



Carderock Division

**NAVAL SURFACE WARFARE CENTER, CARDEROCK DIVISION
9500 MacArthur Blvd., West Bethesda, MD 20817**

**FY08 IN-HOUSE LABORATORY INDEPENDENT RESEARCH (ILIR)
AND INDEPENDENT APPLIED RESEARCH (IAR) ANNUAL REPORTS**

ILIR and IAR Director:

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DEPARTMENT OF THE NAVY
NAVAL SEA SYSTEMS COMMAND
NAVAL SURFACE WARFARE CENTER
CARDEROCK DIVISION

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From: Technical Director, Naval Surface Warfare Center,
Carderock Division
To: Office of Naval Research, ILIR Program Director
Subj: NSWC CARDEROCK DIVISION IN-HOUSE LABORATORY INDEPENDENT
RESEARCH (ILIR) PROGRAM FY08 ANNUAL REPORT
Ref: (a) ONRINSTR 3900.37b
Encl: (1) NSWC ILIR Annual Report for Fiscal Year 2008

1. In accordance with reference (a), the annual report on the accomplishments, impacts, and management of the Naval Surface Warfare Center, Carderock Division's In-House Laboratory Independent Research Program for fiscal year 2008 is enclosed.

2. If you have any questions regarding the ILIR Program, please contact Dr. John Barkyoub, ILIR/IAR Program Manager, at 301-227-1275 or via e-mail at john.barkyoub@navy.mil

C. RANDY REEVES

**NSWC CARDEROCK DIVISION FY08
IN-HOUSE LABORATORY INDEPENDENT RESEARCH (ILIR)
AND INDEPENDENT APPLIED RESEARCH (IAR) ANNUAL REPORTS**

I. Executive Summary and Program Management

The ILIR and IAR programs serve as a cornerstone of our Technology and Innovation program. The Technology and Innovation program at NSWCCD consists primarily of ILIR & IAR, our Innovation Center, Technology Stewardship program, ONR Visiting Faculty and Naval Research Enterprise Intern Program, our Bid and Proposal (B&P), and our Tech Transfer and Patent Portfolio Process. (The Innovation Center, Tech Stewardship, B&P and to a large extent patents, are funded through our internal discretionary overhead.)

The above programs (including ILIR and IAR) are managed at a Division level under the Director of Technology and Innovation. This gives coherence to the programs and allows us to exploit synergies in the programs to further our goals.

A key strength of our ILIR and IAR program is that each of the 5 technical Departments has an S&T coordinator who stewards and promotes ILIR/IAR within their respective Departments. The Department level is where hiring and decisions are made and the Department heads are best placed to work with the ILIR/IAR S&T managers to transition ILIR/IAR to programs of record. In this way we strive to get the maximum strategic benefit of the ILIR/IAR program to further our goals for mentoring, education, collaboration and high-risk, high-payoff research.

It is important to recognize that, as basic research, the results of this program can and should have implications across Division and Enterprise lines. The best way to do this is to foster collaborations. Dynamic external and internal collaborations are essential for maintaining the health and productivity of the ILIR and IAR programs. All projects have significant publications. Some of the metrics such as Ph.D. thesis research and book chapters are inherently collaborative. (The bibliographic numbers are listed in the Program Accomplishments section below.) Indeed one can make the case that the problems of importance to the Navy are inherently multidisciplinary and can only be best solved with a team approach.

The Carderock Division ILIR and IAR programs are executed in-house, and aligned with our technical capabilities. A summary abstract of all the FY08 projects is appended to this report with a detailed bibliography for each project.

II. ILIR/IAR Program Selection Process

The NSWCCD ILIR/IAR selection process is designed to best implement the investment strategy of fostering the highest quality research; focusing on Navy S&T investment goals, and supporting the mission of NSWCCD and NAVSEA.

Most ILIR and IAR proposals concepts originate with the Principle Investigator or team working with their management, program managers and colleagues. The submitted proposal is first evaluated by the originating Department and ranked relative to the vision of that Department where specific knowledge of ongoing programs and the relevant technologies resides. The written proposals are submitted to the NSWCCD Director of Research and circulated among all

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the departments electronically. This allows for opportunities to establish both internal and external collaborations. Proposals that make the departmental and initial Director of Research screening are presented orally to the NSWCCD Science Panel for evaluation. Each Science panel member submits a written evaluation of each proposal based on scientific quality, knowledge of the state-of-the-art in their field, innovation, payoff, transition potential and cooperation with scientists outside their immediate organization. The IAR process is identical to the ILIR process except that the reviewing panel is the Division Science and Technology Council. This Council is larger in size and has a broader technology stewardship charter for the Division than does the Division Science Panel. After both the ILIR and IAR presentations and evaluation, a strawman program is constructed based on the Department review and the scores of the Science Panel (ILIR) or Science and Technology Council (IAR). This proposed program is then briefed to the Science Panel for comment and then to the Division Technical Director and the Director of Technology and Innovation. Each proposed project is discussed and approved by the Technical Director and the Division Commander.

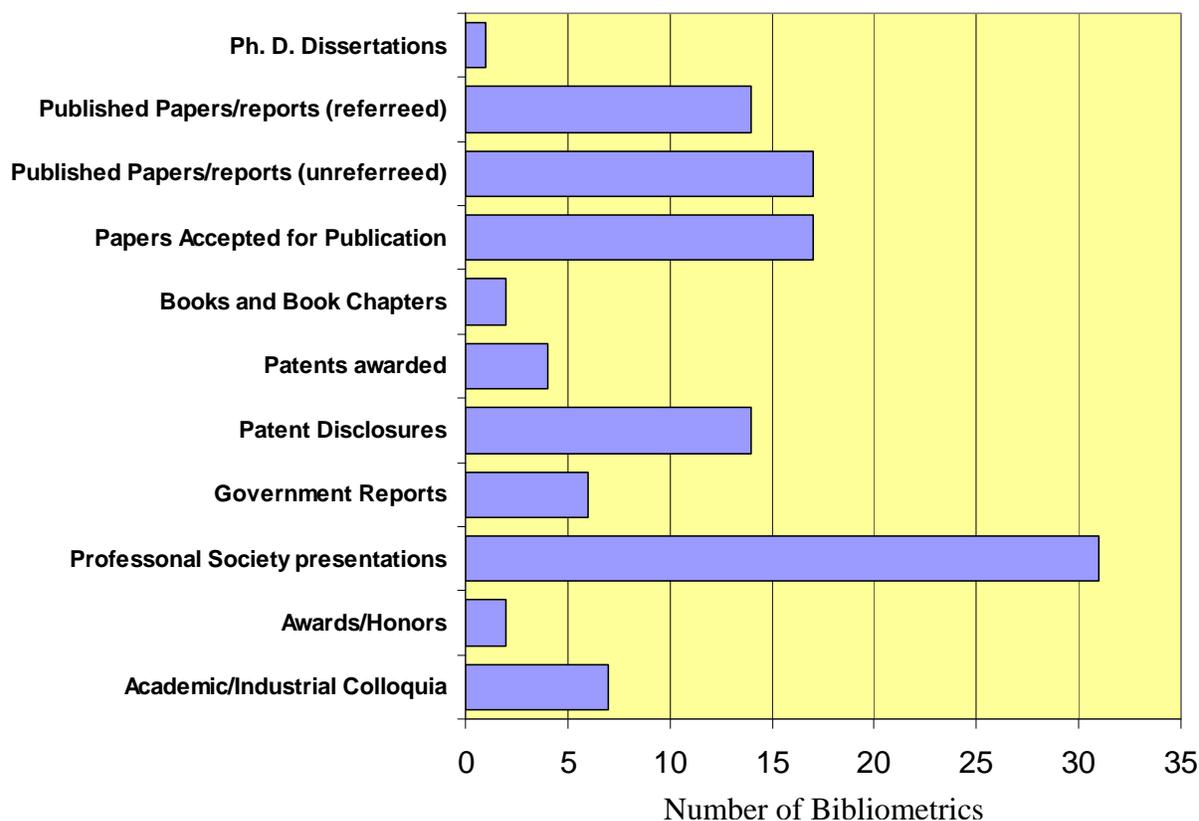
The above process insures that the top senior Navy technical experts have a voice in the program selection with the final selection made by the Division Director. In this way, buy-in is insured throughout the line management and support of the scientist to test his idea is broad-based. Each project is limited to three years unless very special circumstances warrant an extension.

Program balance is an important supporting criterion in the program selection process. Historically, the research program has been a bottom-up process where a bench scientist submits an idea for evaluation. This approach has the advantage that the principal investigator has a vested interest in the idea that promotes productivity. However, in rare circumstances, the senior management becomes aware of a special problem requiring immediate attention. In this case a top-down strategy is implemented where the Division Director will authorize forming a special team from his knowledge of his scientific staff's strengths. Balance in content is also important since all core areas should be represented in order to maintain a healthy organization. Although this is an important measure for the organization, it is secondary to scientific quality, potential payoff, and transition which are the prime factors governing the program selection. Appendix 1 has a breakdown of the ILIR and IAR programs by Navy S&T focus area as outlined in the Strategic Plan.

III. ILIR Program Summary Accomplishments

In FY08, the Carderock Division received \$2,209,000 in the ILIR program and \$890,000 in the IAR program. The ILIR program consists of 21 projects with an average of \$102 K per project. There were 9 ILIR and IAR researchers who were working on Ph.D. degrees using the ILIR research to fulfill their dissertation requirements. One Ph.D. was awarded in FY08. Each of these Ph.D. dissertation projects represents a true collaboration between NSWC Carderock and the University that hopefully will lead to further opportunities. In FY08 a total of 115 publications, presentations, patents and patent disclosures were produced from research performed in the ILIR and IAR programs as is detailed in the Figure 1 below.

Program Productivity (Bibliometrics)



We also have 8 demonstrable transitions from the ILIR and IAR programs.

FY08 ILIR PROGRAM TRANSITIONS

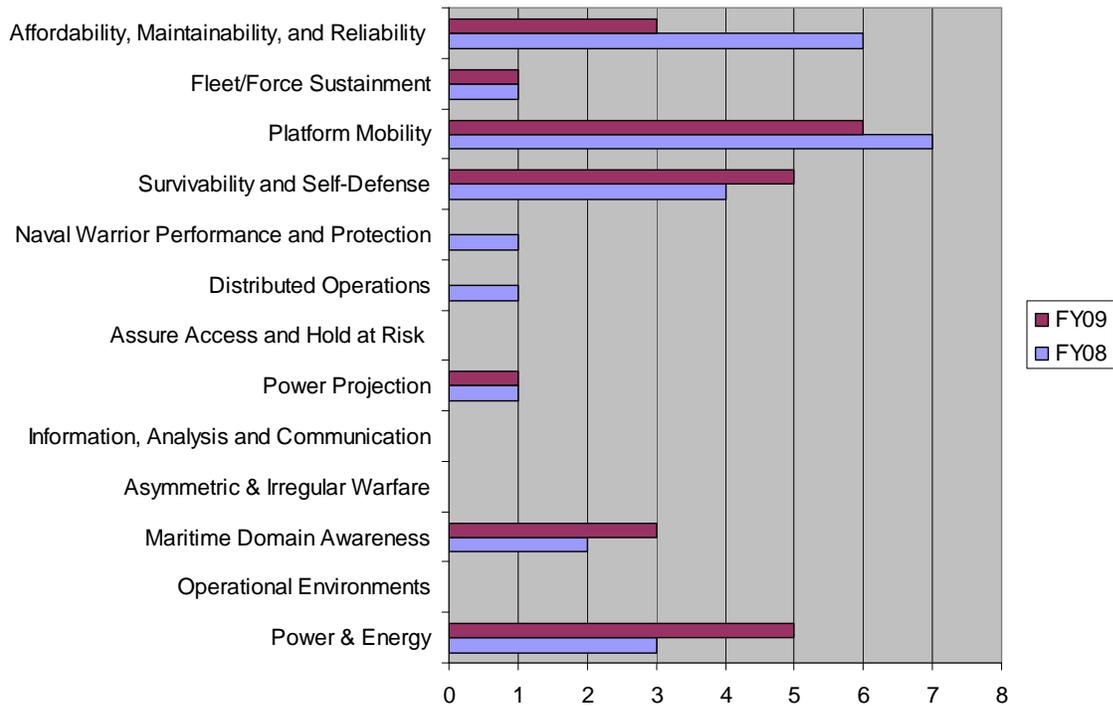
| ILIR PROJECT | PI | TRANSITION PROGRAM |
|--|----------|----------------------------|
| Investigation into Physiochemical Properties | Smith | ONR Supercapacitor Program |
| Iron-Based Magnetoelastic Interactions | Restorff | Etrema Products |
| Friction Stir Welding | Posada | PMS-LHA-6 |
| Friction Stir Welding | Posada | NAVSEA Tech Authority |
| Towards Design of Fouling-resistant Surfaces | Holm | VA Class |
| Towards Design of Fouling-resistant Surfaces | Holm | ONR Biofouling Program |
| Development of Advanced Surface Ship Topsides | Hess | USSV |
| Liquid Phase Desulfurization Sorbent Activity and Selectivity Maintenance Characterization | Heinzel | ONR 331 SOFC Demonstrator |

