



iMAST

Institute for Manufacturing and Sustainment Technologies

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DIRECTOR'S CORNER



Timothy D. Bair

To our loyal readers I want to first say thanks for your continued interest and apologize for the delay in

this next edition of the iMAST newsletter. Since the holidays we've been scrambling between major program reviews, customer visits and conferences. The push to identify the FY19 portfolio of projects has begun and we've held our winter RepTech Working Group to review ongoing life cycle cost saving projects and discuss new candidates. After writing this I realize I'm probably preaching to the choir! So what else is new?

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Fluorescence-Based NDE of Aircraft Composites

Polymer matrix composites (PMCs) have come into widespread use to construct the wing, fuselage, and other major structural components of high-performance military aircraft, replacing metals such as aluminum, magnesium, and titanium that became prevalent in the twentieth century. This design trend stems mainly from the high strength-to-weight ratio and improved resistance to fatigue and corrosion of PMCs relative to metals. But PMCs are prone to substantial loss of strength and flexibility from exposure to high heat fluxes from such contingencies as fire, engine exhaust gases, equipment overheats, solar radiation and even routine operations. These materials can suffer substantial degradation in strength and other properties without exhibiting any evidence of discoloration, delamination, or other indications either visually or through traditional non-destructive evaluation (NDE) methods — a condition that has come to be termed incipient heat damage. There is currently no fielded NDE method to assess incipient heat damage, resulting in expensive aircraft composite components being scrapped as a precaution. If the heat damage could be assessed and found to be limited to a small volume of the composite component in question, it can be repaired in many cases. Besides the substantial cost savings, repairing an existing component also greatly reduces the down time of the aircraft, allowing the depot to return it to service within weeks instead of months. There is often a long lead-time to procure a replacement component, and once delivered, its installation will likely require considerable effort and expenditure.

In collaboration with the Naval Air Systems Command (NAVAIR), ARL Penn State, under the auspices of its Navy ManTech center of excellence, the Institute for Manufacturing and Sustainment Technologies (iMAST),

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PennState Institute for Manufacturing and Sustainment Technologies

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U.Ed. ARL TBD

DIRECTOR'S CORNER

The biggest news for iMAST over the last quarter has been the turnover in leadership. Please join me in congratulating Mr. Greg Woods on the occasion of his retirement. Greg dedicated 42 years of his life to the service of our nation, all of it within the Department of the Navy. He started out working as a shipyard laborer at 18 years of age and worked to get his Engineering Management degree nights. About 12 years ago, he accepted a new posting in support of the Navy's Manufacturing Technology program as the program officer over the iMAST and NMC programs. Greg's leadership of this program was insightful and passionate. He obviously loved what he did and he will be missed. God speed Greg and enjoy some much deserved downtime!

Early in April I traveled to Hill AFB to attend the annual Commercial Technologies for Maintenance Activities "Partners Meeting." CTMA, hosted by NCMS, supports projects that transition mature (or nearly mature) technology from the commercial sector to our yards, depots and flightlines. My mission was to learn more about collaborative opportunities with CTMA and share a little about iMAST, ONR ManTech and the RepTech program. As frequently happens when attending these types of events, it's refreshing to talk to folk that share your mission, frustration, and successes. CTMA and iMAST have collaborated very successfully in the past and I plan to seek out opportunities in the future to repeat that synergy for the benefit of the Navy.

Finally, I mentioned we are starting to work on the FY19 program for iMAST and ManTech in general. The process this year is again concentrating on innovation and programmatic savings for the Navy's big acquisition programs. The new Chief of Naval Research, Rear Admiral David J. Hahn has elected to sustain last year's list of program's for ManTech investment, specifically, the VCS, CLB (newly named Columbia Class Submarine program), CVN, DDG, F-35 and CH-53K programs as well as the iMAST managed RepTech program. The annual cycle will begin in late April with OEM's presenting their innovation thrust areas to be followed by the COE's proposing technology opportunities to support those areas of emphasis. Finally, specific projects will evolve that support making those ships and aircraft cheaper, more reliable and/or available. The RepTech program review last March at Norfolk Naval Shipyard and Intermediate Maintenance Facility also approved 5 new projects for further development. If you have a great idea for an innovation that would save the Navy funds in acquisition or life cycle, please contact us. We are always open to new ideas and will provide honest feedback as to ManTech or RepTech program applicability.

