Newsletter 2014 No.2

iMAST

Institute for Manufacturing and Sustainment Technologies

IN THIS ISSUE

DIRECTOR'S CORNER

The center's leadership team and engineering staff have been working to support the DoD, so we wanted to share some of the progress we've achieved in the last few months. This newsletter includes ARL work in cutting-edge manufacturing technology (additive manufacturing) and innovations in the use of more mature maintenance technology [Ultra-High Pressure (UHP) water jet tools]. Additive manufacturing begins at the lowest levels of the Technology Readiness Level scale whereas UHP begins about mid-range. In both cases the objective is the same—successful transition to the appropriate community of practice within DoD and supporting industry. It's exciting to see what's maturing in our labs—and equally exciting to be a part of solving everyday challenges that cost the DoD precious funds and (occasionally) precious lives.

Timothy D. Bair

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Manufacturing the Future

Additive manufacturing reimagines critical components from the ground up

by David Pacchioli

[**Editor's note:** *As a member of the Office of Naval Research (ONR) Manufacturing Technology family, iMAST expertise in diverse technology domains brings an expectation from ONR that we will assist in the discovery and development of new or emerging materials and manufacturing trends. ARL Penn State's new center aims to push the boundaries of 3D printing; therefore expanding the state-of-the-art as it pertains to advancing manufacturing capabilities.*]

Rich Martukanitz, director of Penn State's Center for Innovative Materials Processing through Direct Digital Deposition known as CIMP-3D, holds a prototype jet engine bracket, while co-director Tim Simpson, holds another. Both are models for the same jet engine. The holes where the brackets would attach to the engine line-up exactly, and the overall dimensions of the parts are roughly equal, but that's where the similarities end.

The first design, a thick, heavy chunk, would make a good doorstop. The second is a hollowed out set of spider arms, like a splayed but sturdy rack of ribs.

The prototypes are the before and after of an open competition sponsored by GE to redesign an actual engine bracket, making it 30 percent lighter while retaining its strength and mechanical properties. The difference illustrates some of the promise of additive manufacturing.

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DIRECTOR'S CORNER

The iMAST staff, in support of the ONR ManTech program, has kicked off its future year planning efforts. We have submitted our FY15 budget proposal to ONR. We are also working to identify new acquisition cost savings projects for FY16. As in years past, our emphasis for specific projects is saving "per hull" dollars on the big ship programs (VCS, ORP, CVN and DDG) as well as the F-35. The process begins with the nomination of candidate projects by the OEM's. It is vetted by the ManTech Centers, and then the program offices. A typical project lasts 2–3 years. That can include one or two of the centers, the OEM and, in some cases, participating subcontractors that may have technology to contribute or will play a part in the eventual implementation.

The emphasis on projects remains risk mitigation. Risk, for ManTech, comes in various forms. The first is technical. For instance, does the solution exist (COTS), or does it require cutting edge innovation? Is there an industrial base to transition to and/or supply the raw material? The second is programmatic. Questions in this category include design changes required, capital investment needed to implement and/or adequate time to pay back the investment (ROI). One other question in the programmatic category involves the nature of the approval process. In the case of a RepTech project working with a depot or shipyard, who has the authority to approve a solution—a Technical Warrant Holder or local repair source representative? These questions are critical, requiring coordination with various program and government authorities in order to ensure ManTech funds are invested in projects with predictable potential for implementation. We're not always perfect on this, but we have a good track record.

While the info above may seem less than flexible, the points of entry are numerous and not limited by the calendar. iMAST is hosting the next RepTech Working Group meeting here at Penn State's Applied Research Laboratory September 17/18. This semi-annual review is attended by representatives from NAVSEA, NAVAIR and MARCOR as well ONR ManTech and iMAST staff. Project participants and interested parties from the public shipyards and depots are welcome to attend, as are industry representatives with a stake in the project. If you'd like to be a part of this next meeting as a stakeholder, or have an idea to present, call us and we'll put you in touch with the right SYSCOM representative to host you.

