



# iMAST

Institute for Manufacturing and Sustainment Technologies

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## DIRECTOR'S CORNER

Lately it seems the center of most conversations, at least in the circles we walk, has been current events and the DoD budget. I frequently get asked how iMAST and ONR ManTech are doing under sequestration. The short answer is we are all adapting and continuing to make a difference in acquisition cost savings—as well as life cycle savings. While the ManTech budget



Timothy D. Bair

has paid its share of the budget cut, just like everyone else, it's apparent ONR and Congress recognize the contributions to cost savings, as well as combat capability. Thankfully, it looks like the concerns for our future are limited to just a fair share of the cost—not more! I am personally proud of the contributions made by the ARL engineers and staff within our Navy ManTech program and doubly so since it includes savings throughout the ship and weapons system life cycle. Your ideas and our technical expertise have combined into millions of dollars saved on new ships and more efficient shipyards.

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## PHN Shipyard/iMAST Collaborate on latest new Maintenance Technology

by David Tomiyama, Public Affairs Officer,  
Pearl Harbor Naval Shipyard

*[iMAST is pleased to pass, with permission, the following article published in Pearl Harbor Naval Shipyard's bi-monthly news journal: Shipyard Log]*

The Shipyard and The Pennsylvania State University's Applied Research Laboratory (ARL) engineers and scientists recently conducted nonskid removal trials aboard the USS Texas (SSN 775) as part of a cost avoidance project that could potentially be implemented by late summer 2013.

ARL Penn State's Institute for Manufacturing and Sustainment Technologies (iMAST), a U.S. Navy Manufacturing Technology Center of Excellence (COE) sponsored by the Office of Naval Research, conducted the trial with the Shipyard. iMAST's charter is to address challenges related to Navy and Marine Corps weapon system platforms in: mechanical drive transmissions, materials and laser processing, advanced composites, manufacturing systems, repair and sustainment, and complex systems monitoring.

The nonskid removal trials proved that the Shipyard and iMAST are on the right path towards removing nonskid from the surface of submarines hulls in an expeditious, safe and cost-effective manner. Nonskid is a slip-resistance substance painted on Virginia- and Seawolf-class submarines that enables Sailors to walk topside without slipping.



Pearl Harbor Naval Shipyard engineers examine nonskid removal device during course of nonskid material removal trials.

While in depot maintenance phase, all nonskid must be thoroughly removed in order to lay a new, uniform coat across the boat. "The nonskid removal process on Virginia-class submarines is a challenge. It is difficult to efficiently remove multiple layers of nonskid without damaging the underlying

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ARL

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**DIRECTOR, iMAST &  
NAVY/MARINE CORPS REPAIR  
TECHNOLOGIES**  
Timothy D. Bair  
(814) 863-3880 tdb14@arl.psu.edu

**MATERIALS PROCESSING TECHNOLOGIES**  
Timothy J. Eden, Ph.D.  
(814) 865-5880 tje1@arl.psu.edu

**LASER PROCESSING TECHNOLOGIES**  
Richard P. Martukanitz, Ph.D.  
(814) 863-7282 rxm44@arl.psu.edu

**COMPOSITES MATERIALS  
TECHNOLOGIES**  
Kevin L. Koudela, Ph.D.  
(814) 863-4351 klk121@arl.psu.edu

**MANUFACTURING SYSTEMS TECHNOLOGIES**  
Mark T. Trabant, Ph.D.  
(814) 865-3608 mt1@arl.psu.edu

**SYSTEMS OPERATIONS AND AUTOMATION/  
COMPLEX SYSTEMS MONITORING**  
Eddie C. Crow  
(814) 863-9887 ecc1@arl.psu.edu

**DRIVETRAIN TECHNOLOGIES**  
Suren B. Rao, Ph.D.  
(814) 865-3537 sbr1@arl.psu.edu

**iMAST ADMINISTRATION and EDITOR**  
Gregory J. Johnson  
(814) 865-8207 gjj1@arl.psu.edu

**FINANCIAL COORDINATOR**  
Brenda E. Kephart  
(814) 865-3264 bew3@arl.psu.edu

**WORLD WIDE WEB**  
www.arl.psu.edu/imast.htm

**NAVY PROGRAM MANAGER**  
Gregory D. Woods  
(703) 696-4788 gregory.woods1@navy.mil

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Parcel delivery address (UPS, FedEx, USPS):  
N. Atherton St. Rear; Research Building West,  
State College, PA  
16804