Thank you for your interest in iMAST and Navy ManTech and please contact us if we can help you in better supporting our men and women in uniform!

Tim Bair



MATERIALS
PROCESSING
TECHNOLOGIES



MECHANICAL DRIVE
TRANSMISSION
TECHNOLOGIES



LASER
PROCESSING
TECHNOLOGIES



COMPLEX SYSTEMS
MONITORING
TECHNOLOGIES



COMPOSITES
MATERIALS
TECHNOLOGIES



NAVY/MARINE
CORPS REPAIR
TECHNOLOGIES



MANUFACTURING
SYSTEMS
TECHNOLOGIES

Fluorescence-Based NDE of Aircraft Composites

recently completed a Repair Technology (RepTech) project that points the way to a robust, portable instrument to perform NDE of incipient heat damage in aircraft hangars, aboard aircraft carriers, and in other field environments. An apparatus was assembled to exploit fluorescence — the well-known phenomenon that causes many substances to glow when exposed to ultraviolet (UV) light (so-called “black light”). Figure 1 illustrates the basic concept of fluorescence: the specimen to be analyzed is irradiated by a source of (usually) ultraviolet or visible light, which elicits the fluorescence from the specimen, which in turn is collected by optical components into a spectrometer for analysis. While the so-called excitation light may be limited to a single wavelength, the fluorescence

is always spread over a range of wavelengths, and in fact the spectrum (the particular relationship between intensity and wavelength) of two different substances will always differ to some extent — although that difference may be too small to measure.

Prior work by a number of researchers has established that the spectrum of a given type of PMC will change after being heated beyond the limits it was designed to endure, and that spectral changes are measurable in cases where strength has been degraded without any visible indications, i.e. in cases of incipient heat damage. Our study report¹ reviews the relevant prior work and describes our research, which is summarized in the following paragraphs.

...the specimen to be analyzed is irradiated by a source of (usually) ultraviolet or visible light, which elicits the fluorescence from the specimen, which in turn is collected by optical components into a spectrometer for analysis.