Tim Bair

PROFILE

Charles Tricou is an Associate Research Engineer at ARL Penn State. Mr. Tricou manages projects involving paint application and removal for maintenance and repair of DoD assets, and new construction in shipbuilding. His current projects include development of high transfer efficiency painting processes, development of long-life nonskid flight deck coating systems, and UHP waterjet surface preparation and cleaning equipment.

Mr. Tricou earned a B.S. in engineering science and mechanics, and an M.S. in theoretical and applied mechanics at the University of Illinois at Urbana-Champaign, where he studied material design and analysis, with a minor in computer applications. Mr. Tricou can be reached at (814) 863-4459, or by e-mail at <cst101@arl.psu.edu>.

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

Ultra-High Pressure Innovation

by
Charles Tricou & Matthew Kelly

U.S. Navy released photo by Dannielle Jones

ARL's motto is Discover, Develop, Deploy. The iMAST program works every day to fulfill this mandate by providing innovative solutions to Navy challenges with emphasis on ensuring implementation. In recent years ARL has become a leader in the safe and innovative use of Ultra-High Pressure (UHP) waterjet technology to solve some of the Navy's most challenging preservation problems. In the process, ARL's Manufacturing Systems group has become one of the Navy's foremost UHP waterjet subject matter expert. UHP has been used for many years for surface cleaning and coating removal, but safety concerns associated with open-cycle hand-lance operations have limited the scope of application. ARL has developed and implemented equipment and processes to facilitate the use of UHP waterjet technology to areas and applications not previously possible. Examples include: oil, grease and salt removal within the confined spaces of Normal Fuel Oil (NFO) tanks on submarines and nonskid removal from sensitive substrates. In this article you'll see several examples of how UHP waterjet technology has been re-invented to dramatically improve ship's maintenance processes in terms of time saved, corrosion mitigation, and waste reduction.

UHP CLEANING OF SEAWATER COMPENSATED FUEL OIL STORAGE TANKS

In the battle against corrosion, Naval Sea Systems Command (NAVSEA) has instituted a conservative strategy for coating system selection, surface preparation, coating application, and quality control. The primary cause of premature coating failure is inadequate surface preparation. Inadequate removal of hydrocarbon contamination and soluble salts from the steel present the greatest impediment to coating longevity.

NFO tanks contain diesel fuel used to power backup systems on U.S. Navy nuclear vessels. Diesel fuel is consumed as backup power systems are periodically tested. As the fuel is consumed, the NFO tank is compensated with seawater to maintain the tank at a full level. The fact that these fuel oil storage tanks would be compensated with seawater was initially overlooked by OEMs. NFO tanks of submarines produced between about 1976 and 1992 (amounting to ~70 boats) were not painted, resulting in excessive corrosion in the bottoms of these tanks. In the 20 years since OEMs began painting these NFO tanks, the coatings in the bottom of these tanks have begun to break down. Seawater lying in the bottom portion of unpainted NFO tanks—or NFO tanks in which there is substantial coating breakdown—results in extensive corrosion damage which can require as much as 600 man-days of effort to repair. To reduce the recurring cost of corrosion-related repairs in NFO tanks, a method of thoroughly cleaning the steel is necessary to enable these tanks to be painted. Incomplete cleaning of oil-soaked steel will result in premature coating failure and loss of corrosion protection. Large-scale coating delamination, should it occur, would also pose a risk of clogging diesel fuel intake filters.

Mechanical methods of surface preparation such as abrasive blast cleaning are not effective at removing oil and grease contamination. An important property of UHP water jet blasting is the effectiveness with which it will remove even deeply-embedded oil, grease and soluble salts from steel surfaces.

