of hull curvature, stool height and gap size.
- Correlate the numerical tool with existing model test data
- Perform a large number of simulations with the numerical tool, systematically varying hull curvature, gap size and stool height.
- Develop expressions to account for the influence of hull curvature, gap size and stool height that can be applied to low aspect

Magnon Interconnect System – Modeling and Characterization

ILIR, Year 3/3

Principal Investigator

C. Arthur Nwokoye, Ph.D.

C. Arthur Nwokoye

Dr. Nwokoye is an electrical engineer in the Radio Frequency (RF) Technology Development Branch (Code 744), where he covers projects focused on electromagnetic composite materials, applied magnetics and metamaterials.

He has B.S. and Ph.D. degrees in Electrical Engineering from the George Washington University, and an M.S. degree in Electrical Engineering from Johns Hopkins University. He has 11 years of experience in ferromagnetic resonance measurement systems, low temperature magneto-optical measurement systems, antenna systems design, radar systems, and electronic warfare analysis.

He is the author of seven peer-reviewed technical papers and is the recipient of the Twelfth Annual NAWCAD Commanders Award and the 2014 BEYA's Modern Day Technology Leader Award. He is also a member of the American Physical Society (APS), the Institute of Electrical and Electronics Engineers (IEEE), and the Association of Old Crows (AOC).

Applications/Payoffs - Technical amd Scientific

- Technical/scientific knowledge gained: A comprehensive understanding of the theory and experimentation of the excitation, propagation, and detection of magnons.
- Benefit to the warfighter: Magnons are known to be electrically neutral and, therefore, interact weakly with the surroundings. Thus developing magnon-based communication networks instead of the current electron-based network systems will provide the Navy warfighter with network systems that are robust to address current and future needs.

Associate Investigators

Jin-Hyeong Yoo, Ph.D.

Jin-Hyeong Yoo

Dr. Yoo is a Mechanical Engineer in the Physical Metallurgy and Fire Performance branch, (Code 612), where he covers projects focused on application development using magnetostrictive materials for the Navy.

He holds a B.S., M.S. and Ph.D. degrees in Mechanical Engineering from Yonsei University (South Korea). He has 5 years of experience working with the US Army and 3 years of experience working with the US Navy.

He has co-authored over 29 journal articles and contributed over 55 papers to international conference proceedings, and has two patent applications in process. He is a member of the American Society of Mechanical Engineers (ASME, 2005-2020).

Nicholas Jones, Ph.D.

Nicholas Jones

Dr. Jones is a materials engineer in the Physical Metallurgy and Fire Performance Branch (Code 612), where he covers projects focused on magnetostrictive materials, multifunctional materials, high entropy alloys, and aluminum alloy kinetics.

He received his B.S., M.S., and Ph.D. degrees in Materials Science and Engineering from Carnegie Mellon University, receiving the Department of Defense (DoD) Science, Mathematics, and Research for Transformation (SMART) Scholarship for the Ph.D.

He has seven years of experience working in magnetic materials and aluminum alloys for the Navy, and has co-authored 25 journal articles in the fields of magnetic materials and crystal growth and 6 Technical Reports. He is a member of the IEEE Magnetics Society and the Minerals, Metals, and Materials Society (TMS), and has two patent applications in process.

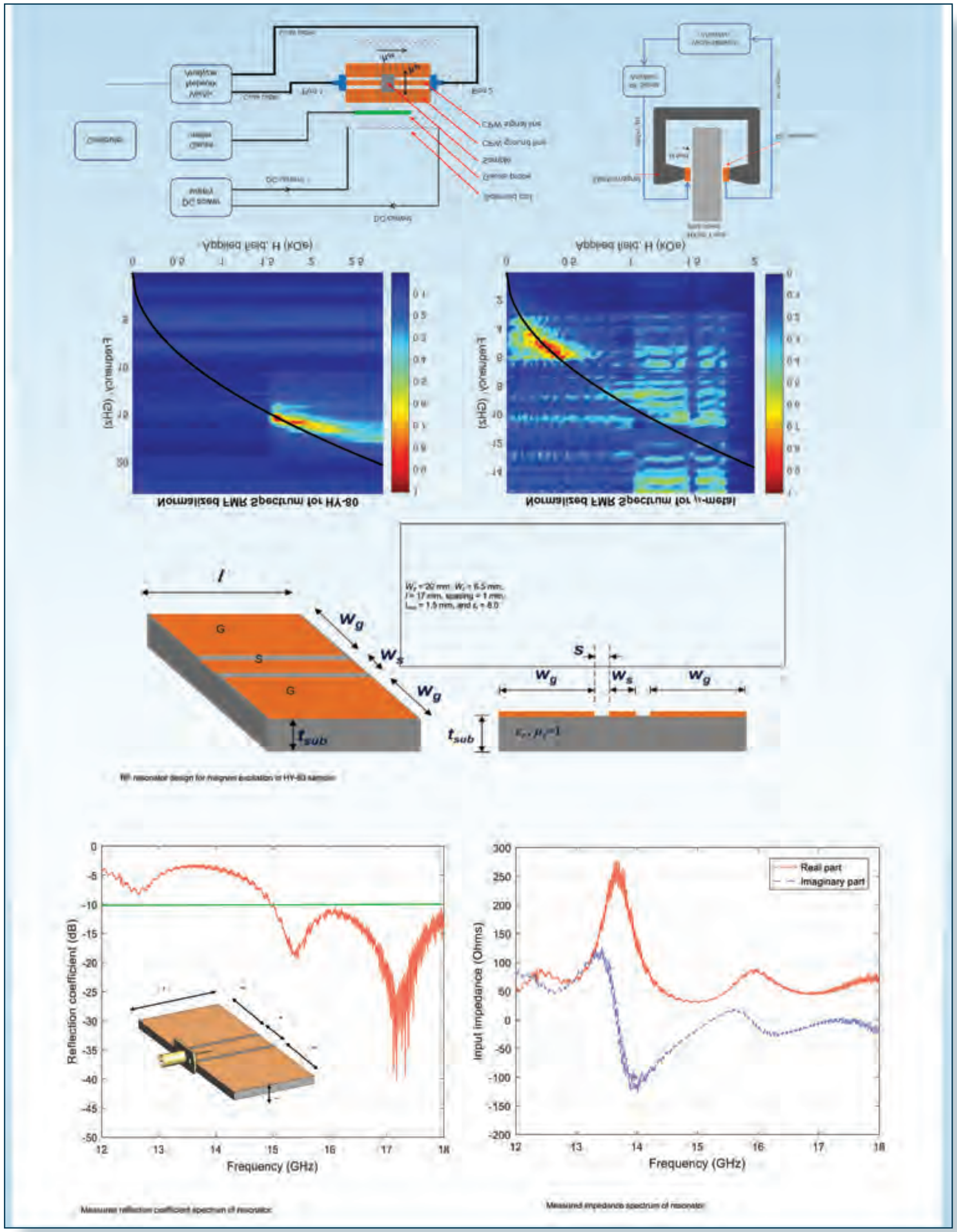
External Collaboration

Dr. Michael Lowry - NSWC Dahlgren
Mr. Randolph Brent - Morgan State University
Prof. JinjieLiu - Delaware State University

NAVSEA WARFARE CENTERS Dahlgren

MORGAN STATE UNIVERSITY

DELAWARE STATE UNIVERSITY DOVER



Object

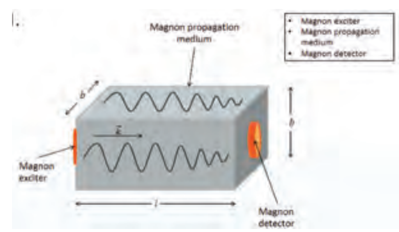
Understanding the behavior of magnon excitation, propagation, and detection in a magnetic alloy medium.

Utilize the results of the study to design, fabricate and test a prototype magnon interconnect system. The system will be tested to address an appropriate US Navy communication need.

Background

Magnons are energy quanta of collective wave excitations in a magnetically ordered ensemble of magnetic moments.

The magnon interconnect system will consist of a magnon exciter, detector and a magnetic medium of propagation as depicted below.



Magnons are considered as bosons and the amount of magnons in a state is modeled using the Bose-Einstein distribution. Their dynamics are described by Landau-Lifshitz-Gilbert equation.

Approach

- Understand the wave nature of magnons by investigating the relationship between the magnon propagation constant, group velocity, phase velocity and attenuation constant with the medium's magnetic properties.
- Derive the magnetostatic modes from the magnon dispersion relation.
- Measure magnetic characterization on the chosen ferromagnetic samples.
- Extract the magnon frequency for each studied sample from magnetic measurements data via empirical modeling.
- Design and build a VNAFMR spectrometer to measure the broadband FMR spectrum and compare measured results with empirical modeling.

Results

The results indicate that the FMR frequency (magnon frequency) of the HY-80 sample ranges from approximately 15 GHz to 18 GHz when the DC bias magnetic field ranges from 1500 Oe to 2800 Oe. The FMR frequency (magnon) of the µ-metal ranges from approx. 4 GHz to 6 GHz for DC bias magnetic field ranging from 100 Oe to 500 Oe. This finding concurs with the trend of the predicted FMR spectrum from the empirical modeling in the region of sample saturation.

Nonlinear Multiphysics Based Acoustic Metamaterials

ILIR, Year 3/3

Principal Investigator

Alexey Titovich, Ph.D.

Alexey Titovich

Dr. Titovich is a mechanical engineer in the Structural Acoustics and Target Strength Branch (Code 722), where he covers projects focused on acoustic metamaterials for underwater applications, encompassing structural acoustics, sonic crystals, phononic crystals, gradient index devices, resonance-based devices, and nonlinear non-reciprocity, as well as other extraordinary wave bearing materials.

He holds B.S., M.S., and Ph.D. degrees in Mechanical and Aerospace Engineering from Rutgers University.

He has five years of experience, has co-authored 27 technical papers, and been granted one patent with two others filed. He is a member of the Acoustical Society of America (ASA), and is a part of the Structural Acoustic and Vibration Technical Committee.

Associate Investigator

Jason Smoker, Ph.D.

Jason Smoker

Dr. Smoker is a mechanical engineer in the Structural Acoustics and Target Strength Branch (Code 722), where he covers projects focused on the design, planning, and execution of scale model testing, which supports Research and Development (R&D) and Science and Technology (S&T) efforts as well as structural acoustic investigations for future ship concepts.

He holds an M.S. degree in Control Systems and a Ph.D. in the area of Active Acoustic MetaMaterials, both from the University of Maryland, College Park. He has seven years of experience with the U.S. Navy and is the recipient of the 2015 NAVSEA Commander's Award for Innovation.

He has been a member of the Acoustical Society of America (ASA) since 2011 as well as the American Society of Mechanical Engineers (ASME) since 2001.

Approach

This project focuses on non-natural nonlinearities through two thrusts. The first thrust centers around material geometry-based nonlinearities (i.e. cracks).

The second, closely related thrust of this study addresses the fact that acoustic metamaterials have struggled to keep up with practical realizations which have been found in the Electro-Magnetic (EM) domain due to a lack of inherent coupling. Electro-acoustic coupling can be leveraged to design desired nonlinear properties.

The analysis includes:

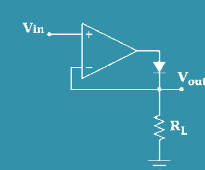
- Analytical Predictions
- Numerical Analysis
- Finite Element Simulations
- Experimental Verification
  - Nonlinear acoustical properties (air)
  - Unique wave propagation in a periodic array of such discontinuities (air)
  - An in-water impedance tube test showing transmission and reflection spectra

Piezo transducers exhibit electro-mechanical coupling through the strain as:

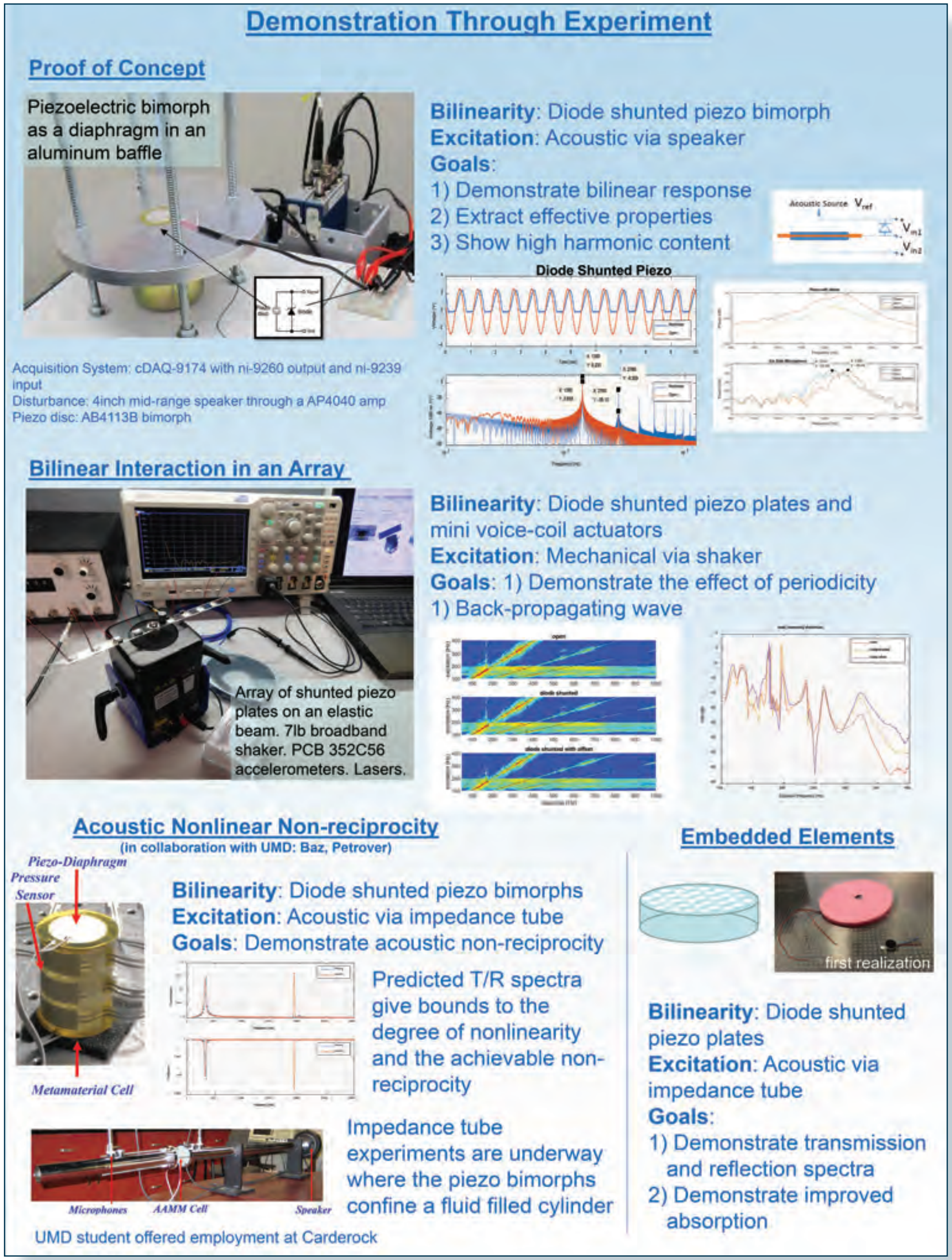
$$S_1 = s_{11}^D T_1 + g_{31} D_3$$

Throughout the course of this study the electrical nonlinearity of a diode was used to affect acoustic properties.

However, we can greatly increase the bandwidth of the non-linear regime by eliminating the forward voltage limitation of basic diodes with the "super-diode" circuit below.



This precision rectifier design will yield a truly bi-linear material. In order to realize this benefit, a very low power parasitic DC voltage source would have to be provided.

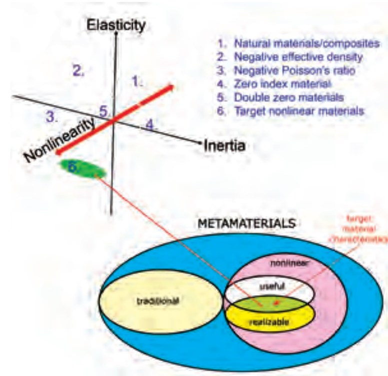


Objectives

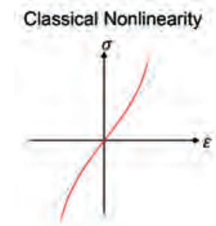
Design a novel metamaterial utilizing amplitude independent nonlinear dynamics to control and/or dissipate incident acoustic waves. Investigate such materials in the context of high energy impulse loading as well as nonlinear non-reciprocity.

Background

Though the field of acoustic metamaterials has existed for over a decade, most designs have focused on linear dynamics to achieve desired effects. At this point, the search for new metamaterials by expanding the parameter space of the linear acoustic state variables (density and bulk modulus) is near saturation, we believe it can be expanded by considering highly nonlinear materials.

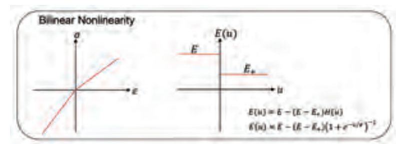


Amplitude Independent Nonlinearity



Unlike classical nonlinearities, a bilinear material exhibits different properties between compression and rarefaction.

Cracks exhibit this discontinuous behavior.



Technical Pay-offs

A new class of metamaterials that can be applied to

- Energy spectra diffusion
- Non-reciprocal waveguides
- Novel sensor and actuators
- Metacrack: diode shunted piezo used for NDE calibration
- Such materials can be self diagnosing due to the propagating transitional impulse
- Stretch goal: Material wise convolution through the nonlinear response

Organizational Technical Health As A Complex System

ILIR, Year 1/3

Principal Investigator

Judy Conley, D.Sc.

Judy Conley

Dr. Conley is the Science & Technology (S&T) coordinator for the Platform Integrity Department, and assists the Director of Research to guide his Laboratory Directed Research and Development (LDRD) portfolio.

In addition, she also assists the Director of Innovation, in facilitating a culture of innovation via guiding the Technical Director Innovation Challenge (TDIC) effort and Human Centered Design (HCD) practices, as well as the Director of the Disruptive Technologies Laboratory (DTL) in exploration of non-traditional product areas through assembly of ad-hoc interdisciplinary teams to explore the technical potential and naval relevance of new technology.

Dr. Conley received a Doctorate of Science and Masters of Science in Structural Engineering each from The George Washington University in 1997 and 1985, respectively. Her Bachelors of Science degree in Civil Engineering (Structures) is from Michigan State University in 1982. Dr. Conley has been employed by NSWC Carderock Division from 1982 until the present.

Associate Investigator

Jack Price, Ph.D.

Jack Price

Dr. Price is the Director of Research for the NSWC Carderock Division. He provides vision for the role of Science and Technology (S&T) in developing future Maritime needs. He is the Division's lead for the oversight, planning, and execution of the internal directed research program and the Division Technical POC for S&T funding agencies (ONR, DARPA, etc.). In addition, he is responsible for overall S&T strategic planning.

Dr. Price is a 1976 cum laude graduate from Norwich University with BS degrees in Physics and Mathematics. In 1978, he earned a MS degree in Space-Plasma Physics from the University of Kansas (KU), and in 1986 he earned a PhD from the University of North Texas specializing in Atomic Collision Physics. Dr. Price was Adjunct Faculty at Montgomery College, Germantown, MD for 20 years and an Adjunct Professor at the American University Physics Department, Washington, DC. He has served on doctoral review panels for students at George Washington University and the Catholic University of America.

Future work

Obtaining interview results from Operations Departments (Comptroller, Acquisition & Contracting, Chief Information Officer, Legal, Security, Facilities) as well as Technical Departments. Looking to see common complexities arising from constraints and unseen opportunities.

S&T Products:

- Tasking Statement: J. Price; "Organizational Technical Health as a Complex System"
- Internal Report: J. Conley/G. Jensen; "Technical Health: Understanding, Assessing, and Intervening in The System: A Complexity Aware, Design Driven, Empirical Approach"
- Working Paper: J. Conley/G. Jensen; "A Perspective on Technical Health"
- J. Liebowitz; "Knowledge Management in the TIC/Library of a Navy Lab" International Conference on Knowledge management, Durham, NC; DEC 2020
- 5. J. Liebowitz/J. Price; Seminar & Briefing "Metrics for the Scientific Health of NSWC-CD"

Future Customer/Transition

- NSWC Carderock BoD Recommended organizational changes to improve Knowledge Management at Carderock
- Three seminars to NSWC Carderock management on Knowledge Management and Metrics
- Improved Portfolio balance to maintain a healthy Science and Technology progression and application.

External Collaboration

Consulting Panel: Dr. James Roche (DAU), Ms. Danielle M Paynter (NSWC CD), Mr. Brian L Fuller (NSWC CD), Mr. Garth Jensen (Director of Innovation, NSWC CD)

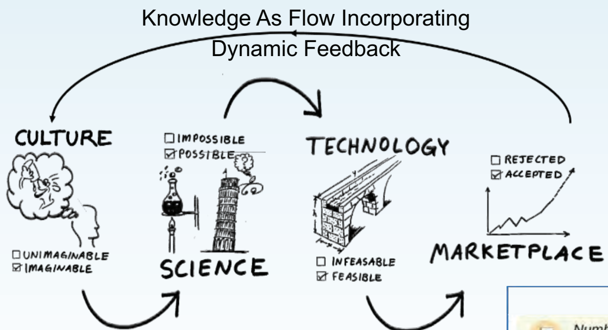
Results/Achievements/Future Work/Recommendations

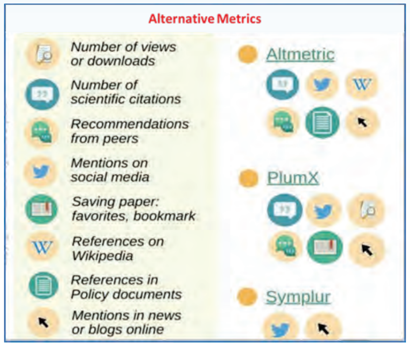
Tasking statement Framing Questions:

- **Define or investigate meaning of key words in Tasking Statement:**
  Research, Laboratory, Value, Stakeholders, Knowledge, Metrics, Health, Investment
- **Relate Value for different Stakeholders:**
  Internal: Parent HQ, Director of Research, Leadership (TD, Dept. Heads, etc.), First-line Management, Rank & File or Scientists & Engineers
  External: ONR, DARPA, ASN/DASN, Prof. Societies,

Proposed Five Metaphorical Frameworks as "Complexity Aware" Ways of Understanding and Making Sense of Technical Health:

- **Collective Intelligence/Collective Knowledge as an Emergent Property**
- **Knowledge as Flow**
- **Adapting or Extending the "Atlas of Economic Complexity" to Carderock**
- **A System of "Organized Complexity"**
- **A Portfolio Based Approach**





Workforce Development:

Summer Faculty: Dr. J. Liebowitz (Harrisburg Univ. of Science & Tech.) "Knowledge Management and Tech Health Metrics"

Purpose, Motivation and Objective

Examine the NR&DE lab as a complex system to understand the nature of the laboratory and provide a basis for future work to extract the proper metrics for determining the laboratory's science and technology health. Your results should document required definitions of important terms, concepts of laboratory operations, analysis of those things which may be hindrances or enablers, and recommendations for actions and further research.