IV. Highlights and Scientific Impacts of the ILIR and IAR programs in FY08 are:

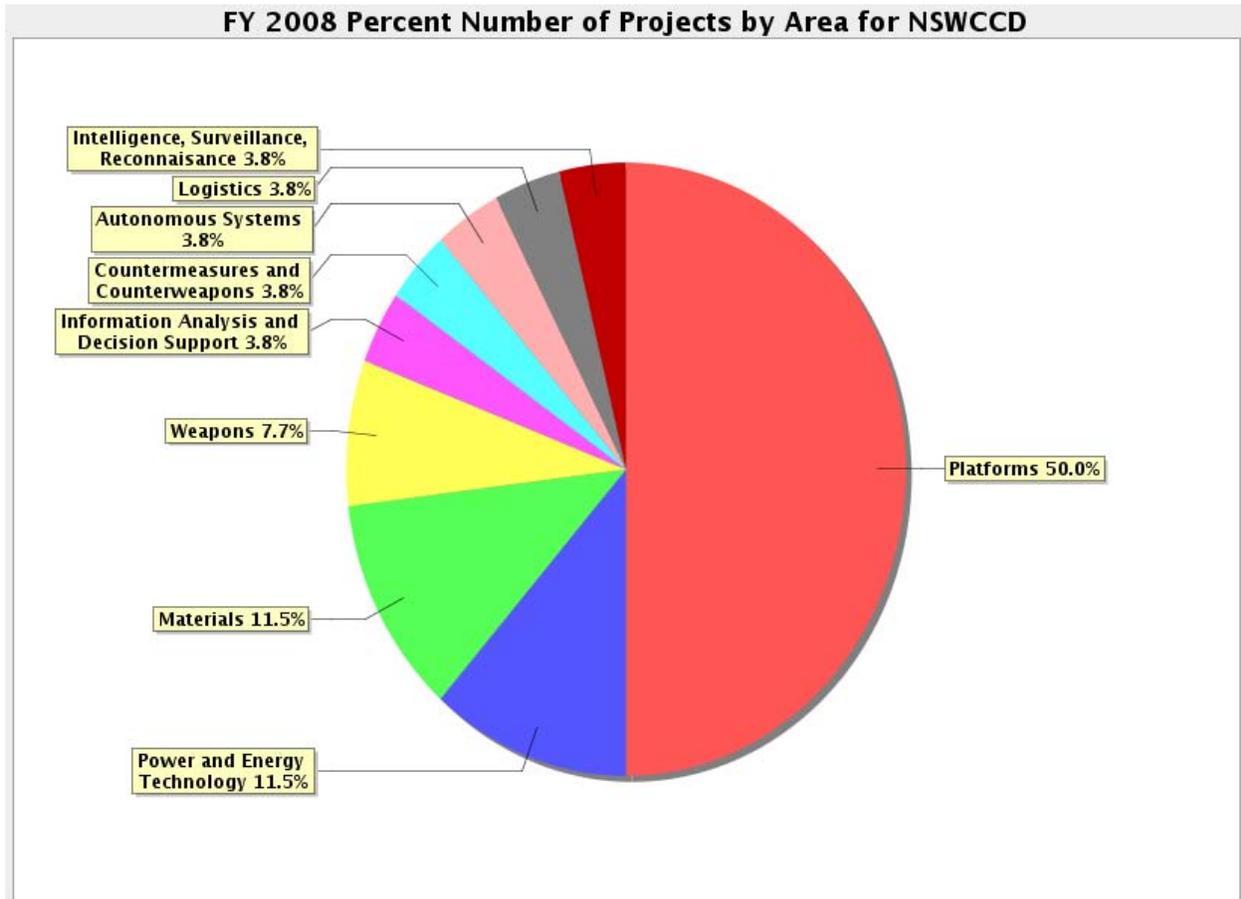
- 1) In the ILIR project “**Six-Degree-of-Freedom Ship Motion Model**” a computational tool was developed to predict viscous roll damping from first principles including bilge keels and appendages. A fundamental challenge in this work is that the appendage-wave interaction also generates sub-scale flow structures that are beyond numerical model resolution. To account for such effects, we developed a methodology similar to a traditional “wave-breaking mechanism”, with one explicit difference; the wave-breaking effect is considered based on the wave number instead of wave slope. This new approach was tested with landing craft (AAV7A1) data. Correlation of the numerical simulation with full scale data shows that the predicted effect of damping on the ship motion averages less than 5%. Sometimes it can be substantially higher: e.g. 20% or above. This tool also correctly predicted pitch instability and bow plow-in in the AAV7A1 that was validated through model testing. This more complete, high-nonlinear modeling capability has been applied to a number of active development and acquisition programs saving testing time and money. The research in this ILIR project has resulted in 15 refereed journal publications.
- 2) In the ILIR project “**The Role of the Plastic Deformation on High Impact Protection of Novel ERC Polyureas**”, polyurea coatings on steel plates have been observed to enhance the protective capability of the plate to withstand shock speed projectile impacts. The long term goal of our study is to provide an optimum impact protection polyurea coating to meet specific survivability requirements corresponding to given impact load and loading rate. This research uses small angle x-ray scattering (SAXS) simultaneously with tensile and recovered impact tests to obtain a fundamental understanding of the cause of the beneficial protective effect at the molecular level. From the FY08 work, we have indentified a possible mechanism for the polyurea coating on the plate. Our results show that the polyurea at the impacted site is plastically deformed and relaxes while more distant points are elastically deformed. The relaxation at the impact point implies a polyurea hysteresis that absorbs energy and is a possible mechanism in the protection of the metal plate. This research is an active collaboration with NSWC Dahlgren Division and continues work started in a CRADA with a major manufacturer of these coatings. A patent disclosure and a paper were produced this year documenting these advances.
- 3) The objective of the IAR project “**A Novel Propulsion System for Unmanned Underwater Vehicles**” is to develop and demonstrate a maneuverable and stealthy propulsion system for UUVs using the Hazelton cyclic pitch propulsor concept. In FY08 the initial demo vehicle testing was conducted in the Maneuvering and Seakeeping basin at NSWCCD Bethesda. Measurements were made of net hull forces and moments and compared to calculations and predictions performed in the first year of the program in FY07. Validation and refinement of the cyclic pitch propeller force models are underway. The preliminary controller development is in progress leveraging on UUV controller efforts at NUWC. A paper detailing these results was presented at the UDT Europe 2008 conference in Glasgow, England on June 10-12, 2008.

Appendix 1. – FY08 ILIR and IAR Projects by Research Area

COMPARISON OF FY08 AND FY09 NAVY S&T FOCUS AREAS

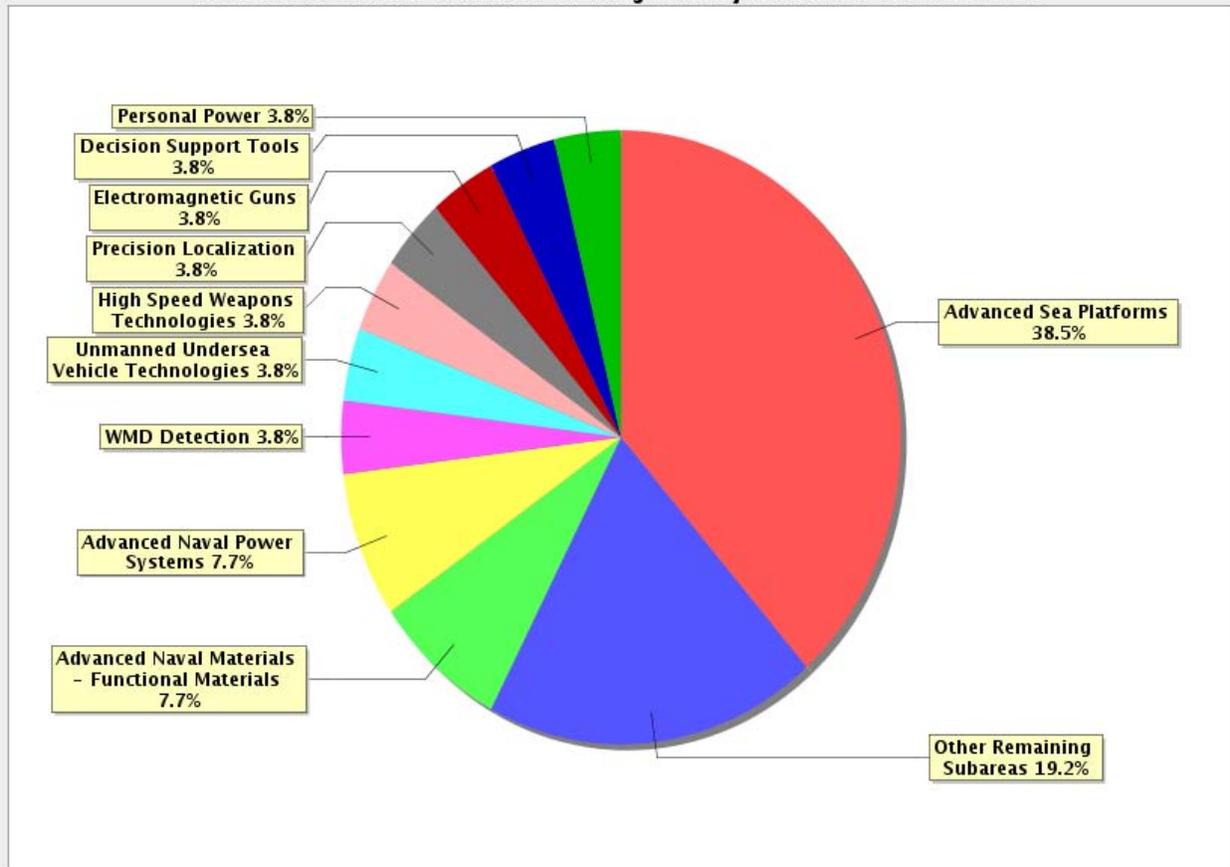


The above figure shows the breakdown of number of projects by Focus Area. This clearly shows that the Carderock Division primarily supports Platform Mobility, Affordability, Survivability and Power and Energy. This is consistent with our mission in Ships and Ship Systems and our Strategic Plan goals in high-speed vessels, mobility, and full-spectrum affordability and cost-savings. In FY08 there was increased emphasis in Maritime Domain Awareness and its connection to GWOT, power, and energy savings in response to guidance from ONR.



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FY 2008 Percent Number of Projects by Subarea for NSWCCD



Appendix 2. – FY08 ILIR Projects Project Summaries

FY08 ILIR PROJECTS

Title: *Development of computational methods to analyze impact forces from breaking waves*

Funding Year: New

Principal Investigator: Susan Brewton, Code 5400, NSWC Carderock
Phone: 301-227-5405 , E-mail Address: susan.brewton@navy.mil

Associate Investigators: Anne Fullerton, Code 5600, NSWC Carderock, and Ann Marie Powers, Code 653, NSWC Carderock

S&T Focus Area: Platform Mobility

Abstract: As the Navy moves toward higher speed ships and non-traditional structures on submarines and surface ships, it must also return to a better understanding of the impact loads these structures withstand under slamming and breaking waves. Recent experimental studies at the Naval Surface Warfare Center at Carderock and elsewhere have demonstrated that the impact load of a breaking or plunging wave may be more than twice the current design guideline of 1000 pounds per square foot. In the fleet, incidents of damage to the Dry Deck Shelter (DDS), the Advanced Swimmer Delivery System (ASDS), and submarine hatches provide anecdotal evidence that current designs need fundamental research to provide improved guidance for estimating extreme loads. This project seeks to build on initial experimental research on breaking wave loads by bringing the analysis into the computational realm using Reynolds Average Navier Stokes (RANS) codes. The project consists of four general phases: creating consistent, repeatable breaking waves; creating these waves so that they break on a surface to analyze impact forces; validating those impact forces with existing and additional experimental data; and exploring the scaling effects of the impact forces. The goal of the project is not only to gain a much clearer understanding of the fundamental physics of breaking waves and the loads they create, but also how to replicate these characteristics in a computational environment. This will allow the use of the computational capability to provide guidance for future fleet designs and to better couple our understanding of hydro loads on the structural considerations for ship design.

Bibliometric Information:

Published paper (Unreferreed)

Fu, T.C., A.M. Fullerton, S. Brewton, and D. Dommermuth, *An Experimental and Computational Study of Breaking Wave Impact Forces*, 27th Symposium on Naval Hydrodynamics, Seoul, KOREA, (5-10 October 2008)

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Kim, S-E., S W Brewton, *A multiphase approach to turbulent cavitating flows*, 27th Symposium on Naval Hydrodynamics, Seoul Korea, (October 2008)

Title: *Bow wave dynamics of simple model geometries in various incoming wave fields*

Funding Year: Second

Principal Investigator: Jason Carneal, Code: 5600, NSWC Carderock
Phone: 301-227-1540, E-mail Address: jason.carneal@navy.mil

Associate Investigator: Paisan Atsavapranee, Code: 5600, NSWC Carderock

Primary External Collaborations: Dr. James Duncan, University of Maryland

S&T Focus Area: Platform Mobility

Abstract: In recent years, there has been a specific interest in understanding and modeling bow wave dynamics and air entrainment around Navy vessels. Due to the complexity of these multi-phase flows, CFD computations still rely heavily on experimental data for the development of numerical models of the breaking and bubble generation mechanisms. Current measurements of bow wave breaking phenomenon have been limited to ship models traveling at forward speed in calm water. Even though breakers are naturally unsteady, the measurements are usually designed to capture only mean flow and do not consider the important effects of incident waves and ship motions. Full-scale measurements exist, but the measured data are of limited value due to the uncontrolled environments during the trial performance and limitations on measurement techniques available for use in the field. Therefore, there is a clear need for controlled experiments that capture the unsteady nature of bow wave breaking and include effects of incident waves. This experimental work examines the dynamics of the bow wave and air entrainment processes around simple hull geometries in regular head waves in both fresh and simulated seawater. Detailed time-resolved measurements of the surface wave profile and bubble entrainment will be performed over a range of forward speeds, incident wavelengths, and wave steepness' in fresh water and simulated seawater on each model. The mean and fluctuating components of the entrained air bubbles and features of the bow wave will be correlated with the mean and harmonics of the incoming wave field. This set of experiments will transition to the development of advanced measurement capabilities, future testing on realistic models, and provide data for the principal investigator's Ph.D. dissertation.