For safety reasons, open-cycle UHP blasting in confined spaces using hand-lances is not generally permitted. To clean oil- and grease-contaminated surfaces within the confined spaces of NFO tanks, ARL designed and fabricated a suite of closed-cycle UHP waterjet tools with integral 'electronic-over– air' safety systems. Closed-cycle tools capture the majority of water and steam, improving operator visibility and reducing fatigue. Specialized enclosures (containments) were designed to provide two layers of protection between the waterjet and operators. The NFO tank cleaning tool set included: a closed-

FEATURE ARTICLE

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cycle flat-surface tool (Figure 1); an array of enclosures within which a track-mounted UHP nozzle is used to clean T-bars (Figure 2) and corners (Figure 3); three innovative enclosures to clean the forward, center and aft bottom pockets of the tank bays (Figure 4); and a multi-purpose 'detail tool' (Figure 5) to get the small percentage of areas the other tools may not be able to reach. This design effort required specific knowledge of the cleaning power of UHP waterjet nozzles at specific distances and pressures. The tools sets and enclosures were custom-designed to ensure deep-cleaning of the steel into the roots of the king-frames, T-bars, and corners.

The electric-over-air safety systems that ARL invented, designed, built, tested and delivered (Figure 6) have order-of-magnitude improvements in response time compared to the industry-standard pneumatic emergency shutoff systems. The integral electronic safety system only allows tools or enclosures to be operated when pointed directly in close proximity to steel. Control signal response time is reduced to milliseconds at any length of control line (compared to seconds of pneumatic-only safety systems when there are long distances between operator and control units). Additionally the safety system provides indicators of in-tank operations and provides emergency-stop pendants for assistants, observers and safety watch personnel.

To date, seven NFO tanks have been preserved with this technology, with fifteen additional boats scheduled for the process.

TOPSIDE NONSKID REMOVAL

Nonskid coatings used on the top surface of submarines are prone to fading, cracking and disbonding. For these reasons new nonskid coatings are routinely applied over

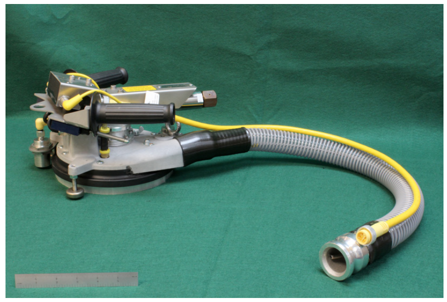

Figure 1. Flat-Surface Blaster

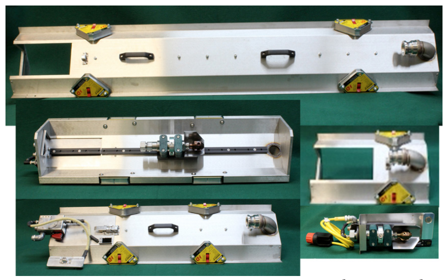

Figure 3. Corner Containments and Cartridge

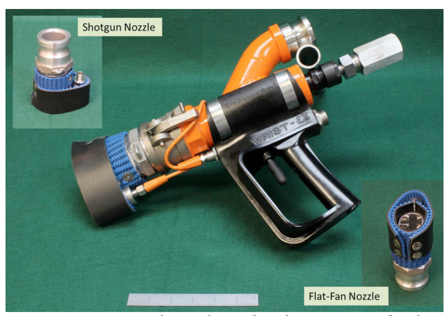

Figure 5. Detail Tool with Shotgun and Flat-Fan Nosepieces

existing nonskid for cosmetic reasons or to rejuvenate worn or slick nonskid. Repair yards understand that customers want uniform-looking and well-adherent topsides following availabilities, requiring 100% removal of old coatings. Nonskid removal is typically performed using hand-sanders and/or grinders. Abrasive blasting is also used. Both of these methods are time-consuming and have

Figure 6. 24VDC Power Supply and GFCI-Protected Power Cord

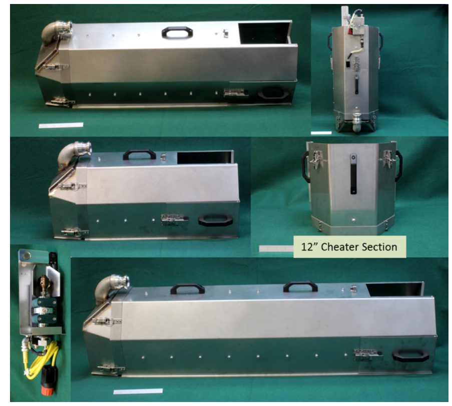

Figure 2. T-Bar Containments and Cartridge (Cartridge is common to T-Bar and Corners)