Background

With the advent of advanced information systems and data analytics, coupled with near instantaneous speed of communication, dramatic advances in computational capability, ubiquitous environmental sensors, massive compilation and archiving of varieties of data, and the democratization of all the above along with the vast infusion of funding from all sources, the Federal Government Laboratory faces challenges to its relevance and existence. Government laboratories are persistently being asked to demonstrate value and quickly provide products to the consumer, customers, sponsors, clients, or stakeholders. NR&DE labs, such as NSWC Carderock, are told to justify receiving research funds, answering: "What have you transitioned to the Warfighter, lately?"

These justifications has spurred a surge in the demand for metrics for measuring that value. Laboratory knowledge stewards need to incorporate the capability and health of their respective organization, which includes the lab's organic structures: facilities, processes, and personnel and its partners, funding agents, stakeholders, management, contractors, and collaborators.

Procedure, Set-Up and Approach

Initially set up as a four phase study:

1. Problem Exploration Phase
2. Research Phase
3. Consolidation Phase
4. Final Report

Research complex adaptive systems from other disciplines (organization science, etc.) and establish analogies.

Using literature sources from ecology and networks, conduct thought experiments to probe the relationships, constraints, enablers, and structure of the NSWCCD for characteristics that demonstrate or do not demonstrate complexity.

Applications/Pay-off/ Deliverables

Study on Alternative Metrics for measuring Science and Technical productivity (Value, Health) briefed to Leadership.

Properties of FeCoNiCrX-based High-Entropy Alloys

ILIR, Year 3/3

Principal Investigator

Nicholas Jones, Ph.D.

Nicholas Jones

Dr. Jones is a materials engineer in the Physical Metallurgy and Fire Performance Branch (Code 612), where he covers projects focused on magnetostrictive materials, multifunctional materials, high entropy alloys, and aluminum alloy kinetics.

He received his B.S., M.S., and Ph.D. degrees in Materials Science and Engineering from Carnegie Mellon University, receiving the Department of Defense (DoD) Science, Mathematics, and Research for Transformation (SMART) Scholarship for the Ph.D.

He has seven years of experience working in magnetic materials and aluminum alloys for the Navy, and has co-authored 25 journal articles in the fields of magnetic materials and crystal growth and 6 Technical Reports. He is a member of the IEEE Magnetics Society and the Minerals, Metals, and Materials Society (TMS), and has two patent applications in process.

Associate Investigators

Suok-Min Na, Ph.D.

Suok-Min Na

Dr. Na is a materials engineer in the Physical Metallurgy and Fire Performance branch (Code 612), where he covers projects focused on high entropy alloy design, magnetostrictive materials, and thermomechanical processing.

He received his B.S., M.S., and Ph.D. degrees in Metallurgical Engineering from Sungkyunkwan University (South Korea). He has 16 years of experience in materials engineering, has co-authored 65 journal articles and conference proceedings, and filed a patent. He is a member of the Institute of Electrical and Electronics Engineers (IEEE) Magnetics Society and the Korean Magnetics Society.

Jin-HyeongYoo, Ph.D.

Jin-HyeongYoo

Dr. Yoo is a Mechanical Engineer in the Physical Metallurgy and Fire Performance branch, (Code 612), where he covers projects focused on application development using magnetostrictive materials for the Navy.

He holds a B.S., M.S. and Ph.D. degrees in Mechanical Engineering from Yonsei University (South Korea). He has 5 years of experience working with the US Army and 3 years of experience working with the US Navy. He has co-authored over 29 journal articles and contributed over 55 papers to international conference proceedings, and has two patent applications in process. He is a member of the American Society of Mechanical Engineers (ASME, 2005-2020).

Paul K. Lambert ,Ph.D.

Paul Lambert

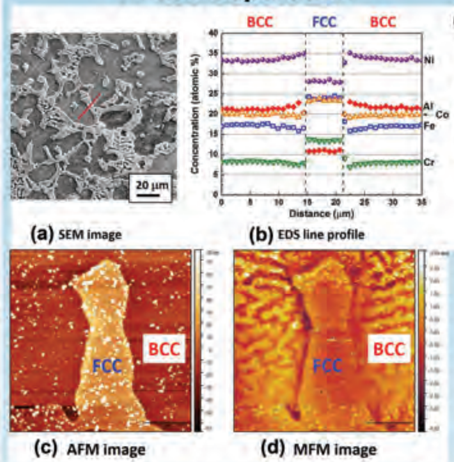
Dr. Lambert is a materials engineer for the Physical Metallurgy and Fire Performance Branch (Code 612), where he covers projects focused on characterizing the processing/microstructure/property relations of iron-based alloys, advanced structural steels, magnetostrictive materials, and high-entropy alloys.

He holds B.S. and M.S. degrees in Materials Science and Engineering from the University of Maryland, College Park, and a Ph.D. in Materials Science and Engineering from Johns Hopkins University. He has over 7 years of experience working on naval-relevant metallurgical engineering. He has co-authored 3 journal articles in the field of the mechanical behavior of materials at high strain rates and 3 articles in the field of magnetic materials.

External Collaboration

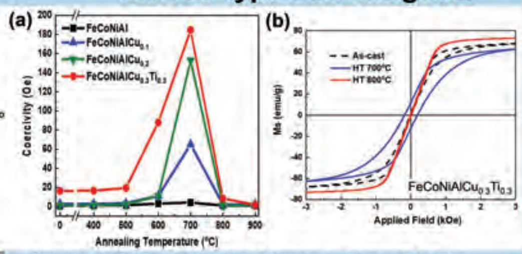
Prof. Gabriela Petculescu - University of Louisiana at Lafayette
Dr. Todd Henry - Army Research Laboratory
Drs. HyunsooKim and Jung-JinPark - University of Maryland, College Park

Phase Separation



Correlation between (a) microstructure, (b) composition and (c, d) magnetism in as-cast $FeCoNi_{1.5}Cr_{0.5}Al$ HEAs; the FCC phase (Fe, Co, Cr-rich) is paramagnetic, while the BCC phase (Ni, Al-rich) is ferromagnetic.

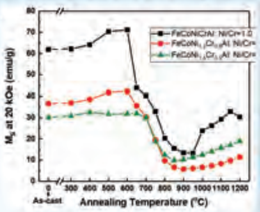
AlNiCo-type Hard Magnets



(a) Coercivity FeCoNiAl-base HEAs with the addition of Cu and Ti as a function of annealing temperature. These changes are associated with phase separation due to spinodal decomposition.

(b) Magnetic hysteresis loops of $FeCoNiAlCu_{0.3}Ti_{0.3}$ in the as-cast and annealed states, showing a large coercivity after a 700 °C anneal, and practically anhysteretic behavior after an 800 °C anneal.

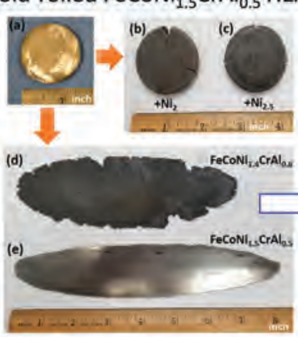
Effect of Annealing



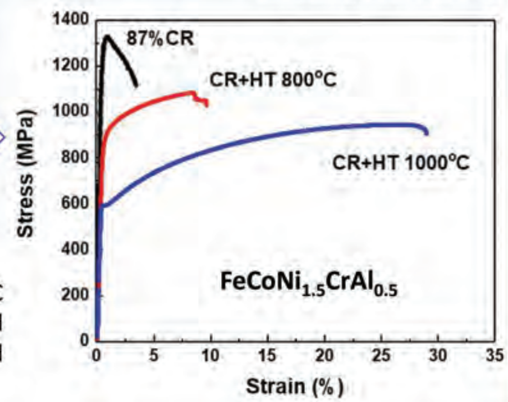
A steep decline in magnetization after annealing above 600 °C.

Mechanical Properties

Photos of (a) arc-melted button, (b)-(c) rolled $FeCoNi_2CrAl$ and $FeCoNi_{2.5}CrAl$ HEA buttons with cracks during hot rolling at 900 °C, (d) $FeCoNi_{1.4}CrAl_{0.6}$ HEA sheet hot-rolled at 900 °C, and (e) cold-rolled $FeCoNi_{1.5}CrAl_{0.5}$ HEA sheet at room temperature.



Tensile test of single-phase FCC $FeCoNi_{1.5}CrAl_{0.5}$ HEA prepared by cold rolling (CR) and subsequently heat-treated (HT) at 800 and 1000 °C, respectively.



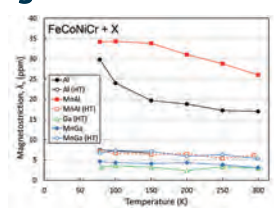
Objectives

The goal is to measure the mechanical, magnetic and corrosion properties in FeCoNiCr**X** alloys (X = Al, Mnand Ga) with small additions of boron and carbon, and to understand the mechanisms related to those property changes in light of the thermomechanical processing and the interstitial additions.

Background

Some high entropy alloys (HEAs) have been shown to exhibit superior mechanical and physical properties, including ultrahigh fracture toughness, high strength with good ductility, and significant resistance to corrosion. These alloys have also shown to be potentially useful for magnetocaloric applications (like magnetic refrigeration), spanning a large temperature range. The addition of interstitial atoms such as boron and carbon in the HEAs, however, has never been systematically investigated; these small atoms may occupy the interstitial sites and/or form nano-precipitates which could enhance mechanical strength and maintain ductility.

Magnetostriction of HEAs



Magnetically-induced strain in FeCoNiCrXHEAs measured in the as-cast and annealed conditions (800 –1,000 °C). Only the as-cast samples showed substantive isotropic magnetostriction.

Approach

- Ingots of HEAs are prepared by arc melting under a high purity argon atmosphere.
- Samples are then rolled and annealed to alter the microstructure (grain size, texture and crystallographic phases)
- Tensile specimens are cut from rolled sheet according to ASTM standard E8/E8M-16a
- Disc samples are cut from the ingot buttons to examine microstructure and magnetic properties
- Magnetic measurements are performed from 2 –1200 K using the magnetic properties measurement system (MPMS) and the vibrating sample magnetometer (VSM).
- Magnetic force microscopy (MFM) measurement are performed to verify magnetism for each phase.
- Magnetically-induced strain (magnetostriction) is measured using strain gages

Technical and Scientific Achievements

- Publications (1):1. AIP Advances Vol. 9, p. 035010 (2019)
- Presentations (5):Joint Intermag/ MMM 2019 Conference; The 2nd International Conference on High-Entropy Materials (ICHEM) 2018; MS&T 2018

Ring Vortex (RV) Breakdown in Propeller Crashback

ILIR, Year 2/3

Principal Investigator

Chandrasekhar Kannepalli

Chandrasekhar Kannepalli

Dr. Kannepalli, is a mechanical engineer in the Computational Analysis and Design Branch (Code 871), where he covers projects focused on large eddy simulation (LES) applied to crashback and wall-bounded flows.

He has a B.S. degree in Naval Architecture from the Indian Institute of Technology, Madras and M.S. and Ph.D. degrees in Mechanical Engineering from the University of Maryland, College Park.

He has co-authored 30 technical papers, and has over 15 years of computational fluid dynamics (CFD) experience. He is a member of the American Institute of Aeronautics and Astronautics (AIAA).

Associate Investigator

Jonathan Tu, Ph.D.

Jonathan Tu

Dr. Tu is a mechanical engineer in the Onboard Signatures and Fleet Support Branch (Code 713), where he covers projects focused on reduced-order modeling, dimensionality reduction, data science, and machine learning, researching and developing new algorithms for application to various Navy problems.

He received B.S. degrees in both Aeronautics and Astronautics and Mathematics from the University of Washington, and his Ph.D. in Mechanical and Aerospace Engineering from Princeton University.

Future Customer/Transition

Virginia Block 6 and 7; SSNX; Digital twin

External Collaboration

Prof. Mahesh Krishnan,
Univ. of Minnesota

S&T Products

Conference Paper (in preparation for FY21)

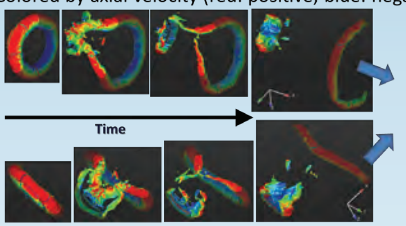
Workforce Development

Mentoring

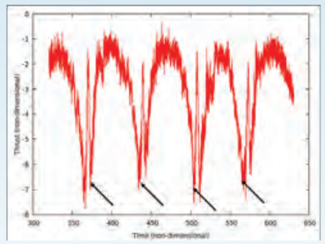
Applications and Pay-offs Technical and Scientific

- Physics of ring vortex formation and breakdown is applicable to:
  - Propeller crashback
  - Pulsed propulsors (e.g., for UUVs)
- Developed skill set for high quality propeller meshing
  - Essential for continued success of LES efforts supporting crash analysis/design for warfighter propulsor programs such as Ohio/Virginia/Columbia etc.
- Use of reduced-order (DMD) models/methodologies
  - Reduce millions of degrees of freedom to just a few-used in Machine Learning (Digital Twin)

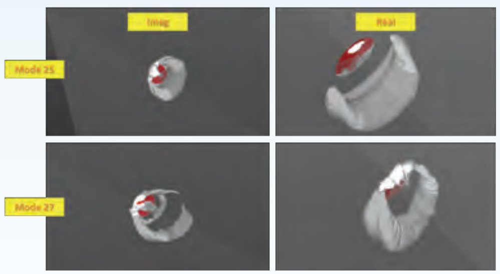
- Iso-surfaces of pressure showing RV formation/breakdown
  - Colored by axial velocity (red: positive; blue: negative)



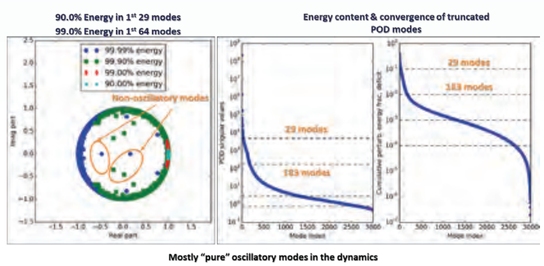
- Force distribution on propeller plane showing 4 RVB events



- DMD Modes



- Application of DMD to RV breakdown dataset
  - 3000 snapshots



Purpose, Motivation and Objective

Technical Goals

- **Motivation:** To understand the physics of Ring Vortex (RV) formation and breakdown
- **Hypothesis:** RV breakdown is responsible for high blade stresses in propeller crashback

Annual Technical Objectives

- **Year 1:** Explore Propeller Mesh techniques, DMD implementation
- **Year 2:** Perform Large-Eddy Simulations (LES) of RV formation and breakdown in simplified counter-flow configuration (representative of an open propeller in crashback)
  - Velocity ratio = 1 completed
  - Velocity ratio = 1/2 and/or 2 (to be completed)
- **Year 3:** Perform Large-Eddy Simulations (LES) of RV formation and breakdown in simplified counter-flow configuration (representative of an ducted propeller in crashback)

Background

Propeller Crashback

- Deleterious effects occur during Ring Vortex Breakdown
  - High blade stresses
  - Low-speed maneuvering difficulties
- Very large margins of safety are placed on Safe Operating Envelope (SOE)

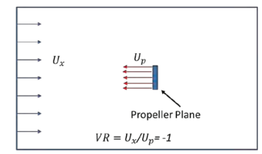
Ring Vortex Research

- Helicopters/Rotorcraft
- RV formation experiments
  - Piston-in-cylinder with imposed counterflow

Procedure, Set-Up and Approach

Approach

- Perform LES of RV in simplified counter-flow configuration (representative of open propeller in crashback)
- DMD



Results/Achievements/ Future Work/ Recommendations

- Idealized counter-flow ring vortex (RV) configuration case of velocity ratio = -1.0 was completed. Dynamic Mode Decomposition (DMD) of the dataset shows only 0.5% of modes are responsible for 99% of energy dynamics!
- Simulations for velocity ratios = -0.5, -2.0 were also completed. DMD of these datasets is underway
- Conditionally sampled DMD is under consideration as the flow dynamics is significantly different around the RVB stage of flow evolution

STAIRS Analysis and S&T Metrics

ILIR, Year 2/2

Principal Investigator

Danielle Paynter

Danielle Paynter

Ms. Danielle M. Paynter has been a Chemical Engineer for the Naval Surface Warfare Center, Carderock Division's (NSWCCD) Environmental and Energy Division since 2012. She received her Master's Degree in Environmental Engineering from North Carolina State University in 2016 and her Bachelor's Degree in Chemical Engineering from Virginia Polytechnic Institute and State University in 2011. In addition to environmental research on formation and stabilization of oil-in-water emulsions, she has focused experience in improving science and technology investment strategies. She was the lead developer of NSWCCD's inaugural Science and Technology (S&T) Strategic Roadmap, was a detailee with USD(R&E) Tech Watch/Horizon Scan, and is currently supporting the Office of Naval Research's Data and Analytics Office. She has participated in a number of strategy and futuring working groups including Carderock's Long Range Research and Development Plan (LRRD), the Navy Wide Aperture Futuring (WAF) effort, and Naval Undersea Warfare Center Headquarters' Undersea Warfare External Scan (USW EXSCAN).

Associate Investigator

Brian Fuller

Brian Fuller

Mr. Brian L. Fuller: B.S. Aerospace Engineering (1996) and M.S. (1998), University of Florida, employed at NSWC Carderock (1998 – present) as an Aerospace Engineer. Brian has more than 20 years of experience with USN aviation health monitoring – leading teams in developing and fielding demonstrations and prototypes for condition-based maintenance and military flight operations quality assurance. While working in Carderock's Sea-Based Aviation branch, he led the team in fielding a post-flight health monitoring system to USN helicopter squadrons in 2014. He is currently an aerospace engineer in the Platform Integrity Department's In-Service Ship Structures Branch and the PI of an ONR project to stand up a CBM+ Data Analytics Environment for USMC ground vehicles. He is also heavily involved as the analytics lead on Carderock's Structural Health Monitoring (SHM) Steering Committee as well as working to establish a robust culture of analytics at NSWC Carderock through the Data Science and Analytics Community of Practice.

Applications/Pay-off Technical/Scientific

- Carderock's STAIRS data contains roughly 400 records for a given year many are missing objectives, descriptions, and accurate financial information.
- This type of analysis (unsupervised LDA topic modeling) requires a larger pool of data for analysis.
- Meaningful results also require that the data be of higher and more consistent quality.

Future Work

Further collaborations with ONR and other Warfare Centers and discussions with future data collection efforts such as TIPERS would be useful to ensure utility of data for analytical contribution to the decision making process.

S&T Products:

- NAVSEA Data Science and Analytics Workshop – poster session – November 2019
- NSWC Carderock C882 Lunch and Learn – October 2019

Future Customer/Transition

Warfare Center CTO offices

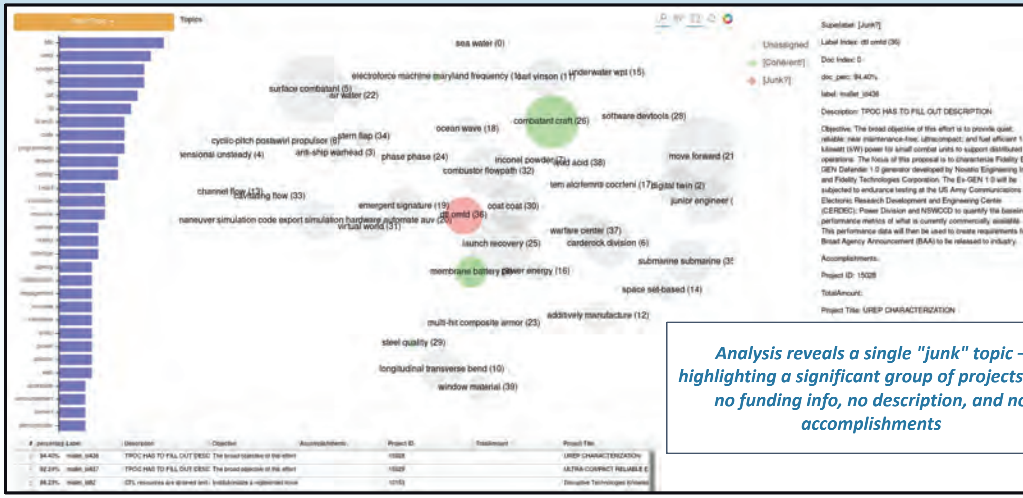
NAVSEA NISE Program Managers

Customer Advocates

External Collaboration

ONR Data and Analytics Office (Zelnio/Javier)

Results



- Results from this effort were limited because of the low number of records affiliated with the projects in STAIRS, resulting in noisy topic clusters
- Low quality data provided in the STAIRS database were also a challenge to the effort, as many fields were blank or placeholders

Motivation

- Current methods of portfolio analysis are limited to review of projects using either a highly detailed project submission interface (STAIRS) or Excel spreadsheets. These two views are limited to higher order analysis and project investment decision making.