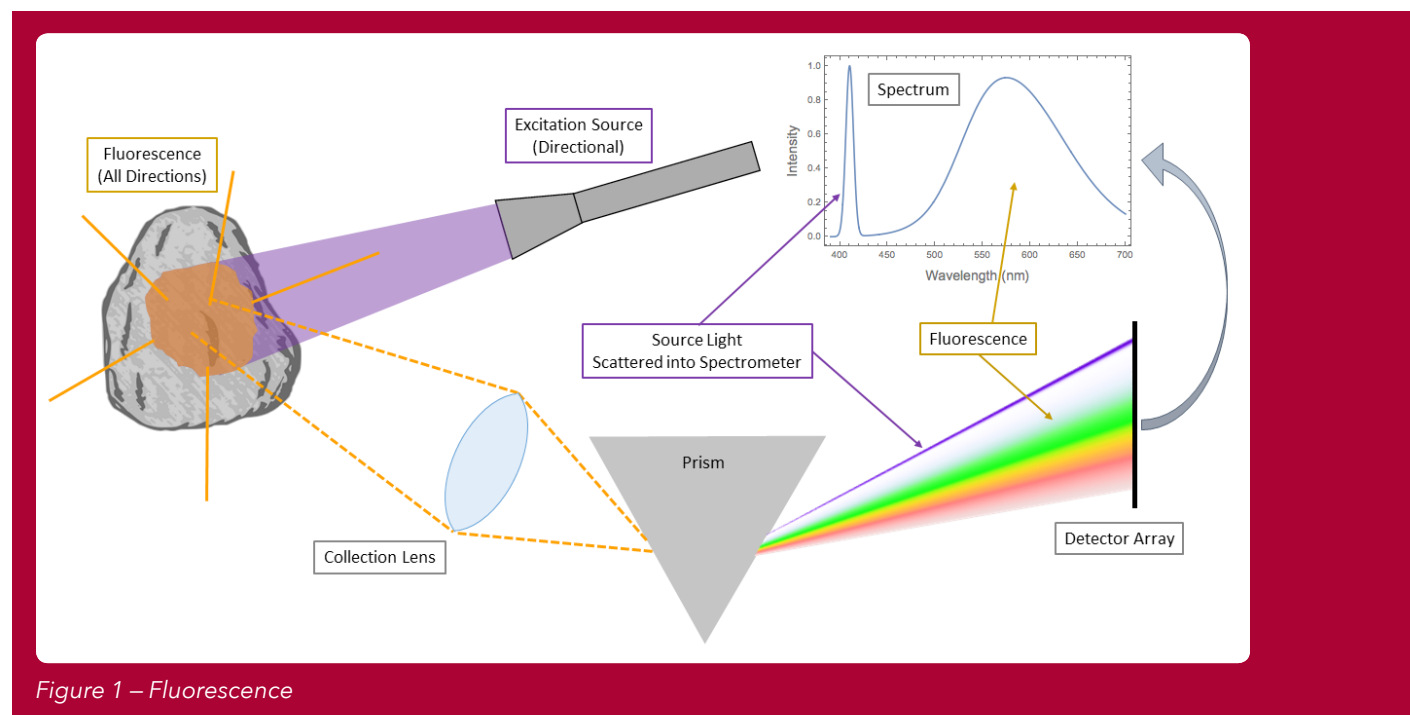


Figure 1 – Fluorescence

¹ Daniel W. Merdes, et. al., *Laser Induced Fluorescence (LIF) nondestructive Evaluation of Incipient Heat Damage in Polymer Matrix Composites*, ARL Penn State Technical Report TR 16-000, February 15, 2017.

FEATURE ARTICLE

***These specimens,
along with others
used in our recent study,
were selected from the
NAVAIR Composite Heat
Damage Standards...***

Figure 2 shows the apparatus we developed at ARL Penn State to measure the spectra of fluorescence emitted by a specimen of material under irradiation by a source of visible or UV light. Following the precedent of previous researchers, we used a small diode laser emitting violet light as the irradiation source. Lasers are commonly used for

fluorescence work because they provide a bright, highly-directional light beam at a specific wavelength. A pair of lenses focuses the irradiated spot on the mounted specimen into the entrance optics of a fiber-optic cable, which transmits the collected fluorescence into a portable spectrometer. Software running on a laptop computer accesses the spectral data from the spectrometer through a USB cable, displays the spectrum in real time, and stores it for subsequent analysis.

Figure 3 shows spectra measured against some specimens of the epoxy-based PMC AS4/35016 5HS (meaning a PMC in which the epoxy matrix material 35016 is reinforced with type AS4 carbon fiber woven into a five-harness-satin fabric). One specimen is a piece of unheated “virgin” material, while each of the others had been baked at

a different temperature for one hour. The shift to longer wavelengths with increasing treatment temperature is evident. These specimens, along with others used in our recent study, were selected from the NAVAIR Composite Heat Damage Standards—a large collection consisting of sets of aircraft-grade PMCs that have been subjected to varying degrees of incipient heat damage under carefully controlled conditions. Importantly, NAVAIR recorded strength measurements for each treatment case of every PMC represented in those standards, which facilitates the computation of mathematical correlations between spectral changes and strength degradation from incipient heat damage. We are grateful to NAVAIR for making some of their sample sets in their standards collection available for our research.