Bibliometric Information:

Published paper (Unreferreed)

Atsavapranee, Paisan, A. Engle, D. Grant, J. Carneal, T. Beirne, A. Etebari, *Full-scale investigation of viscous roll damping with particle image velocimetry*, 27th Symposium on Naval Hydrodynamics, Seoul Korea, (October 2008)

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Etebari, A., P. Atsavapranee, J. Carneal, S.Percival, D. Grant, C.H.Sung and I.Y.Koh, *Experimental measurements on a SUBOFF model in a turning maneuvering*, 27th Symposium on Naval Hydrodynamics, Seoul, Korea, (October 5-10, 2008)

Government Report

Atsavapranee, P., A.Etebari, J.Carneal, D. Grant, T. Forlini, S. Percival J. Hering, C.H.Sung and E.Ammeen,, *A Hydrodynamic study of a submerged body(SUBOFF) in rotation*, NSWCCD-50-TR-2008/030.

Carneal, J., S. Percival, A. Etebari, P. Atsavapranee, T. Farabee, M. Goody, *Optical bubble measurements in the breaking bow region of model 5488*, NSWCCD-50-TR-2008/054

Carneal, J., A. Etebari, A. Percival, *Typical derivation & application of two-dimensional particle image velocimetry uncertainty analysis procedures*, NSWCCD-50-TR-2008

Carneal, J., A. Percival, A. Etebari, P. Atsavapranee, T. Farabee, M. Goody, *Development of an optical measurement technique for determination of bubble population & size distribution*, NSWCCD-50-TR-2008/011

Title: *Six Degree of Freedom Ship Motion Model-Additional Development to Add Coursekeeping*

Funding Year: Third

Principal Investigator: Dr. Ray-Qing Lin, Code: 5500, NSWC Carderock
Phone: 301-227-3945, E-mail Address: ray.lin@navy.mil

Primary External Collaborations: Dr. Weijai Kuang, NASA GSFC Code 926,
Prof. R. W. Yeung, UC Berkeley.

S&T Focus Area: Platform Mobility

Abstract: Our goal is within three years (2006-2008) using new technology to add course keeping to the Six-degree Freedom Ship Motion Model (ILIR project 2003-2005). This will extend the current model, which allows modeling of a vessel at a constant speed and heading, to allow the modeled vessel to be steered either by control surface position (from model tests or full scale) or modeling of the control surfaces, that are in turn controlled by an auto pilot. This will allow prediction of ship motions which include the effects of control surface(s).

In FY06 we developed a nonlinear damping method, which is based on fundamental fluid dynamics blocking theory. This method can accurately model the effect of bilge keels on roll damping from the geometry of an arbitrary hull form in an arbitrary environment, and it is very computationally efficient (Lin and Kuang, 2006b). In FY06 we also examined the impact of experimental mass measurement errors to determine which measurements were least susceptible to measurement error. This examination evaluated the effect of errors in physical model mass measurements on numerical model results and determined which measurements are least susceptible to error (Lin and Kuang, 2006c). These results are not only useful when choosing mass characteristics to use in our model when comparing with model data, but also are very useful when using other time dependent ship motion models.

In FY07 we developed two optimal approximation methods for appendage damping effects. The first method extends the “Blocking Theory” by Lin and Kuang (2006b, ILIR project FY06) to small scale appendages in potential flow (e.g. T-Foil). In this method, we calculate the equivalent dynamic pressure using the effective blocking area of the appendages, instead of using direct surface integration. The results can provide accurate results and the method is generic for all ship hulls (Lin and Kuang, 2007, Engle and Lin, 2007). The second method is “Wave Breaking Theory” for large scale appendage damping effects, such as bow vane, rudder, etc. The appendage-wave interaction also generates sub-scale flow structures that are beyond numerical model resolution. To account for such effects, we developed a methodology similar to a traditional “wave-breaking mechanism”, with one explicit difference; the wave-breaking effect is considered based on the wave number instead of wave slope. This new approach was tested with landing craft (AAV7A1) data, which is currently the major amphibious vehicle for Marine Corps in the coastal region. Correlation of the numerical simulation with full scale data shows that the predicted effect of damping on the ship motion averages less than 5%. Sometimes it can be

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substantially higher: e.g. 20% or above. The wave breaking type effects increase as the water depth decreases. The numerical results from the new ship motion model show that numerical simulations with breaking effects agree better with experimental data than those without (Lin and Kuang, 2007, Hoyt and Lin, 2007, Engle and Lin 2007).

Bibliometric Information:

Published paper/report (Referreed

Lin, R.-Q. and W. Kuang, *Modeling Nonlinear Roll Damping with a Self-consistent, Strongly Nonlinear Ship Motion Model*, Journal of Marine Science and Technology, Vol. **13**, 127-137, (2008)

Paper accepted for publications

Lin, R.-Q., and W. Kuang, , *Solid-body motion in fully nonlinear ship motion model*, submitted to J. Marine Science and Technology, (2008)

Lin, R.-Q. and W. Kuang, *Impact of The measurement Errors to the Numerical Ship Motion Model*. Submitted to Journal of Marine Science and Technology, (2008)

Lin, R.-Q., and J. Hoyt, *A New Numerical Tool for Fast Ship in Following Sea*, submitted to Journal of OMEA, (2008)

Lin, R.-Q., and M. Hughes, *Prediction of ship steering capabilities with a fully nonlinear ship motion model, Part 1: maneuvering in calm water*, to be submitted to journal, (2008)

Lin, R.-Q., and W. Kuang, , *Solid-body motion in fully nonlinear ship motion model*, submitted to J. Marine Sciences and Technology, (2008)

Government Report

Hoyt, J. and Lin, R.-Q., *Studying the Effect of Dearise in the Bottom of Tracked Amphibions Vehicles Ehicles by Using DiSSLE Ship Motion Model*, first draft (will be a technical report), (2008)

Title: *A practical application-oriented CFD tool to compute flow about a ship in steady motion*

Funding Year: New

Principal Investigator: Francis Noblesse, Code 5200, NSWC Carderock
Phone: 301-227-7018, E-mail Address: francis.noblesse@navy.mil

Primary External Collaborations: Prof. Chi Yang, George Mason Univ., and Prof. Gerard Delhommeau, Univ. of Nantes (France)

S&T Focus Area: Platform Mobility

Abstract: The objective of this research project is a practical (i.e. robust, user-friendly, and highly-efficient, both computationally and in terms of user-time requirements) method and CFD tool for computing free-surface flow about a ship in steady motion. A distinguishing feature of the envisioned method and CFD tool is that it will be suited for routine practical applications to hydrodynamic hull-form evaluation, design, and optimization, notably at preliminary and early design stages. The tool will also be suited for installation and real-time utilization on the towing-tank carriage.

This CFD tool will significantly extend the capabilities of an existing, highly-practical computer code. This existing code, called FKS, has been found useful for many practical applications to hull-form evaluation, design, and optimization. However, FKS is based on simplifying approximations and, as a result, is not sufficiently accurate for many applications.

The envisioned new CFD tool will be based on important recent theoretical developments by the PI and Prof. Chi Yang of GMU. A main result of these recent theoretical developments is a new flow model, called Neumann-Michell (NM) model. Preliminary numerical applications of this new flow model show very promising results. The NM flow model needs to be further considered, extended, and applied. The simple analytical relations for ship bow waves obtained recently by the PI and Prof. Gerard Delhommeau of the Univ. of Nantes will also be included in the envisioned new code, to be called NM. This CFD tool will compute near field flow, notably near field waves and the velocity and pressure distributions at a ship hull surface, farfield waves, hydrodynamic lift and moment, sinkage and trim, and the wave and viscous components of the drag. A wake model that accounts for flow separation at a ship stern, notably at a transom stern, and models of overturning and unsteady bow waves, will also be included. The code is expected to be especially well suited for high-speed vessels, including multihulls.

Bibliometric Information:

Published paper/report (Referreed)

Guilbaud M., David L., Delhommeau G., Noblesse F., *Etude experimentale et theorique de la vague d'etrave des navires*, European JI of Environmental and Civil Engineering, Vol.12, pp.629-40, 2008.

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Noblesse, F., G. Delhommeau, M. Guilbaud, and C. Yang, *The rise of water at a ship stem*, JI Ship Research **52**:89-101, (2008)

Noblesse, F., G. Delhommeau, M. Guilbaud, D. Hendrix, and C. Yang, *Simple analytical relations for ship bow waves*, JI Fluid Mech , Vol **600**:105-32, (2008)

Published paper (Unreferreed)

Delhommeau G., Noblesse F., Kim H.Y., Yang C. , *Flow about a ship with rake and flare*, Proc. of 8th Intl Conf. on HydroDynamics (ICHHD-08), Nantes, France, pp.399-406, (Sep.30-Oct.3, 2008)

Kim H.Y., Yang C., Lohner R., Noblesse F. (2008) *A practical hydrodynamic optimization tool for the design of a monohull ship*, Proc. of 18th Intl Society of Offshore and Polar Engineering (ISOPE-08) Conf., Vancouver, pp. 98-107, Canada, (July 6-11, 2008)

Kim H.Y., Yang C., Lohner R., Noblesse F., *Practical hydrodynamic optimization of ship hull forms*, Proc. of Grand Challenges in Modeling and Optimization (GCMS-08) Conf., Edinburgh, pp.435-44, UK, (June 16-19, 2008)

Noblesse F., Delhommeau G., Kim H.Y., Yang C., *Practical Green function for thin-ship theory*, Proc. of 18th Intl Society of Offshore and Polar Engineering (ISOPE) Conf., Vancouver, Canada, pp.368-74, (July 6-11, 2008)

Paper accepted for publications

Yang, C., and F. Noblesse, *Practical evaluation of the drag of a ship*, JI Ship Research , in preparation, (2008)

Delhommeau, G., M. Guilbaud, L. David, C. Yang, and F. Noblesse, *Boundary between unsteady and overturning ship bow wave regimes*, JI Fluid Mech , submitted, 2008

Noblesse F., Delhommeau G., Kim H.Y., Yang C., *Thin-ship theory and influence of rake and flare*, JI of Engineering Mathematics, submitted (2008)

Noblesse, F., G. Delhommeau, and C. Yang, *Practical evaluation of steady flow due to a free-surface pressure patch*, JI Ship Research , submitted (2008)

Yang C., Noblesse F. *A practical method for predicting sinkage and trim*, II JI of Offshore and Polar Engineering, submitted (2008)

Professional Society Presentations

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Noblesse F., Delhommeau G., Kim H.Y., Yang C., *Practical Green function for thin-ship theory*, Proc. of 18th Intl Society of Offshore and Polar Engineering (ISOPE) Conf., Vancouver, Canada, pp.368-74, (July 6-11, 2008)

Title: *Fast and Accurate Simulation of Unsteady Submarine Maneuvering*

Funding Year: New

Principal Investigator: Chao-Ho Sung, Code: 5600, NSWC Carderock

Phone: 227-1865, E-mail Address: chao.sung@navy.mil

Primary External Collaborations: Dr. Li Jiang, Department of Mathematics, University of Texas at Arlington, Arlington TX, 76019 ljjiang@uta.edu

S&T Focus Area: Fleet/Force Sustainment

Abstract: The Multi-vortex code has successfully supported the U.S. submarine fleet for many years. It is one of the most important and useful prediction tools. It is both fast and accurate provided adequate database is available to adjust the parameters required. A major improvement needed is the capability to simulate non-circular body. The objective of the proposed research is to develop the next generation prediction tools based on RANS such that arbitrary complex geometries including non-circular body can be handled and the reliance on empiricism can be drastically minimized. It should also be fast and accurate. It may not be fast enough to do real time analysis (trainer) at this time but it should be fast enough to support submarine design and to do submarine Submerged Operating Envelope (SOE).

Major obstacles for RANS in engineering application to complex geometries such as a maneuvering submarine are the lack of confidence in computed solution and the long CPU time required to obtain a solution. The IFLOW code developed under the support of ILIR and In-house research has overcome a significant amount of these difficulties. A new capability to simulate the 6 degrees of freedom (6DOF) unsteady maneuvering submarine is proposed to add to IFLOW. Since this type of simulation by RANS requires a very long CPU time, a new approach which requires much less CPU time will be proposed. In the traditional approach, the formulation is based on the inertial frame. In this formulation, the computational grid and the 9 components of metric coefficients plus cell volumes need to be recomputed at every new time step. This can be very costly. In the new approach, the formulation will be based on the non-inertial frame. In this formulation, the grid is fixed at the moving body therefore the geometric features mentioned above need to be computed only once at the beginning time step. This approach significantly reduces CPU time. To avoid contamination of solution near the singularity at 90 degrees pitch angle, the quaternions will be used instead of traditional Euler angles.

The outcome of this project not only will be useful for design support but it can also be coupled with other existing codes to develop recovery boundaries for a submarine Submerged Operating Envelope (SOE) for US submarine fleet.

Bibliometric Information:

Published paper/report (Referreed)

FY08 CARDEROCK DIVISION ILIR PROJECT SUMMARIES

Sung, C.H., B. Rhee and T.M. Shih, *A vorticity-preserving artificial dissipation model for vortical wake prediction*, AIAA Journal Vol.46.No.9, (September 2008)

Paper accepted for publications

Shih, T.M., C.H. Sung and B. T. Yang, *A numerical method for solving nonlinear heat transfer equations*, accepted to appear in Numerical Heat Transfer, Part B: Fundamentals.