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U.Ed. ARL 13-20

## DIRECTOR'S CORNER

Allow me to expand on that last sentence...It is a largely true statement that iMAST and ARL succeed as a source of innovative technology and applications, but that's not completely to our credit. Every project we execute successfully includes ship and weapons system platform builders or depot/shipyard technicians and engineers who are dedicated to performing their mission faster, better and/or cheaper. They are the source of the majority of our project ideas, as well as the guidance we rely on through a project's life cycle—for application and transition oversight to ensure the investment is successfully implemented. It is truly a team effort that is critical to success. Ask any of our project engineers and they will tell you technical success is prerequisite, but project success is predicated totally on implementation. Over the course of several years contributing to the Navy ManTech mission, the iMAST team has done phenomenally well successfully implementing project efforts. But we have not been perfect. Occasionally a new technology emerges that demands consideration in a naval application, but proves only to be a small improvement in comparison to the current process or else it is too expensive to implement. We work hard to keep those occurrences to a minimum, while not stifling innovation. It's a narrow line to walk but we seem to be pretty good at it. What's the bottom line? If you have a problem that you think might be a great project idea, and one

that saves the Navy some money—call us. We will be happy to talk. Dreaming out loud is occasionally the greatest source of innovation to product/process improvement!

In our final 2012 iMAST newsletter we mentioned recognition of an environmental award that a team of iMAST project leaders received as part of an additive process used in a corrosion prevention application. This process is called Cold Spray, which is being perfected at Penn State's Applied Research Laboratory. This project is part of iMAST's Repair Technology effort. Summarily, it has continued to excel in multiple applications for NAVAIR. I am pleased to note that our feature article is dedicated to that technology and will bring you further up to speed on the technology, which remains one of several capabilities resident here within ARL. Cold Spray technology and the applications we're looking at in support of the depots and shipyards is a great example of mature technology being applied innovatively to improve DoD system maintenance and availability. I hope you enjoy our short update and please don't hesitate to contact us if you have questions or ideas about new challenges or technologies that might make a great contribution to our National Security!

*Tim Bair*

## PROFILE



**Dr. Timothy J. Eden** holds Ph.D. and M.S. degrees in Mechanical Engineering from The Pennsylvania State University. He received a B.S. in Mechanical Engineering from the University of Utah. Dr. Eden is head of the Materials Processing Division within Penn State's Applied Research Laboratory. The Materials Processing Division includes the Advanced Coatings Department, the Metals and Ceramic Processing Department, and the High Pressure Test Facility.

Dr. Eden has been working in Cold Spray technology for the past 15 years. Other areas of active research include high performance (ultra-high strength and high-temperature) aluminum alloys, thermal management systems, corrosion and wear resistant coatings, materials characterization and testing, process improvement and optimization, functionally tailored and laminate materials, and consolidation processes for materials. Dr. Eden can be reached at (814) 865-5880 or by email at <tje1@arl.psu.edu>.

# Portable Cold Spray Repair and Restoration of NAVAIR Assets

by Timothy J. Eden, Ph.D.

In response to current DoD emphasis on cost reduction through the repair and sustainment of critical assets, the Office of Naval Research's Navy Manufacturing Technology Program is using the vehicle of its Repair Technology (RepTech) effort to assist the Naval Air Systems Command in developing, validating and transitioning repair of critical aluminum and magnesium components by use of the Cold Spray repair process. The Institute for Manufacturing and Sustainment Technologies (iMAST), at Penn State's Applied Research Laboratory, has been tasked to manage this effort under RepTech project number A-2366 (titled: Portable Cold Spray Repair and Restoration of Aluminum and Magnesium Components).

As part of this effort, several components have identified that did not have an approved repair process, had long lead times or were very expensive. Repair criteria were developed and several different repair processes were evaluated against the criteria. It was determined that the repairs could be made using a portable Cold Spray system. Advantages of using a portable Cold Spray system include lower equipment, facility, and operation costs, reduction in repair time and the ability to perform repairs without transporting the hardware to depot-level facilities.