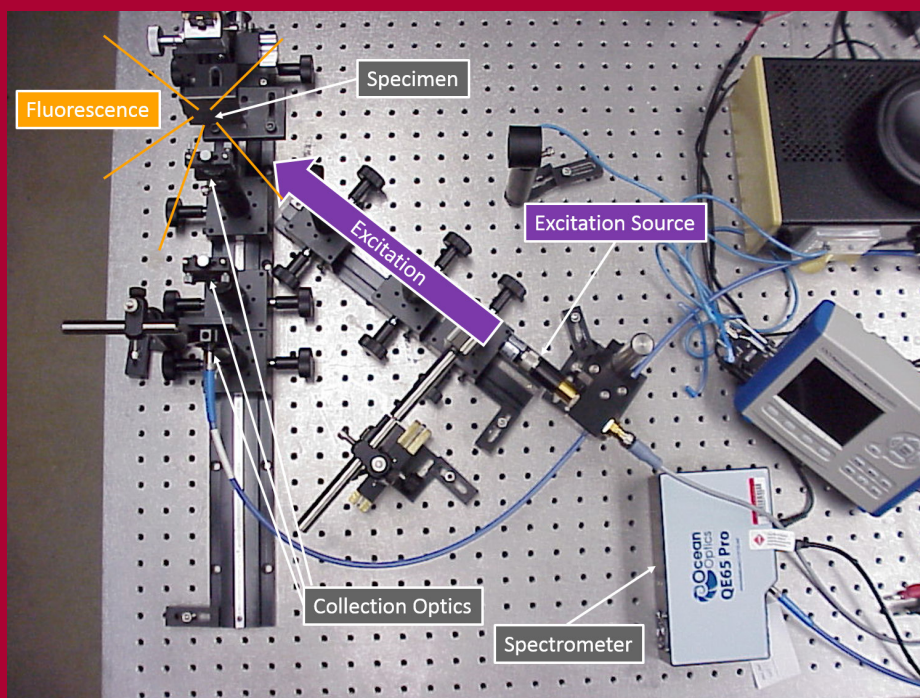


Figure 2 – The ARL Penn State Fluorescence Apparatus

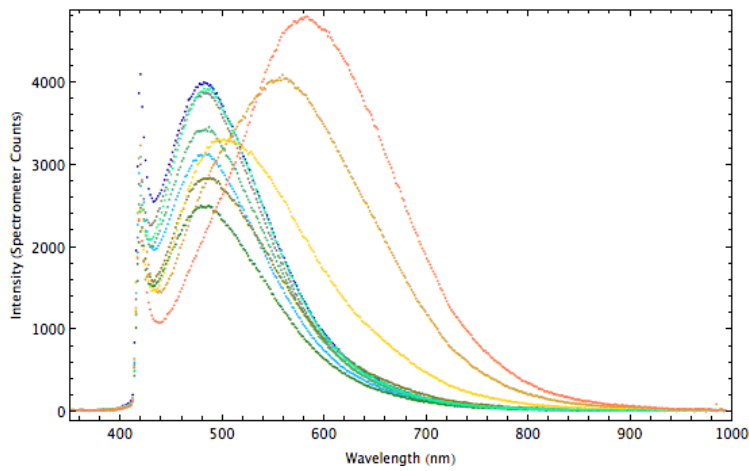


Figure 3 – Treatment Temperature Effect on PMC Fluorescence Spectra

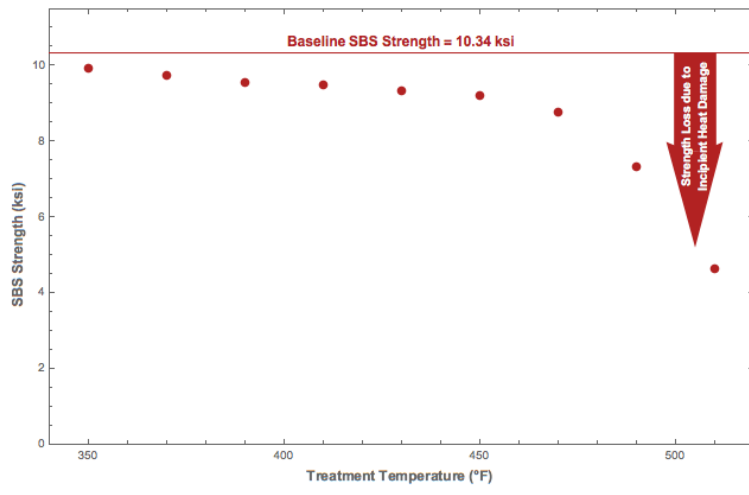


Figure 4 – Treatment Temperature Effect on PMC Strength

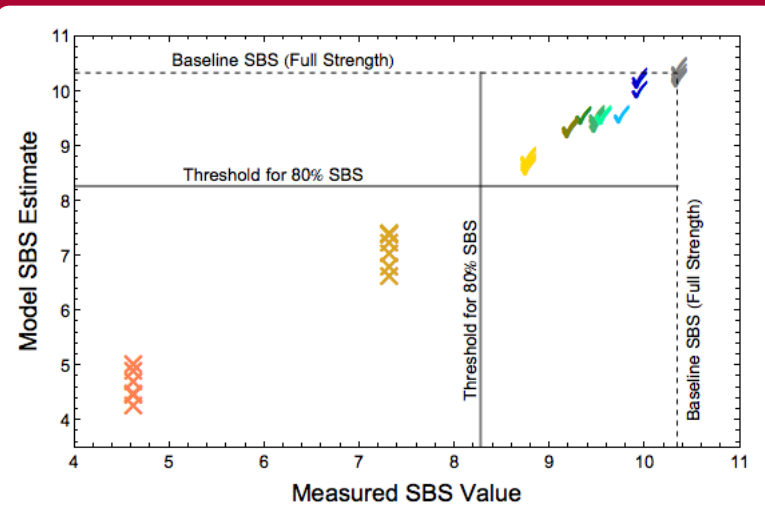


Figure 5 – Validation Chart of Fluorescence-Based PMC Strength Estimates

Such an instrument should be rugged, small enough to hand-carry, and ideally would be self-powered rather than requiring an external electrical connection.

Figure 4 is a plot showing how the strength of the aforementioned PMC degrades with increasing treatment temperature. The strength loss is moderate for treatment temperatures up to about 450°F, beyond which a pronounced falloff sets in. Using a chemometric analysis technique called principal components regression, we constructed a model that was able to classify whether a given specimen has suffered 20% or more loss of strength based on its fluorescence spectrum, as is demonstrated by the validation chart shown in Figure 5. In that chart, the strength measured according to the short-beam shear method is plotted on the abscissa (horizontal axis), while the strength estimated from the model is plotted on the ordinate (vertical axis). Our study report provides details of how this model was developed, and documents results of the same methodology applied to three other types of aircraft-grade polymer-matrix composite.

FEATURE ARTICLE

Figure 6 illustrates the manner in which a trained technician could employ a portable fluorescence-based NDE device to assess the degree of incipient heat damage on an aircraft wing and prepare it for repair. The charred paint and any obviously-damaged composite would be sanded away, leaving a shallow depression in the wing surface showing no sign of degradation. Using the hand-held optical probe, the sanded surface would be checked to seek places where the fluorescence spectrum indicates that strength had fallen below some established threshold. Those places would be sanded further, and the process repeated until no unacceptable spots remained within the depression. Assuming that the resulting depression is not too large, a patch would subsequently be applied to restore the wing to its design contour. After curing, final inspection, and painting, the affected aircraft would be restored to service.

We are now planning a follow-on project to develop a prototype instrument to give maintenance and repair personnel at all levels, from the depot to the hangar to the aircraft carrier, the capability to inspect PMCs for incipient heat damage in-place on an aircraft. Such an instrument should be rugged, small enough to hand-carry, and ideally would be self-powered rather than requiring an external electrical connection. We plan to evaluate whether a light-emitting diode (LED) could be used in place of the laser as the excitation source. The advantage