Sung, C.H., H. Shan, L. Jiang and T.M. Shih, *A non-inertial frame formulation of a 6 DOF rigid body motion in fluids*, submitted to the Journal of Computational Physics (2008)

Professional Society Presentations

Sung, Chao-Ho, *Vortices-Preserving Artificial Dissipation Model for Vortical Wake Prediction*, Invited Presentation, 2008 Department of Mechanical Engineering, University of Maryland, College Park, MD. (Sept 5, 2008)

Academic/industrial colloquium

Atsavapranee, Paisan, Chao-Ho Sung, Edward Ammeen, *Experimental Measurements for CFD validation of the Flow About a Submarine Model (SUBOFF)*, Submarine Hydrodynamics Working Group Meeting, (May 14, 2008)

Title: *The Role of the Plastic Deformation on High Impact Protection of Novel ERC Polyureas*

Funding Year: Second

Principal Investigator: Edward Balizer, Code: 617, NSWC Carderock
Phone: 227-4758, E-mail Address: edward.balizer@navy.mil

Associate Investigators: Gilbert Lee, Code 617, NSWC Carderock and Jeffrey Fedderly, Code 617, NSWC Carderock

Primary External Collaborations: Willis Mock, NSWCDD, code G 22, 540-653-8687
Jay Shultis, NSWCDD, code G22, 540-653-2390, Prof. Benjamin Hsiao, Department of Chemistry SUNY Stony Brook and NLSL Brookhaven National Laboratory.

S&T Focus Area: Naval Warfighter Performance

Abstract: The long-term goal is to provide an optimum impact protection polyurea coating in order to meet specific survivability requirements corresponding to a blast load and loading rate. The objective of our research is to quantify by Small Angle X-ray Scattering and Tensile Mechanical Tests the structural transitions corresponding to the mechanical mechanisms for the beneficial protective response for different polyurea chemistries. We then would characterize the limits of this response in terms of strain and high strain rates ($10E-1/s - 10E4/s$) that would ensure specific impact loading levels would be in the protective range of the polyurea coating. The strain rate material responses both elastic and plastic would be incorporated into a constitutive equation needed for modeling and for hydrocode simulations for further calculations of geometries and layer thickness. To obtain the mechanical responses new measurement methods at high strain rates will be developed for the Split Hopkinson Bar ($10E3/s$) and Gas Gun ($10E4/s$) specifically for polymers. The quantification of the structural changes for the protective response and its strain rate limits will lead to new directions for extending the protection by selected chemistries and physical processing.

Bibliometric Information:

Published paper (Unreferreed)

Balizer, Edward, *Investigation of the elastic and plastic deformation of polyurea with different molecular weights using time-resolved SAXS/WAXS*, Fall 174th Technical Meeting of the Rubber Division of the American Chemical Society, Inc. October 14-16, 2008, Louisville, KY

Patent approved by invention award board

Navy Case No. 99,386 Disclosure Date: June 2008
Name(s): Jeffrey J. Fedderly, Gilbert F. Lee, Curtis A. Martin, and Edward Balizer
Title: *Polyurea Armor Materials From Low Molecular Weight Versalink TM Polyamines*

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Professional Society Presentations

Balizer, Edward, Gilbert Lee, Jeffrey Fedderly, *Investigation of the Elastic and Plastic Deformation of Polyurea with Different Molecular Weights Using Time-Resolved SAXS/WAXS*, presented at the Fall 174th Technical Meeting of the Rubber Division of the American Chemical Society, Inc. Louisville, KY (October 14-16, 2008)

Title: *Towards design of fouling-resistant surfaces: effects of alkanethiol monolayers on contact angle of barnacle cement*

Funding Year: Third

Principal Investigator: Eric R. Holm, Code: 617, NSWC Carderock
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Associate Investigators: Robert A. Brizzolara, Code 617, NSWC Carderock and Elizabeth G. Haslbeck, Code: 613, NSWC Carderock

Primary External Collaborations: Duke University Marine Laboratory (Dr. Daniel Rittschof)

S&T Focus Area: Platform Mobility

Abstract: Permanent attachment of fouling organisms to an immersed material (such as a ship hull) arises from the interaction between the material's surface and organismal adhesives. We propose to quantify two facets of this interaction, the ability of adhesives to wet experimental surfaces, and the ability of the surfaces to modify the curing of the adhesive. Experiments will focus on the barnacle *Balanus Amphitrite*, an important fouler of ship hulls, and experimental alkanethiol self-assembled monolayers possessing similar hydrophobicities/hydrophilicities, but differing in the chemical functionalities at their surfaces. Uncured adhesive will be harvested from 15-20 individual barnacles, and its ability to wet the test materials measured by contact angle. Change in contact angle over time will be recorded using time-lapse photography and will be interpreted as an indicator of rate of curing of the adhesive. Statistical analyses will be used to examine differences among the materials in their interaction with the barnacle adhesive. The proposed research will improve our understanding of the interaction between the adhesives of fouling organisms and the substrates to which these organisms adhere, and could yield information invaluable to the design of materials or paints that more effectively release fouling. The research impacts the Structures and Materials core equity under the objective for development of environmentally-resistant materials. Such materials support the strategic goals of high speed ships, improved operator performance through reduced manning, and improved affordability of platforms and systems throughout their life cycle. The work is also relevant to the Naval S&T Strategic Plan under the Affordability, Maintainability, and Reliability focus area.

Bibliometric Information:

Professional Society Presentations

Holm, Eric R., *Variation among families in larval response to surface wettability for the barnacle *Balanus Amphitrite**, 2008 Benthic Ecology Meeting, Providence, R.I., (April 9-13, 2008)

FY08 CARDEROCK DIVISION ILIR PROJECT SUMMARIES

Holm, Eric R., R Brizzolara, *Contact angle analysis for barnavle adhesives*, Poster Presentation at the 14th ICMCF, Kobe, Japan, (July 28-31, 2008)

Title: *Lattice Dynamics and Electronic Structure of Thermoelectric Materials*

Funding Year: Second

Principal Investigator: Azzam N Mansour, Code: 6160, NSWC Carderock
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Primary External Collaborations: Dr. R. Venkatasubramanian, Research Triangle Institute, Research Triangle Park, NC and Professor S. J. Poon, Physics Department, University of Virginia, Charlottesville, VA.

S&T Focus Area: Power and Energy

Abstract: Thermoelectric (TE) devices are used for waste-heat recovery and its conversion to electrical energy. The conversion efficiencies of TE devices are related to a dimensionless figure of merit referred to as “ZT”. Current devices have low efficiencies due to a low value of “ZT”. The objective of the proposed research is to provide an improved understanding of the materials’ physical and chemical properties, which may lead to an increase in the value of “ZT” and subsequently an increase in conversion efficiency. An increase in the value of ZT can be accomplished by reducing the lattice thermal conductivity and increasing the Seebeck coefficient and electrical conductivity of TE materials.

Complex bulk materials such as the half-Heusler alloys, skutterudites and clathrates are being investigated to engineer a material with reduced lattice thermal conductivity. Reduction in lattice thermal conductivity due to phonon-phonon scattering can be induced by anharmonic terms in the crystal potential. We propose to use temperature dependent X-ray absorption spectroscopy (XAS) to study the dynamics of lattice vibrations. Anharmonic terms in the crystal potential lead to an asymmetry in the pair distribution function (PDF) and can be quantified from analysis of the extended X-ray absorption fine structure (EXAFS) data.

Attempts to increase the Seebeck coefficient have focused on nanostructured material due to an increase in the density of electronic states near the Fermi level compared to bulk materials. Modification of the density of electronic states near the Fermi level via doping/substitution is also being heavily investigated. We propose to use X-ray photoelectron spectroscopy to study the valance band region of nanostructured and bulk materials to investigate the size-effect on density of electronic state. Materials under investigation include Bi₂Te₃/Sb₂Te₃ based super lattices and the half-Heusler alloys with general formula MNiSn (M: Zr, Hf, or Ti).

Bibliometric Information:

Paper accepted for publications

Mansour, A.N., M. Beekman, W. Wong-Ng, and G.S. Nolas, *Local Structure of Cu in Cs₈Na₁₆Cu₅Ge₁₃₁ Type II Clathrate*, accepted for publication in Journal of Solid State Chemistry, (September 2008)

FY08 CARDEROCK DIVISION ILIR PROJECT SUMMARIES

Mansour, A.N., and R. Venkatasubramanian, *XAS study of $\text{Bi}_2\text{Te}_3/\text{Sb}_2\text{Te}_3$ Superlattices and $\text{Sb}_{1.5}\text{Bi}_{0.5}\text{Te}_3$ Alloy Film, Focus session: Thermoelectric Phenomena in Nanostructured Materials*, 2008 APS March Meeting, New Orleans, LA, (10-14 March 2008)

Mansour, A.N., and R. Venkatasubramanian, *XAS Investigation of $\text{Bi}_2\text{Te}_3/\text{Sb}_2\text{Te}_3$ Superlattices*, Direct Energy Conversion Review and Workshop, Vail, Co, (20-23 August 2008)

Title: *Core-Valence Luminescence (CVL) for gamma-neutron discrimination*

Funding Year: New

Principal Investigator: V. K. Mathur, Code: 6301, NSWC Carderock
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Associate Investigators: Noel Guardala, Code 6301, NSWC Carderock and Marlene Skopec, Code 6301, NSWC Carderock

Primary External Collaborations: Dr. Stan Hunter, NASA Goddard Space Flight Center, and Dr. Marko Moscovitch, Georgetown University Medical Center

S&T Focus Area: Maritime Domain Awareness

Abstract: Detection and identification of the radioactive material is one of the prime tasks in the Global War on Terrorism. This requires monitoring of gamma rays and neutrons. Scintillators are key components of portable instruments used for this purpose. However, the detection of neutrons in the presence of gamma rays has been always a challenging task. We propose to study the phenomenon of Core-Valence Luminescence (CVL) in scintillators that has the potential of radiation discrimination without ambiguity which has not been possible by other techniques. CVL is the emission resulting due to radiative transitions between the valence and first core band under gamma excitation. It has some unique spectral properties which can be exploited to discriminate between different types of nuclear radiation. The key properties are the emission wavelength and decay time. The emission wavelength of CVL is quite different than that of impurity or self-trapped excitons (STE). Additionally, the decay time of CVL is shorter by an order of magnitude compared to STE emission. CVL occurs only when the scintillator is exposed to gamma rays but not when exposed to charged particles such as protons and alpha radiation.

In the proposed work, CVL will be studied in the Li based CVL-active crystals which are very promising for the neutron/gamma discrimination. Initially we will study Ce doped LiBaF₃ crystals by exciting it with x-rays or gamma rays both for its optical and radiation detection properties. This will be followed by similar investigations by using charged particle excitation, in this case it is expected that the CVL would be absent. Charged particles may be alpha particles or protons. For neutron detection alpha particles are created by the absorption of neutron in Lithium-6 resulting in the formation of alpha particles and triton. Protons are knocked out from a hydrogenous material when bombarded by fast neutrons. Knocking out of Li ion from the scintillator under fast neutron bombardment is not ruled out and may contribute to the detection of fast neutrons. Positive Ion Accelerator Facility of NSWCCD is capable of producing the gamma rays of required energy by the proton-gamma reaction and fast neutrons by Li₇(p,n) reaction.

Analysis of the fluorescence emission may result in a viable method for neutron and gamma discrimination. Due to the marked difference between the decay times of CVL and STE, pulse

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shape analysis may provide an additional important tool for the radiation discrimination. The statistical techniques of vector representation (VR) and principal component analysis (PCA) will be used for the pulse shape analysis.

This new approach of combining the spectral results with the statistical analysis will result in the development of a robust algorithm for neutron-gamma discrimination.

Bibliometric Information:

Patent Awarded

U.S. Patent No: 7,307,702 Disclosure Date: December 11, 2007

Name(s): Veerendra K. Mathur, and Jack L. Price

Title: *Color Switchable Stress-Fracture Sensor for Damage Control*

Title: *A Study on How Metallurgical Factors are affected by the Solid-State Stirring Nature of Friction Stir Welding*

Funding Year: Third

Principal Investigators: Maria Posada, Code: 611, NSWC Carderock
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Associate Investigators: David Forrest, Code 611, NSWC Carderock and Carrie Davis,
Code: 611, NSWC Carderock

Primary External Collaborations: External collaboration with University of Maryland, Ohio State University, Brigham Young University, Cornell University, and NRL. Each of these institutions have funded work in the various areas of friction stir welding (FSW).

S&T Focus Area: Platform Mobility

Abstract: Friction stir welding of steel and titanium is a potential alternative to conventional joining for lightweight and high strength structural metals and for enhanced platform mobility. Additionally, friction stir welding of steels has shown enhanced survivability compared to conventional welding.

Friction stir welding is a thermal and thermal-mechanical process that involves extreme plastic deformation associated with the solid-state stirring of one base metal into another. The extreme plastic deformation within the stir zone occurs at high temperatures (~1100 °C for steels, and above ~980 for titanium) and at high strain rates. However, in friction stir welding the high temperature and strain rates are not consistent throughout the weld nugget. The kinetics of friction stir welding differ dramatically from traditional hot-rolling processes, as such, we would like to have a better understanding of how metallurgical factors are affected by the solid-state stirring nature of friction stir welding. The uniqueness of our work will be to understand and characterize the extreme superplastic deformation, which occurs in the stir zone and adjacent affected zones.

The objective of this research is to understand the influence of various metallurgical factors on the strengthening or softening mechanisms of Fe-based friction stir welds and the effect of metallurgical factors on the texture and microstructural development on titanium alloys. The ultimate goal is to develop a predictive tool that will interchangeably correlate process parameters to mechanical property requirements for any given material and thickness. The work proposed for this task uses existing deformation-based constitutive models to predict the yield strength as a function of deformation variables such as grain size, dislocation density, temperature, and strain rate.

The potential payoff of this proposed effort is gain the fundamental understanding of the influence of various metallurgical factors to weld properties to establish a FSW process development tool. By understanding the relationship of yield strength as a function of

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metallurgical factors and deformation variables, we can develop the models even further to incorporate the influence of FSW process parameters to individual metallurgical factors and ultimately to the weld nugget yield strength for any given material or thickness. The payoff will be a significant reduction in experimental trial and error methods currently used to show feasibility of FSW and to develop FSW process parameters for new alloys.