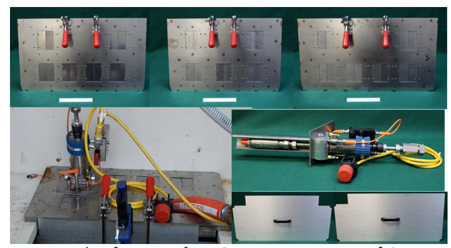

Figure 4. Floor Pocket Containments and Stinger Assembly

the propensity to damage the specialized hull treatment (SHT) over which the nonskid is applied. Hand-sanders and grinders are prone to scratching or gouging the underlying SHT, while abrasive blasting leaves fine ridges in the material not unlike those seen on sand dunes. ARL postulated that the UHP waterjet process could be optimized to remove multiple layers of thick, hard and brittle nonskid coatings without damaging the underlying SHT. ARL performed several experiments using robust Design-of-Experiments (DOE) methodology to identify pressure, flow, nozzle rotation rate, and standoff distances to accomplish the task.

ARL worked with various naval shipyards, performing these experiments on live assets in rip-out areas where the SHT was scheduled for removal. Statistically significant mathematical models were developed to predict post-process condition of the SHT. The DOE approach provides mathematical models that enable process parameters to be chosen that will remove all of the coating while ensuring the SHT will not be damaged.

Prior to these experiments, 'conventional' knowledge within the shipyards was that UHP waterjetting at pressures above 12,000 psi would damage SHT. Following ARL's DOE experiments, ARL identified operating regimes that enabled UHP waterjetting at pressures as high as 28,000 psi that do not damage SHT. Combining experimental design expertise knowledge with industry-leading equipment manufacturer and industrial partner Terydon Inc, a prototype nonskid removal system and process were developed (Figure 7). The key to making the system safe for SHT is to balance pressure and flow through a nozzle with the rotation rate of the nozzle carrier to create fine droplets. Two small rotating heads are mounted on a larger rotating plate which is in turn mounted on a motor-driven cart that prevents the nozzle carrier from dwelling in any one spot. All of these interacting motions conspire to create a system that does not have hot-spots in which the waterjet streams are allowed to retrace the same track. Through this innovative design and process optimization, investigators identified operating regimes that will enable removal of three or more layers of nonskid at removal rates up to 200 ft^2/hour. The mechanism of removal is through optimizing the flow, pressure and force of the water jets to flex and crack the brittle nonskid, enabling water to lift and delaminate the multi-layered coating. For comparison: according to Mil-PRF-24667C the strip rate requirement for removing a single layer of nonskid from SHT using hand-sanders or grinders equates to an hourly strip rate of ~6.4 ft^2/hour. In-service submarines typically have two or more layers of nonskid. The ARL-developed equipment is a closed-cycle process, recovering both water and nonskid debris; eliminating the need for dust-enclosure type containments.

After seeing the effectiveness of the ARL-developed tool in person, Navy stakeholders requested a second generation design be developed to include equipment and process safeguards to guarantee SHT safety when the equipment is used by shipyard personnel. Future efforts will also make the device smaller and more mobile. The new process and equipment eliminates most of the cumbersome work practices associated with the use of hand sanders and grinders that are currently used to remove nonskid. There is less worker fatigue, reduced chance for injury, increased removal rate, and less impact on other services. In addition to removing nonskid, the equipment and process may also be used to clean nonskid or other deck coatings without leaving waterjet traces common with other UHP deck-blasters.