Hypothesis/Objective

- Hypothesis: Providing high level project investment trends will enable a unique portfolio view and enable improved decision making
- Objective: Collect STAIRS data and perform semantic analysis in cooperation with ONR to extract trends.

Background

- Examine topics identified in the 2019 STAIRS database using LDA. Since the project categories, alignments, and bibliometrics that PIs enter in STAIRS do not do an accurate job describing the actual topic of the research, our investigation attempts to determine the actual research topics using an unsupervised topic modeling approach. In order to be as collaborative as possible, we chose to use the ONR OPAL tool that was developed by the ONR Data and Analytics Office.

- The general approach is known as LDA – Latent Dirichlet Allocation. LDA is a generative statistical model that allows sets of observations to be explained by unobserved groups that explain why some parts of the data are similar.

Approach

- Establish collaborative relationship with ONR Data and Analytics Office.
- Analyze NSF awards historic data as a demonstration of the approach and suitability of techniques.
- Obtain and analyze STAIRS data for insights into research investment.
- Obtain additional STAIRS data (or similar) containing information from additional years and warfare centers.
- Refine technique and iterate analysis on STAIRS or similar data.

Recommendations

- For this method of investment analysis to be successful, it requires larger and higher quality data sets. Ideally, a data collection system should be developed to monitor project progress from proposal to product. However, immediate interventions would be:
  - Approving project funding in STAIRS only if data has been reviewed for quality
  - Encourage wider input of projects into STAIRS (i.e. all projects in ERP)
  - Provide 1st and 2nd order tracking numbers to monitor project transition

Simultaneous Transmit and Receive (STAR) Acoustics ILIR, Year 2/3

Principal Investigator

Matthew S. Byrne, M.S.

Matthew S. Byrne

Mr. Byrne is an electrical engineer in the Structural Acoustics and Target Strength Branch (Code 722), where he works on numerical modeling for submarine target strength, writes software for processing submarine scale-model tests, and has contributed to efforts for the testing of new acoustic materials for the Navy.

He holds a B.S. degree in Electrical Engineering and Physics from the University of Pennsylvania, an M.S. degree in Electrical and Computer Engineering from the University of Texas at Austin, and is currently a Ph.D. candidate in the Electrical and Computer Engineering Department of the University of Texas at Austin.

He a member of the Acoustical Society of America, has 8 years of experience in numerical modeling and 2 pending invention disclosures. His first technical paper was published in 2019.

Science and Technology Products

Conference Presentations:

1. M.S. Byrne, (2017, December 04). Compressibility-near-zero acoustic supercoupling.174th Meeting of the Acoustical Society of America.
2. M. Byrne, (2020, May 11). Near-Surface Flaw Detection with Simultaneous Transmit Receive Self-Sensing. 179th Meeting of the Acoustical Society of America. (In Prep.)

Refereed Publications:

1. Published: M. Byrne, (2019, March 24). Acoustic Supercoupling in a Zero-Compressibility Waveguide. Research, 2019.
2. In preparation: M. Byrne, (2019, December). Uniform-phase Acoustic Power Divider with Compressibility Near Zero Supercoupling.
3. In preparation: M. Byrne, (2020, January). Near-Surface Flaw Detection with Simultaneous Transmit and Receive Acoustic Self-Sensing.

Workforce Development

- PhD in Electrical Eng. from UT Austin (Expected May, 2021)

Workforce Development

PhD, Electrical Engineering - University of Texas - Austin (Anticipated May 21)

External Collaboration

Dr. Michael Haberman
University of Texas - Austin

Dr. Andrea Alù
University of Texas - Austin, City University of New York

TEXAS The University of Texas at Austin

ADVANCED SCIENCE RESEARCH CENTER THE GRADUATE CENTER CITY UNIVERSITY OF NEW YORK

Applications/Payoffs - Technical and Scientific

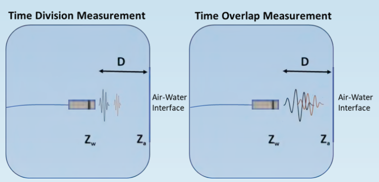
- Decreasing the number of transducers, improving the signal-to-noise ratio (SNR), increasing bandwidth for a given sampling time, and/or reducing minimum range detection for ultrasonic imaging.
- **Improved platform-level energy efficiency** may be possible by decreasing number of transducers for a given level of performance.
- **Enhanced decision making speed and quality** can result from improved SNR and/or increased bandwidth of acoustic systems.

S&T Products

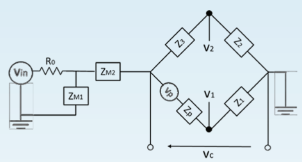
- Conference Presentations: 1) M.S. Byrne, (2017, December 04). Compressibility-near-zero acoustic supercoupling. 174th Meeting of the Acoustical Society of America. & 2) M.S. Byrne, (2020, May 11). Near-Surface Flaw Detection with Simultaneous Transmit Receive Self-Sensing. 179th Meeting of the Acoustical Society of America. (Accepted, delayed until Dec. 2020 due to Covid-19)
- Refereed Publications: 1) Published: M.S. Byrne, (2019, March 24). Acoustic Supercoupling in a Zero-Compressibility Waveguide. Research, 2019. 2) M.S. Byrne, "Acoustic Power Divider Based on Compressibility-Near-Zero Propagation", Phys. Rev. Appl. 14 (2020) 3) In preparation: M.S. Byrne, (2020, October). "Simultaneous Transmit and Receive for Acoustic Measurement Systems"

FY20 Results

The second year of this effort was focused on modeling and implementation of self-interference cancellation (SIC) and the signal-to-interference ratio (SIR) for an ultrasonic STAR system, as a proof-of-concept, which can also be generalized for applicability to lower frequency acoustic systems.



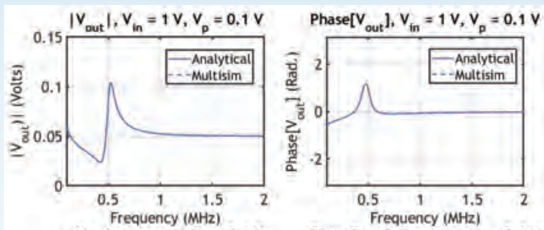
Top-Left: Canonical problem for modeling acoustic propagation and validating performance from an ultrasonic transducer in a STAR setup.



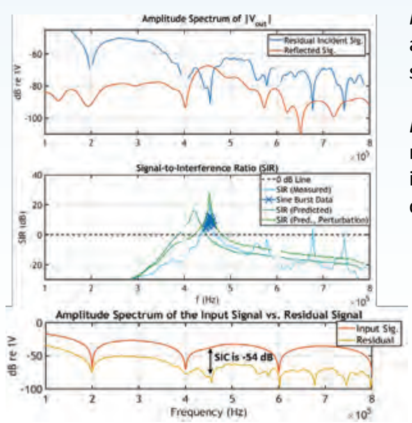
$$v_{out} = C \cdot (A - B) \cdot v_{in} + (B + D) \cdot v_p$$

$$\xrightarrow{A=B} \quad v_{out} \approx \frac{Z_1}{Z_1 + Z_p} \cdot v_p$$

Middle-left: Linear system model for the passive STAR cancellation setup. When *A=B*, the output becomes proportional only to the received signal, even while it is simultaneously transmitting.

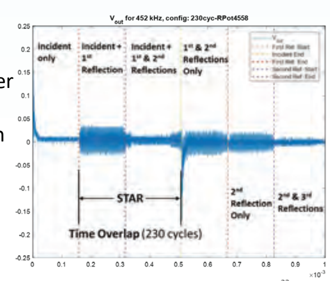


Middle-right: Output predicted by the analytical solution and numerical solution for an implementation of the system on the left with an ultrasonic NDE transducer.



Bottom-left: The spectra of the interfering signal and received signals, the predicted and measured signal-to-interference ratio (SIR) and the self-interference cancellation (SIC) from measured data are shown.

Bottom-right: Time overlap measurement with a single transducer in the reference configuration shown in the top-left figure.

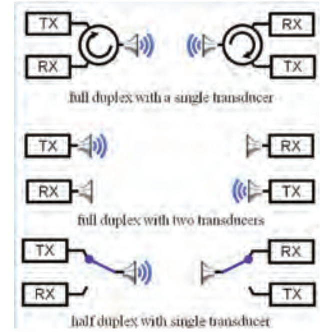


Purpose, Motivation and Objective

Experimentally implement Simultaneous Transmit and Receive (STAR) in an electroacoustic system. Theoretically and experimentally assess challenges unique to STAR acoustics such as compensating for nonlinear transducer dynamics and audio frequency conversion loss. Potential impacts are enhancements to acoustic signal detection (SNR), array beamforming, and near-surface imaging.

Background

STAR systems have recently enabled sending and receiving of Radio Frequency (RF) signals with a single antenna at the same time and at the same frequency. This has led to commercialization efforts with the promise of doubling the throughput of traditional radio systems including Wi-Fi and future 5G cellular communications. Inspired by these developments, we explore the unique challenges in developing simultaneous transmit and receive (STAR) functionality to realize significant advantages for acoustic measurement systems. In one notable difference from communication systems, acoustic measurements often function in a pulse-echo configuration, in which the received signal is a highly correlated copy of the transmitted signal. As a result, we are developing new modeling and measurement methodologies to adapt these concepts for acoustic systems.



STAR systems (also known as in-band full duplex or IBFD systems) use self-interference cancellation (SIC) to achieve full duplex communication with half the number of transducers as traditionally required

Approach

- Implement self-interference cancellation (SIC) with an off-the-shelf acoustic transducer, to enable simultaneous transmit and receive functionality with weakly correlated signals across a limited bandwidth.
- Develop element-and system-level and transducer models in order to describe the STAR signal dynamics, isolate the TX and RX signals, and adjust for non-linear transducer distortion.
- Implement low-noise signal amplification to recover measurements with enhanced signal-to-noise ratio (SNR) and/or near-surface resolution.

Supramolecular Chemistry to Synthesize Novel Polyurethane and Polyurea Polymers ILIR, Year 3/3

Principal Investigator

Jeffry Fedderly

Jeffry Fedderly

Jeffry Fedderly is a polymer chemist in the Non-Metallic Materials Research and Engineering Branch (Code 617), where he covers projects focused on polymer synthesis and characterization for the Navy.

He holds a B.S. degree in chemistry from the University of Maryland, College Park. Fedderly has 38 years of experience in chemistry for naval applications.

He is the author of more than 15 technical papers and 4 patents, and is a member of the Society of Rheology (SOR).

External Collaboration

Dr. Vasant Joshi at NSWC Indianhead

Tonny Bosman at SupraPolix

Associate Investigator

Jaime Santiago

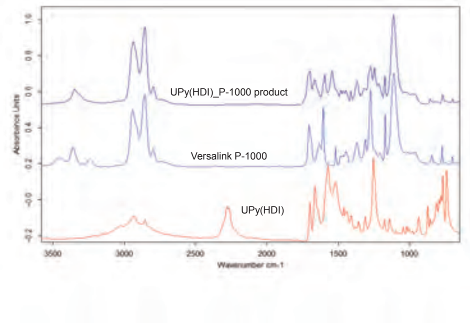
Jaime Santiago

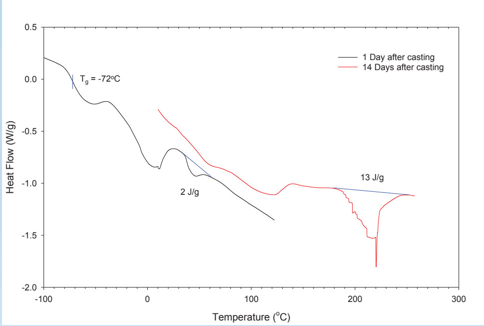
Mr. Jaime R. Santiago is a Materials Engineer at the Naval Surface Warfare Center Carderock Division and has a B.S. degree in Chemical Engineering from the University of Delaware. He has 4 years' experience in research, development, testing, and evaluation of materials including polymers, ceramics, metals, and electrochemistry for various Navy applications. Mr. Santiago has expertise in computer programming languages such as MATLAB, Simulink, Visual Basic, C++, and HT Basic. He has served as Principal Investigator for electro-spun nano-fiber processing and as an Associate Investigator for research and development in supramolecular polymers for applications in electrolyte, composite, and acoustic materials. Mr. Santiago participates in testing and evaluation of Navy and Marine Corps power sources including lithium ion batteries, capacitors, and electrolytes.

Technical Pay-offs

- Knowledge of techniques for synthesis and processing supramolecular polymers
- Expanding the Navy's toolbox and flexibility in polymeric systems
- Potential applications in additive manufacturing, functionalized adhesives, advanced damping materials, power and energy, and shock/blast mitigation materials
- Workforce Development

Chemical Analysis





Left: Fourier Transform Infrared Spectroscopy shows the chemical verification of our UPy-Versalink P-1000 supramolecular polyurea. **Right:** Differential Scanning Calorimetry evaluation of supramolecular polyurea

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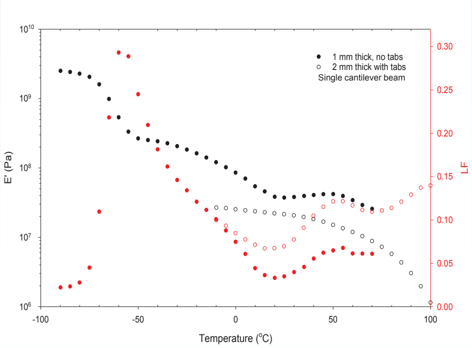
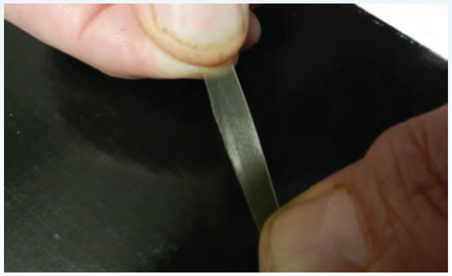
Initial Characterization





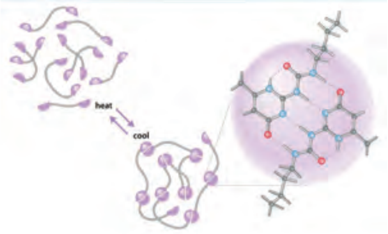
Left: Dynamic Mechanical Analyzer results showing moduli of several supramolecular polyurea samples. **Right:** Novel in-house synthesized supramolecular polyurea image under tension.

Objectives

- Overall objective is to develop an understanding of structure to property relationships of supramolecular polymers.
- The final objective is to create new supramolecular polyureas while gaining proficiency in synthesizing and processing materials tailored to the Navy.
- Specifically, we are motivated by supramolecular properties such as self healing and functionalized reversible transitions.

Background

Traditionally, polymer segments are bound by covalent linkages. Supramolecular polymers have a structure whose segments are held together by non-covalent bonds including hydrogen bonding, metal ligand complexes, and π-π interactions. Hydrogen bonding does not have the bond strength, conventionally, to hold together high molecular weight polymer segments. However, a quadruple hydrogen bonding motif enables the formation of supramolecular polymers as seen below from Sijbesma, et al. 1997.



Approach

- Utilize available commercial precursor supramolecular material from SupraPolix called hexamethylene diisocyanate capped 2-ureido-4[1H]-pyrimidinone (UPy)
- Synthesize polyurea by reacting UPy with polyamines such as Versalink of various molecular weights
- Characterize supramolecular polymers chemically, thermally, and mechanically using Fourier Transform Infrared Spectroscopy, Differential Scanning Calorimeter, Dynamic Mechanical Analyzer, and Rheometer

Conclusions

- Synthesized novel supramolecular polyurea with exceptional mechanical properties
- Established instrument techniques for evaluating dynamic properties
- Found evidence consistent with traditional phase separated polyureast

Summer Faculty Program Projects

As stewards of the Navy's knowledge base for platform technologies, it becomes increasingly important for NSWC Carderock Division researchers to form collaborations with academic and industrial partners. For Carderock, direct contract for Visiting Scientists, the Office of Naval Technology (ONR) Sabbatical Research Program (SRG), and the Summer Faculty Research Program (SFRP) provides host advisors (Carderock Researchers) access to talented collaborators at various academic institutions, thus expanding the foundation of knowledge available for solving basic and early-applied research problems. In addition, opportunities for new and expanded research challenges can be posed to participating faculty members. Participants have opportunities to establish continuing research relationships, which may result in sponsorship at both Carderock and faculty home institutions. These programs support the establishment of collaborations and expand the R&D networks of scientists and engineers at both the NSWC Carderock Division and various Academic institutions. Together, hosts and faculty participate in research of mutual interest for a 10-week period.

Another very important aspect of the SFRP and direct contracting program is to help stimulate research activities and expand the experience available to faculty at Historically Black Colleges or Universities, Hispanic Serving Institutions, or Minority Institutions, (HBCU/HSI/MI). As such, Carderock hosted five faculty collaborators from HBCU/ HSI/MI universities: San Diego State University, Delaware State University, Old Dominion University, the University of Texas – San Antonio, and the University of the District of Columbia. This program also opens doors to highly qualified students at participating universities that form a pool of potential future employees.

In the summer of 2020, Carderock Division hosted seventeen (17) faculty researchers; sixteen (16) through the ONR SFRP and one (1) through direct contract support (Perspecta, Inc.). Seven of the faculty are from Historical Black Colleges and Universities / Hispanic Serving Institutions / Minority Institutions (HBCU/HSI/MI). Of the entire faculty, four (4) were directly supporting ILIR projects, eight (8) supported NISE projects (two in the Center for Innovation in Ship Design - CISD) and eight (8) supported directly funded projects from ONR or DARPA. All seventeen faculty presented Division-wide colloquia that were available by MS Teams to all Carderock sites, hence transmitting the results of their recent research. Since these presentations were open to all at the Division, including summer students and interns, these seminars stimulated student interest the breadth of research and thus in future employment at Carderock.

Microstructural Characterization of Fracture in Fe-10 % Ni Gas Metal Arc Welds

Dr. Richard E. Baumer
LeTourneau University, Longview, TX


Professor Richard Baumer

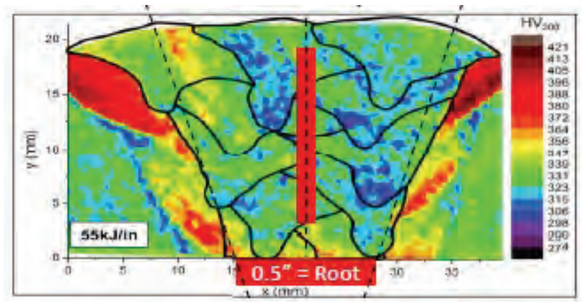
Dr. Richard Baumer is an Assistant Professor and the Omer Blodgett Endowed Professor and Department Chair of Welding/Materials Joining Engineering at LeTourneau University in Longview, TX. Dr. Baumer earned his BSE (Concentration in Materials Joining Engineering) in 2008 from LeTourneau University, his PhD in Materials Science and Engineering from Massachusetts Institute of Technology in 2013, and spent nearly four years as a research engineer at The Dow Chemical Company (2013-2017) before returning to his alma mater to lead the welding engineering program. His research group works at the intersection of welding metallurgy and physical simulative test methods to accelerate welding procedure development for high strength steel alloys for naval and petrochemical applications.

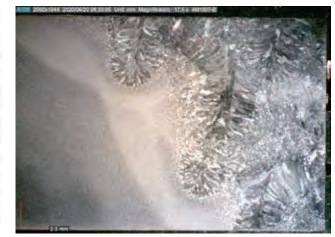
Research Abstract

A Fe-10 percent nickel welding consumable is currently undergoing assessment for use in naval shipbuilding applications. Previous dynamic tear test results of gas metal arc welds (spray transfer; M2 shielding gas) produced at 3 different heat inputs have shown unexplained scatter in the Charpy Vee (CV) notch testing and were also observed in recent and Dynamic Tear (DT) weld metal testing results. The cause of this scatter is currently unknown. The goal of this project is to identify the root cause of observed scatter in DT weld metal tests through characterization of the fracture surface and microstructure of DT specimens using scanning electron microscopy and optical metallography.

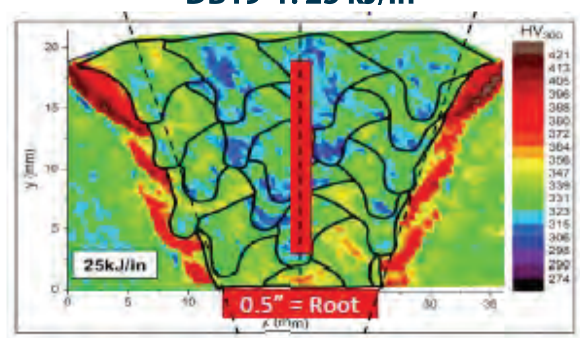
Comparing Microhardness Maps [1] to Microstructure

DB19-2: 55 kJ/in





DB19-1: 25 kJ/in



Preliminary Conclusion: Higher fraction of non-equiaxed (columnar) grains near DB19-1 DT notch increases probability of crack intersecting low toughness regions, reducing DT energy.

[1] Bechetti, Sinfield, Farren, Development of a High-Strength, High-Toughness Welding Consumable Based on the Fe-10Ni Steel System, in: AWS Shipbuilding and Aluminum Conference, New Orleans, LA, 2019.