Bibliometric Information:

Paper accepted for publications

Wolk, Jennifer, Lourdes Salamanca-Riba, Carrie Davis, *Microstructural Evolution in Friction Stir Welding of Ti-5111*, accepted for the proceedings for Trends in Welding Research, (June 2008)

Professional Society Presentations

Wolk, Jennifer, Lourdes Salamanca-Riba, Carrie Davis, *Microstructural Evolution in Friction Stir Welding of Ti-5111*, accepted for the proceedings for Trends in Welding Research, (June 2008)

Award/Honor

Ms. Maria Posada selected as the Top Navy Emerging Investigator Award for FY07

Academic/industrial colloquium

Posada, Maria, J. Warren, *Aluminum friction stir welds for naval structures*, Friction Stir Technologies and Application for Defense Applications Workshop, University of Pittsburgh at Johnstown, Johnstown, PA, (Sept 17-18, 2008)

Title: *Iron-Based Magnetoelastic Interactions*

Funding Year: Second

Principal Investigator: James B. Restorff , Code: 6170, NSWC Carderock
Phone: 301-227-5440, E-mail Address: james.restorff@navy.mil

Associate Investigator: Marilyn Wun-Fogle, Code: 6170, NSWC Carderock

Primary External Collaborations: ETREMA Products, Inc.; Materials Preparation Center, Ames Lab (DoE); University of Maryland, College Park; Iowa State University, Ames, IA; Defense Research and Development Canada-Atlantic

S&T Focus Area: Power & Energy

Abstract: The physics of b.c.c. iron-based Fe-Ga (Galfenol) and Fe-Al (Alfenol) active materials differ substantially from that of rare-earth iron alloys such as Terfenol-D. In spite of the rapidly increasing amount of experimental data available, the mechanism of magnetostriction in the b.c.c. alloys is not understood.

The goal of this project is to understand the origin of the large magnetostriction in b.c.c. iron-based alloys via both experiment and first principles. Iron itself differs from other magnetic alloys such as Ni and Co and appears to be a unique component in both the high power b.c.c. and rare earth magnetostrictive materials.

Secondary goals include an effort to define material properties, improve the existing material, and find new alloys and processing techniques that will facilitate rapid transitioning of these materials into useful naval devices. A full set of piezomagnetic constants (d_{33} , d_{13} , and d_{15}) will be measured as a function of stress and field. The Villari (inverse magnetostrictive) effect, which is useful for energy scavenging devices, sensors and self-sensing actuators that report strain and force, will also be investigated. Finally, ternary and quaternary additions to the base alloy will be investigated in order to improve material properties such as increased magnetostriction, reduced cost, and easier rolling to obtain thin sheets.

This project is in alignment with two of ONR's Naval S&T focus areas. The main area is 'Assured Access and Hold at Risk' and the secondary area is 'Survivability and Self-Defense'. An ancillary focus area is 'Naval Warrior Performance and Protection'. The research performed under this ILIR transitions to ONR Maritime Sensing, Code 321 MS, for ASW and torpedo defense applications.

Bibliometric Information:

Published paper/report (Referreed)

FY08 CARDEROCK DIVISION ILIR PROJECT SUMMARIES

Clark, A.E., J.B. Restorff, M. Wun-Fogle, D. Wu, and T.A. Lograsso, *Temperature dependence of the magnetostriction and magnetoelastic coupling in Fe_{100-x}Al_x (x = 14.1, 16.6, 21.5, 26.3) and Fe₅₀Co₅₀*, *Journal of Applied Physics* **103**, 07B310-1 to 07B310-3, (2008).

Huang, Mianliang, Thomas A. Lograsso, A.E. Clark, J.B. Restorff, and M. Wun-Fogle, *Effect of interstitial additions on magnetostriction in Fe-Ga alloys*, *Journal of Applied Physics* **103**, 07B314-1 to 07B314-3, (2008)

Restorff, J. B., M. Wun-Fogle, and A.E. Clark, *Measurement of d₁₅ in Fe_{100-x}Ga_x (x = 12.5, 15, 18.4, 22), Fe₅₀Co₅₀, and Fe₈₁Al₁₉ highly textured polycrystalline rods*, *Journal of Applied Physics* **103**, 07B305-1 to 07B305-3, (2008)

Ueno, T., T. Higuchi, C. Saito, N. Imaizumi, M. Wun-Fogle, *Micro Magnetostrictive Vibrator using a U-Shaped Core of Iron-Gallium Alloy (Galferol)*, *Journal of Applied Physics* **103**, 07E904-1 to -3 (2008).

Ueno, Toshiyuki, Eric Summers, Marilyn Wun-Fogle, and Toshiro Higuchi, *Micro Magnetostrictive Vibrator using Iron-Gallium Alloy*, *Sensors and Actuators: A Physical* (2007), doi: 10.1016/j.sna.2008.08.017.

Yoo, J-H, J.B. Restorff, M. Wun-Fogle, and A.B. Flatau, *The effect of magnetic field annealing on single crystal iron gallium alloy*, *Journal of Applied Physics* **103**, 07B325-1 to 07B325-3, (2008)

Published paper (Unreferreed)

Yoo, Jin-Hyeong, James Restorff, Marilyn Wun-Fogle and Alison Flatau, *Performance Improvements in Galferol Laminated Rods with Stress Annealing*, *Proceedings of the 2008 SPIE Smart Structures and Materials/NDE Symposium*, San Diego, CA., (9-13 March 2008)

Patent approved by invention award board

Navy Case No. 97,000 Disclosure Date: Feb 2008
Name(s): A. E. Clark, M. Wun-Fogle, and J. B. Restorff
Title: *Method of Achieving High Transduction under Tension or Compression*

Navy Case No. 97,737 Disclosure Date: March 2008
Name(s): A. E. Clark, M. Wun-Fogle, J. B. Restorff, T. A. Lograsso, and R. A. Kellogg
Title: *Magnetostrictive Materials, Devices and Methods Using High Magnetostriction, High Strength FeGa and FeBe Alloys*

Professional Society Presentations

Clark, A.E., J.B. Restorff, M. Wun-Fogle, D. Wu, and T.A. Lograsso, *Temperature dependence of the magnetostriction and magnetoelastic coupling in*

FY08 CARDEROCK DIVISION ILIR PROJECT SUMMARIES

Fe100-xAlx ($x = 14.1, 16.6, 21.5, 26.3$) and *Fe50Co50*, 52nd Conference on Magnetism and Magnetic Materials, Tampa, FL, (November 5-9, 2007)

Clark, A.E., M. Wun-Fogle, and J. B. Restorff, *High Power Magnetostrictive Materials from Cryogenic Temperatures to High Temperatures*, 2008 SPIE Smart Structures and Materials/NDE Symposium, San Diego, CA. [Invited Plenary Talk], (9 – 13 March 2008)

Huang, Mianliang, Thomas A. Lograsso, A.E. Clark, J.B. Restorff, and M. Wun-Fogle, *Effect of interstitial additions on magnetostriction in Fe-Ga alloys*, 52nd Conference on Magnetism and Magnetic Materials, Tampa, FL, (November 5-9, 2007)

Restorff, J.B., M. Wun-Fogle, and A.E. Clark, *Measurement of d_{15} in $Fe_{100-x}Ga_x$ ($x = 12.5, 15, 18.4, 22$), $Fe_{50}Co_{50}$, and $Fe_{81}Al_{19}$ highly textured polycrystalline rods*, 52nd Conference on Magnetism and Magnetic Materials, Tampa, FL, (November 5-9, 2007)

Restorff, J.B., A. E. Clark, and M. Wun-Fogle, *Sensing Figure of Merit of Galfenol Alloys*, 2008 U.S. Navy Workshop on Acoustic Transduction Materials and Devices, State College, PA., (13 – 15 May 2008)

Ueno, T., C. Saito, M. Wun-Fogle, N. Imaizumi, and T. Higuchi, "Micro Magnetostrictive Vibrator using U Shape Core of Iron-Gallium Alloy," 52nd Annual Conference on Magnetism and Magnetic Materials, Tampa, FL, Nov. 5-9, 2007

Wun-Fogle, M., Restorff and A.E. Clark, "Soft and Hard Elastic Moduli of Galfenol Transduction Elements," (Invited) 53rd Annual Conference on Magnetism and Magnetic Materials Conference, Austin, TX, 11-14 Nov 2008

Yoo, J-H, J.B. Restorff, M. Wun-Fogle, and A.B. Flatau, *The effect of magnetic field annealing on single crystal iron gallium alloy*, 52nd Conference on Magnetism and Magnetic Materials, Tampa, FL, (November 5-9, 2007)

Yoo, Jin-Hyeong, James Restorff, Marilyn Wun-Fogle and Alison Flatau, *Performance Improvements in Galfenol Laminated Rods with Stress Annealing*, 2008 SPIE Smart Structures and Materials/NDE Symposium, San Diego, CA., (9 – 13 March 2008)

Yoo, J.-H., J.B. Restorff, M. Wun-Fogle, and A.B. Flatau, "Induced Magnetic Anisotropy in Stress-Annealed Galfenol Laminated Rods," 2008 Conference on Smart Materials, Adaptive Structures & Intelligent Systems, Ellicott City, MD., (28-30 October, 2008)

Award/Honor

Ms. Marilyn Wun-Fogle selected as the Top Navy Scientist of the Year Award for FY07

Academic/industrial colloquium

FY08 CARDEROCK DIVISION ILIR PROJECT SUMMARIES

Wun-Fogle, M., J. B. Restorff, and A. E. Clark, *Soft and Hard Elastic Moduli of Galfenol and Alfenol Transduction Elements*, 2008 U.S. Navy Workshop on Acoustic Transduction Materials and Devices, State College, PA., (13 – 15 May 2008)

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Yoo, Jin-Hyeong, James B. Restorff, Marilyn Wun-Fogle and Alison B. Flatau, *The Performance Improvement of Galfenol Laminated Rod with Stress Annealing*, 2008 U.S. Navy Workshop on Acoustic Transduction Materials and Devices, State College, PA., (13 – 15 May 2008)

Title: *Health Monitoring and Diagnostics for High-Speed Vessels*

Funding Year: Second

Principal Investigator: Liming Salvino, Code: 652, NSWC Carderock

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Primary External Collaborations:

Prof. Darryll Pines, Dept. of Aerospace Engineering, Univ. of Maryland, and Dr. Mark Seaver, Fiber Optic Smart Structures, Naval Research Lab.

S&T Focus Area: Platform Mobility

Abstract: The proposed program contains two interlinking research thrusts. The first involves the development of a wave propagation technique for damage detection. The technique uses directionally-steered phased arrays via piezoelectric actuators and sensors on a large two-dimensional structure to transmit and receive directional waves for in-plane and out-of-plane structural responses. This thrust involves both a theoretical and experimental development of the phased array using piezoelectric actuators and sensors for structural health monitoring.

Fundamental studies have been recently done with success for one-dimensional structures and two-dimensional isotropic plates. In the second thrust, the novel method of empirical modeling and instantaneous phase damage detection, developed under a previous ILIR by the authors, will be implemented to process phased array response signals and used in conjunction with a nonlinear dynamics-based system identification to infer damage. In this task, the array response carrying wave propagation in 2-d structures will be extracted to isolate wave reflections from damaged regions with minimal interference of wave reflections from the edges of a structure. Phased array signals will be decomposed for different time scales and displayed as images, with either time and location or wave number (or frequency) and location as axes. The image extraction approach can also be modified for other types of sensing methods and geometries, such as fiber optic measurements.

The proposed research would be conducted first for an undamaged plate. Then different damage scenarios (such as delaminations, impact, and fatigue damage) will be introduced to investigate sensitivity, consistency, and effectiveness of the method for plate-like structures. This proposed research will also focus on the development of a nonlinear dynamics-based system identification technique and develop criteria to distinguish structural damage from the characteristic general dynamic changes which include environmental effects. If the phased array interrogation/sensing, signal extraction and nonlinear dynamics analysis scheme proves to be effective, it can be automated to provide real-time health monitoring and diagnostic technology with tremendous potential for a variety of applications.

Bibliometric Information:

Published paper (Unreferreed)

FY08 CARDEROCK DIVISION ILIR PROJECT SUMMARIES

Salvino, L.W., & T. F. Brady, *Hull Monitoring System Development using a Hierarchical Framework for data and information management*, Proceedings of 7th International Conference on Computer Applications and Information Technology in the Maritime Industries, (April 2008)

Paper accepted for publications

Nichols, J.M., M. Seaver, S. Trickey, K. Scandell, and L. W. Salvino, *Real-time Strain Monitoring of a Navy Vessel During Open Water Transit*, preprint, submitted to J. of Ship Research, (June 2008)

Book and Book Chapters

Salvino, L.W., and M. Collette, Monitoring Marine Structures, A Chapter in Encyclopedia of Structural Health Monitoring, Sec. Ed, D. Inman, in preparation, John Wiley & Sons Ltd. (2008).

Pines, D.J., and L. W. Salvino, The Hilbert-Huang Transform, A Chapter in Encyclopedia of Structural Health Monitoring, Sec. Ed, W. Staszewski, in preparation, John Wiley & Sons Ltd. (2008).

Government Report

Salvino, L.W., and M. Collette, *Structural Health Monitoring Chapter*, in ONR Aluminum Structural Reliability Best Practice Report, P. Hess and R. Sielski, Eds., April 2008.

Professional Society Presentations

Nichols, J.M., and L. W. Salvino, *Surrogate-based nonlinearity detection schemes for non-stationary data*, 2nd Asia-Pacific Workshop on Structural Health monitoring, Melbourne, AU, Dec 2008 (abstract submitted in March 2008).