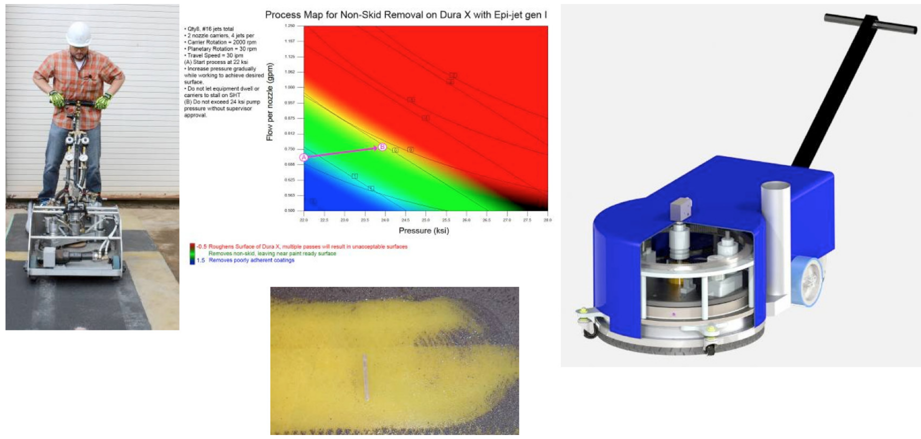

Figure 7. Prototype equipment for non-skid removal from SHT materials, graphical representation of process model for prototype equipment for specific type of SHT, results of non-skid removal from SHT, concept production ready equipment.

UHP SYSTEMS SAFETY AND ONGOING UHP EFFORTS

UHP waterjetting is the only approved method for removal of SHT from newer classes of fast-attack submarines. Unfortunately, UHP waterjetting using hand-lances presents safety concerns due to the severity of UHP waterjet injuries. One of the most common sources of injury during UHP hand-lance operations is caused by triggers failing to shut off the flow of water when the triggers are released.

After a UHP-related lost-time incident at one of the U.S. Navy shipyards, iMAST was contacted for assistance to help the shipyards address some of the more common UHP-related safety issues.

As mentioned previously, it is not uncommon for lances and control units to become locked in the energized position, though most of the time this does not result in injury. In some cases the operator or a nearby observer can alert the pump operator to shut down the pump. In cases where it is not possible to safely alert a pump operator, hand-lance operators have been known to use the lance itself to cut the control lines or water supply line.

A common cause for triggers not responding is due to shredded debris becoming lodged in the trigger assemblies, thereby preventing the trigger mechanism from disengaging. Another cause is debris becoming entrained in the return line of the lance where it migrates to the pilot valve of the tumble box, causing the tumble box to become locked in an energized state regardless of the hand trigger position.

ARL investigators identified COTS solutions to the more common hazards and provided help to the shipyards in implementing the necessary changes to improve the safety of UHP hand-lance operations.

One of the outcomes of this process was to convince shipyard managers that, due to the severity of waterjet injuries, all reasonable measures should be taken to reduce the probability of occurrence. In the simplest terms, this would be accomplished by getting the lances out of the hands of the operators.

To that end, iMAST has begun its latest project entitled: *Ultra High Pressure Special Hull Treatment Removal using Dual-Track Crawler System.* The goal of the project is to dramatically reduce the cost and time required to remove hull coatings from submarines. The primary method of removal is through efficient cutting and undercutting to remove the material in blocks. To accomplish this goal a 2-DOF X-Y motion style, track-mounted UHP waterjet removal system to enable rapid, precise and safe removal of hull coatings was designed.

FEATURE ARTICLE

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SUMMARY

These are a representative cross-section of UHP-related projects ARL has delivered to the U.S. Navy to improve safety, increase productivity, and effect improvements in cost, schedule and performance. UHP waterjet is not a panacea. Rather it is one possible tool amongst many that should be available to Navy planners and project managers. ARL Penn State, with the help of iMAST and the U.S. Navy, has developed the vision and skills to identify appropriate opportunities for UHP waterjet, develop specialty UHP tools to solve difficult problems, and thereby realize cost-effective UHP solutions to a wider range of applications than was previously possible.

ACKNOWLEDGMENT

The authors wish to express appreciation for support of this effort by the Institute for Manufacturing and Sustainment Technologies (iMAST), a U.S. Navy Center of Excellence under contract by the U.S. Navy Manufacturing Technology (ManTech) Program. These project efforts were also supported with a grant by the Technology Insertion Program for Savings (TIPS)—both programs of which are sponsored by the Office of Naval Research. Any opinions, findings, conclusions and recommendations expressed in this article are those of the authors and do not necessarily reflect the views of the U.S. Navy.