Leading-Edge Tubercles for Airfoil Flow Separation Control

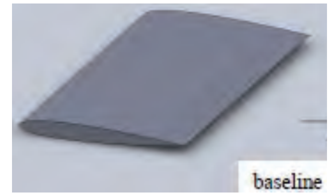
Dr. Isaac Choutapalli
University of Texas - Rio Grande Valley, Edinburg TX

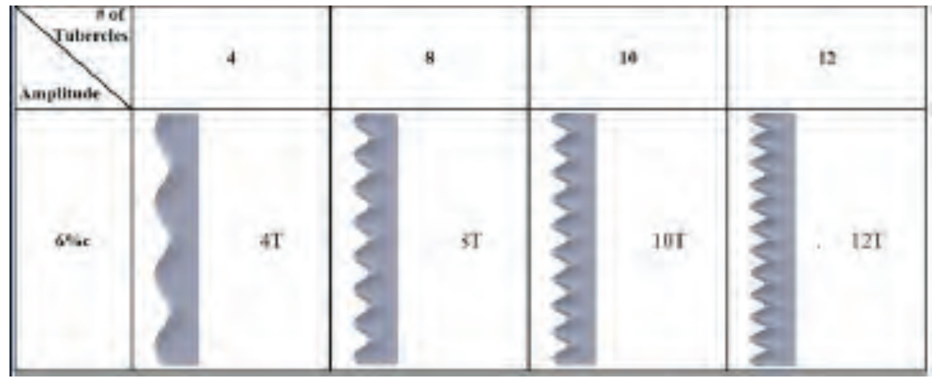
Dr. Isaac Choutapalli is an associate professor of mechanical engineering at the University of Texas – Rio Grande Valley since 2010. He was previously a postdoctoral fellow at the Nuclear Engineering department, Texas A&M University, College Station, TX. He earned a bachelor's degree from NIT-Warangal (India), master's degree from IITMadras (India), and PhD from Florida State University, Tallahassee, FL. His research program focuses on drag reduction, hydrodynamic instabilities, and propulsion. Dr. Choutapalli was named the Lloyd Bentsen Endowed professor in 2018.

Professor Isaac Choutapalli

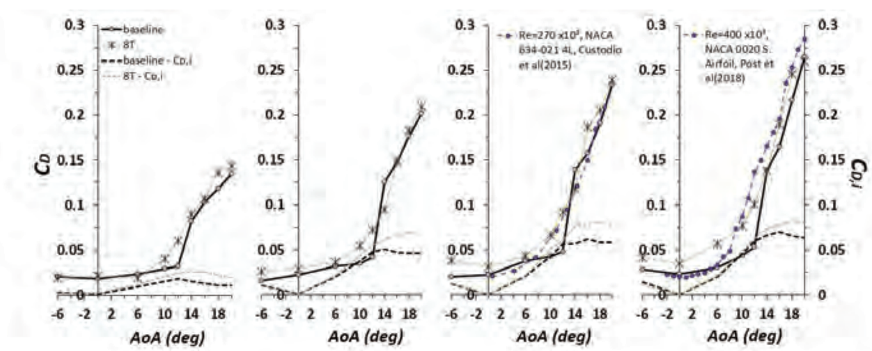
Research Abstract

The bio-inspired motivation of this research is the oversized tubercled pectoral fins in humpbacks which serve many purposes, including thermoregulation, Maneuverability, as well as serving as the whales' rudders and stabilizers. What are the hydro/aerodynamic benefits of tubercles on wings/hydrofoils, including the effect on lift and drag, stall/stall angle, as well as the tubercle efficacy in high free-stream turbulence and during pitch/plunge maneuvers? The relevance to DoD/Navy application of leading-edge tubercles for passive control of flow has potential in the design of control surfaces, wings, propellers, fans, and wind turbines. Implications include increased maneuverability, energy efficiency enhancement, and tonal noise reduction by tubercle addition. The aerodynamic characteristics of four models with leading-edge tubercles and a baseline with NACA 0010 underlying profile are studied measuring force, moment and velocity field data using Particle Image Velocimetry (PIV).





Drag Coefficient - Effect of Reynolds Number



Variation of drag coefficient with angle for 8T and baseline for all Reynolds numbers

Initial Studies on Post-Damage Stability and Resistance

Dr. Raju Datla
Stevens Institute of Technology, Hoboken NJ

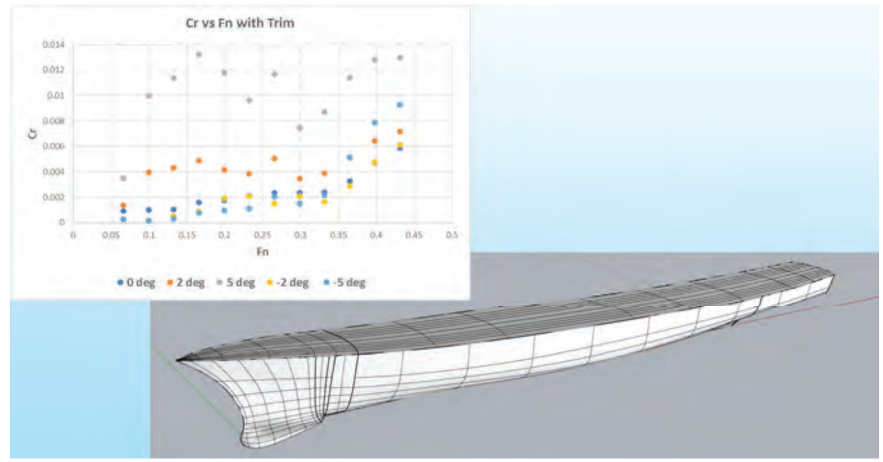
Professor Raju Datla

Dr. Raju Datla is a Research Associate Professor in Naval and Ocean Engineering at Stevens Institute of Technology. He manages the experimental marine hydrodynamics research at the Davidson Laboratory. His expertise is in the areas of high-speed craft hydrodynamics and ocean engineering in which he prepared more than 50 technical articles. He teaches courses to undergraduate and graduate students in naval engineering and ocean engineering at Stevens and served as principal advisor to 6 PhD dissertations and more than 50 master's and undergraduate theses and design projects. He received his Ph.D. in Ocean Engineering from Stevens Institute of Technology.

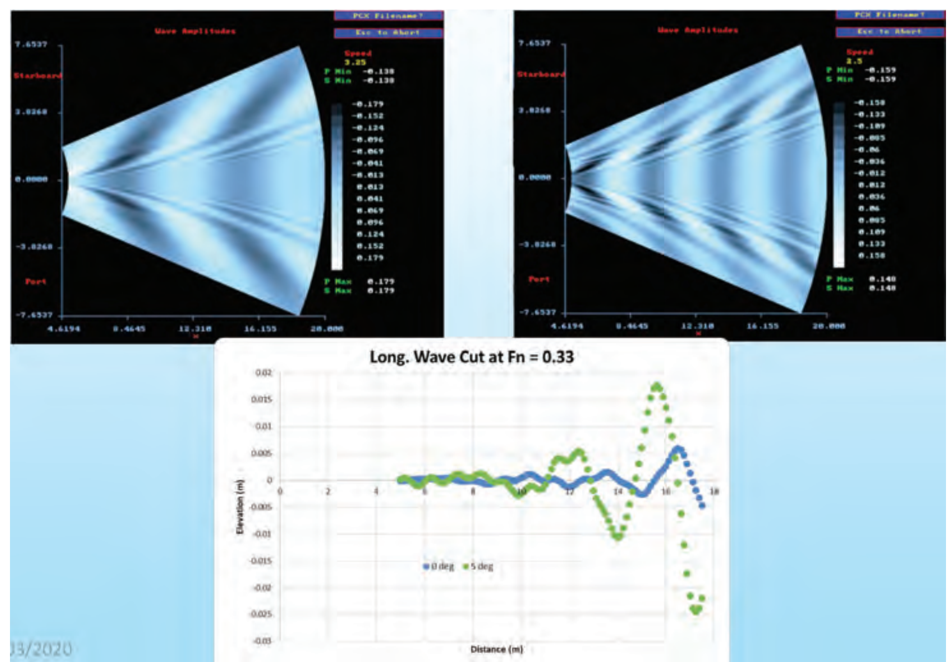
Research Abstract

The Summer Faculty Research Program (SFRP) visiting professor Dr Raju Datla supported The Center for Innovation in Ship Design (CISD) at Naval Surface Warfare Center, Carderock Division, as a mentor in CISD summer college intern design projects, as a subject matter expert in subsystem design integration, hydrodynamics and aerodynamics (especially airfoil and waterfoil design), signatures & noise, ship, submarine, and craft design. Research was conducted on hydrodynamics of ship operability in post damage condition to understand naval vessel performance. The objective was to find the rate of change of resistance and GZmax with trim and heel angles. Preliminary studies were conducted with hullform DTMB 5415 of hydrostatic stability using Rhino/Orca 3D. Slender body theory was used in Low fidelity simulations to determine resistance. Preliminary results show that the presence of bulb and transom depth would have significant effect on righting arm and calmwater resistance.

Resistance

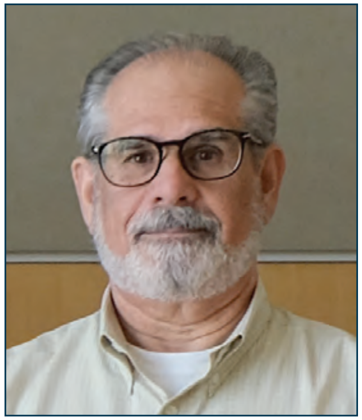


Resistance – Wave Pattern



Fire Suppression System Design for Li-ion Battery Transport Container

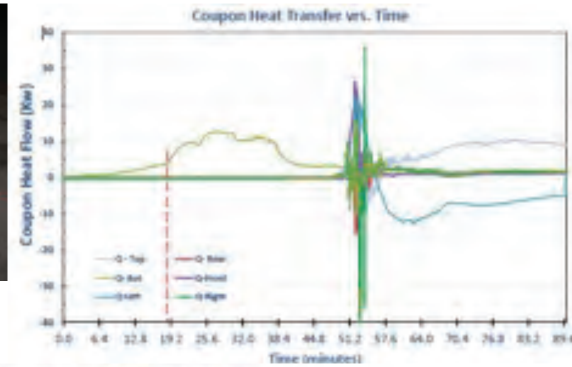
Dr. Peter Disimile, Ph.D.
University of Cincinnati, Cincinnati OH

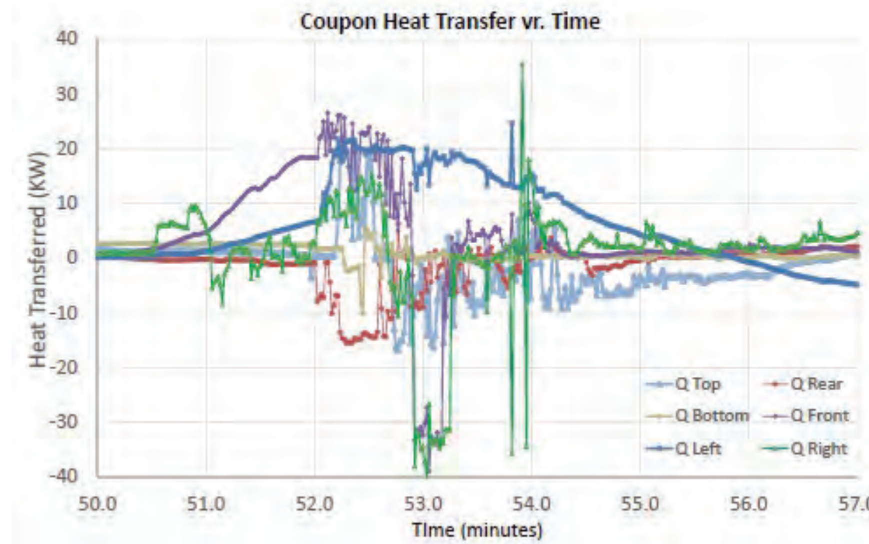


Professor Peter Disimile

Dr. Disimile is an Associate Professor in Aerospace Engineering at the University of Cincinnati where he directs the Fire, Explosion, Science, and Technology research group. He earned his Ph.D. in Mechanical Engineering at Michigan State University with a primary focus on turbulent fluid dynamics and heat transfer. He has performed research in both liquids and air under both single and multiphase conditions, at speeds ranging from 1 cm/sec to Mach 6. In 1999, he received a USAF Summer Faculty Research Fellowship in the Aerospace Survivability & Safety Branch at WPAFB and has since applied his expertise to Fire & Explosion issues. In 2000, he was detailed to the AF as staff scientist and served as a subject matter expert (SME) and PI on several AF programs such as Hydrodynamic Ram, Fire Suppression Transport, Next Generation Fire Protection, and Hot Surface Ignition. Dr. Disimile is also a part-time SME for a small business, Engineering & Scientific Innovations, Inc., where he is responsible for the development of a "Smart High-speed Optical Fire Protection system" using artificial intelligence for the AF, and an imaging system to capture cavity dynamics and the re-entrant jet produced by to an underwater release for the Navy Strategic Programs Office.

Li-ion 6T Locker Test





Research Abstract

The Li-ion Vehicle Transportable Aggregate Storage Container (VTAS) is a multiservice technology that addresses the hazard of aggregating energy-dense Li-ion batteries which may undergo thermal runaway and cause serious fires. The VMAS will be forklift-able and cross-functional among the services. It will possess a charging capability for a range of Li-ion batteries up to the 6T format. It will also host an integrated fire detection and suppression system to arrest propagation of a fire to other stored batteries. Professor Disimile's expertise in the areas of fire detection and targeted suppression was very valuable to the development of the VMAS. He participated in design activities, test data analysis, and consult on materials and construction activity to investigate the rotating cylinder analogy to pipe flow. The impact of surface roughness on the derived relationships is currently under investigation.

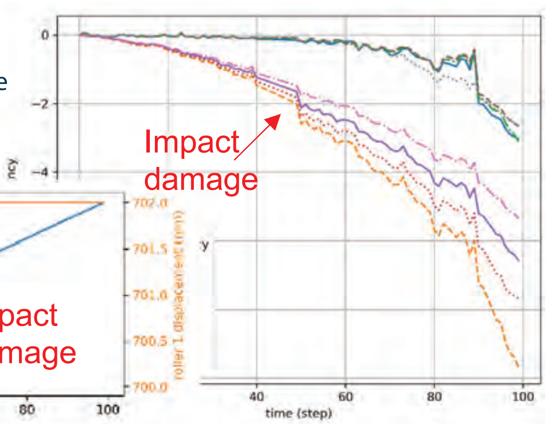
Multi-modal Data Assimilation for Naval Ship Structures

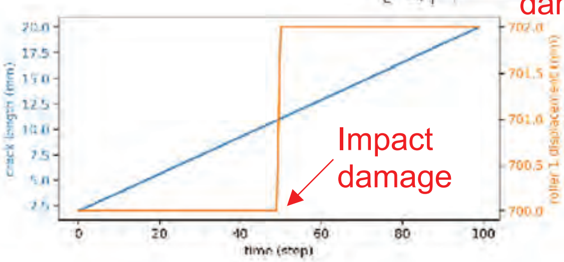
Dr. Austin Downey
University of South Carolina, Columbia SC

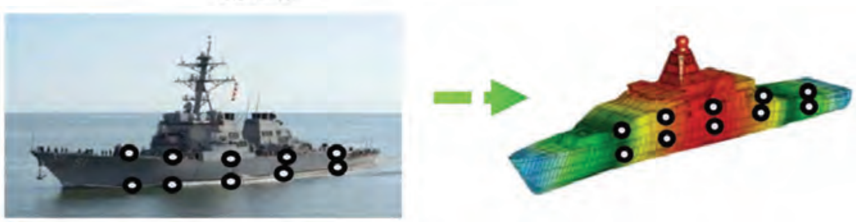
Professor Austin Downey

Dr. Austin Downey is an Assistant Professor at the University of South Carolina in the Department of Mechanical Engineering with a dual appointment in the Department of Civil and Environmental Engineering. His research focuses on increasing the resiliency of mesoscale Structures to both manmade and natural events through real-time monitoring, modeling, and adaptive control of structures. He has authored over 50 publications related to his research and is the lead inventor on two U.S. patents. He obtained his Ph.D. from Iowa State University in 2018 in Engineering Mechanics and Wind Energy Science, Engineering, and Policy (Dual Majors) where he was an NSF-IGERT fellow.

Change in frequencies of the system; For a given measurable frequency, the structure could be in a number of damage states.







Research Abstract

A key challenge in implementing digital twins for naval ship structures is the amount of data that needs to be assimilated (updated) into physics-based, data-driven, or prognostics models. Data comes from a wide range of sources, including design documents, hand-written maintenance notes, point clouds from 3D scans, or strain measurement from sensors embedded in the structure. Moreover, depending on the scope of the digital twin considered, environmental and input forces may also be considered; including wave height, temperature, salinity, and wind direction. While challenging, a digital twin can be used for informed response management that will increase ship lifespans, maintenance intervals, and ship survivability. This project will develop a simplified structure to develop data sets for the investigation of digital twin updating of ship structures. This work will accelerate the adoption of digital twins for ships by investigating the use of the Dynamic Data Driven Application System (DDDAS) frame- work for simultaneously updating a structural model for multiple events (e.g., fatigue, impact). These models will be used in the future for decision-making across multiple timescales (real-time to life-span).

The project was split into two thrusts:

- Thrust 1: Develop a 1-D test structure. This thrust developed a 1-D structural testbed ("beam model") of a ship to produce simplified data sets that will be used for validating multi-model data assimilation algorithms. Due to lab closures, the testbed was modeled numerically using commercial finite element software (Abaqus) and will be constructed for experimental validation once the labs at the University of South Carolina reopen.
- Thrust 2: Develop tools for multi-event data assimilation. This thrust investigated the assimilation of data from different events (fatigue and impact) into a single finite element model with the goal of developing a well-informed digital twin of a naval structural system.

Summary & Analysis of Magnetic & Structural Alloys and Various Industrial Processing

Dr. Tanjore V. (Jay) Jayaraman
University of Michigan, Dearborn,
Dearborn MI

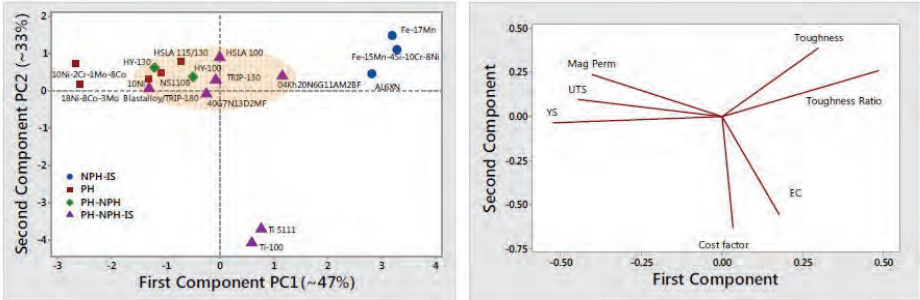
Professor Tanjore Jayaraman

Dr. Jayaraman is currently an Assistant Professor in the Dept. of Mechanical Engineering at the University of Michigan-Dearborn. He obtained his Ph.D. in Metallurgical Engineering from the University of Utah, Salt Lake City. His research areas include magnetic materials, Nonequilibrium processing, corrosion engineering, data-driven materials selection, and nanoscience and technology, and he teaches graduate and undergraduate courses in materials engineering. He has several publications and conference presentations in the area of metallurgy and magnetic materials.

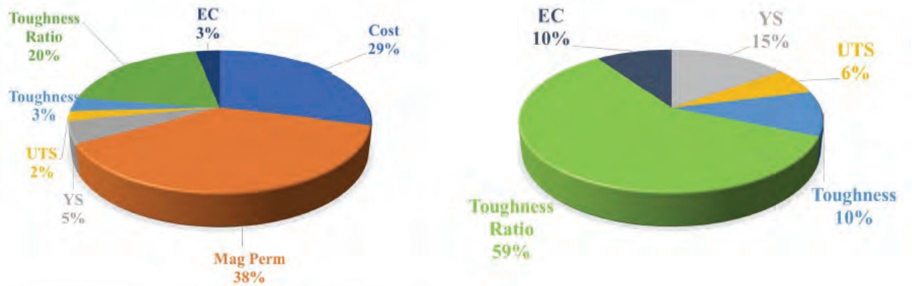
Research Abstract

The research was conducted in three parts. The first part was a review of permanent magnets and magnetostrictive alloys which fulfill the high-entropy alloy criterion. The second part explored the use of statistical analysis for materials selection and the generation of properties charts (similar to Ashby plots), with the primary goal of identifying future structural alloys, as well as permanent magnets for motors for ship propulsion. The third part included efforts made to outline and develop a course on 'Industrial Metals Processing' for interns and new engineers at the NSWCCD.

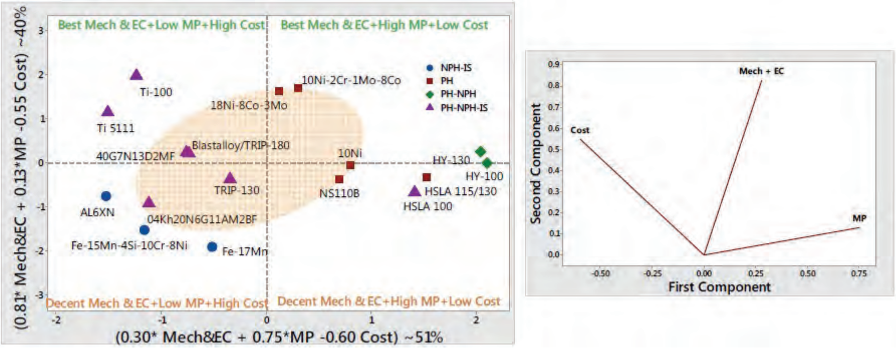
PCA* of cardinal data



Attribute weights - cardinal data



PCA* of ordinal data



*Principal Component Analysis (PCA)

Metrics to Measure the Scientific and Technical Health

Dr. Jay Liebowitz
Harrisburg University of Science and Technology, Harrisburg PA

Dr. Jay Liebowitz is the Distinguished Chair of Applied Business and Finance at Harrisburg University of Science and Technology. He Previously was the Orkand Endowed Chair of Management and Technology in the Graduate School at the University of Maryland University College (UMUC). He served as a Professor in the Carey Business School at Johns Hopkins University. He was ranked one of the top 10 knowledge management researchers/ practitioners out of 11,000 worldwide, and was ranked #2 in KM Strategy worldwide according to the January 2010 Journal of Knowledge Management. At Johns Hopkins University, he was the founding Program Director for the Graduate Certificate in Competitive Intelligence and the Capstone Director of the MS-Information and Telecommunications Systems for Business Program, where he engaged over 30 organizations in industry, government, and not-for-profits in capstone projects. Prior to joining Hopkins, Dr. Liebowitz was the first Knowledge Management Officer at NASA Goddard Space Flight Center. Before NASA, Dr. Liebowitz was the Robert W. Deutsch Distinguished Professor of Information Systems at the University of Maryland-Baltimore County, Professor of Management Science at George Washington University, and Chair of Artificial Intelligence at the U.S. Army War College. Dr. Liebowitz is the Founding Editor-in-Chief of Expert Systems with Applications: An International Journal (published by Elsevier). He is a Fulbright Scholar, IEEE-USA Federal Communications Commission Executive Fellow, and Computer Educator of the Year (International Association for Computer Information Systems). He has published over 40 books and a myriad of journal articles on knowledge management, analytics, intelligent systems, and IT management. Dr. Liebowitz served as the Editor-in-Chief of Procedia-CS (Elsevier). He is also the Series Book Editor of the new Data Analytics Applications book series (Taylor & Francis). In October 2011, the International Association for Computer Information Systems named the "Jay Liebowitz Outstanding Student Research Award" for the best student research paper at the IACIS Annual Conference. Dr. Liebowitz was the Fulbright Visiting Research Chair in Business at Queen's University for the summer 2017 and a Fulbright Specialist at Dalarna University in Sweden in May 2019. He has lectured and consulted worldwide.