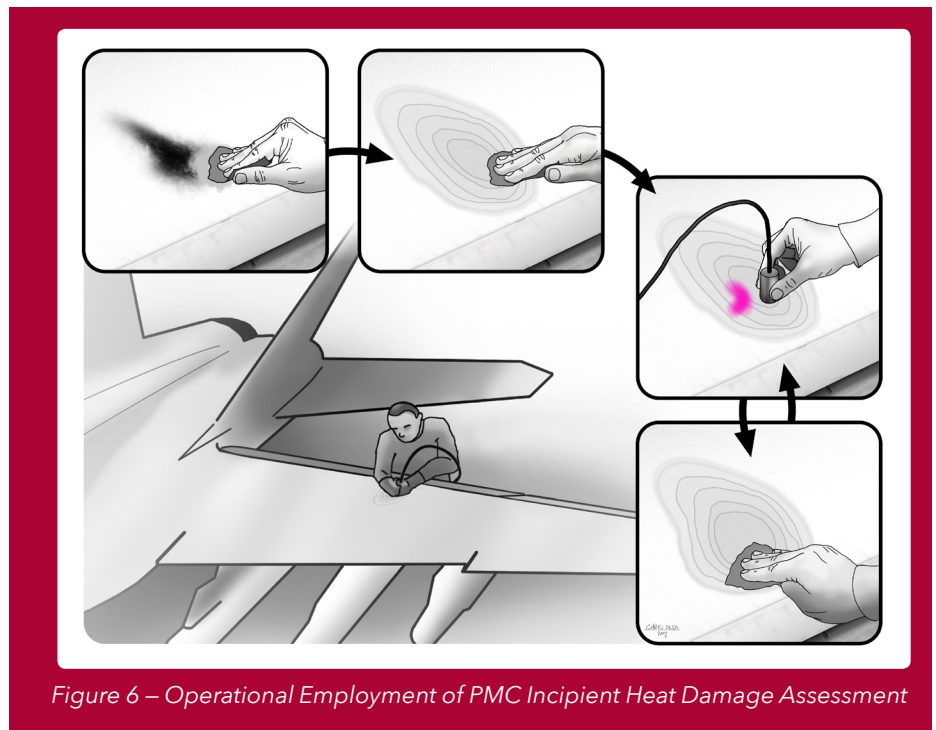


Figure 6 – Operational Employment of PMC Incipient Heat Damage Assessment

***For today's
front-line aircraft,
that would mean
savings of millions
of dollars per incident
and facilitate rapid
restoration of the
heat-damaged aircraft
to operational service.***

would be to vastly reduce the size and power requirement of the envisioned instrument as well as the cost of any manufactured instrument based on the new design. In recent years, inexpensive single-wavelength LEDs have become available for the entire visible spectrum and a large part of the UV spectrum as well. Experiments will be performed to augment NAVAIR's Composite Heat-Damage Standards with additional materials and treatment cases, to include sets of specimens taken from aircraft parts that were scrapped for reasons unrelated to overheating — so-called aged specimens that have seen years of environmental exposure under routine flight conditions. A self-calibration capability will also be developed to enable the instrument to automatically correct for the

so-called drift in the wavelength and intensity measurements, which is an inevitable characteristic of all spectrometers. Finally, several optical probes will be configured to accommodate different surface geometries, from flat or gently curved wings to right-angle joints in the interior of the fuselage.

We have demonstrated the basic efficacy of fluorescence-based non-destructive evaluation of incipient heat damage in four different aircraft-grade polymer-matrix composite materials. Referring back to Figure 6, the ability to determine how much heat-damaged material one must remove in order to be confident of the remaining structure can make the difference between deciding to repair it or replace it. The instrument we are proposing to develop, will enable the maintainer to make an informed decision and more frequently choose to repair. For today's front-line aircraft, that would mean savings of millions of dollars per incident and facilitate rapid restoration of the heat-damaged aircraft to operational service.

PROFILES



Daniel W. Merdes received his Ph.D. in Physics from The Pennsylvania State University (1984) and his B.S. in Physics from Tulane University (1971). He served as an active-duty officer in the United States Navy from 1971 to 1975 and continued as a reserve officer through 2001, retiring at the rank of Captain. He is a Research Associate at the Applied Research Laboratory.

Dr. Merdes is currently working on problems involving the modeling of optical energy deposition into metal powders for additive manufacturing processes, the application of spectroscopy to composite material characterization, and hazard analysis for a developmental explosive ordnance disposal system. In his varied career he has addressed problems involving spectrometric methods of detecting chemical and biological contaminants, detection issues in underwater acoustics, mine countermeasures modeling, and numerous other problem domains involving the measurement and interpretation of physical signatures to inform operational decision making.

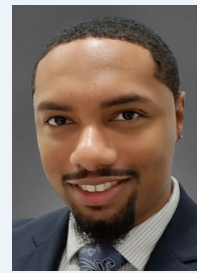
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Clark A. Moose received his M.S. in Ceramic Science from The Pennsylvania State University (1991) and his B.S. in Ceramic Science and Engineering from The Pennsylvania State University (1988).

Clark Moose is a research and development engineer at the Applied Research Laboratory of The Pennsylvania State University. He has been employed at ARL Penn State for over 21 years, during which time he has led a variety of advanced nondestructive inspection projects and tasks as they relate to in-situ manufacturing and in-service monitoring of complex structures. His research focuses on acoustic emission and ultrasonic nondestructive monitoring efforts over several projects including machinery diagnostic monitoring, in-situ materials fabrication monitoring, structural composite inspection, structural modeling, condition-based maintenance, and real-time non-contact quality control.