Cover Story

Continued from Page 1

"You're reimagining components from the ground up," says Martukanitz. "You can manufacture components having features and characteristics that are near-impossible to do with conventional processes. And you drastically cut manufacturing time, materials—and cost."

Additive manufacturing, sometimes known as 3D printing, is exactly what it sounds like. Working from a computer-generated 3D model, a "printer" puts down layer after layer of material, adding layers until the design is realized in a finished part.

Admittedly, there is a lot of hype attached to this new technology. But there is plenty of real-world promise, too. "It gives new freedom and flexibility to design engineers," Martukanitz says. "There's lots of excitement about this in the aerospace, medical, and oil and gas industries. Additive manufacturing is leading the resurgence of manufacturing in the U.S."

CIMP-3D, created in early 2012, aims to be a world-class resource for that resurgence. A University-wide collaboration, the Center draws faculty from the College of Engineering, the College of Earth and Mineral Sciences, the Materials Research Institute, and the Applied Research Laboratory. It has its roots in a quarter century of ARL expertise in laser-based deposition technologies—the core of the region's powder metal industry.

"We were doing this before additive

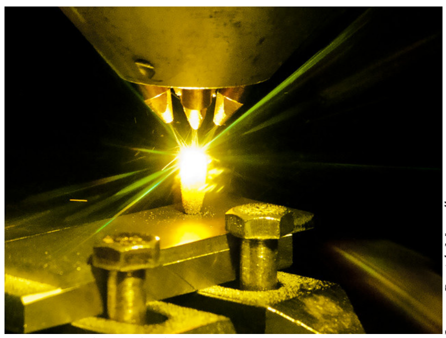

Image: Patrick Mansell

A laser-based direct deposition system, one of several housed in Penn State's Center for Innovative Metal Processing by Direct Digital Deposition (CIMP-3D).

manufacturing was in vogue," says Martukanitz, "so we have a leg up. When the field got hot, we were able to respond very quickly, because we had the infrastructure and the expertise already in place. CIMP-3D just brings everything together."

In early 2013, when President Obama announced the National Network for Manufacturing Innovation (NNMI), a network of advanced manufacturing hubs, the Center was designated as the metals node for the pilot National Additive Manufacturing Innovation Institute, now known as America Makes.

The 8,000 square-foot facility, located in Penn State's Innovation Park, is operated by ARL, with industrial partners Sciaky Inc., an electron-beam welding manufacturer based in Chicago, and Battelle Memorial Institute of Columbus, Ohio. It includes a design lab outfitted with a polymer prototyping machine, and a manufacturing demonstration facility that houses, in addition to an array of laser-, electron beam-, and ink jet-based deposition systems, an x-ray computed tomography machine that scans the interiors of finished parts, detecting defects and allowing for reverse engineering.

BREADTH AND DEPTH

Researchers focus on advancing the technology, which means everything from improving design and manufacturing processes to basic materials science. Modeling is a major emphasis, and covers not just design but the ability to predict material properties and performance.

"It's really virtual experimentation before we build a part," Martukanitz says. "We have to address concerns that these processes produce the characteristics required for critical applications.

"We're not making doorstops, or trophies," he adds. "We want to make critical components: components for electrical and mechanical systems, orthopedic implants, and jet engine parts."

For now, the focus is mostly on metal components, which are produced in both near-net and net shape. The first need finish machining, Martukanitz explains, while the latter are ready to go right out of the printer. Already, though, Center researchers are looking at the possibilities for making parts from advanced materials, including ceramics and composites.

Gary Messing, co-director of the Center, is head of the department of Materials Science and Engineering and a ceramic scientist. “Additive manufacturing conditions can be radically different from those for conventional processes,” he says. “There’s a lot of materials science to be done to understand microstructures and properties. But I think ceramics have a role to play in this.”

The Center was recently named the manufacturing demonstration facility for additive manufacturing by the Department of Defense. Among other things, that means industrial partners can try out processes on the Center’s advanced systems, and also get expert advice. A recent change in the University’s intellectual property policy whereby intellectual property that results from industry-sponsored research no longer is mandated to be owned by the University has helped attract interest in the facility from large corporations like Boeing, Northrup Grumman, Moog Corporation, Pratt & Whitney, and Siemens, as well as small start-ups and individual entrepreneurs. Martukanitz reports more than 800 visitors to the Center since its opening.