Professor Jay Liebowitz

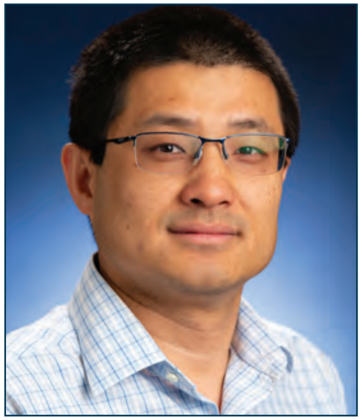
Research Abstract

The first part of the Summer Faculty Research Fellowship addressed knowledge management issues and strategies involving the TIC/ Library and NSWC-Carderock, as an enterprise. A survey of Library Directors (both external and internal), interviews at NSWC-CD, and a literature review/industry best practices were used as the methodologies for research data triangulation. A webinar was presented on these findings in June. The second part of the summer research addresses metrics to measure the scientific and technical health of a R&D lab like Carderock. A literature review and industry best practices, along with interviewing key individuals at NSWC-CD, were used to address the specific questions raised by the NSWC-CD sponsor.

M&S Development of Magnetostrictive Materials High-frequency Response

Dr. Jinjie Liu, Ph.D.
George Mason University

Dr. Jinjie Liu is an associate professor of mathematics at Delaware State University. He received his PhD in Computational Applied Mathematics from Stony Brook University in 2006. Dr. Liu's research interests lie in the area of numerical analysis and scientific computing with applications to computational electromagnetism, fluid dynamics, metamaterials, and nonlinear optics.



Professor Jinjie Liu

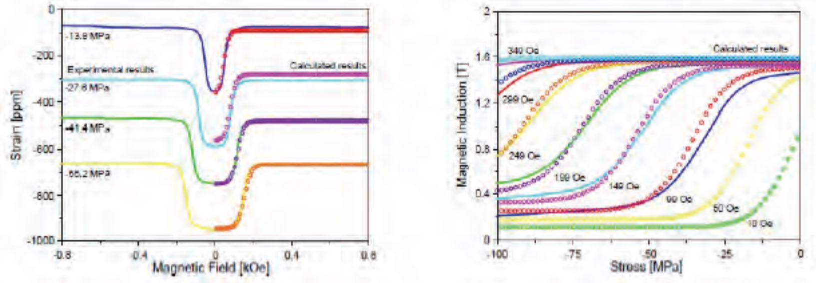
Research Abstract

Building upon last year's research at Carderock, Dr. Liu helped the development of theoretical models for describing the behavior of magnetostrictive materials at high frequencies (up to ~10GHz) and the comparison of these models with experimental results. Utilizing his background in numerical analysis and computer simulations for electromagnetic problems, Dr. Liu continued his work on implementing numerical algorithms for solving the magnon and microwave photon interaction modeling equations and the Magnetostriction governing equation. The following tasks were reported:

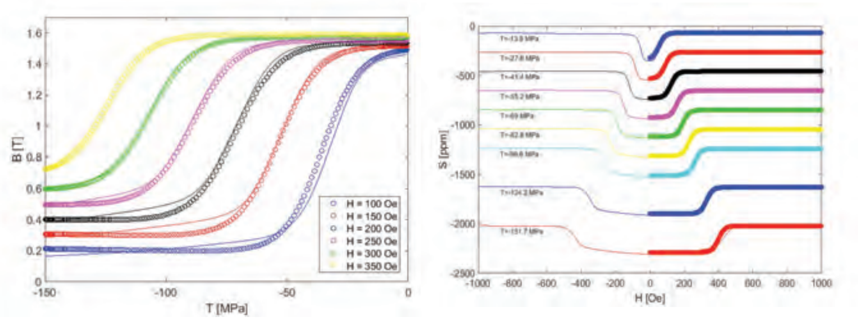
1. Continued study of the nonlinear magnetostrictive constitutive equations for modeling the three-dimensional responses of strain and magnetic flux density as functions of applied stress and magnetic field. We expect to draft a proceeding or journal paper to report our research discoveries.
2. Continued study of the theory on magnon (spin waves) and microwave photon interactions and working on the computer code that simulates the effects of bias magnetic field on microwave photon and magnon coupling in ferromagnetic materials.
3. Help to the group members on their projects using Dr. Liu's expertise in mathematics and computer programming.

Nonlinear Coupling Equation

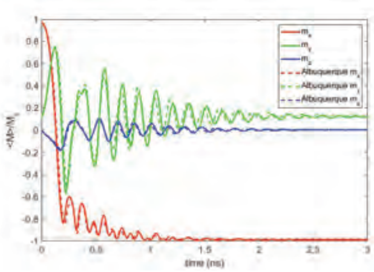
$$S = s_1(T) \cdot \tanh(s_2(T) \cdot (H + s_3(T))) + s_4(T),$$
$$B = b_1(H) \cdot \tanh(b_2(H) \cdot (T + b_3(H))) + b_4(H).$$



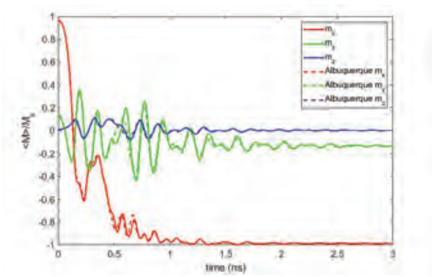
B-T and S-H Fitting curves (Galfenol sample 1529)



Result #1



Result#2



Maritime Traffic Generation for AI and Perception Research and Testing

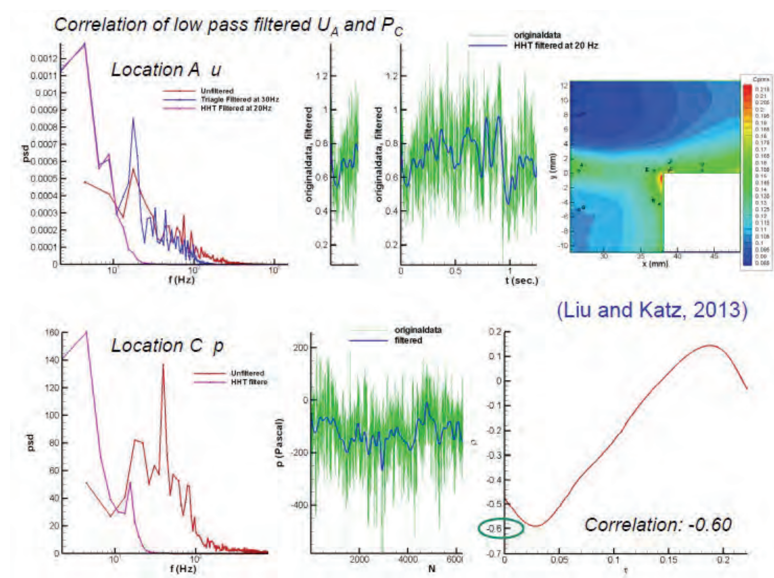
Dr. Xiaofeng Liu, Ph.D.
San Diego State University, San Diego, CA

Professor Xiaofeng Liu

Dr. Xiaofeng Liu, an associate fellow of the American Institute of Aeronautics and Astronautics (AIAA), is currently an associate professor at the Department of Aerospace Engineering at San Diego State University. Before joining SDSU, he was first a postdoctoral fellow, and subsequently an assistant research scientist and adjunct principal research engineer at the Department of Mechanical Engineering at Johns Hopkins University. He received his Bachelor and Master degrees in aerodynamics from Beijing University of Aeronautics and Astronautics, and a Ph.D. degree in aerospace engineering from University of Notre Dame. Prior to coming to the U.S. for his Ph.D. studies, he was a lecturer at the Department of Engineering Mechanics at Tsinghua University. Before joining the Tsinghua faculty, he was a project manager involved in satellite launch services at the Division of International Cooperation at the China Academy of Launch Vehicle Technology. Dr. Liu has extensive experience in flow diagnostics including hotwire, seven-hole probe, laser Doppler velocimetry and Particle Image Velocimetry. His research expertise includes high-lift aerodynamics, turbulent shear layer flows, wake flows, vortex dynamics, cavitation, flow-structure interactions, acoustics, supersonic wind tunnel testing, evaporative cooling and heat transfer, image processing, and development of optics based pressure field measurement techniques. Dr. Liu has been a U.S. citizen since 2010. He has been appointed as an Office of Naval Research Summer Faculty Fellow in 2016, 2018, 2019, and 2020, respectively. He is the recipient of the Best Faculty Award in Aerospace Engineering in 2017 and the Most Influential Faculty Award from SDSU College of Engineering in 2019.

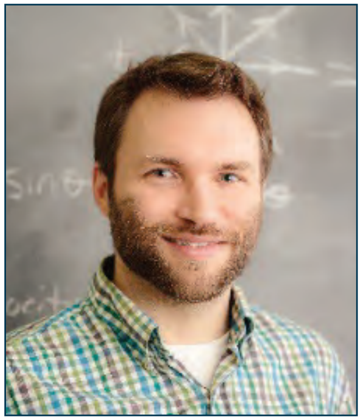
Research Abstract

Complex flow fields above and around ship deck often exhibit a wide range of temporal and spatial features in fluid motion, which affects not only the ship performance, but also Launch and Recovery (L&R) of air vehicles. To characterize such flow fields, Particle Image Velocimetry (PIV) is often used in wind tunnel tests, which can generate an extremely large volume of data. Newly emerged data analysis techniques, such as machine learning and data-driven modelling, may be implemented to improve the efficiency in data analysis and usage. Since machine learning heavily relies on pattern recognition and statistical inference, as a preliminary step for the application of machine learning techniques to PIV data analysis, indicative flow patterns from the Proper Orthogonal Decomposition (POD) modes and/or Ensemble Empirical Mode Decomposition (EEMD) need to be identified. Subsequently, the relationship between the indicative patterns with the corresponding flow events and properties can then be established. With the new findings through the research, possible methods for prediction and mitigation of hazardous flow conditions for L&R operation will be discussed.



Developing a Machine Learning Model for Quantifying Flow Interactions in Schooling Fish

Dr. Keith Moored
Lehigh University, Bethlehem PA



Professor Keith Moored

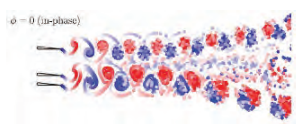
Dr. Keith Moored is an Associate Professor in the Department of Mechanical Engineering and Mechanics at Lehigh University. He received a B.S. in Aerospace Engineering and a B.A. in Physics in 2004 and his Ph.D. in Mechanical And Aerospace Engineering in 2010, from the University of Virginia. From 2010-2013, he was a Postdoctoral Research Associate and Lecturer in Mechanical and Aerospace Engineering at Princeton University. In 2012, he sailed as faculty on Semester at Sea for the Engineering Maymester, short-term voyage through South and Central America. Dr. Moored's research interests are in bio-inspired propulsion, unsteady aerodynamics and fluid-structure interaction. He is currently a PI on an ONR MURI topic of non- traditional propulsion and he has received an NSF CAREER award for examining the fluid dynamic interactions among swimmers in a school.

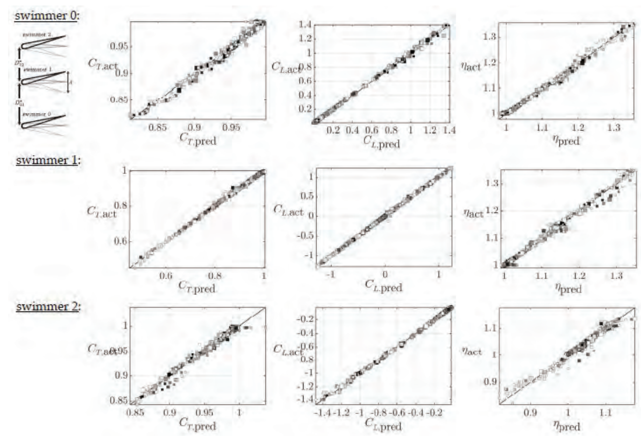
Research Abstract

Self-organization of living systems is one of Nature's most ubiquitous and mesmerizing phenomena. Fish schools have inspired the imagination and with it a host of hypotheses for their function ranging from social behaviors and enhanced protection against predators to improved foraging and a reduction in the energetic cost of swimming. Regardless of the prime function, animals in a collective encounter fluid dynamic interactions from their neighbors that may modify their locomotion energetics, force production, or push and pull them in different directions or into a particular arrangement. Gaining a comprehensive understanding of hydrodynamic interactions that occur in fish schools can help scientists parse out the function of group behaviors and give insight into the fragility of biological networks to overfishing, loss of habitat and the changing climate. Beyond the implications for biology, engineers can take inspiration from the locomotion solutions found in nature. Over the past two decades there has been vigorous research into developing a new class of unmanned underwater vehicles with unprecedented efficiency, maneuverability, agility and stealth. We believe that the next step toward improving bio-inspired underwater vehicles is understanding how to have them operate as a multi-agent collective. This will enhance their performance and permit a wide range of new tasks and missions.

Most experimental or numerical studies on schooling interactions only consider a minimal school of two swimmers. This limits the size of the parameter space to allow for a comprehensive understanding of the interactions. However, the question remains: how does our understanding of two-body interactions scale to N-body interactions? A machine learning model was developed that can take data from a small number of bodies interacting (e.g. two or three) and project the expected interactions and performance up to a large number of bodies. New numerical data on three body interactions will be presented. A simple superposition model will be compared with various machine learning models of the interactions. The work, although focused on schooling, has broader impacts towards developing hydrodynamic interaction models for large numbers of swarming traditional unmanned underwater vehicles.

Machine Learning Model: Deep Neural Network





Simulating Intelligent and Realistic Maritime Ambient Traffic for USV Decision Making

Dr. Yiannis Papelis, Ph.D.
University of West Florida

Professor Yiannis Papelis

Dr. Papelis obtained a BSEE degree (CS minor) from Southern Illinois University, and Master's and Ph.D. degrees in ECE at Purdue and University of Iowa respectively. He is a Research Professor at Old Dominion University. Before joining ODU, Dr. Papelis' research focused on high-fidelity driving simulators and studying advanced automotive technologies, and in-vehicle devices. His research on the effectiveness of ESC was referenced by the Dept. of Transportation when making its use mandatory in all passenger vehicles built after 2012. His current research interests include the application of artificial intelligence techniques to unmanned/autonomous systems and robotics, and behavioral modeling/simulation in immersive VR. Dr. Papelis has developed several immersive simulation environments used in training applications in a wide range of disciplines, including military simulations for autonomy testing, military robotic peace- keepers, nursing simulations, virtual operating rooms, and preschool teachers virtual training. Dr. Papelis has been awarded consecutive summer Faculty Fellowships from the Office of Naval Research and assigned to work with the US Navy Combat Craft Division, focusing on USV simulation techniques, frameworks, formal methods for assessing unmanned vessel on-board health and autonomy testing.

Research Abstract

The US Navy is increasingly depending on use of unmanned autonomous systems to accomplish its mission and as a result, it is imperative to advance overall capabilities related to development, testing and certification of autonomous vessels of varying sizes. Modeling and Simulation (M&S) is a key enabling technology that can facilitate in-laboratory (lab-ashore) testing, which is typically less costly than in-situ (lab-afloat) testing. Currently, both in laboratory and in-situ testing have research and technology gaps that must be addressed. One of these gaps is having realistic stimuli for testing broad decision-making and environment perception algorithms, both in virtual and real environments. The project aims to address this gap by investigating techniques for generating intelligent and realistic maritime ambient traffic in various levels of timing. Faster than real-time is particularly important as it allows batch simulations to complete at reasonable time intervals. The work involved experimentation with Scrimmage and utilizing various real-time and faster than real-time execution strategies.

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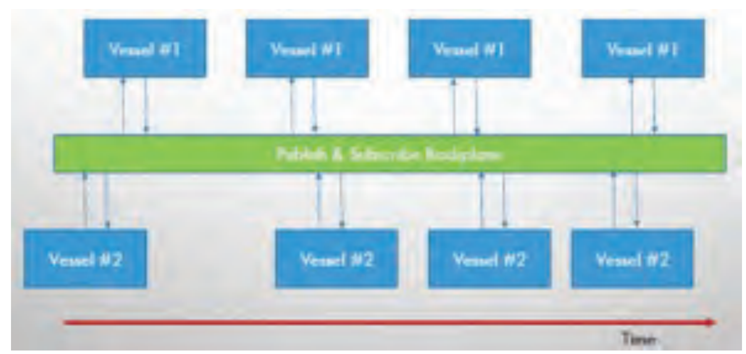


Probabilistic Analysis of Whipping Effects on Vertical Bending Moments

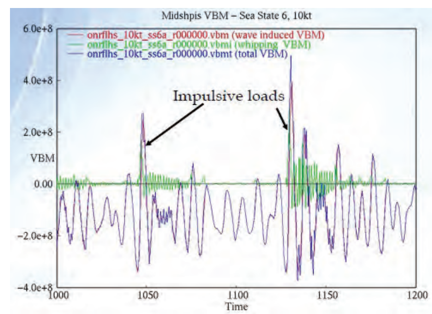
Themistoklis Sapsis , Ph.D.
Massachusetts Institute of Technology

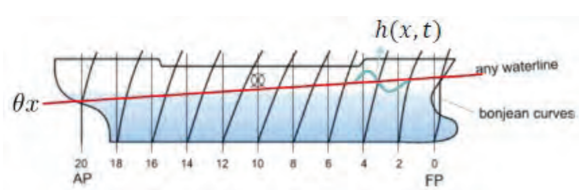
Professor Themistoklis Sapsis

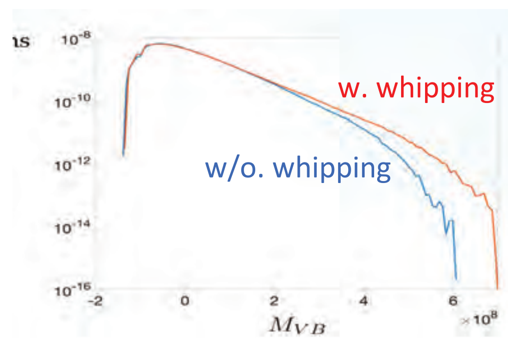
Dr. Themis Sapsis is the Doherty Associate Professor of Mechanical and Ocean Engineering at MIT, where he has been on the faculty since 2013. He received a diploma in Ocean Engineering from Technical University of Athens, Greece and a Ph.D. in Mechanical Engineering from MIT. Before becoming faculty at MIT, he was a Research Scientist at the Courant Institute of Mathematical Sciences, New York University, where he worked on stochastic methods for turbulence. Dr. Sapsis' work lies on the interface of nonlinear dynamical systems with probabilistic modeling and data-driven methods. He has numerous contributions on the development of robust and efficient statistical prediction algorithms that account for challenges and constraints imposed by real world problems, primarily in ocean engineering applications. He has published in the areas of uncertainty quantification for turbulent fluid flows in engineering and geophysical systems and his methods & algorithms have been extensively adopted and applied by others in fields such as data assimilation and filtering, CFD and optimization, probabilistic dynamical systems and others. A particular emphasis of his is the formulation of mathematical methods predicting and statistically quantifying extreme events in complex engineering and physical systems (i.e. extreme ship motions, mechanical vibrations, rogue waves in the ocean, and hot-spots in turbulence). His work was featured by major news organizations, including the BBC and The Economist. He is the recipient of three Young Investigator Awards (Naval-, Army- and Air-Force- research office), as well as the Alfred P. Sloan Foundation Award for Ocean Sciences.

Research Abstract

Analytical approximations are derived for the pdf for vertical bending moments (VBM) acting on the ship due to whipping effects. Last year's efforts had focused on the analysis of VBM statistics induced by static nonlinear interactions with water waves. It was shown that the nonlinear character of this interaction induces highly non-Gaussian tails. Based on a second order expansion, we were able to approximate analytically these non-Gaussian statistical features. This year we include the effect of slamming events (and induced whipping loads) on this analysis by first formulating the slamming events as an up-crossing problem. Using the ship characteristics and the statistics for pitch motion (which were studied thoroughly last year), we derive closed expressions for the frequency of slamming events. The intensity of these events depends on the impact force acting on the hull which is expressed in terms of the impact velocity using existing hydrodynamics results. The next step involves the analysis of the whipping response, using a standard beam approximation for the ship structure and maintaining only the first normal mode. The derived expression for whipping loads are synthesized with the static VBM loads using a decomposition-synthesis statistical method. The result is an analytical approximation for the VBM at any location of the ship, in terms of the hull geometry and the water waves spectrum. The form of this pdf will be discussed and connections with direct numerical simulations will be provided.