## F/A-18 AMAD REPAIR

The initial component selected for repair was the Airframe Mounted Accessory Drive (AMAD) transmission housing. The AMAD transmission housing is made of A357, a cast aluminum-silicon alloy. During operation, the AMAD housing periodically sustains damage. Once the damage reached a certain level, the AMAD housing had to be removed from service. Attempts to repair the housing using thermal spray and welding were not attempted due to the excessive heat input such remedies impart in the material. The Cold Spray process, however, imparts very little heat to the substrate during the deposition which

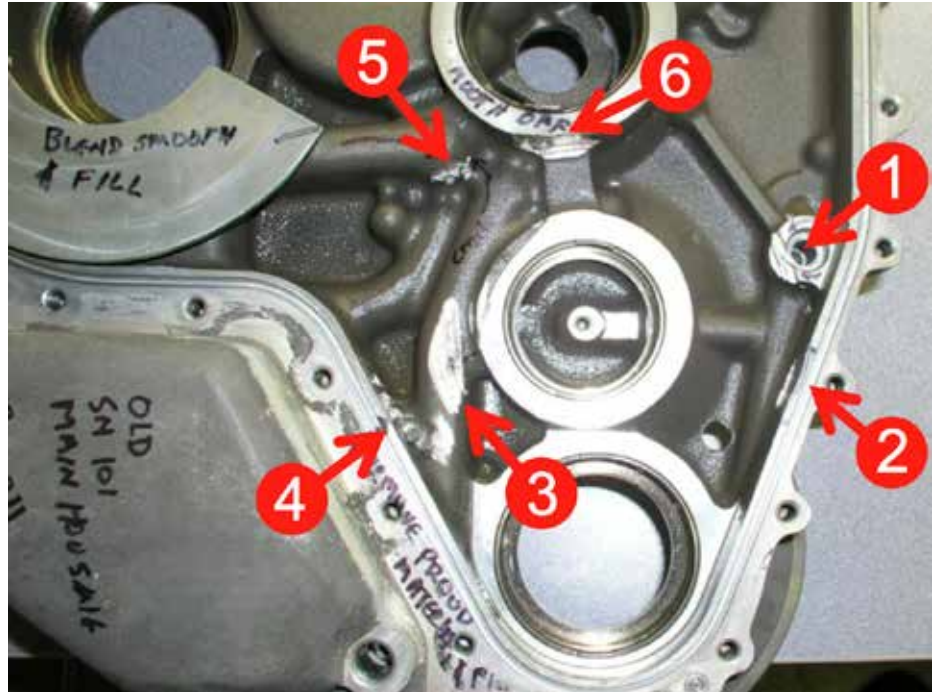


Figure 1. Photograph showing internal damage to an AMAD transmission housing.

makes it possible to perform repairs on the A357 and other aluminum and magnesium alloys that are sensitive to heat input.

There can be damage to both the internal and external surfaces of the AMAD transmission. The internal damage results from impact of gears that become displaced during operation while fretting or pitting damage on mounting rings is the most common external damage. Damage to six different areas on the inside of an AMAD transmission housing is shown in Figure 1. The damage for the different areas is #1 – material removal from an oil port, #2 – material removed from a sealing surface, #3 – material removed from the wall of an oil passage, #4 – gear impact damage, #5 – cracked oil passage, and #6 – material removed from a great shaft support.

The criteria for the repair of the AMAD transmission housing included a close match to the hardness (113 VHN), thermal coefficient of expansion (CTE) and machinability (RA of 125  $\mu$ m or better) of A357 with high adhesion strength. Several powders including

Al 4047 (Al-12 Si), Al 6061, Al-5Mg, and Al 7075+25Ni were evaluated through measuring the particle size distribution (PSD), the morphology (shape) using a scanning electron microscope (SEM) and commercial availability. The powders were deposited on coupons and evaluated for microstructure, hardness, adhesion strength and machinability. Al 4047 (Al-12Si) and the Al 7075+25 Ni were selected for further development. The powders were applied with a Centerline Portable Cold Spray system with helium as the main process gas at 200°C (390°F) and 1.4 MPa (200 psi). All powders were -325 mesh (particle less than 45 $\mu$ m diameter)

Subscale test articles were developed that matched the repairs to the housing as closely as possible. Loading was applied to the subscale test articles that matched the operating conditions as closely as possible. Once the process was validated using the subscale test articles, the AMAD housing was repaired. Fixtures were developed to hold the housing during the initial machining to prepare the surfaces for deposition, coating and final



## FEATURE ARTICLE

### Continued from Page 3

machining. Prior to coating, the housing was masked to protect areas that did not need to be coated and to prevent powder from entering into passages or bolt holes. The surfaces were blasted with alumina media at an angle of 45° to roughen the surface. After the coating application, the housing is machined back to the original dimensions.