Last but not least, CIMP-3D boasts a robust education and training program for students and companies. Center co-director Tim Simpson, professor of mechanical and industrial engineering, leads this effort in partnership with Penn State’s Digital Fabrication Network, known as DIGI-Net, and the Learning Factory, where teams of engineering students partner with industry to help solve real-world engineering problems for their senior design projects.

“What distinguishes us from other facilities of this type is both our breadth and depth of technologies,” says Martukanitz. “We can cover a wide range of enabling technologies relevant to additive manufacturing, such as design, analysis, materials, processing, characterization, and validation. We have faculty interests all over the board. We really are one-stop shopping. I don’t think there’s anyone else that can say that.”

INSTITUTE NOTES

ARL’s Additive Manufacturing facilities director, Dr. Ken Meinert (left) shows Navy ManTech program director John Carney (center) sample metal powders used in the additive manufacturing process.

iMAST Hosts Joint ManTech Review Meeting

iMAST recently hosted a joint Navy ManTech Program DDG 51, Virginia-class Submarine, CVN 78, and Littoral Combat Ship project review meeting. The meeting, which was held at ARL Penn State, reviewed various Navy ManTech projects supporting the combat systems noted. Meeting participants included NAVSEA program office representatives from PMS 450, as well as Navy ManTech Center of Excellence staffs from iMAST, Navy Metalworking Center, Center for Naval Shipbuilding Technology, Composites Manufacturing Technology Center, Penn State Electro-Optics Center, and the Energetics Manufacturing Technology Center. Mr. John Carney, head of the Office of Naval Research (ONR) Manufacturing Technology Program, provided an update on the ONR Navy ManTech program. The programs addressed at the review represent part of Navy ManTech’s Strategic Investment Plan, which is focused on improving affordability issues for naval platforms critical to the future force. The meeting also provided an opportunity for participants to tour ARL’s Water Tunnel, High Pressure Laboratory, and its new Additive Manufacturing Facility.

CH-53K Affordability Initiative Kickoff

Members of iMAST recently attended an Office of Naval Research (ONR)-sponsored affordability initiative meeting with Naval Air Systems Command’s (NAVAIR) PMA-261 program office at an off-site location in Lexington Park, Maryland. The purpose of the meeting was to address the potential for Navy ManTech support of the CH-53K King Stallion. The CH-53K has been added to the Office of Naval Research’s Strategic Investment Plan. Navy ManTech investments are focused on manufacturing technologies that will assist key acquisition program offices in achieving their respective affordability goals. The King Stallion will be a large heavy-lift multi-mission cargo helicopter. At 88,000 pounds gross weight, the Sikorsky King Stallion will be capable of lifting 35,000 pounds with a 110 nautical mile combat radius, while achieving speeds of up to 170 knots. The aircraft will have a service ceiling of 14,400 feet. Approximately two hundred CH-53K models are slated for service with the U.S. Marine Corps.

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"We have to balance the force requirements with the budget. And we have to consider the industrial base in the shipbuilding plan."
—Sean Stackley, Assistant Secretary of the Navy for Research, Development, and Acquisition

CALENDAR of EVENTS

2014

9–10 Sep	Fleet Maintenance & Modernization Symposium	** Virginia Beach, VA
23–25 Sep	Modern Day Marine Symposium	** Quantico, VA
13–15 Oct	AUSA Expo	Washington, D.C.
19–22 Oct	Logistics Officer Association	** Crystal City, VA
17–20 Nov	DoD Maintenance Conference	Birmingham, AL
1–4 Dec	Defense Manufacturing Conference	** San Antonio, TX

2015

13–15 Jan	Surface Navy Association Symposium	** Crystal City, VA
4–5 Feb	ONR S&T Conference	** Washington, D.C.
13–15 Apr	Navy League Sea-Air-Space Expo	** National Harbor, MD
5–7 May	AHS Forum 71	** Virginia Beach, VA

** Visit iMAST booth