High-Reynolds Number Stratified Wakes

Dr. Tyler Van Buren
University of Delaware, Newark, DE

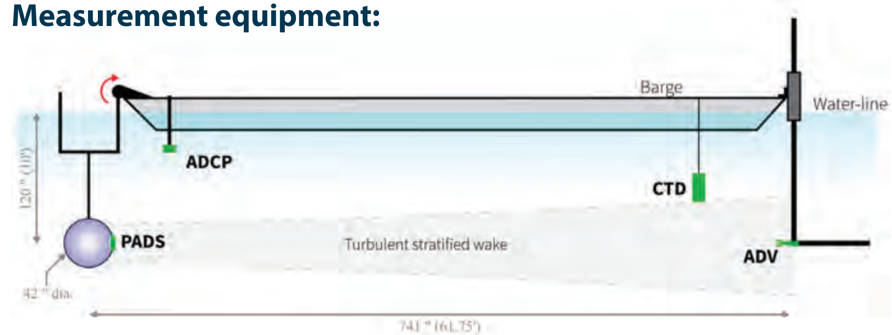
Professor Tyler Van Buren

Dr. Van Buren is an Assistant Professor in the Mechanical Engineering Department at the University of Delaware. His research group and studies systems that sense, respond to, and manipulate an unsteady fluid flow around them. These include flows that are unsteady purposefully (fish swimming) or chaotically (turbulence). Particularly, he focuses on bioinspired propulsion, wall-bounded turbulence, vortex dominated flows, and flow control. He received his Ph.D. from Rensselaer Polytechnic Institute (RPI) under the advisement of Prof. Michael Amitay. He then continued on to become a Research Scholar at Princeton University, under Prof. Alexander Smits, where his research covered unsteady aerodynamics/ hydrodynamics; drag reduction using hydrophobic surfaces; turbulent structure, stability, and stratification; and the interaction of living cells with turbulence.

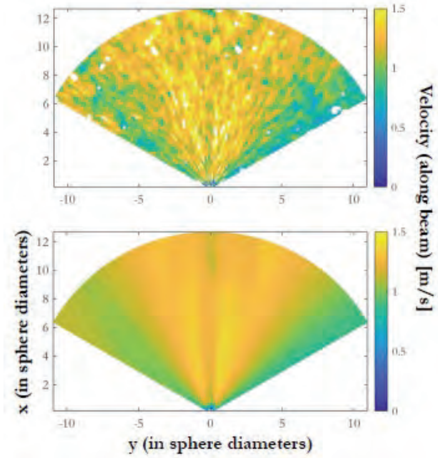
Research Abstract

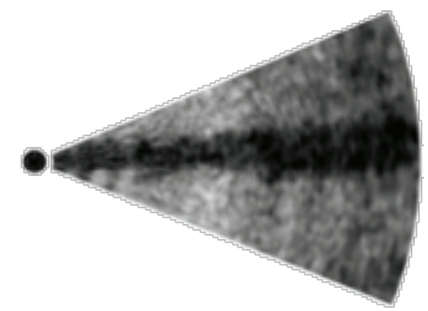
Perform unclassified data analysis on canonical stratified wake measurements that were completed at the Bangor Waterfront in June. Quantify uncertainty related to the individual measurement devices as well as the overall test setup. Develop data reduction tools to combine Phased Array Doppler Sonar (PADS), single-point turbulence, Acoustic Doppler Current Profiler (ADCP), and environmental data into a coherent data product.

Measurement equipment:

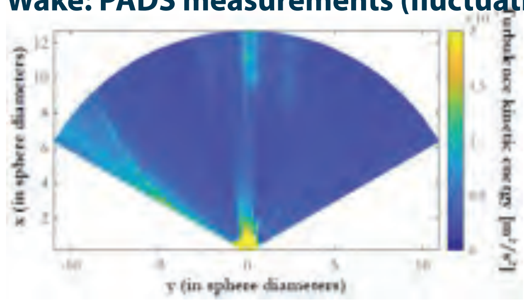


Wake: PADS measurements (mean flow)





Wake: PADS measurements (fluctuations)



Assessment & Improvement of Immersed Boundary Method in OpenFOAM

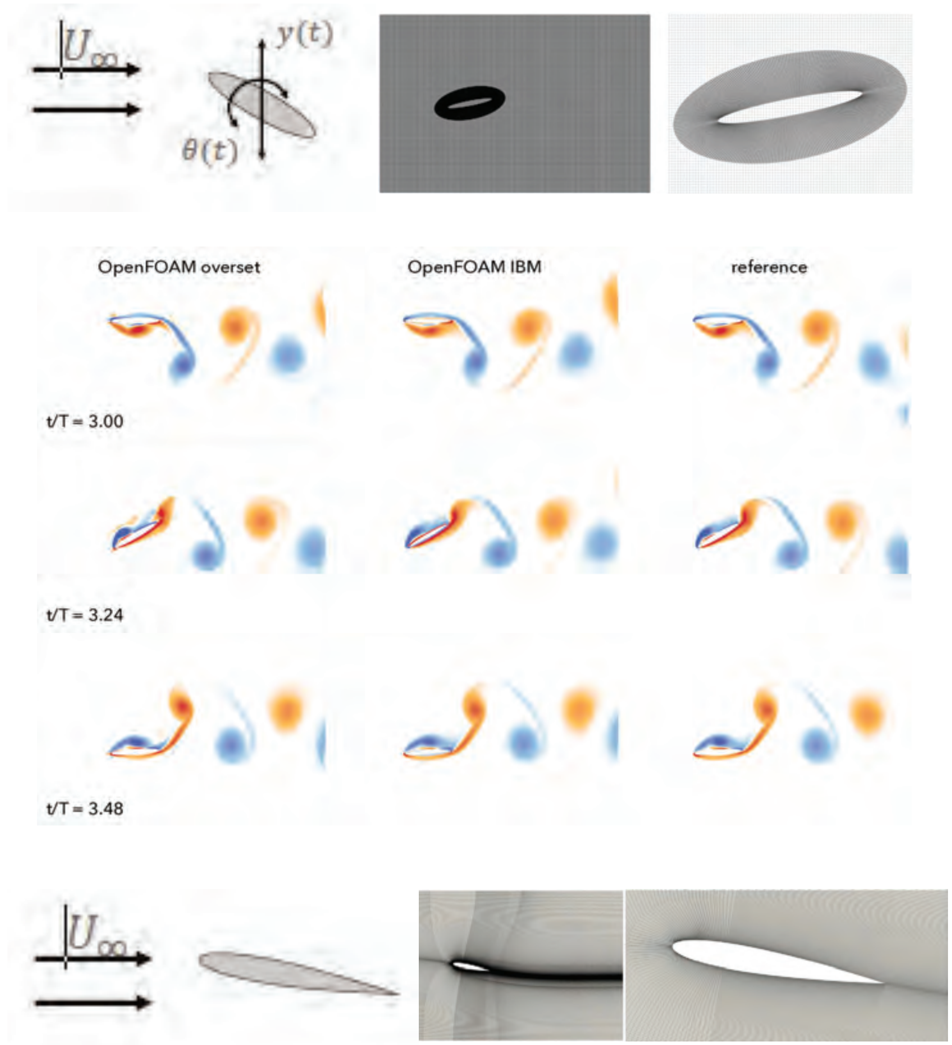
Dr. Wim van Rees
Massachusetts Institute of Technology

Professor Wim van Rees

Wim M. van Rees is Assistant Professor in the department of Mechanical Engineering at Massachusetts Institute of Technology. He is affiliated with the Center for Ocean Engineering and is currently the MIT Sea Grant Doherty Professor in Ocean Utilization. He received his BSc and MSc from Delft University of Technology in Marine Technology, and his PhD from ETH Zurich in 2014. In 2015, he performed research as a postdoctoral fellow in the School of Engineering and Applied Sciences at Harvard University, and joined the MIT faculty in 2017. His main research interests are to apply advanced numerical simulations to solve bio-inspired forward and inverse problems in fluids, solids, and fluid-structure interaction. He has applied these ideas in the fields of vortex dynamics, design and control of biolocomotion, and non-linear elasticity of plates and shells. His vision for future research is to exploit bio-inspired active and passive deformation of flexible structures in fluid flows for actuation, locomotion, and renewable energy harvesting. In 2020, he received an Early Career Award from the Department of Energy for his research on multi-resolution embedded boundary flow solvers.

Research Abstract

This project focused on extending OpenFOAM with an immersed boundary method (IBM). In the IBM, the body is represented through a set of Lagrangian markers or a scalar distance field. This allows a single computational grid to be used throughout the entire simulation, even if the body undergoes large motion or deformation. The effect of the body on the flow is incorporated by adding a distributed forcing term to the governing flow equations in the immediate vicinity of the body-flow interface. The force distribution is chosen so that the flow satisfies the no-through and no-slip boundary conditions. This approach circumvents the meshing issues related to complex geometries, and bodies that are moving or deforming due to fluid-structure interactions.



Fabrication, Characterization, and Application of High-Rate Electrode Materials

Dr. Cunlei (Peggy) Wang
Florida International University, Miami FL

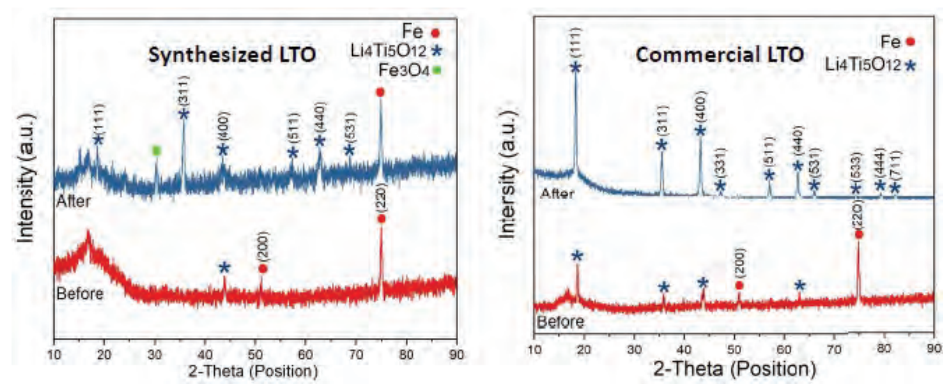
Professor Cunlei Wang

Chunlei Wang is a full professor in the Mechanical and Materials Engineering Department at Florida International University (FIU). She received her PhD (1997) in Solid State Physics from Jilin University. Before joining FIU on 2006, she held various research positions at Osaka University and University of California Irvine. At FIU, her group focuses on the development of micro and nanofabrication methods for building novel micro and nanostructures and synthesizing nanomaterials that have unique structures and useful properties for energy and biological applications. She has published about 150 peer reviewed journal papers. She is a recipient of FIU faculty award in research and creative activities (2013), FIU Kauffman Professor Award (2009), and DARPA Young Faculty Award (2008). She was also a co-founder of Carbon Microbattery Corporation (now: Enevate Corp), a consultant at Intel Lab (2012), a guest scientist at Max Planck Institute (2012-2013), a visiting professor at Jilin University (summer, 2016-2018), a visiting professor in the Alabama Transportation Institute (ATI) at University of Alabama (2019), and a JSPS fellow at Kochi University of Technology (2019). Since spring 2020, she has been working at NSWCCD as a Sabbatical and Summer Faculty Fellow.

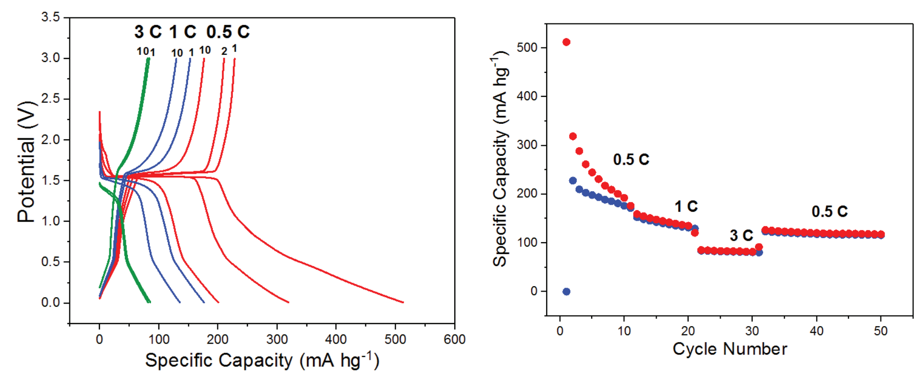
Research Abstract

Develop basis for two proposals in collaboration with NSWC Carderock researchers focusing on (1) Fabrication and Characterization of Hetero-structured 2D Electrode Materials by Bipolar electrochemistry, and (2) Development of Fast Charging and High Energy Density Li-Ion Batteries. In particular, (1) Characterize 2D Materials (graphene and black phosphorene) using data derived from experiments at the XPS Facility at NSWCCD. The samples under investigation include graphene, black phosphorene, and black phosphorene/graphene composites, synthesized by the bipolar electrochemistry (BPE) approach. Symmetric super-capacitors based on the composites will be constructed and evaluated. Examine correlations of surface functionality and charging/discharging behavior (e.g. memory effect). (2) Develop Fast Charging and High-energy Density Li-Ion Battery Materials using Electrostatic Spray Deposition. Synthesize electrostatic spray deposited LTO/Si/Graphene anodes and nickel rich NMC (such as 523, 622, or 881811) cathodes. Examine, select, and characterize suitable electrolyte materials. Conduct full cell evaluation using both FIU and NSWCCD facilities.

ESD Based Full Cell



ESD Based LTO Anode



Multi-Physics Models of Lithium-Ion Batteries Undergoing Abuse Conditions

Jiajun Xu, Ph.D.
University of the District of Columbia

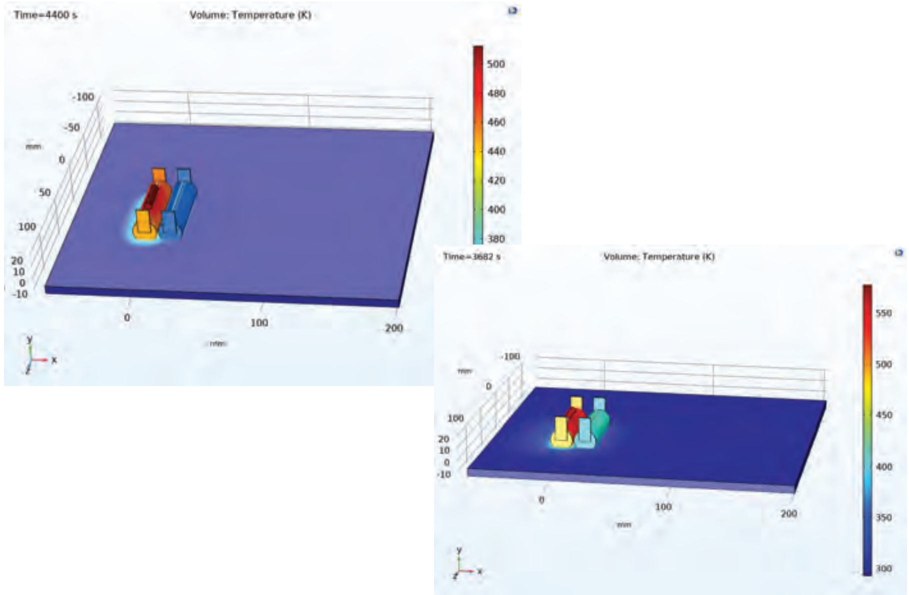
Professor Jiajun Xu

Dr. Jiajun Xu is an Associate Professor in the Department of Mechanical Engineering and the director of Center for Advanced Manufacturing at the University of the District of Columbia (UDC). He is also a registered Professional Engineer in the state of Maryland. He received his Ph.D. in Mechanical Engineering from University of Maryland-College Park. His current research interests include the following: (I) in-situ characterization and multi-scale modeling of energy transport inside nanostructured materials, (II) thermal management and energy conversion using nano-enhanced phase change materials, (III) in-situ monitoring and process optimization of direct metal laser sintering (DMLS) based additive manufacturing, and (IV) environment-friendly wastewater treatment using nanoparticle infused mesoporous materials. His current research is sponsored by National Aeronautics and Space Administration, National Science Foundation, Department of Defense, Department of Energy, and U.S. Department of Agriculture.

Research Abstract

Lithium-ion batteries (LIB) have found a wide range of applications in the last 25 years including consumer products, electric vehicles, grid storage, and the military. The United States Navy and Marine Corps have various applications requiring LIB, and safety is one the primary considerations for shipboard carriage or integration. One of the most important safety considerations for LIB is their behavior under various abuses such as incipient failure due to manufacturing imperfections, exposure to heat, external short circuit, and mechanical abuse. Several exothermic reactions can occur as the inner cell temperature increases, and if the heat generation is larger than the dissipated heat to the surroundings, this leads to heat accumulation in the cell and acceleration of the chemical reactions, which can then lead to a thermal runaway. Therefore, much effort has been focused on understanding the progression of thermal runaway in LIB under abuse conditions, and how to model and predict behavior. Based upon previous work that has successfully developed multi-scale models (i.e., electrochemical and thermal-mechanical models) for modeling the thermal runaway inside large-format LIB, this study focus on how to model and predict temperature distributions within packs of cells based on various battery-pack design constraints. In the current study, a multi-physics model of LIB is developed using COMSOL Multi-physics simulation software and the model is also validated using experimental cell data collected at NSWC-Carderock. The temperature distribution within a simplified LIB cell pack is also developed to assess various battery-pack design constraints, and it will provide useful insights on future experimental design of LIB pack.

Simulation Results IV



Study and Prototyping of Prussian Blue based Mediator Supercapacitor

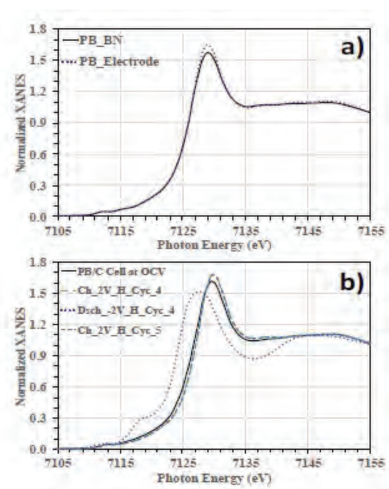
Dr. Xiangyang Zhou
Florida International University, Miami FL

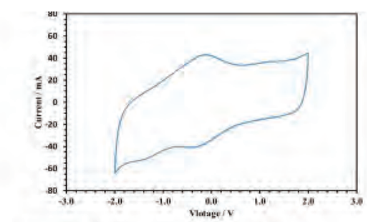
Professor Xiangyang Zhou

Dr. Xiangyang Zhou is currently a Professor in Department of Mechanical and Aerospace Engineering, University of Miami. Professor Zhou obtained his B.S. in Physics at Wuhan University (Wuhan, China) in 1984, his M.S. (1988) in Materials Engineering at the Institute of Metal Research, Academy of Science (Shenyang, China), and his Ph.D. (1996) in Manufacturing Engineering at the University of Newcastle upon Tyne (UK). Professor Zhou worked as a Research Associate at the Institute of Metal Research, Academy of Science (China). He was a Post-Doctoral Scholar at Center for Advanced Materials, Pennsylvania State University and a Research Associate at the Energy Institute at Pennsylvania State University. Professor Zhou was a Research Assistant Professor at the Applied Research Center at Florida International University from 2003 to 2005. Over the years Prof. Zhou has received more than $3 million in funding for several research projects. He has been cited in more than 800 journal articles and publications.

Research Abstract

The first goal of the present research was to define the effect of Prussian blue (PB) as a mediator in supercapacitors and to elucidate the mechanisms of redox reactions during the charge/ discharge process. The second goal is to develop the process for fabricating a porotype with a large capacitance of 80 F. PB was synthesized using a wet chemistry method and a solid state asymmetrical supercapacitor was fabricated with the configuration of (active carbon)/polymer electrolyte membrane/ (active carbon+PB). A KCl saturated Ag/AgCl reference electrode was inserted in the cell to monitor the potentials of the positive and negative electrodes during the charge/discharge process. Both the Electrochemical Impedance Spectroscopy (EIS) and Cyclic Voltammetry (CV) measurements indicate that the supercapacitor had a capacitor-like behavior. Upon negative polarization of the PB-containing electrode the specific capacitance was increased 60-110% while upon positive polarization, there was a much less enhancement of the specific capacitance. The potentials of the two electrodes versus the reference electrode were displaced proportionally with increasing the voltage of the cell. X-ray photo- electron spectroscopy (XPS) results indicate that the potassium concentration in PB is 0.5 at% suggesting that iron ions have valence close to +3. In situ X-ray absorption spectroscopy (XAS) characterization results indicate that upon positive polarization of the Pb containing electrode a small degree of redox activity occurred. On the other hand, upon negative polarization of the PB-containing electrode-initiated, significant degree of redox activity occurred due to reduction of Fe3+ to Fe2+. Both the XPS and XAS results are consistent with the electrochemical measurement results. A process was established to fabricate SC prototypes with a large capacitance of 80 F. A prototype was tested using EIS and galvanostatic charge / discharge measurements. The prototype was cycled between zero to 3 V for 8000 times. More than 80% of its initial capacitance was retained.





CV with scanning rates of 10 mV s^{-1} of *In-stiu* XAS measurement

Summary of XPS Composition of various mediators

Sample	C	N	O	K	Fe
$K_4Fe(CN)_6$	40.7	22.8	9.8	22.5	4.2
$K_3Fe(CN)_6$	43.8	26.5	6.6	18.5	4.7
$KFeFe(CN)_6$	46.1	27.2	13.3	0.5	12.9

Both Fe ions are +3, so they only can be reduced during negative polarization, and on large redox reaction during positive polarization.

Featured Summer Intern Innovation Projects

The Naval Research Enterprise Internship Program (NREIP) interns from the Office of Naval Research (ONR) were hosted remotely with Carderock mentors this year. There were 44 total interns, 3 of which were hosted by 2 separate mentors in the Structures Division of the Platform Integrity Department. The remaining 41 were hosted by the Center for Innovation in Ship Design (CISD) which devised a digital internship program. The program consisted of splitting the interns into small groups of four or five led by a NSWCCD junior engineer team leader. The CISD staff assembled seven projects that presented unique Naval Engineering challenges and require innovative thinking to solve. The projects are non-Navy missions and developed entirely from sources in the public domain to ensure the data presented, derived, and produced remains cleared for public release. Each intern team spent two weeks performing three of the seven projects during the eight-week internship. For the remaining two weeks,the interns explored work completed at Naval Surface Warfare Center Carderock Division (NSWCCD), interviewed for employment opportunities, received lectures related to the US Navy, and became acquainted with their teammates, colleagues, and mentors. The success of the program relied heavily on robust video communication tools for large group meetings to ensure an intimate and personal experience, meeting the standards of a CISD NREIP program.