Salvino, L.W. and T. F. Brady, *Hull Monitoring System Development using a Hierarchical Framework for data and information management*, The 7th International Conference on Computer Applications and Information Technology in the Maritime Industries, Liege, Belgium, (April 21-23, 2008)

Salvino, L.W., *Vibration Analysis and Damage Identification in Large Structures*, AMS Annual Meeting, San Diego, CA, (invited), (January 6-9, 2008)

Salvino, L. W., HHT for Ship Structures – from signal analysis research to structural health monitoring tool, AMS Annual Meeting, San Diego, CA, January 6-9, 2008

Title: *Investigation into the Physicochemical Properties of Electrochemical Double Layer Capacitor Materials*

Funding Year: Second

Principal Investigator: Patricia H. Smith, Ph.D., Code: 616, NSWC Carderock
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Associate Investigators: Michelle Cervenak (Jr. Invest.), Code 616, NSWC Carderock, Jeffrey Fedderly, Code: 617, NSWC Carderock, and Azzam Mansour, Ph.D., Code: 616, NSWC Carderock

Primary External Collaborations: Glenn Amatucci, Ph.D., Rutgers University, and Glenn Zoski, Ph.D., G.J. Associates

S&T Focus Area: Power and Energy

Abstract: Electrochemical double layer capacitors, because of their high rate of charge and discharge, are prime candidates for use as load-leveling devices for the all-electric ship. They are also being considered as a power source for surveillance systems requiring high-power pulses for the unmanned surface vehicles. These relatively new energy storage devices are composed of a pair of high surface-area carbon electrodes and an organic liquid into which a conductive salt is dissolved. They derive their energy on the basis of the Guoy-Chapmann and Stern-Geary electrochemical double layer theory. Charge is stored by the adsorption of the electrolyte's ions on the carbon's surface. There is no charge-transfer reaction occurring during the charge-discharge process.

Even though electrochemical double layer capacitors display an order of magnitude greater capacitance than conventional dielectric capacitors, substantial improvement is needed to reach the energy density required for future naval systems. In addition, the high self-discharge rates of these devices are a problem of concern. To date, only limited fundamental investigations have been conducted to determine the chemical and physical characters relevant to achieve high capacitance and maintain high cell voltages.

We will seek to increase the energy density and lower the self-discharge rate of these energy storage systems by identifying the physicochemical properties of the electrode/electrolyte interface associated with capacitance and its loss. Our research will focus on novel carbons and lithium electrolytic salts (as opposed to tetraethylammonium tetrafluoroborate used in today's capacitors) to complement our 6.2 investigations on non-aqueous, asymmetric hybrid double layer capacitors (a cross between a lithium ion battery and a supercapacitor). Cyclic voltammetry and constant current discharge experiments will be conducted to identify the nature and the degree of cell polarization and voltage decay. Information obtained from these investigations will be correlated to carbon's surface area, pore-size distribution, impurities, and oxygen functional groups employing such techniques as gas adsorption (BET), Fourier transform infrared spectroscopy, X-ray photoelectron spectroscopy, energy dispersive spectroscopy, and

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AC impedance spectroscopy.

This project is in alignment with ONR's Naval S&T focus area, Power and Energy. The knowledge gained by this effort will support the Efficient Energy & Power Conversion Objective. It will transition to ONR Physical Sciences Division, Code 331's Capacitor Program Science and Technology Objective for load leveling and back-up power applications.

Bibliometric Information:

Published paper (Unreferreed)

Cervenak, Michelle, and Patricia Smith, *Effect of high temperature storage on electrochemical double layer capacitor performance*, Power Sources, Philadelphia, PA., (July 7-11, 2008)

Title: *Virtual Shaping for Surface Ship Radar Cross Section Reduction*

Funding Year: New

Principal Investigator: Robert A. Stark, Code: 655, NSWC Carderock
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S&T Focus Area: Survivability and Self-Defense

Abstract: Virtual Shaping (VS) is the process of causing the radar-apparent shape and orientation of an object to be different from its actual shape and orientation. VS is implemented by introducing a phase shift gradient in the reflected wave along a structural surface, which causes the reflection of an incoming plane wave to be in a non-specular direction, minimizing the chance of detection by the emitter. The VS concept could be implemented by surface treatments, such as appliqué containing micropatch arrays, constructed to simulate the effects of shaping when applied to ship structures. The VS concept is similar to the reflect array, a device in common use which employs a micropatch arrays to produces a phase shift gradient that directs the electromagnetic radiation from a horn antenna into a mono-directional beam. By decoupling the direction that energy is scattered by a surface from its physical shape and orientation, VS could provide a revolutionary new freedom in the design of ships consistent with low radar cross section. Potential benefits are reduced need for tumblehome design for stealth and reduced surface area of topside structures, and retrofitting of existing ships to reduce their RCS.

The work proposed here builds on previous studies of the VS concept by NSWCCD scientist, which includes literature surveys, as well as an initial quantitative investigation (performed by Dr. Stark and Dr. Donald Rule) of the phase shift requirements of a VS appliqué, and the performance of a patch-stub system for VS. These studies indicate that, while a VS appliqué can readily be constructed to have a bandwidth of a few percent, the primary challenge to successful application of the VS concept for ship topside signature control is to make the bandwidth broad enough (multiple GHz's) for Navy applications.

To this end, work is proposed to determine the requirements on the phase shift gradient and micropatch element performance for virtual shaping, and to evaluate various patch geometries and substrate, including both lossless and resistive elements, for broadband VS. In addition, it is proposed that a demonstration VS appliqué be designed and fabricated, and that its performance be measured and compared with that predicted by full wave electromagnetic codes.

This proposal addresses objective to “Reduce above water and subsurface signatures” of the Survivability and Self-Defense Focus Area of the Naval Science and Technology Strategic Plan.

Title: *Creep Behavior of Non-Oxide Ultra-High-Temperature Ceramics*

Funding Year: Third

Principal Investigator: Dr. James Zaykoski, Code: 617, NSWC Carderock
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Associate Investigators: Mr. Curtis Martin, Code 617, NSWC Carderock, Dr. Mark Opeka, Code: 617, NSWC Carderock, and Dr. Inna Talmy, Code 617, NSWC Carderock

Primary External Collaborations: ONR, AFOSR, University of Missouri Rolla, Pennsylvania State University.

S&T Focus Area: Power Projection

Abstract: Non-oxide ceramics are being considered for use in applications where superior chemical and mechanical behavior at high temperatures is essential. High strength, oxidation resistance, and creep resistance will define whether these materials will find acceptance in such applications.

The objective of the proposed research program is to provide fundamental analysis of high-temperature deformation of non-oxide ceramics to identify the controlling creep mechanisms and brittle-ductile transitions as a function of processing parameters, phase composition and microstructure over ranges of temperatures, loads, and time. The effort will be focused on the characterization of non-oxide ultra-high-temperature ceramics (UHTC), which can be used as structural components above 1600°C for several short-term applications, including hypersonic flight vehicles, weapons system components (rocket nozzles and nosetips), and leading edges for hypersonic missiles, as well as for applications in long lifetime components, such as gas turbine, heat exchangers, and reciprocating engine parts, missile launchers, and guns. The leading classes of candidate materials are based on transition-metal (Hf, Zr, Ta) carbides, nitrides and borides. Data on creep degradation will provide an upper thermal limit to their use. Creep is a thermally activated process, which requires passing a certain energy barrier to occur. Creep deformation can be described by the Arrhenius equation: $A \exp(-Q_c/RT) \sigma^n$, where n is the rate of creep; A is the structure factor; Q_c is the activation energy; R is the gas constant; T is the absolute temperature in K; σ is the stress; n is the stress exponent, which is constant for the given mechanism. Both stress exponent and activation energy provide information about the controlling creep mechanism (viscoelastic flow, diffusion, movement of dislocations, grain-boundary sliding). The creep deformation can be studied using all types of stresses (tension, bending, shear, torsion, and compression). The difficulty of preparation of ceramic test samples for determining tension deformation makes it necessary to rely more on bending (three or four points) and compressive deformation. Most of the creep studies of single- and multi-phase ceramics are dedicated to Al₂O₃- and Si₃N₄- based materials with the use temperatures below 1600 C.

There are very limited literature data on creep studies of transition-metal-based non-oxide ceramics. Additional work is planned on UHTC-based cermet materials containing various

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amounts of refractory metal (Ta, W, Re). The presence of a metal phase is expected to completely change the creep mechanisms, with grain boundary sliding and viscous flow becoming more predominant with increasing metal content, especially at increasing temperatures. The results of this creep investigation will help enable broader applications of ceramic materials in Naval systems which will support the Power Projection, Platform Mobility, and Affordability, Maintainability, and Reliability elements of the ONR S&T Strategic Plan. A cooperative relationship is established with the University of Missouri Rolla (Professors William Fahrenholtz and Gregory Hilmas).

Bibliometric Information:

Published paper/report (Referreed)

Zaykoski, J., C. Martin, I. Talmy, *Creep of ZrB₂-SiC Ultra-High Temperature Ceramics*, Proceedings of 32nd Annual Conference on Composites, Materials, and Structures Daytona Beach, FL, (January 2008)

Published paper (Unreferreed)

Zaykoski, J., C. Martin, I. Talmy, *Creep of ZrB₂-SiC Ultra-High Temperature Ceramics*, Proceedings of 32st Annual Conference on Composites, Materials, and Structures Daytona Beach, FL (January 2008)

Paper accepted for publications

Zaykoski, J., C. Martin, I. Talmy, *Creep Behavior of ZrB₂-SiC Ceramics*, Journal of American Ceramic Society, (accepted for publication), (2008)

Professional Society Presentations

Zaykoski, J., C. Martin, I. Talmy, E. Wuchina, *Creep of ZrB₂-SiC Ultra-High Temperature Ceramics*, 32nd Annual Conference on Composites, Materials, and Structures Daytona Beach, FL (January 2008)

Zaykoski, J., C. Martin, I. Talmy, E. Wuchina, *Creep Behavior of ZrB₂-SiC Ceramics*, AFOSR Program Review, (May 12-16, 2008)

Zaykoski, J., C. Martin, I. Talmy, E. Wuchina, *Creep Behavior of ZrB₂-SiC Ceramics*, ONR Program Review, (May 28-30 , 2008)

Zaykoski, J., C. Martin, I. Talmy, *Creep Behavior of ZrB₂-SiC Ceramics*, Ultra-High Temperature Ceramics: Materials for Extreme Environments Applications, (invited presentation), (Aug. 3-8, 2008)

Title: *Intelligent Underwater Electrolocation of Littoral Sea Mines*

Funding Year: New

Principal Investigator: Rocco Arizzi, Code: 7510, NSWC Carderock

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Primary External Collaborations: Dr. Mark Mirotznik, Department of Electrical Engineering, The Catholic University of America

S&T Focus Area: Maritime Domain Awareness

Abstract: When it is necessary or desirable to utilize electromagnetic means for underwater detection, a unique set of issues arises with regard to scaling, resolution, detection range, bandwidth, attenuation, and scattering. Observations of certain species of weakly electric fish (WEF) suggest the possibility of sophisticated near-field underwater detection capabilities through the use of electric fields. Extensive study has shown that WEF have the remarkable ability to not only detect and locate potential prey but also to characterize and track relative target movements.

This biological process is known as electrolocation. A system featuring a dipolar electric field source, analogous to the electric discharge organ of weakly electric fish, and an arbitrary array of electric potential sensors could provide environmental input to a computer program that takes advantage of soft computing methods to detect, characterize, locate and track objects of interest within the detection range of the system in real time.

Among the potential applications of such a system is that of detecting, characterizing, locating and tracking mines and other objects within the near-field of a small autonomous underwater vehicle (AUV).

Bibliometric Information:

Published paper (Unreferreed)

Arizzi, Rocco V., *Applications of Artificial Electrolocation*, Joint Undersea Warfare Technology – 2008 Fall Conference, Groton, CT., Sept 8-11, 2008)

Title: *Passive Millimeter Wave Imaging Phenomenology of Basic Materials & Shapes in a Maritime Environment*

Funding Year: Third

Principal Investigator: Thomas J Miller, Code: 7410, NSWC Carderock
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Associate Investigators: Jerry R Smith, Jr., Code 741, NSWC Carderock, Mark S. Mirotznik, Code: 741, NSWC Carderock, Ozlem Kilic, Code: 741, NSWC Carderock

Primary External Collaborations: David Wikner (Army Research Lab), Dennis Prather (Univ. of Delaware)

S&T Focus Area: Survivability and Self-Defense

Abstract: Millimeter waves are defined as electromagnetic waves having wavelengths of 1 to 10 millimeters. Passive Planck radiation is observable in the millimeter wave regime and passive millimeter wave sensors are being proliferated into many land-based weapons that threaten Navy platforms within the littorals. The passive millimeter wave signature of platforms in a maritime environment is poorly understood as is its mitigation.

The primary goal is to develop an understanding of passive millimeter wave phenomenology in a maritime environment so that accurate signature models can be developed. This is accomplished by combining experimental observations of poorly quantified phenomenology with theoretical extension of radiation models.

This project will experimentally determine the emissivities of Navy specific materials and quantify the effects of thick coatings and appliqué. Additionally, the statistics of the Bi-Directional Reflection Distribution Function (BRDF) of a rough ocean surface at millimeter wave frequencies will be experimentally quantified. Additional tests will observe canonical shapes in an ocean scene to quantify the polarization-specific effects that must be included within the models.

Leveraging this experimental data, the project will adapt the Navy's "in-house" infrared radiation models and absolute calibration techniques to the millimeter wave regime. This will lead to expanding the infrared radiation models to include the millimeter wave material database, the millimeter radiance/reflection of a rough ocean, and polarization effects.

The products of this project will include a basic understanding of millimeter wave radiation in a maritime environment, understanding of the effect of thin coatings on millimeter wave radiation, and knowledge about impact of polarization effects in a scene. Future designs that operate within littorals and are exposed to traditional land-based passive millimeter wave threats will benefit from the effort, e.g. LCS or Marine vehicles.