An example of a repair that was originally reported in iMAST Newsletter 2011 No. 4 is the repair of the oil port. The damaged area is shown in Figure 2a and the repaired subscale test article is shown in Figure 2b. A tube with an o-ring must fit snugly into the oil port to ensure proper oil flow through the transmission housing. The repaired oil port was tested to verify that the tube fit tightly in the hole and the o-ring achieved the desired seal. All six areas of the damage housing were repaired and the housing was returned to Fleet Readiness Center-South West for evaluation as shown in Figure 3.

The hydraulic pad on the external surface of a different AMAD transmission housing suffered fretting and pitting damage during operation. The pad is a matting flange where a hydraulic pump is mounted. The damaged hydraulic pad is shown in Figure 4. A fixture was developed to hold the housing during the coating process. Metal masks and tape were used to protect critical surfaces and to prevent build-up of overspray. The masked housing mounted in the coating fixture is shown in Figure 5. The flange was machined back to remove the damaged and then blasted with glass bead at a 45° angle. A thick layer of Al 4047 was applied to the housing. The coated surface machined back to the original dimension. The repaired housing, shown in Figure 6 was returned to FRC-SW where it was evaluated on an engine test stand before being returned to service. The AMAD currently has over 450 flight hours.

An analysis was performed to determine the cost avoidance realized through the Cold Spray Repair of the AMAD transmission

housing. This analysis was for the AMAD that had internal damage at six different locations. The fixturing, masking and pre-machining required eight hours of time and \$20 in supplied and materials. The surfaced preparation and coating required four hours of time and \$480 in powder and He. Final machining and inspection required 10 hours and \$20 in supplies and materials. The total cost for supplies and materials was \$520 and the total number of hours was 22. The costs are for the Cold Spray repair of the housing. Using \$100/hr for the total labor cost, the Cold Spray repair of the housing was less than \$3,000. At the time of the repair, the cost of the AMAD transmission housing provided by DLA was \$97,000. The total repair costs would include the labor to disassembly and reassemble the transmission housing. This analysis shows that costs avoidance that Cold Spray offers. The delivery time on a new housing can be twelve-eighteen months. Cold Spray repair allows the parts to be quickly be repaired and returned to service.



Figure 2. a) photograph of the damaged oil port b) the cold spray repaired oil port on a sub-scale test article.



Figure 3. Photograph of repaired AMAD housing which had internal damage.



Figure 4. Photograph of a damaged hydraulic pad.



Figure 5. Photograph of the masked hydraulic pad in the coating and machining fixture.



Figure 6. Photograph of the cold spray repaired hydraulic pad.

Based on the successful repair of the AMAD transmission housings, repairs for several other components are being developed. The components and the types of repair include the F/A-18A-D AMAD Housing PTS Axis – fretting repair, F/A-18E/F Radar Rack Assembly – dimensional restoration, F/A-18A-D GCU Tube Flange – pitted repair, and the V22 Window Sill – dimensional repair. The cost avoidance for these repairs ranges from \$25,000 for the GCU Tube Flanges to \$200,000 for the radar racks. Repairs for the first three are currently under review by the respective program offices.

## COATING INSPECTION

Methods are needed to inspect the coatings after the part has been repaired and machined. The most common inspection is visual where the coating is inspected for any indications of voids, delaminations, or missing coating. Dye Penetrant (Dye Penn) is also used to check for voids and pits on the surface of the repair and Ultrasonic (UT) inspection techniques are being used to look at the quality of the coating and the coating/substrate interface.

An inspection test article was produced to evaluate the inspection techniques on different Cold Spray repairs. The substrate was Al-6061 and the coating was commercially pure aluminum (CP-Al). The substrate, shown in Figure 7, had material in several locations that represented different levels and types of material damage. The three grooves on the left and the three holes on the top varied in depth and width (aspect ratio) and represented damage that had to be machined before the coating could be applied. The other four areas are typical of corrosion pits that have been ground down to the base metal. The surface was prepared by blasting with alumina at an angle of 45°, the damage was repaired and the plate was machined. No indications of voids or exposed defects were identified by dye pen inspection (see Figure 8). The differences in color are due to the differences in coating material (CP-Al) and the substrate (Al 6061).