The goal was to provide a digital NREIP program for college students from across the country. The program is exposing these students to the type of work conducted at Carderock, engaging and exposing them to Naval Engineering exercises, recruiting future workforce, and promoting the innovation, flexibility, and robustness of the NREIP program across academia. CISD has nearly two decades of experience in hosting successful summer internship programs. CISD's reputation and success with NREIP consistently lead to the recruitment and retention of future workforce for NSWCCD.

CISD Director

Michael Bosworth

Michael Bosworth

Michael Bosworth is the Director of the Center for Innovation in Ship Design (CISD). He is a graduate of the U.S. Naval Academy and served for twenty years as a naval officer. After retirement, Mr. Bosworth serves as senior naval architect and program manager in the Ship Concepts and Design Group in NAVSEA (SEA 05D), rebuilding and restructuring the Naval Advanced Concept and Technologies program.

He began Division Director of the Ship & Force Architecture Concepts Division (SEA 05D1). Mr. Bosworth was assigned SEA 05 as Technical Director and later its deputy director. He became the Science and Technology Director for PEO LCS (now Unmanned and Small Combatants, USC), and recently transferred to NSWC Carderock Division where he serves as CISD Director.

SUMMER MENTORS

Michael Alban – CISD Deputy Director

Rachel Luu – CISD Intern Coordinator

Haley R. Kirby – CISD Intern Assistant Coordinator

Senior Mentors

Paul Collier, *RCN Exchange Officer to NSWCCD*

Anthony Madalena, *(Acting) Director of Operations, CISD*

Jack Ingram, *UK ESEP Engineer to NSWCCD*

Raju Datla, *Summer Visiting Professor, Stevens Institute of Technology*

Jaime Corzo, *Mechanical Engineer, Code 651*

Jenna Nunes, *Mechanical Engineer, Code 88*

Richard Meyer, *Mechanical Engineer, Code 86*

Skylar Stephens, *Ocean Engineer, Code 654*

Ben Grisso, *Mechanical Engineer, Code 654*

Florida Institute of Technology

FAMU-FSU College of Engineering

UD

HARRISBURG UNIVERSITY OF SCIENCE AND TECHNOLOGY

GEORGE MASON UNIVERSITY

Cornell University

RIT ROCHESTER INSTITUTE OF TECHNOLOGY 1829

FAU FLORIDA ATLANTIC UNIVERSITY

UNIVERSITY OF MARYLAND 1856

UNIVERSITY OF SOUTH CAROLINA

STEVENS INSTITUTE OF TECHNOLOGY THE INNOVATION UNIVERSITY 1870

VT VIRGINIA TECH

UNIVERSITY of VIRGINIA

UNIVERSITY OF MICHIGAN

HAMPDEN SYDNEY COLLEGE 1776

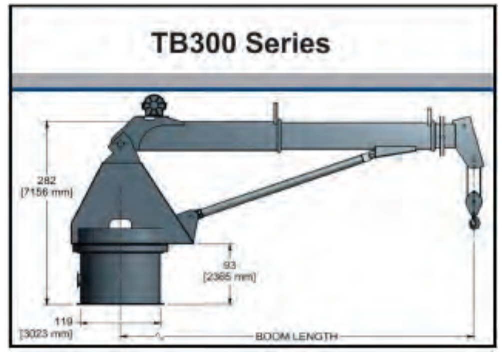
VIRGINIA STATE UNIVERSITY SINCE 1882

RENSSELAER POLYTECHNIC INSTITUTE 1824

Crane Integration

Mentor: LCDR Paul Collier, RCN Exchange Officer to NSWCCD

Teams: 1, 2, 3, 5, 9



Project Objective

Replace the aft lifting equipment on the T-ARS 50 class, which will be decommissioned and replaced by the modern T-ATS.

Project Description:

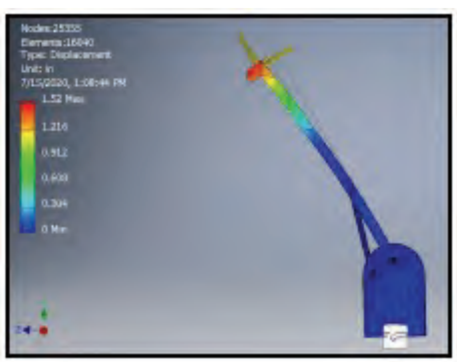
To simplify operation and increase reliability, replace the aft boom system with a crane of similar lifting capabilities currently installed on the T-ARS 50. Propose courses of action for a new crane including, but not limited to:

- Size the basic crane structure, gear and determine the requirements of the mechanical system
- Maintain ship capability and improve if possible
- Quantify all ship impacts for this integration
- Present a selection matrix assessing the designs and justify recommendations.

The Fire TRUNC (Telescopic Retractable Utility Nautical Crane)

Deliverables

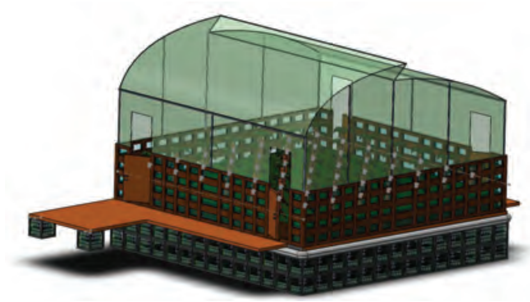
Selection matrix with details on cranes investigated and selection recommendation, presentation on ship integration of selected crane.



Specific References

- USNS NAVAJO (T-ATS 6) Class Towing, Salvage, and Rescue Ship by Chris Paulus, APM PEO Ships – PMS325.
- Guide for Certification of Lifting Appliances published by ABS in January 2018.
- Department of Defense Interface Standard for Shipboard Systems Section 301A Ship Motion and Attitude. Published July 1986

Sea Level Rise



Mentor: Tony Madalena, (Acting) Director of Operations, CISD

Teams: 1, 4, 5, 6, 8, 9

Project Objective

Research, develop requirements, conceptualize, and down-select portions of a Distro A maritime engineering design for rising sea levels to assist countries or cities located in low lying coastal areas.

Project Description:

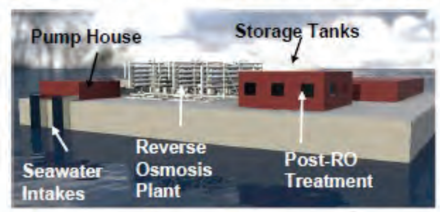
The team received background information on climate change and the subsequent rise in sea levels and face challenges to understand how to address the issues. There are several 'different twists', and the team will choose any of the following: land/coastal terraforming, mobile maritime solution, underwater habitats, uninhabited location, or own unique proposed solution.

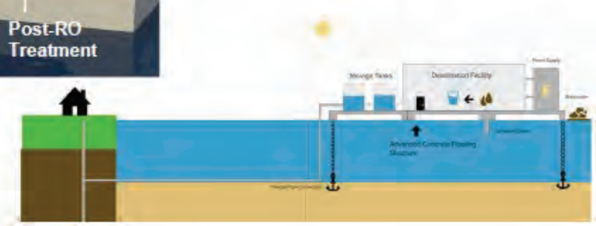
Deliverables

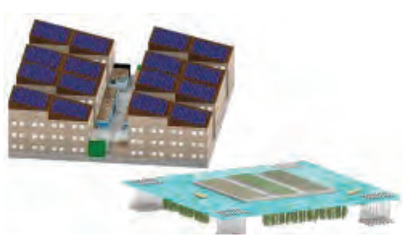
Present individual/group research. Produce as many rudimentary concepts with down-select after the first week for one concept to evaluate further. Final deliverable is a suggested and tentative design, presentation to senior staff/judges on final days, and brochure selling their design to perspective countries for acquisition.

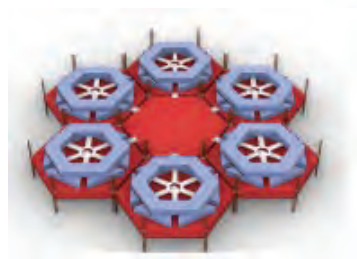
Floating City Project

Floating Littoral Operation Aquatic Treatment Structure (FLOATS)





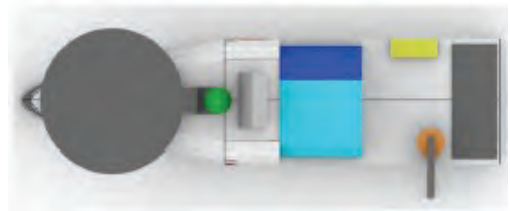




Specific References

- https://www.independent.co.uk/environment/islands-sea-level-rise-flooding-uninhabitable-climate-change-maldives-seychelles-hawaii-a8321876.html
- https://advances.sciencemag.org/content/4/4/eaap9741
- https://coast.noaa.gov/slr/#/layer/fld/0/-8556105.862192767/4573934.423837723/7/satellite/none/0.8/2050/interHigh/midAccretion
- https://www.climatecentral.org/news/report-flooded-future-global-vulnerability-to-sea-level-rise-worse-than-previously-understood
- https://www.thenation.com/article/archive/climate-military-navy-flooding/
- https://climate.nasa.gov/vital-signs/sea-level/

Buoy Launch & Recovery Support Craft



Mentor: Jack Ingram, UK ESEP Engineer to NSWCCD

Teams: 2, 3, 4, 7, 8, 10

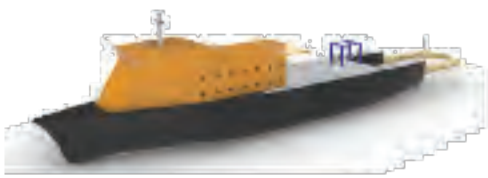
Project Objective

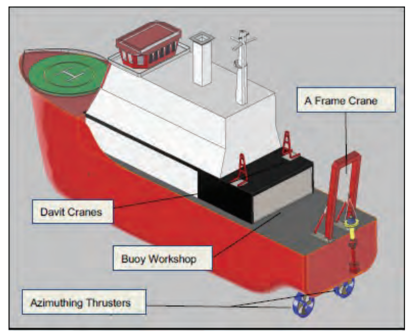
To develop a viable pre-concept design for an Ocean Monitoring Device Support Vessel Capable of transporting launching and recovering a variety of ocean going platforms.

Project Description:

The purpose of this project is to develop a ship to support a variety of ocean going platforms. The ship design will be capable of supporting the devices by transporting to the monitoring area, replenishment, repair, and refueling in the operational area. The operating area is to be determined, but will be one of the following Atlantic Ocean environs:

- The UK-Iceland Gap
- The Gulf of Mexico
- The Northwest Passage



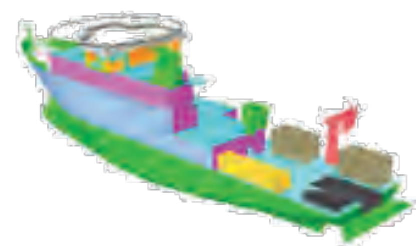


Top: Stern view of BWB Vessel; Bottom: Bow view of BWB Vessel

Deliverables

A design of a multipurpose civilian support ship. A stability analysis is not necessary, however elementary (first-year naval architecture level) resistance and powering assessment expected along with internal and topside layout development. Deliverables will be in the form of a brochure (max four pages) offering the ship to the customer (CISD Staff). The brochure should include key characteristics and capabilities it can offer to governments, non-governmental organizations, and industry. At the conclusion of the project, the team will brief a presentation on the design and process.

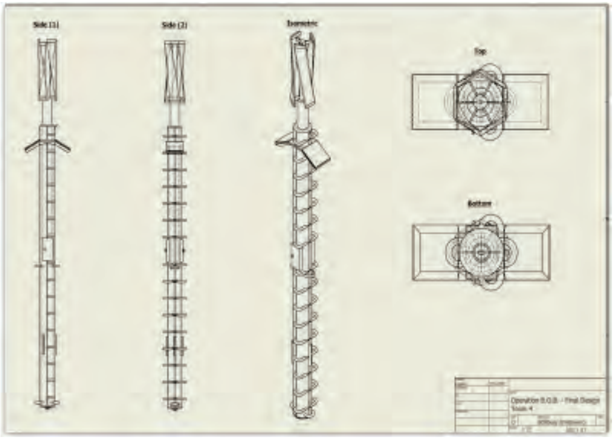
The Twin Hull Marine Buoy-Tender [THuMB]



Specific References

- Concept Design Handbook for Surface Ships Revision 2.0. Surface Ship Design and Systems Engineering Group NAVAL SEA SYSTEMS COMMAND (SEA 05D). June 14th 2013. This document is already cleared for public release.
- Intro to Naval Architecture Principals. Michael Alban. Cleared for public release May 2020.

Sea Monitoring Buoy fleet



Mentor: DR Paul Collier, RCN Exchange Officer to NSWCCD

Teams: 2, 4, 7, 10

Project Objective

To design reconfigurable persistent loitering ocean observation capability.

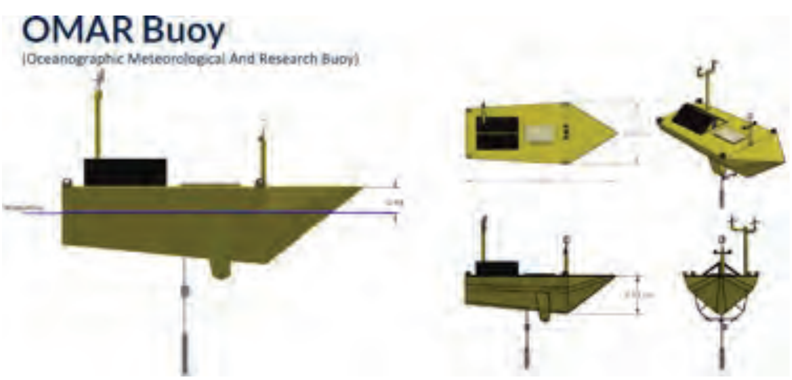
Project Description:

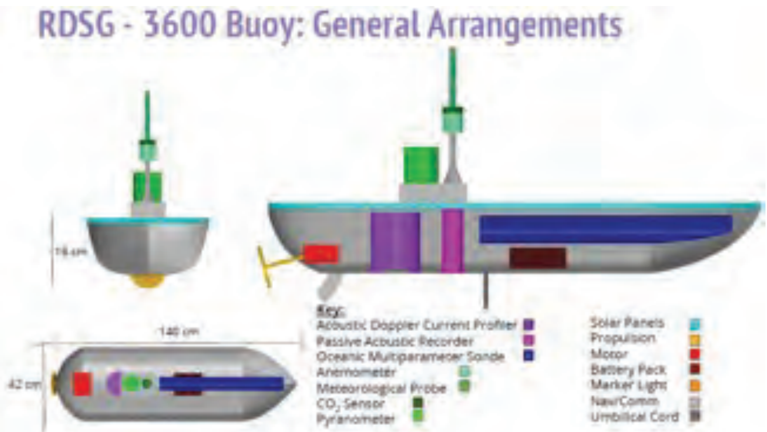
The purpose of this project is to develop a body that can monitor various at sea variables depending on the mission. These include collecting meteorological, oceanographic, water quality parameters, act as a navigational aid, track the migration patterns of aquatic life, and marine traffic. The device will be required to operate autonomously for no less than 60 days without manual intervention under prescribed environmental conditions; contact via uplink for data download/mission change is acceptable; any manual intervention such as charging or refueling at sea as an SS3 threshold.

Rubber Duck Surface Glider - 3600 Buoy

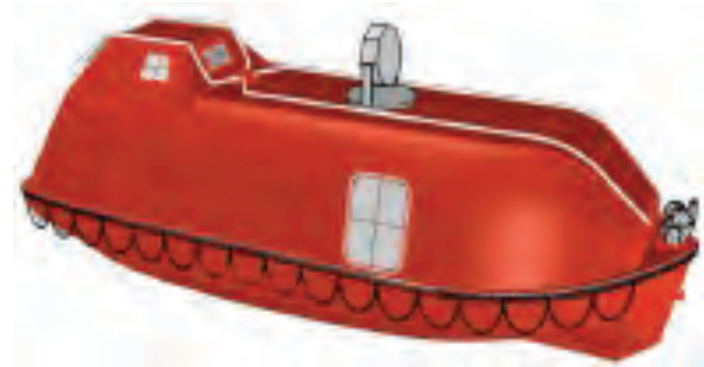
Deliverables

A design of a reconfigurable ocean module (stability analysis is not expected). Deliverable a sales brochure(max four pages) offering the device. The brochure should include key characteristics and capabilities it can offer to governments, non-governmental organizations, and industry. A short presentation is also required.





Autonomous Lifeboats



Mentor: Jaime Corzo, Mechanical Engineer, Code 651

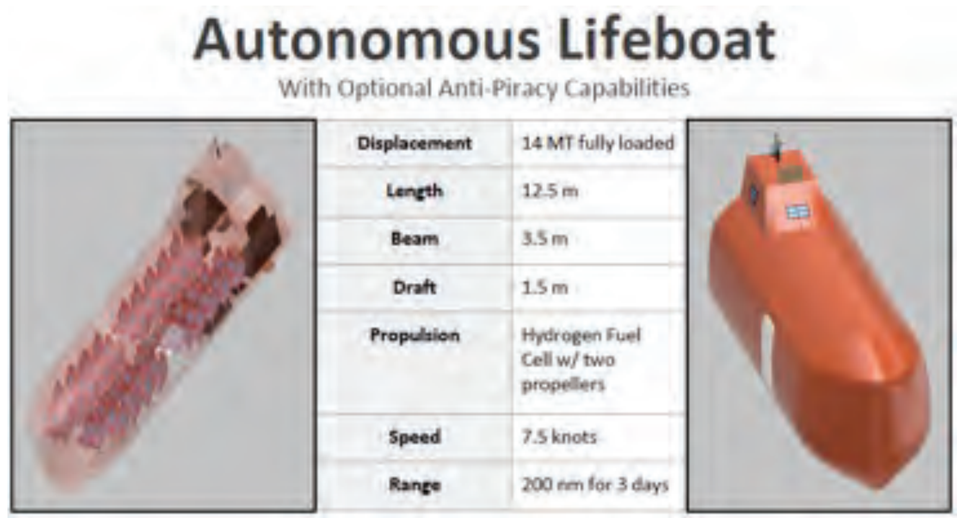
Teams: 6, 8, 10

Project Objective

To design a concept for an autonomous lifeboat capable of safely self-deployment, search-and-rescue, and high survivability under extreme conditions.

Project Description:

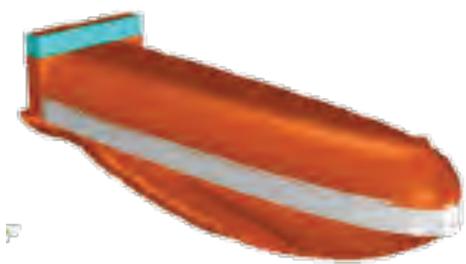
The purpose of this project is to develop an autonomous lifeboat that is automatically deployed with minimum human intervention and can serve as search-and-rescue. Crews are better utilized to help passengers evacuate the ship without having to worry about controlling the lifeboats. On cargo ships transiting through dangerous places, unmanned lifeboats could be used as pirate deterrents. Cruise ships utilize lifeboats to ferry passenger on places where the cruise ship cannot dock. An autonomous lifeboats system can help make this process more efficient for cruise ship companies.



Displacement	14 MT fully loaded
Length	12.5 m
Beam	3.5 m
Draft	1.5 m
Propulsion	Hydrogen Fuel Cell w/ two propellers
Speed	7.5 knots
Range	200 nm for 3 days

Deliverables

A report describing the system architecture and capabilities and the operational concept. Final deliverable is a suggested and tentative design, presentation to senior staff/judges on final days, and brochure selling their design to commercial companies for acquisition



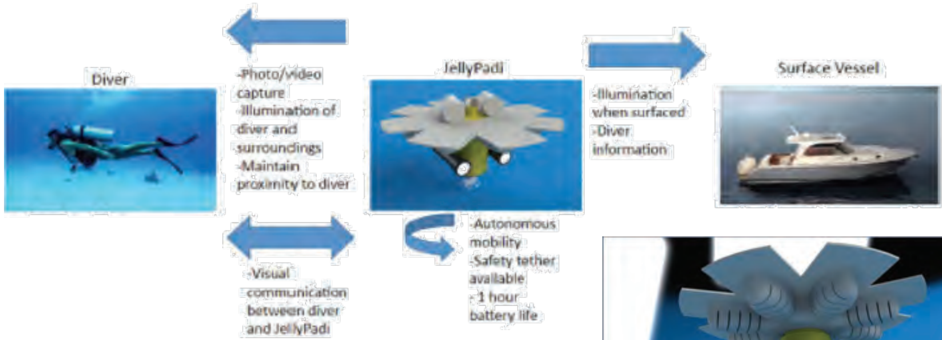
Specific References

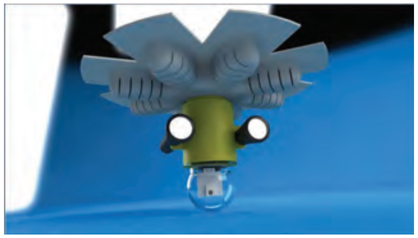
- The design and development of modern lifeboats. Hudson, Hicks, and Cripps. Pennsylvania State University. May 2018 http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.882.2568&rep=rep1&type=pdf
- Robert Allan Unveils Latest Self-Righting SAR Lifeboat Design. gCaptain. July 2013. https://gcaptain.com/robert-allan-unveils-latest-self-righting/
- Navy to Contract New Class of Unmanned Surface Vehicle by Year's End. LaGrone, Sam. USNI. https://news.usni.org/2019/03/06/navy-contract-new-class-unmanned-surface-vehicle-years-end

Sea Jelly Glider

Mentor: Jenna Nunes, Mechanical Engineer, Code 88

Teams: 1, 3, 9





Project Objective

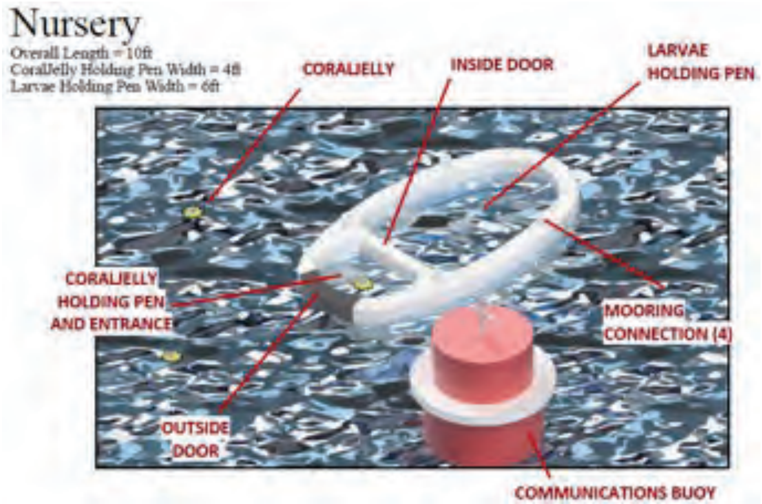
To design a concept for biomimetic platform mimicking a jellyfish for long range ocean monitoring similar to a sea glider. Design energy harvesting capabilities into the Sea Jelly.