Title: *Mid-Frequency Spatial-Bandlimited Acoustic Radiation Analysis Tool*

Funding Year: Second

Principal Investigator: Stephen O'Regan, Code: 7220, NSWC Carderock
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S&T Focus Area: Survivability and Self-Defense

Abstract: Ever increasing sophistication of sensor systems have made mid- and high-frequency acoustic signature identification possible. To counter this vulnerability, new ship classes are given tight acoustic budgets, driving the exploration of new and novel concepts for hull form, materials, and propulsion, and therefore driving the development of structural and acoustic analysis tools to evaluate them. This proposal focuses on acoustic analysis tools.

Boundary, finite, and infinite element methods (BEM, FEM, IEM) have proven useful for solving the 3D acoustic wave equation at low frequencies. For high frequency, localized formulations such as plane-wave and ray-tracing methods have been applied. These methods are impractical, inaccurate, or both for treating mid-frequency problems. Low-frequency methods make very large demands on computer processing while high-frequency methods do not account for non-local effects. Known attempts for low/high frequency hybrid methods are known to be inaccurate in the mid-frequency range.

The situation is similar for structural analysis. Low- and high-frequency problems are respectively treated by FEM and statistical energy analysis (SEA). Hybrid low-high frequency methods are actively being developed by others for mid-frequency structural analysis.

The goal of this research is to develop a method for efficiently addressing a class of mid-frequency vibration problems highly relevant to naval vessels. This class deals with structural surfaces characterized by a moderate number of major sections in which the spatial wavenumber vibration content is bandlimited and known a priori. The objective is to capture directly the mid-frequency physics rather than apply a hybrid approach.

The expected value of the results is a computer code for solving mid-frequency acoustic problems. Input and output variables will be compatible with structural-acoustic analysis codes to replace their inaccurate acoustic representations. Validation and verification procedures will be executed to ensure accuracy.

Title: *UNREP with Payload Stabilization Control in the Presence of Uncertainties*

Funding Year: New

Principal Investigator: Qing Dong, Code: 981, NSWC Carderock
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Associate Investigator: Frank Ferrese, Code: 981, NSWC Carderock

Primary External Collaborations: Prof. Saroj K. Biswas, Temple University, Philadelphia, Pa.

S&T Focus Area: Fleet/Force Sustainment

Abstract: Anti-swing control of cargo transfer between ships has been a subject of considerable research for over thirty years, and has drawn the attention of applied control engineers as well as fundamental researchers, including Navy and industry. In recent research, the principal investigator has developed multiple anti-swing feedback control algorithms for a gantry crane, and successfully implemented it to a laboratory scale crane. Experimental results confirmed excellent performance of the anti-swing control algorithm.

Recently a linear feedback control method has been developed by the principle investigator for stabilization of cargo pendulation using a two-dimensional inverted Stewart platform applying a different method of controllers. These works were presented at several ASNE conferences (2004 ASNE Sea Basing Conference, 2007 ASNE Fleet Maintenance Conference and 2007 ASNE Automation and Control Conference). However, in this research, the cargo was assumed to have two-dimensional motion control using an inverted Stewart platform. In reality, cargo pendulation is a highly nonlinear large scale system with multiple degrees of freedom, highly coupled with ship motion, and is stochastic due to uncertainties of sea waves.

This research proposes to extend the previous work to develop mathematical concepts and control algorithms for stochastic dynamic systems with multiple degrees of freedom. These control algorithms apply to stabilization of large scale systems with multiple interconnected subsystems. Each subsystem is designed to perform a specific function that is highly interconnected, simultaneously features diverse degrees of couplings, and is subject to resource constraints. By its nature, the system is highly integrated, distributed, and subject to uncertainty arising from incomplete knowledge of parameters, sensor data errors, errors derived from modeling, as well as external disturbances. Feedback controls based on stochastic and robust control theories will be used for optimal performance of the closed loop system.

Bibliometric Information:

Published paper (Unreferreed)

FY08 CARDEROCK DIVISION ILIR PROJECT SUMMARIES

Ortiz, A. , F Ferrese, Q Dong, S Biswas, *Output feedback & trajectory tracking control of a gantry crane: theory & experiment*, 2008 Maritime Systems and Technology (MAST) Conference, Cadiz, Spain, (Nov 12-14, 2008)

Patent approved by invention award board

Navy Case No. 99,242 Disclosure Date: April 2008

Name(s): Qing Dong, Albert Ortiz, Donald D. Dalessandro and Saroj Biswas

Title: *Multiple Highlines with an Inverted Stewart Platform Payload Stabilization for Navy Unrep System*

Navy Case No. 99,559 Unclassified Disclosure Date: August 2008

Name(s): Albert Ortiz, Donald D. Dalessandro, Qing Dong, and Dr. Li Bai

Title: *Design of a Reliable Distributed Secure Database System*

Navy Case No. 99,573 Unclassified Disclosure Date: September 2008

Name(s): Qing Dong, Albert Ortiz, Donald D. Dalessandro, and David J. Kocsik

Title: *Over the Air Interrupt Autonomous Sensor for Machinery Automation and Control*

Title: *Model Based Failure Detection on Nonlinear Systems*

Funding Year: Third

Principal Investigator: Dr. Kimberly J. Drake, Code: 986, NSWC Philadelphia
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Associate Investigator: Patrick Violante Code: 986, NSWC Philadelphia

Primary External Collaborations: Prof. Stephen Campbell, North Carolina State University, and Ms. Kelly Sweetingham, North Carolina State University

S&T Focus Area: Power and Energy

Abstract: Recently an approach for robust failure detection and multi-model identification (FDMI) in the presence of bounded energy noise over short time intervals has been introduced (Campbell, Horton and Nikoukhah 2002.) This approach to failure detection is based on a multi-model identification algorithm. Increased modeling and simulation in the design and testing of new systems will make it easier and less expensive for failure detection and diagnostic methods based on model identification to be implemented. This approach to failure detection and model identification has been primarily applicable to systems that can be modeled using linear, analytical models (Campbell and Nikoukhah 2004. For broader application, the approach needs to be extended to models that are nonlinear as many physical processes and devices are most realistically modeled by nonlinear systems. During the past two years, we have seen excellent results. We have shown that signals designed using linearized models of nonlinear systems produce a signal that works well with the original nonlinear system, analyzed the error bounds that result in approximation and begun investigating extension of this algorithm for use with data driven models.

Additionally, we have begun transitioning the work by starting a small test project. The test project has also been successful and we anticipate it continuing through the coming year. We propose to continue the development of these promising algorithms. In the coming year we will continue to investigate the use of data driven models and how the system noise can be used to enhance the detection process. Extending this algorithm will make it widely applicable to support Naval efforts in intelligent systems and condition-based maintenance (CBM), increasing both reliability and survivability of the systems. Moreover, while there are problems which the proposed technology can solve for the Navy today, advances in modeling and simulation along with advances in sensor designs will make the proposed technology grow in value to the Navy over time rather than having it become obsolete as new technologies emerge.

Bibliometric Information:

Published paper/report (Referreed

Violante, Patrick, Kimberly J. Drake, Steven Latman, Shreekanth Mandayam, "Virtual Environments, Data Fusion, and Video in Support of Remote Health Management Systems."

FY08 CARDEROCK DIVISION ILIR PROJECT SUMMARIES

IEEE 7th International Workshop on Haptic Audio Visual Environments and Games (HAVE 2008). Ottawa, Ontario, Canada. 18-19 October, 2008.

Patent approved by invention award board

Navy Case No. 99,212 Disclosure Date: March 2008

Name(s): David C. Woodward, Sara E. Wallace, Michael Robinson, Chris J. Dafis, Julie E. Palmer, Timothy C. Klingensmith, Kimberly J. Drake, William R. Sheppard, Brian J. Brady, Sean M. Gallagher, Kristen A. Izganics, Frank P. Scazzuso, Mark M. Zerby, Patrick J. Violante

Title: *Tool for Early Stage Evaluation of Sub-system Level Technology for Use in a System of Systems Environment*

Title: *Liquid Phase Desulfurization Sorbent Activity and Selectivity Maintenance Characterization*

Funding Year: Second

Principal Investigator: Mr. John Heinzl, Code 9823, NSWC Philadelphia

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S&T Focus Area: Power and Energy

Abstract: The technology development programs ongoing as part of the ONR Advanced Fuel Cell Program are addressing numerous areas of process improvements. One of the most critical is the ability to remove sulfur from F-76 and JP-5 Navy logistics fuel, in liquid phase at ambient temperature and pressure, with high regeneration capability over high numbers of cycles. Such removal of refractory sulfur compounds is a challenge due to the nature of the molecules themselves, as well as their high concentrations, up to 10000 ppm of sulfur. The ability to remove sulfur from fuel at such conditions is important, as it provides benefits in process simplification and system safety.

Liquid-phase desulfurization allows systems to become far more compact, due to the removal of pressure vessels, large valve and actuator assemblies and high inventory reactors, which contain large amounts of vaporized fuel and other combustibles.

This research proposes to continue upon the process of further development of knowledge pertaining to the fundamental aspects of adsorption/desorption of most refractory compounds, which was initiated in an FY07 ILIR.

This effort will continue to explore the activity and selectivity maintenance requirements of the top new sorbent materials, which have indicated high initial performance characteristics in the ONR sorbent development efforts.

Due to the nature of the makeup of the state of the art sorbents, there are multiple potential failure mechanisms which can be expected, based upon the use of similar materials in related chemical processes. For example, in FY07, ILIR efforts determined the extent of metal migration and agglomeration upon support structures, as well as the effects of material loading and regeneration upon active surface area and poremouth hindrance. Similarly analysis of the collapsing of pore and ridge structure in doped metal oxide materials, particularly during the high temperature oxidative regeneration, was shown to reduce capacity of said materials, if not carried out within the correct operational window. Further, the understanding of stepwise cracking behavior, and the binding of sulfur that adsorbs to the active sites of the sorbent materials provides knowledge into why these compounds may not completely be desorbed under regeneration conditions, and thus reduce capacity. NSWC Philadelphia intends to utilize state of the art methods of determining fundamental sorbent deactivation characteristics, as well as regeneration performance in terms of remaining bound sulfur on sorbent surfaces, surface properties before and after multiple cycles of sorbent usage, and failure modes of sorbent materials, both with respect to the active surface and

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sorbent particle characteristics.

Bibliometric Information:

Patent approved by invention award board

Navy Case No. 99,238 Disclosure Date: April 2008
Name(s): John M. Heinzl, Steven P. Miller, Donald J. Hoffman, and John H. Kuseian
Title: *Soot-Inducing Regenerable Particle Trap*

Navy Case No. 99,239 Disclosure Date: April 2008
Name(s): John M. Heinzl, Donald J. Hoffman, and John H. Kuseian
Title: *Regenerative Gas-Phase Polishing Unit*

Navy Case No. 99,241 Disclosure Date: April 2008
Name(s): John H. Kuseian, John M. Heinzl, and Donald J. Hoffman
Title: *Energy Recovery System for Fuel Processor / Reformer System*

Navy Case No. 99,246 Disclosure Date: April 2008
Name(s): Steven P. Miller, John M. Heinzl, Donald J. Hoffman, John H. Kuseian, and Edward M. House
Title: *Rotary Regenerative Steam Reformer*

FY08 IAR PROJECTS

Title: *Porous Hull Form for Reducing Combatant Craft Shock Loads*

Funding Year: Third

Principle Investigator: Tim Coats, Code 23, NSWC Norfolk
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Associate Investigators: Young Shen, Code 5800, NSWC Carderock, Scott Gowing, Code 5800, NSWC Carderock, and Don Jacobson, Code 23, NSWC N

S&T Focus Area: Naval Warfighter Performance and Protection & Platform Mobility

Abstract: This is a Phase III proposal for completion of in-house applied research that has demonstrated in a laboratory setting the shock mitigation benefits of a novel porous hull form for small combatant craft.

Special-forces combatant craft suffer repetitive wave ‘slamming’ shock loads that impose extreme physical requirements on the boat crew. These extreme shock levels reduce the operational effectiveness of the craft (i.e. limited speed and duration), reduce the operational envelop of the craft, and cause repetitive trauma with acute crew injury of the lower back, knees, and neck. While internal shock isolation mounts have been used to address this problem, the isolation mounts offer only “point-solutions” with limitations based on space, mission requirements, and modes of operation.

Experimental data acquired during Phases I and II demonstrates the porous hull approach could offer a full-scale solution that mitigates the shock loads throughout the entire craft.

This proposed Phase III effort transitions the Phase 1 and 2 laboratory testing to open water demonstration testing using a full-scale prototype craft. A craft will be selected; design modifications will retrofit a porous hull section into an existing surrogate craft; test data will be recorded and analyzed, and the efficacy of the novel porous hull design will be documented in a technical report.