The plate was then inspected using an ultrasonic transducer in the pulse-echo mode (single transducer that send and receives the sound waves). The scans were performed with 1, 2, 5 and 10 MHz planar transducers. C-Scan (amplitude) imaging was used to



Figure 7. Photograph of the Al 6061 inspection test plate prior to Cold Spray repair.



Figure 8. Photograph of the repaired and machined test plate inspected with dye penetrant.

inspect the coating/substrate interface and the coating half way between the front and back surface of the coating. Results showed that the 1 MHz transducer produced the best interrogation of the coating/substrate interface (see Figure 9) and the 10 MHz transducer

produces the best interrogation of the coating volume (see Figure 10). The inspection indicated that there were no internal voids in the coatings and that indications at the coating/substrate interface were due to internal geometry and material density variations.

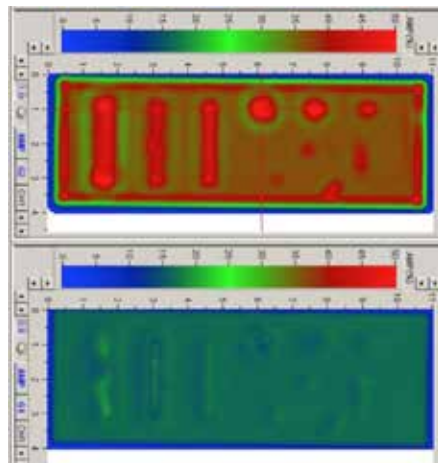


Figure 9. Results of UT inspection using a 1MHz transducer showing the coating/substrate interface.

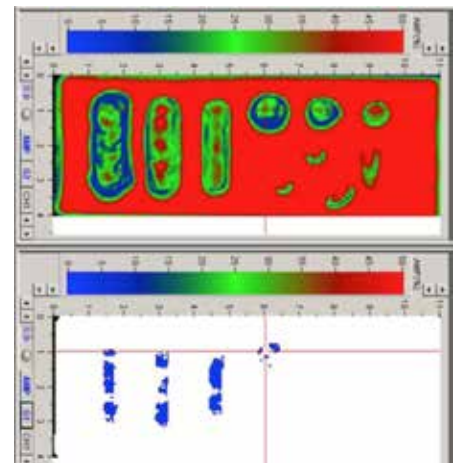


Figure 10. Results of UT inspection using a 10MHz transducer showing the coating/substrate interface. Variations are due to geometry and material density variations.

# FEATURE ARTICLE

## Continued from Page 5

The test article was sectioned to determine the accuracy of the UT inspections. Cross sections of the coating were polished and imaged. The coating/substrate interface on the groove that was 0.25 inches wide and 0.25 inches deep at the base is shown in Figure 11. There are not voids or delaminations at the interface. The dark areas are embedded grit.

A standard is being developed that has voids at the coating/substrate interface and in the volume of the coating that will be used as a calibration standard for UT inspection of Cold Spray Coatings.

## TECHNOLOGY TRANSFER

A critical part of implementing a new repair process is the development of standard repair procedures, inspection requirements, equipment and powder specifications, along with training, and coordination with the FRCs, OEMs, and the technical lead for each component. ARL/PSU has been working closely with the Materials Engineering Division of the NAVAL Air Systems Command at Patuxent River and the lead engineer for the AMAD Transmissions at FRC-SW to transfer and implement the technology.

Pax River and FRC-SW, SE, and E all purchased portable Cold Spray systems from Centerline Supersonic Spray Technology (SST), Windsor, Canada. ARL/PSU has extensive experience with the Centerline portable system and is working with Pax River and FRC-SW in the following areas:

- Equipment set-up and training – ARL has made several trips to train the operators and engineers on the set-up, operation and trouble-shooting of the portable Cold Spray systems.
- Facility Set-Up – Provide information on power and compressed gas requirements, layout of the Cold Spray work cell, powder collection systems and recommendations for personal protection equipment (PPE)
- Powder Handling and Analysis – Provide recommendations for powder testing including PSD and SEM imaging. Performing these tests when requested and providing information on powders that have been used. Recommendations