Project Description:

The purpose of this project is to develop an autonomous long endurance energy scavenging biomimetic platform. The design will be constrained to a submerged platform mimicking the motions and form factor of a jellyfish. This is an extension of the existing and already cleared NSWCCD STEM Project Sea Jelly. This will be a larger persistent ocean-monitoring submersible. Fundamentals in submersible design will be examined as part of the Sea Jelly investigation.

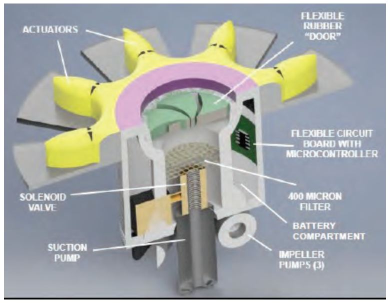
Deliverables

A report describing the system architecture and capabilities and the operational concept. Final deliverable is a suggested and tentative design, presentation to senior staff/judges on final days, and brochure selling their design as a long range Sea Jelly capable of extended endurance and energy harvesting.



Specific References

- NSWCCD STEM Project Sea Jelly already cleared for public release. https://www.navsea.navy.mil/Home/Warfare-Centers/NSWC-Carderock/STEM-Outreach/STEM-Programs/SeaJelly/
- Biomimetics: lessons from nature–an overview. Bhushan, Bharat. April 2009. https://royalsocietypublishing.org/doi/10.1098/rsta.2009.0011
- Changing Face Of Drone Warfare: Robot Sharks. Sutton, HI. November 2019. https://www.forbes.com/sites/hisutton/2019/11/06/changing-face-of-drone-warfare-robot-sharks/



Humanitarian Aid Sea Plane

Mentor: Richard Meyer, Mechanical Engineer, Code 86

Teams: 5, 6, 7

Project Objective

To design a concept for a Sea Plane capable of providing disaster relief to areas hit by hurricanes or earthquakes where ports or harbors are destroyed, damaged, or unusable

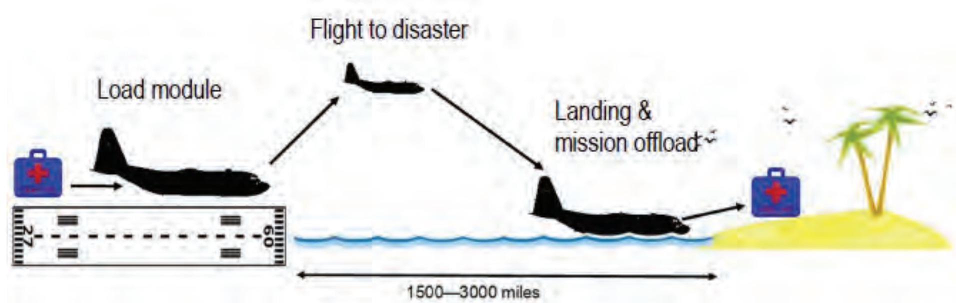
Project Description:

The purpose of this project is to develop a long endurance, high payload Sea Plane to provide disaster and humanitarian aid to countries affected by natural disasters. The design is for a scenario in which runways, ports, and harbors are unavailable. A seaplane can quickly and efficiently fly to aid a country as a first response to a disaster bringing supplies, power, and first responders. The team will be responsible for determining the payload, capabilities, and design of a seaplane. This will be a progressive project with each group of interns building on the previous group's design/requirement choices.

Mother Goose 576 Render

Deliverables

Group 1: a presentation and paper outlining the concept of operations of a seaplane designed for disaster relief. Group 2: Development of requirements of a seaplane capable of completing the previously designed concept of operations. Group 3: Concept design meeting requirements and CONOPs previously derived. All three groups will still need to present their individual findings to the senior staff at the end of each cycle and the larger audience at the conclusion of the effort.



Specific References

- Seaplanes: The Beginning. Alman, David. January 2018. https://www.navalhistory.org/2018/01/31/seaplanes-the-beginning
- Validation of Seaplane Impact Load Theory and Structural Analysis of the Martin 270. Sell, Carrie. December 2011. University of New Orleans These and Dissertations. 1365. https://scholarworks.uno.edu/cgi/viewcontent.cgi?article=2397&context=td
- General Aviation Aircraft Design: Applied Methods and Procedures. Gudmundsson, Snorri. 2013. Elsevier. https://booksite.elsevier.com/9780123973085/content/APP-C3-DESIGN_OF_SEAPLANES.pdf

Structural Design Optimization via Producibility

Mentor: Skylar Stephens
Teams: 11A

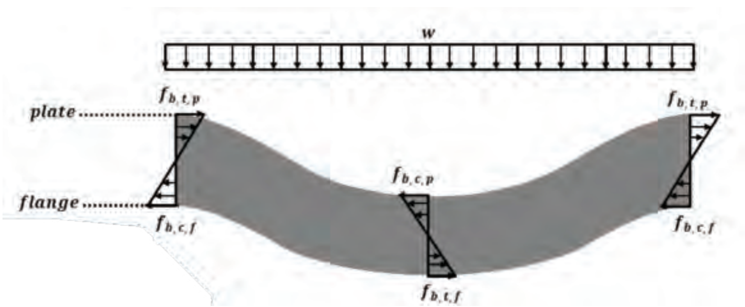
This team explored two project paths, as follows:

Producibility:

- Is there a way to quantify the metrics?
- How do you put this into code form?

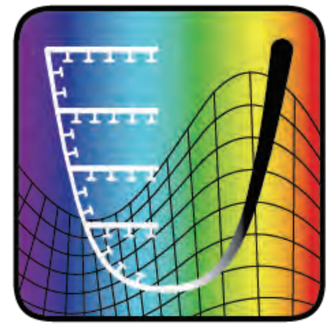
Software Integration:

- Verification
- Validation
- Algorithm Creation

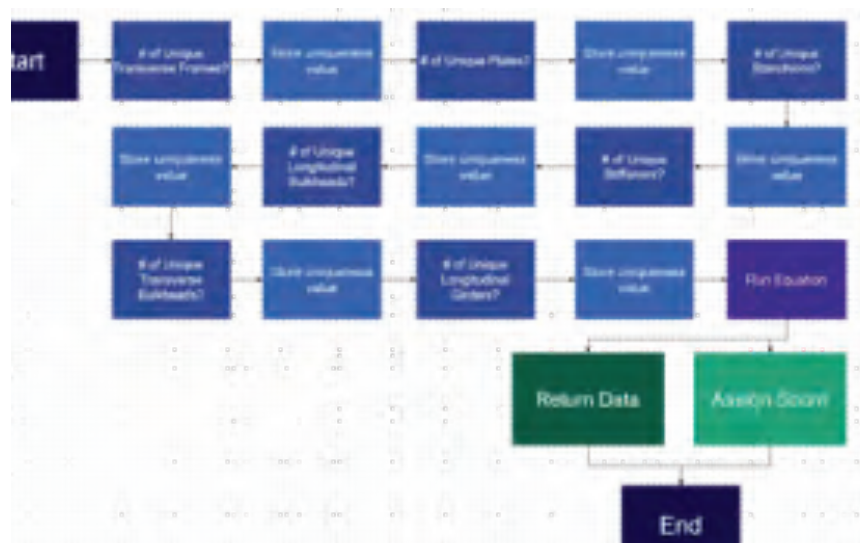


Navy needs to design robust and versatile ships while also addressing the following in concept design:

- Production engineering
- Lean Design (LD) Objectives
- Total Ownership Cost



Unique Piece Parts Flowchart Algorithm



Multi-Model Data Assimilation (MMDA)

Mentor: Dr. Ben Grisso

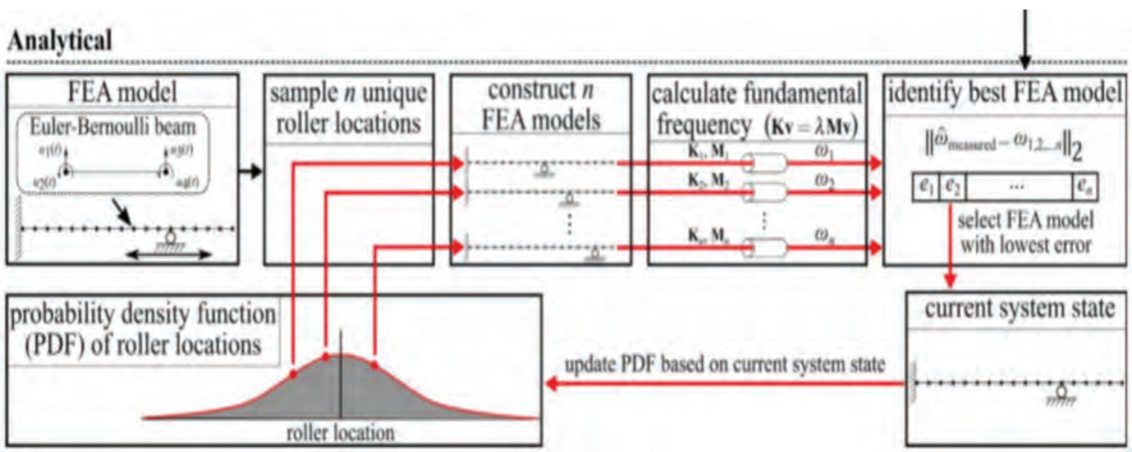
Teams: **11B**

- A key challenge in implementing digital twins for naval ship is the amount of data that needs to be updated into different models.
- Dynamic Data Driven Application System (DDDAS)- Measurements drive the simulations and vice-versa.
- Simultaneously update multiple models. This is used for decision-making from real-time to life-span of the ship.

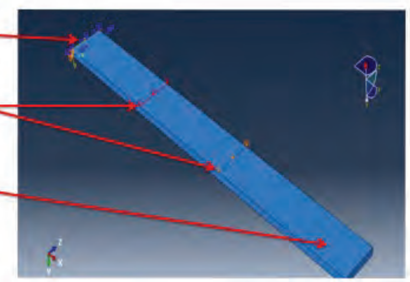
Plan of Execution:

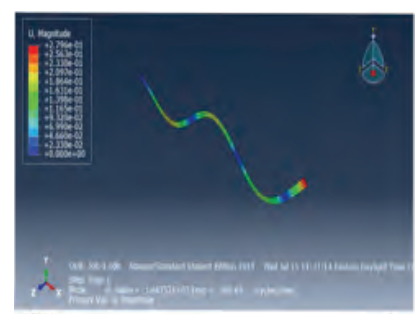
- Task 1: Build FEA model.
- Task 2: Build Python function.
- Task 3: Develop a model updating technique.

Update an FEA model of the "Smart Beam" in real time.



- Hinge (top left)
  - Only a Z rotation
- Stepper motors (middle lines)
  - Fixed lines across width
- Shaker force (bottom right)
  - Single point sinusoid load





Team #1

Kylon Payne, *Team Lead*

Elizabeth Garner
Cornell University, *Electrical Engineering*

Hunter LeClair
Virginia Tech, *Materials Engineering*

Timothy McIntyre
University of Maryland College Park
Mechanical Engineering

Alex Wiggins
Stevens Institute of Technology, *Naval Engineering*

Project Assignments:

- **Crane Integration**
- **Sea Jelly Glider**
- **Sea Level Rise**

Team #2 (Team Rubber Ducks)

Olivia Roe, *Team Lead*

Philip Pullen
Hampden Sydney College, *Engineering Physics*

Andrew Sherwood
University of Maryland College Park
Mechanical Engineering

McKenna Steele
Virginia Tech, *Ocean Engineering*

Paco Yeung
University of Maryland College Park
Mechanical Engineering

Philip Pullen

Andrew Sherwood

Project Assignments:

- **Buoy Launch & Recovery Support Craft**
- **Crane Integration**
- **Sea Monitoring Buoy fleet**

McKenna Steele

Paco Yeung

Team #3 (The Fray)

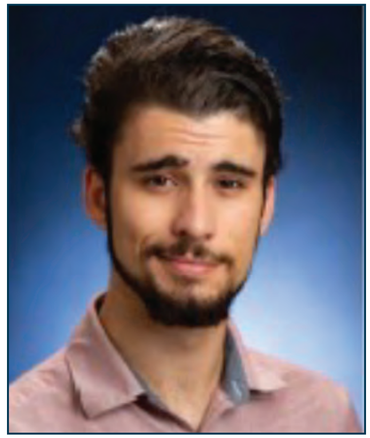
Marc Carlo, *Team Lead*

Max Anstine
Stevens Institute of Technology, *Naval Engineering*

Shane Carroll
Virginia Polytechnic Institute and State University
Ocean Engineering

Troyan Chaney
Harrisburg University of Science and Technology
Interactive Media

Sam Murphy
Stevens Institute of Technology, *Naval Engineering*

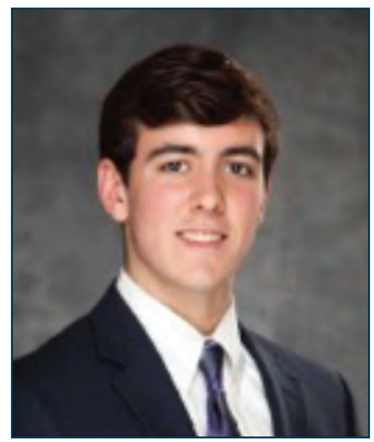

Max Anstine


Shane Carroll

Project Assignments:

- **Sea Jelly Glider**
- **Buoy Launch & Recovery Support Craft**
- **Crane Integration**


Troyan Chaney


Sam Murphy

Team #4

Andrew Hicks, *Team Lead*

Mitchell Bowser
University of South Carolina
Mechanical Engineering

Joshua Graham
Stevens Institute of Technology
Naval Engineering

Gabija Karosas
Florida Institute of Technology
Ocean Engineering

Jade Sherrod
FAMU-FSU College of Engineering
Industrial Engineering

Mitchell Bowser

Joshua Graham

Project Assignments:

- **Sea Level Rise**
- **Sea Monitoring Buoy fleet**
- **Buoy Launch & Recovery Support Craft**

Gabija Karosas

Jade Sherrod

Team #5

Greg Miller, *Team Lead*

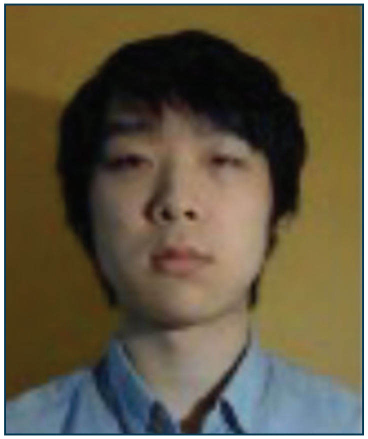
Tyler Armstrong
Stevens Institute of Technology, *Naval Engineering*

LeeYung Chang
University of Virginia
Aerospace Engineering

David Fehrle
Virginia Tech, *Aerospace Engineering*

Jack Ognisty
University of Maryland College Park
Mechanical Engineering


Tyler Armstrong


LeeYung Chang

Project Assignments:

- **Humanitarian Aid Sea Plane**
- **Sea Level Rise**
- **Crane Integration**


David Fehrle


Jack Ognisty

Team #6

Madeleine Koerner, *Team Lead*

Jeremy Cain
Virginia Tech, *Aerospace Engineering*

Trevor Conklin
University of Maryland College Park
Mechanical Engineering

Daniel Flanick
University of Maryland College Park
Aeronautical Engineering

Amanda Fosbrook
Florida Atlantic University, *MS Ocean Engineering*

Lukas Hyde
University of Michigan,
Naval Architecture & Marine Engineering

Project Assignments:

- **Autonomous Lifeboats**
- **Sea Level Rise**
- **Humanitarian Aid Sea Plane**

Jeremy Cain

Trevor Conklin

Daniel Flanick

Amanda Fosbrook

Lukas Hyde

Team #7

Justin Freyburger, *Team Lead*

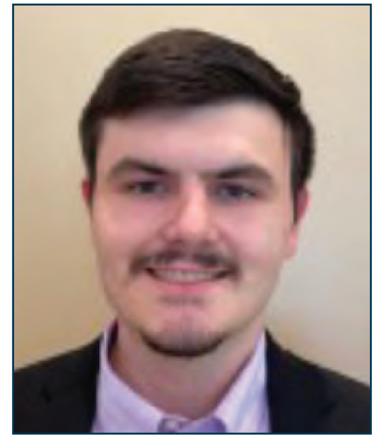
Connor Arrigan
University of Michigan
Naval Architecture & Marine Engineering

Austin Colbert
Stevens Institute of Technology, *Naval Engineering*

Xavier Nguyen
Virginia Tech, *Aerospace Engineering*

Aaron Tice
Rensselaer Polytechnic Institute
Mechanical Engineering

Connor Arrigan



Austin Colbert

Project Assignments:

- **Sea Monitoring Buoy fleet**
- **Buoy Launch & Recovery Support Craft**
- **Humanitarian Aid Sea Plane**

Xavier Nguyen

Aaron Tice

Team #8 (Team Gr8)

Marcus Thaw, *Team Lead*

Tyler Ellis
Virginia Tech
Ocean Engineering Major
Naval Architecture Minor

Julia Jenkins
Florida Institute of Technology
Ocean Engineering Major
Business Administration Minor

Frances Lee
Cornell University
Electrical & Computer Engineering Major
Mechanical Engineering Minor

Gillian Lee
University of Maryland College Park
Electrical Engineering

Tyler Ellis

Julia Jenkins

Frances Lee

Gillian Lee

Project Assignments:

- **Buoy Launch & Recovery Support Craft**
- **Autonomous Lifeboats**
- **Sea Level Rise**

Team #9 (Team Leviathan)

Davius Dupree, *Team Lead*

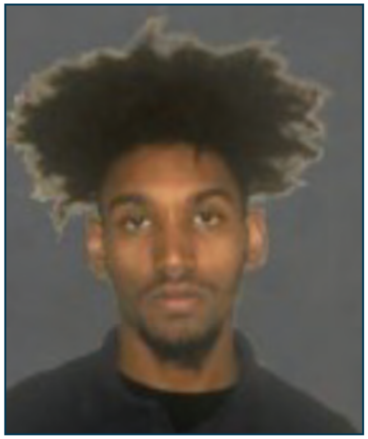
Regan Alex
Virginia Polytechnic Institute and State University
Ocean Engineering

Salaah Alston
Virginia State University, *Mechanical Engineering*

Danielle Maynard
George Mason University
Mechanical Engineering B.S.
Computational Science M.S.

Britney Wang
Rochestor Institute of Technology
Electrical Engineering

Regan Alex

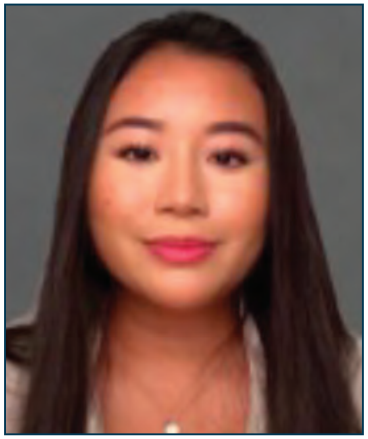


Salaah Alston

Project Assignments:

- **Sea Level Rise**
- **Crane Integration**
- **Sea Jelly Glider**

Danielle Maynard



Britney Wang

Team #10

Niel Alam, *Team Lead*

Edward Angelinas
University of Michigan
Naval Architecture & Marine Engineering

Claire Brizzolara
University of Delaware, *Applied Mathematics*

Andrew Falsone
Virginia Tech, *Ocean Engineering*

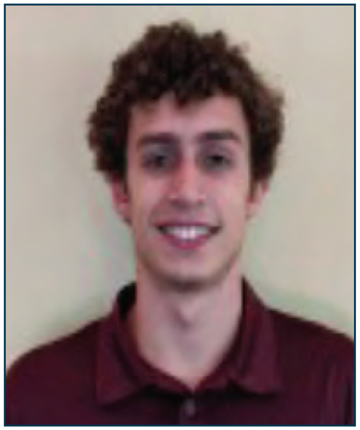
Kyle Mummey
University of Maryland College Park
Mechanical Engineering

Edward Angelinas

Claire Brizzolara

Project Assignments:

- **Buoy Launch & Recovery Support Craft**
- **Sea Monitoring Buoy fleet**
- **Autonomous Lifeboats**



Andrew Falsone

Kyle Mummey

Team #11A

Need, *Team Lead*

Meredith Blanco
Virginia Tech, *Ocean Engineering Major*
Computer Science, Naval Engineering, & Math Minors

Vivek Nathan
University of Maryland College Park
Mechanical Engineering Major
Technology Entrepreneurship Minor

Meredith Blanco

Vivek Nathan

Project Assignments:

- **Structural Design Optimization via Producibility**

Team #11B

Jason Smith
University of South Carolina, *Mechanical Engineering*

Project Assignments:

- **Multi-Model Data Assimilation (MMDA)**

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