Bibliometric Information:

Published paper (Unreferreed)

Coats, Timothy, Young Shen, Scott Gowing, *Porous Hulls for High-Speed Craft Shock Mitigation*, Multi-Agency Craft Conference, Little Creek Amphibious Base, Norfolk, VA., (June 3, 2008)

Paper accepted for publications

FY08 CARDEROCK DIVISION ILIR PROJECT SUMMARIES

Coats, Timothy, *High Speed Craft Motion*, High Speed Boat Operations Conference, Gothenburg, Sweden, (April 1-3, 2008)

Patent approved by invention award board

Navy Case No. 96,701 Disclosure Date: April 2008

Name(s): Young T. Shen, Scott Gowing, William G. Day, and Timothy W. Coats

Title: Permeable Hull to Mitigate Impact Load in Water

Professional Society Presentations

Coats, Timothy, Young Shen, Scott Gowing, *Porous Hulls for High-Speed Craft Shock Mitigation*, Multi-Agency Craft Conference, Little Creek Amphibious Base, Norfolk, VA., (June 3, 2008)

Title: *A novel propulsion system for unmanned underwater vehicles*

Funding Year: Second

Principle Investigator: Benjamin Y.-H. Chen, Code 5400, NSWC Carderock,
Phone: 301-227-2258, E-mail Address: benjamin.chen@navy.mil

Associate Investigators: Mr. Stephen K. Neely, Code 5400, NSWC, Carderock, Dr. Cheng-I. Yang, Code 5400, NSWC, Carderock, Mr. Scott Gowing, Code 5400, NSWC, Carderock, Dr. Edward S. Ammeen, Code 5600, NSWC, Carderock, Mr. Douglas A. Noll, Code 7250, NSWC, Carderock, Mr. Michael L. Mimmagh, Code 991, NSWC, Philadelphia, Dr. Stephen A. Huyer, Code 8233, NUWC, Newport, RI, and Lt. Cmdr David Robinsonm Naval Architect & Ocean Engineering Dept., USNA, Annapolis, MD

Mentored Junior Investigator: Mr. Thad J. Michael, Code 5800, NSWC Carderock

S&T Focus Area: Platform Mobility & Affordability, Maintainability, and Reliability

Abstract: The primary objective of this proposal is to develop and demonstrate a novel high maneuvering and stealthy propulsion system for unmanned underwater vehicles. We envision a vehicle that can stop and hold a position, reverse, rotate or revolve without forward motion. An added benefit of this concept will be to increase operational range. In addition, the low cost UUV is always a required goal in the UUV master plan. This novel propulsion system substantially provides not only the enhancement of low speed maneuvering for operational flexibility but also procurement and operational cost savings.

The maneuvering capability for tactical scale vehicles will be significantly enhanced by the thrust vectoring from the novel propulsion system. This enhanced maneuvering capability allows the vehicle to conduct tight tactical maneuvers in a hostile environment, such as mined waters, to achieve multi-mission functions. UUV recovery, which currently poses significant challenges, will be improved when docking with host vessels such as SSN or surface craft in a high-sea state. Additionally, the operation of the Synthetic Aperture Sonar and the Undersea Distributed Network battlespace will be achieved because of the capability of the UUV's precise station keeping to counteract the hydrodynamic forces generated by eddies and currents.

The stealth performance will be enhanced through maneuvers, due to the flexible composite material blades. The propulsor will be operated in low RPM, which, in turn, generates low broadband vibration noise (BRN).

The procurement cost saving comes from the composite material fabrication. The operational cost saving occurs due to maximizing propulsor efficiency. If it is feasible, this concept would be eventually applied to the large-scale underwater vehicle to enhance the low speed maneuvering capability

Bibliometric Information:

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Published paper (Unreferreed)

Chen, B. Y.-H., S. K. Neely, K. A. Junghans, D. P. Bochinski and D. C. Robinson (USNA) , *A Feasibility Study of a Novel Propulsion System for Unmanned Underwater Vehicles*, UDT (Underwater Defense Technology) Europe 2008 Symposium, Glasgow, UK, (June 10-12 2008)

Professional Society Presentations

Chen, Benjamin, Y.-H, Stephen K. Neely, Kurt A. Junghans and David P. Bochinski, *A Feasibility Study of a Novel Propulsion System for Unmanned Underwater Vehicles*, Underwater Defense Technology (UDT) Symposium, Glasgow, UK, (June 10-12, 2008)

Title: *A Novel Thermo-Power Generator*

Funding Year: New

Principle Investigator: Thanh Tran, Code 616, NSWC Carderock
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Associate Investigators: Mr. Kevin King, Code 985, NSWC Carderock

Mentored Junior Investigator: Mr. Gregory Anderson, Code 985, NSWC Philadelphia

Primary External Collaborations: Dr. John Lafemina – Alloys Surfaces Company, Inc., Mr. Norbert Elsner – Hi-Z Technology, Inc., and Dr. Bao Yang – University of Maryland College Park

S&T Focus Area: Power and Energy

Abstract: The objective of this research is to develop and demonstrate a unique power generating capability that addresses limitations presently imposed upon mission capability and the warfighter by existing power sources such as batteries and generators, including fuel cells. This innovative power system is called a Thermo-Power Generator (TPG).

A TPG is a stand-alone, scaleable power source that uses a self-sustained heat source, and thermoelectric technology to provide power generation capabilities greater than currently fielded batteries. The heat is generated by an exothermic reaction of pyrophoric special material (SM) that reacts with oxygen in the air. This material is unique in the amount of heat that it can produce. It is a non-isotopic reaction and is only outperformed by nuclear (isotopic) reactions. Given the enormous amount of heat that this material creates, its use as an expendable power source for a thermoelectric generator presents a unique opportunity to provide the warfighter with a lighter, smaller, more energy dense option than current battery technology.

An added benefit is the pyrophoric material is non-toxic and does not have to be treated as a hazardous material, as is the current practice with batteries. Thermoelectric power generation is a solid-state process that is silent, vibration-free, and rugged. The heat generated from the reaction of SM material is supplied to the hot side of thermoelectric modules where the difference in temperatures at the hot side and cold side of the modules generates a DC voltage. Generator power density is a function of the temperature difference across the thermoelectric device and the heat to power conversion efficiency of the thermoelectric materials. In this project, the temperature difference will be controlled and optimized by advanced electronic controls and high performance heat exchangers. Quantum Well thermoelectric materials will also be used for higher conversion of heat to electrical power.

Project goals include safely controlling the temperature and burn rate of the pyrophoric material, reducing thermal resistances across interfaces, incorporating advanced, high efficiency thermoelectric materials, and minimizing heat losses.

Bibliometric Information:

Published paper/report (Referreed

Yang, Bao, Herwin Ahuja, Thanh N. Tran, Thermoelectric Technology Assessment: Application to Air Conditioning and Refrigeration, published in HVAC&R Research, Volume 14, Number 5, September 2008

Lowhorn, N.; W. Wong-Ng; W. Zhang; Z.Q.Lu; M. Otani, Round-Robin Studies of Two Potential Seebeck Coefficient Standard Reference Materials, published in the IEEE Proceedings of The 2007 International Conference on Thermoelectric, pp. 366 (2008).

Patent approved by invention award board

Navy Case No. 99,207 Disclosure Date: March 2008

Name(s): Thanh N. Tran

Title: *Thermal Power Generator with Integrated Optoelectronic Power Management and Monolithic Silicon Carbide Heat Source Module*

Dissertations

Gregory Anderson, Ph.D thesis. *Development and Testing of a Multiplexed Temperature Sensor*, University of Maryland, Defended July 21, 2008, Awarded August 22, 2008

Professional Society Presentations

Tran, Thanh, Development of a Seebeck Coefficient Standard Reference Material, ICT2007, Jeju Island, Korea, June 3-8, 2007

Tran, Thanh, Development of a Standard Reference Material (SRM*) for Low Temperature Seebeck Coefficient, International Conference on Thermoelectrics, Aug 3-8, 2008 Corvallis, OR

Title: *Multifunctional Materials for Railgun Conductor and Armature*

Funding Year: New

Principal Investigator: A. P. (Dave) Divecha, Code 611, NSWC Carderock
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Mentored Junior Investigator: Guiseppe Iorio; Code 610, NSWC Carderock

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Primary External Collaborations: Dr. Sikhanda Satapathy, Institute for Advanced Technology (IAT), University of Texas at Austin

S&T Focus Area: Power Projection

Abstract: There are many reasons to pursue electromagnetic (EM) Railgun development. For example, it can fire a projectile at 2.5 km/sec and hit a target greater than 200 miles away fairly accurately with minimum collateral damage. It is safer than the legacy guns because no gun propellant is needed. It has all weather capability. Both Army and Marines can benefit by Railgun deployment. There are numerous technology challenges in Railgun development including, but not limited to, the launcher, the projectile and the power system. This proposal is specifically aimed at extending the railgun bore life.

Problem Definition: At the present, railguns use a C-shape armature. Commercial aluminum alloys, 7075-T6 and 6061-T6 are typically used as armature materials. Rail conductor materials include pure Cu, Cu-Ag alloys, Cu-Cr alloys and GlidCop (alumina dispersion strengthened copper alloy). Due to high current and high voltage at launch, both the copper based rail conductor and aluminum based armature experience extraordinary thermal, electrical and mechanical forces at the interface. Regardless of surface roughness or smoothness of the copper rail (M.P. 1083 C) and the aluminum armature (M.P. ~ 660C), the atomic asperities prevent good electrical contact between the two.

Constriction effects cause excessive heating at discrete contacts. Experimental evidence indicates that for current densities appropriate for tactical launchers, the armature starts moving only after the interface melts. But liquid aluminum and the copper rail conductor alloy almost instantaneously with formation of brittle CuAl_2 . While liquefaction of the armature leads to good electrical contact and motion of the projectile, alloying at R/A interface must be avoided because, in certain situations, grooving occurs in the start up region as the alloying (CuAl_2) deteriorates tribological properties and exacerbates wear. The alloying continues along the bore surface as the armature accelerates (from left to right, rail schematic at the bottom) on its own liquid. This significantly abets gouging in the high-speed region. Finally arc transition takes place in the

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hypervelocity region before armature exits at the muzzle. The sequence is repeated in subsequent shots, with one exception. The armature rides on its own liquid aluminum as before, but instead of depositing on copper rail, the new liquid layer solidifies over the previously deposited aluminum layer. Of course, the total thickness of aluminum layer increases with each shot and the bore size decreases. As expected, a thin alumina layer forms on each aluminum layer. On exposure to atmosphere, the oxide converts to aluminum hydroxide. As the launching continues, the temperature rises. Alloying at layer 1 will proceed as dictated by the kinetics and diffusion, only approximated by Cu-Al equilibrium diagram. Accurate measure of the phases is not possible because these events occur under non-equilibrium conditions. Simultaneously, aluminum hydroxide, $\text{Al}(\text{OH})_3$, will decompose and liberate hydrogen at or above 250 C per the equation shown in Figure 2. All these factors cumulatively limit the bore life of contemporary railguns, large and small, to fewer than 100 shots.

In contrast, the baseline legacy Navy guns require repair or refurbishment only after several thousand shots. Hence the bore life must be extended significantly beyond 100 shots to realize the full potential of the Railgun. Specifically, innovative techniques must be developed to prevent/mitigate alloying at the R/A interface by metallurgical manipulation and lubrication. Each rail section must be composed of functionally graded MMCs and monoliths (W/Cu, Gr/Cu, steels, etc) along the bore length and through the thickness to withstand varying electrical, thermal, metallurgical, tribological and mechanical forces as the armature, riding on the rail, accelerates and propels the projectile to the target.

Bibliometric Information:

Academic/industrial colloquium

Divecha, A.P. (Dave), *Recent Progress in Graded MMCs for Railgun Applications*, presented to ONR 35 and Dahlgren Railgun Pgm Principals.NSWCCD, Bethesda, MD., (20 February 2008).

Divecha, A.P. (Dave), *Functionally Graded MMCs via Centrifugal Casting*, Materials and Tribology Working Group (MTWG), Sandia National Laboratories, Albuquerque, NM, (31 July 2008)

Divecha, A.P. (Dave), *Development of Functionally Graded Composites for Railgun Bore Life Extension*, DoD Innovative S&T Em-Railgun Workshop, Sandia National Laboratories, Albuquerque, NM, (23-25 September 2008)

Appendix 3. – FY09 Carderock Division ILIR Program

| Proposal title | PI Surname | Year | FY09 Funding |
|--|------------|------|--------------|
| Development of computational methods to analyze impact forces from breaking waves | Brewton | 2 | \$90 K |
| A New Approach to Satisfy Dynamic Similarity for Surface Ship Model Experiments | Shen | New | \$90 K |
| Development of a Methodology to Predict The Six-degree of Freedom Ship Motions When The Ship Maneuvers in a Seaway | Lin | New | \$100 K |
| A practical application-oriented CFD tool to compute flow about a ship in steady motion | Noblesse | 2 | \$100 K |
| Wave Evolution in the Presence of Wind Gusts and Ocean Currents | Wundrow | New | \$75 K |
| The Role of the Plastic Deformation on High Impact Protection of Novel ERC Polyureas | Balizer | 3 | \$90 K |
| Lattice Dynamics and Electronic Structure of Thermoelectric Materials | Mansour | 3 | \$110 K |
| Core-Valence Luminescence (CVL) for gamma-neutron discrimination | Mathur | 2 | \$100 K |
| Iron-Based Magnetoelastic Interactions | Restorff | 3 | \$110 K |
| Health Monitoring and Diagnostics for High-Speed Vessels | Salvino | 3 | \$100 K |
| Investigation into the Physicochemical Properties of Electrochemical Double Layer Capacitor Materials | Smith | 3 | \$120 K |
| Virtual Shaping for Surface Ship Radar Cross Section Reduction | Stark | 2 | \$90 K |
| Friction Stir Weldability of Titanium Alloys | Wolk | New | \$90 K |
| Electrochemical Detection of Sensitization in 5XXX Aluminum Alloys/ Sc-Zr Al Alloys | Bumiller | New | \$150 K |
| Mid-Frequency Spatial-Bandlimited Acoustic Radiation Analysis Tool | O'Regan | 3 | \$90 K |
| Intelligent Underwater Electrolocation Of Littoral Sea Mines - Artificial Underwater Electrolocation | Arizzi | 2 | \$110 K |
| Advanced Processing For Vector Sensor Arrays | Daniels | New | \$90 K |
| Liquid Phase Desulfurization Sorbent Activity and Selectivity Maintenance Characterization | Heinzel | 3 | \$100 K |
| Investigation and Concerns with High Frequency Vibration Isolation Mount Performance for Use on Variable Speed Large Scale Electric Machines | Graesser | New | \$90 K |
| Optimal Selection of State and Control Weighting Matrices for Linear Quadratic Controller | Ferrese | New | \$75 K |