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Christopher M. Bowie earned his B.S. in Optical Engineering from Norfolk State University (2011). His senior thesis work at Norfolk State University involved the investigation of nano-electrodes for biomedical sensing applications in the brain. Christopher performed the work described here as part of his graduate study at The Pennsylvania State University and expects his Master's degree in Engineering Science & Mechanics to be awarded later this year. He is currently a Mechanical Engineer at Ocean Optics, Inc., where he designs, builds, and tests optical systems for various applications.

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INSTITUTE NOTES

RepTech Working Group Meeting

The Institute for Manufacturing and Sustainment Technologies (iMAST) is leading the Navy-Marine Corps team's repair, overhaul, and sustainment initiative as established by the Office of Naval Research (ONR). As part of the implementation process, a RepTech Working Group (RWG) meeting occurs bi-annually to review current projects, as well as to identify and evaluate potential new projects. Members of the RepTech Working Group solicit potential issues from systems command representatives before submitting them for consideration to the Navy Manufacturing Science and Technology director at the Office of Naval Research (ONR). The RepTech Working Group meeting was hosted this March at the Norfolk Shipyard (NNSY), Norfolk, Virginia. Michael Joyce conducted a tour of the shipyard for all those present for the RepTech working meeting. Twelve (12) current projects and six (6) new projects briefings were presented to the group, followed by final updates and news by the SYSCOMS from NAVAIR, MARCOR, and NAVSEA.

The National Shipbuilding Research Program (NSRP) All Panel Meeting

The National Shipbuilding Research Program (NSRP) All Panel Meeting was held March 7–9, 2017 at the Francis Marion Hotel in Charleston, SC. Two years ago the NSRP and Office of Naval Research Manufacturing Technology (ManTech) Program expanded on the already collaborative relationship by organizing alternate years of combined conferences designed to keep the ManTech and NSRP participants aware of each other's initiatives and successes. Next March 2018, ManTech will be hosting the NSRP at the semi-annual ShipTech conference to be held in Charleston SC. The event was attended by over 340 attendees and featured an Augmented Reality and Virtual Reality (AR/VR) forum as well as numerous technical breakout sessions and NSRP panel meetings. It kicked off with keynote addresses by the NSRP Executive Control Board Vice Chair, Richard McCreary (BAE Systems-Southeast Shipyards), Vice President of Central Planning

& Process Excellence Rick Spaulding (Ingalls), and RDML Lorin Selby, Chief Engineer (NAVSEA 05). The NSRP Panel Chairs also presented "State of the Panel" briefs. Twenty-two NSRP, ManTech and general interest technologies were showcased in the walk-through Project Expo. iMAST featured a booth at the event which highlighted several of our current projects. Tim Bair, Todd Palmer, Brenda Kephart, Dan Finke, Chris Ligetti, Jeff Banks, and Terri Merdes all attended NSRP and staffed the booth during the event. Dan Finke and Chris Ligetti presented an overview of the Advanced Manufacturing Enterprise tools with some emphasis on specific applications at several of the participating shipbuilders. Jeff Banks presented on condition-based maintenance technologies relevant to shipbuilding infrastructure, capital and facilities and Todd Palmer presented on an early applied research project his team is working on to develop additive manufacturing tools,



Tim Bair providing an overview of ARL.

characterization and design rules for naval applications. Finally, Tim Bair gave the NSRP All Panel Meeting participants an overview of ARL Penn State and current/recently completed iMAST projects of potential interest to the audience.



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There's no shortage of good ideas, I'll say that, so where I'm trying to focus is the much less exciting process development, so that when you have a genius idea, what's the quickest way to make that thing real?

— Admiral John Richardson USN, Chief of Naval Operations

CALENDAR of EVENTS

2017

30 May–1 June	Showcase for Commerce 2017	**Johnstown, PA
4–7 June	GEOINT 2017	San Antonio, TX
20–22 June	Mega Rust 2017	**Virginia Beach, VA
14–16 August	Fleet Maintenance & Modernization Symposium	San Diego, CA
19–21 September	Modern Day Marine 2017	Quantico, VA
9–11 October	AUSA Annual Meeting & Exposition	Washington DC
20–21 July	Naval Future Force Science and Technology (S&T) Expo 2017	**Washington, DC
4–7 December	DOD Maintenance Symposium	Salt Lake City, Utah
4–7 December	Defense Manufacturing Conference 2017	**Tampa Florida

**** Please Stop and Visit the iMAST booth**