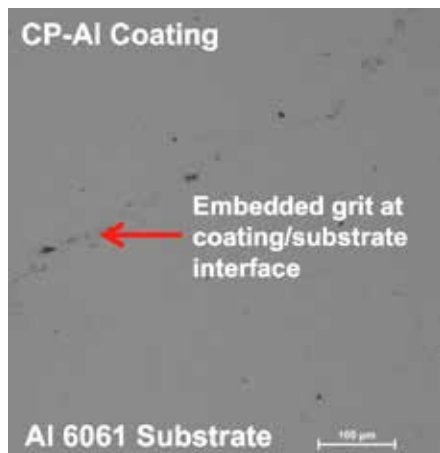


Figure 11. Micrograph of the coating/substrate interface of the inspection test plate. No visible voids are observed.

for powder storage, handling procedures and equipment and disposal methods for unwanted powders.

- Surface Preparation and Masking – Provide procedures for preparing the surface prior to coating application. Surface preparation methods include grinding, machining, and blasting. Guidelines are being developed for the aspect ratio (depth-to-width) ratio and blending needed to apply a successful coating. Material and methods for masking are also being provided.
- Process Procedures – A standard procedure for applying Cold Spray coatings has been provided. The procedure contains recommendations for process parameters, equipment settings, type of nozzle, main process gas, and types of powders for different coating requirements. Trouble shooting procedures are included and detail how to repair equipment that is not functioning properly and what process parameters to check when the powder will not deposit. Provide runsheet for recording all relevant process information and storing the information in a database. Developing inspection methods and evaluation criteria.
- Coating Characterization – Provide a procedure for preparing and testing bond bars to measure the adhesion strength following ASTM C633. Provide design for fixture for preparing the bond bars. Provide information on mounting and polishing samples for microstructural analysis. Perform coating evaluation upon request.

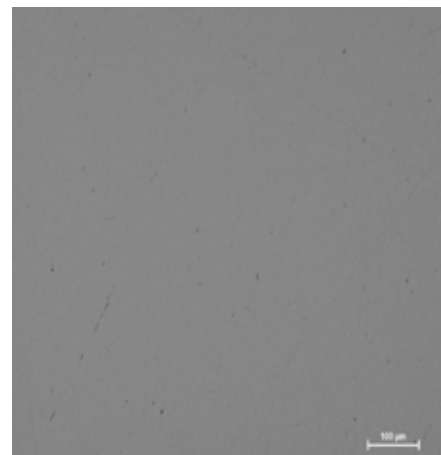


Figure 12. Micrograph of the CP-Al coating for the groove in the inspection test plate.

- Technical Support and Data Requests – Provide data and support meetings to request approval for implementation of Cold Spray repairs at the FRCs.
- Purchase of Consumables – Provide information on powder suppliers and nozzle manufactures.
- Post Coating Processing – Develop machining or grind methods needed to resort the component to its original dimensions. This includes types of tools and machine parameters.

## SUMMARY

The viability of using Portable Cold Spray technology to repair select aluminum components have been demonstrated through REPTECH Project #2366, Portable Cold Spray Repair and Restoration of Aluminum and Magnesium Components. Several AMAD transmission housings have been repaired one has over 450 flight hours. The Cold Spray Process offers significant cost avoidance and can be used to repair assets that had to be removed from service and replaced with new components.

In addition to developing the Cold Spray repair process, ARL/PSU providing information/knowledge needed to successfully transition and implement the technology.





*Dr. Tom Donnellan, ARL Associate Director for Materials and Manufacturing discusses program efforts with Christina Brown, who serves on Senator Robert Casey's staff in Washington, D.C..*



## Johnstown Showcase for Commerce

The annual Johnstown Showcase for Commerce (PA) event continues to provide a vehicle for iMAST's outreach into the manufacturing and materials supply world within the Commonwealth of Pennsylvania. The western region of Pennsylvania is home to numerous defense contractors and suppliers who vie for support from organizations like ARL Penn State and the iMAST program. Key Senate and congressional leaders typically attend this event. This year Senators Robert Casey and Patrick Toomey attended the event, along with Pennsylvania 12th District Congressman Keith Rothfus and Texas Congressman Mac Thornberry. The event also brought several senior members of the government acquisition sector, who provided special briefings.

## JDMTP Review

iMAST recently completed the first of three annual Joint Defense Manufacturing Technology Panel (JDMTP) reviews at ARL Penn State. As part of a review process designed to prevent duplication of effort across the DoD ManTech spectrum, iMAST hosted a visit by the JDMTP Metals Processing and Fabrication Subpanel. The subpanel reviews (and grades) program progress relative to multiple project activities. At the same time the panel de-conflicts the potential for S&T duplication efforts. The subpanel also seeks to identify potential solutions to technical challenges that may have applicability across a joint service spectrum. Members of the iMAST team also participate in similar off-site reviews within the JDMTP's Composites Processing & Fabrication (CPS) subpanel, as well as the Advanced Manufacturing Enterprise (AME) subpanel.

## PHN Shipyard/iMAST Collaborate

### Continued from Page 1

mold-in-place (MIP) layer," said Eric Tadaki, a Code 250 engineering technician. "Texas is the Shipyard's first Virginia-class inducted for depot-level maintenance. What we're encountering with this nonskid removal is unlike anything we've had to work with before."

The Shipyard and iMAST tested an ultra-high pressure blast machine using a water jet stream to remove several layers of the nonskid material. The machine uses two small, rotating heads mounted on opposite sides of a circular plate, which rotates within a larger, motor-driven wheeled cart. The cart is guided across the hull of the boat with water blasting away at the nonskid material.

During removal trials, the engineering team tested various water pressures, flow rates, distances, and head rotation speeds to find the ideal removal condition for the machine.

"Through a series of controlled experiments, we were able to come up with a set of operating parameters for the removal device while leaving the MIP intact," said Eric Petran, Code 220's new naval technology program

manager. "The trials showed this machine has that capability."

The traditional nonskid removal process is time-consuming and has potential to damage the MIP on submarines, which lies underneath the nonskid coating. Traditionally, shipyard workers use abrasive blasting to remove the material—a slow process with an average removal rate of 70 to 100 square feet an hour. The work is tedious and can lead to accidents involving damage to the MIP. MIP damage is costly and requires a massive time-consuming repair effort. The removal machine is expected to cut down the work from an effort measured in weeks, to a few days—while leaving the MIP substrate intact. It also has a vacuum that immediately collects the nonskid material following removal, thus ensuring it does not have a negative environmental impact.

The nonskid removal machine is awaiting final approval from Naval Sea Systems Command (NAVSEA). If approved, the machine will be transitioned to PHNSY & IMF, as well as Puget Sound Naval Shipyard & IMF (Washington), for their respective work on Seawolf-class submarines.

Shipyarders are excited about the possibility of

using the nonskid removal machine as part of the submarine maintenance effort—especially since the Shipyard is on track for becoming the Virginia-class center of excellence.

"The potential in time and cost savings are huge," said Tadaki. "One of iMAST's long term goals is to save so much time that ships cannot only have their nonskid removed (and reapplied during depot maintenance), but also have it available for shorter availabilities during intermediate level maintenance opportunities."

The Shipyard and iMAST have collaborated on numerous cost saving/avoidance projects since 2004. Some of the more recent successes include a vertical launch system repair procedure, ship alignment using laser trackers, and ultra-high pressure cleaning of tanks and voids. All of the iMAST/NAVSEA-approved projects and processes for surface ships and submarines are shared among the four shipyards in order to ensure Best Practices are being used to keep the U.S. Navy's fleet "Fit to fight!"

*[For more information on this project effort, contact Mr. Charles Tricou at (814) 863-4459, or by e-mail at <cst101@psu.edu>]*



*“On time and on budget is a baseline, not a target.”*

*—Ray Mabus, Secretary of the Navy*

## CALENDAR of EVENTS

**2013**

10–13 Aug	Expeditionary Warfare Conference		Panama City, FL
27–28 Aug	Fleet Maintenance & Modernization Symposium		** San Diego, CA
11–12 Sep	Materials and Manufacturing Board Meeting (Repair, Sustainment, and Affordability)		State College, PA
24–26 Sep	Modern Day Marine Expo		** Quantico, VA
14–17 Oct	Logistics Officers Association Conference	CANCELLED	** Dallas, TX
21–23 Oct	AUSA Expo		Washington, D.C.
18–20 Nov	DoD Maintenance Conference	CANCELLED	** Long Beach, CA
2–4 Dec	Defense Manufacturing Conference		** Orlando, FL

**2014**

14–16 Jan	Surface Navy Association Symposium		** Crystal City, VA
7–9 Apr	Navy League Sea-Air-Space Expo		** National Harbor, MD

\*\* Visit iMAST booth