2021 Additive Manufacturing Workshop

Executive Summary

Additive manufacturing (AM) is a versatile technology that provides technical advantages across a range of defense applications in order to build a more lethal and ready force. AM supports rapid design and prototype cycles that can significantly reduce production timelines, improve repair part availability, and increase speed to the warfighter for new systems. In order to maximize this potential, the Additive Manufacturing for Maintenance Operations Working Group (AMMO WG) and America Makes have been hosting annual AM wargames or workshops as an opportunity for government, industry, and academia to assemble and collaborate on the most challenging AM focus areas.

This year, the AMMO WG and America Makes worked closely with the DoD's Joint Additive Manufacturing Working Group to identify seven workshop topics that address foundational aspects of additive manufacturing necessary for DOD-wide adoption of this capability. The topics were: research and development to advance AM qualification and certification; cybersecurity; common AM data package approach; education and AM workforce development; AM standards – defense industry priorities and addressing the research and development gaps; integrated AM network response – how industry and government can work together to respond to urgent and important needs; and AM decision making – business case analysis for AM in the defense industry.

A working group was developed for each of the seven workshop topics, and four additional topics were added as optional informational break-out sessions. These four topics were: the role for technology in meeting the multiple workforce challenges in manufacturing; training: Joint Additive Manufacturing Model Exchange (JAMMEX) introduction; DoD additive manufacturing draft guidebook review; and cybersecurity in the manufacturing workforce The virtual workshop was spread over five days consisting of afternoon sessions only, two each for the working groups and one for the optional break-out sessions.

The results of the 2021 AM Workshop are the progressive steps forward achieved by the working groups in addressing these AM critical areas in a collaborative manner to developing solutions that will enable the successful adoption and implementation of AM within the DoD.

Below is a Summary of the Key Findings and Accomplishments of the 2021 AM Workshop Organized by Workshop Topic Area:

Research and Development to Advance AM Qualification and Certification

Addressing gaps identified tended to offer weeks of time savings or better (76 out of 95 identified by the group)

Prioritized Near Term Gaps (out of 38 identified by the group):

- Materials data for dynamic applications including process-structure-property relationships
- E.g. Fatigue data, effect of defects, design allowables
- Improved inspection throughput and techniques
- Machine calibration
- ICME tools/Distortion prediction/residual stress measurement
- In-situ monitoring and data registration with inspection data

Prioritized Long Term Gaps (out of 57 identified by the group):

- ICME methods for qualification, including dynamic property (fatigue life) prediction
- AM equipment equivalency for qualification and vender to vendor validation
- AM material specific acceptance criteria
- AM system designs which promote reliability and repeatability (ex. sensors)
- Use of industry standards compared to proprietary standards to enable vendor certification/approval

Cybersecurity

Top Five Needs:

- Make security more invisible and unobtrusive
- Make key security properties or controls “built in”
- Additive Manufacturing machine providers provide secure machine environments
- Case studies of where security improvements paid off in ways that matter to manufacturer/different messaging
- Keeping the security posture up to date so it doesn’t get stale/ vulnerable

Small manufacturers are leasing equipment with no control abilities so they aren’t able to make security improvements

Small manufacturers may be able to implement cybersecurity easier due to having a flatter organizational structure

Common AM Data Package Approach / Joint Additive Manufacturing Acceptability (JAMA)

Presented our AM Data Package approach to the Common JAMA AM Data Package risk categorization, content requirements, structure, and formatting

Gathered feedback from industry peers through workgroup surveys and open dialogue

Developed recommendations based on our feedback to refine our approach to AM Data Package risk categorization, content requirements, structure and formatting

Education and AM Workforce Development (EWD)

Deployed a pilot of the “Optimizing for AM” Instructor Led Training

AM Standards – Defense Industry Priorities and Addressing the Research and Development Gaps

Received 66 responses to a pre-workshop survey on top defense industry standards gaps in the AMSC roadmap

Developed final list of 10 highest priority gaps:

- AM Part Classification System for Consistent Qualification Standards
- Machine Qualification
- Contents of a TDP
- Harmonization of AM Q&C Terminology
- Design Allowables
- Machine Calibration and Preventative Maintenance
- Material Properties
- Recycle & Re-Use of Materials
- AM Process-Specific Metal Powder Specifications
- Design of Test Coupons

Integrated AM Network Response – How industry and government can work together to respond to urgent and important needs

An integrated AM Network is important in times of crisis and normalcy, to convene, catalyze, and coordinate AM efforts across the ecosystem

There are critical needs along two primary pathways

- Drive Innovation & Collaboration to enable effective response and technology development
- Be the source of truth to help the AM ecosystem navigate the regulatory complexities of a crisis response

Educational gaps in a time of crisis – Design, Quality, Technology, Post Processing, Materials

AM Decision Making – Business Case Analysis for AM in the Defense Industry

Drafted business case equations

Developed mathematical frameworks for objective evaluation of business case

Identified potential use cases for AM:

- New AM designs
- Replace or supplement traditional part supply with AM supply
- AM lead time replacements

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Additive Manufacturing Workshop 2021

Purpose

This additive manufacturing workshop is a follow up to the AM Workshop held virtually on, 23-25 June 2020. The purpose of this workshop is to address select foundational aspects of additive manufacturing necessary for DoD's wide adoption of this game-changing capability. The workshop was sponsored by DoD's Joint Additive Manufacturing Working Group (JAMWG), America Makes Additive Manufacturing for Maintenance and Sustainment Advisory Group and the Additive Manufacturing for Maintenance Operations (AMMO) Working Group. Participants included members from the government, industry and academia.

Background

DoD has completed two AM business model simulations, known as the 2016 and 2017 Business Model Wargames, a 2018 Business Model Workshop, to address the aspects of employing AM technology and techniques to sustain DoD equipment in multiple scenarios, a 2019 AM Workshop to collaborate on five critical AM topics, and a 2020 AM Workshop to work seven foundational AM topic areas.

In May 2016, the AMMO WG and America Makes conducted the first AM Business Model Wargame, a simulation that focused on the business transactions involved when DoD requires that repair parts be additively manufactured at a DoD depot or third-party location to support immediate readiness goals. In response to the 2016 wargame, the AM Business Model Wargame II took place in May 2017 at the Lockheed Martin Global Vision Center in Arlington, Virginia. The results of the simulation revealed common issues among all teams and unique opportunities and business model considerations particular to each team. The issues included the need to negotiate a value for access to intellectual property (IP), warranty impacts, liability shifts, brand risk concerns, and an increased reliance on data and the security of that data.

In 2018 the organizers switched to a workshop format to address five business model aspects of AM for sustainment and production in parallel with ongoing AM technology community efforts. The five aspects were: develop an AM contracting guide for Navy / DoD, information assurance on 3D technical data packages (TDPs) and blockchain, pathfinder scenario study of AM repair parts, 3D model exchange, and AM intellectual property management. Similarly, the 2019 AM Workshop divided into five workgroups that focused on data standards and data / model sharing, qualification and certification, AM business practices, workforce development, and DoD AM policy development.

For 2020, the AMMO WG and America Makes decided to build upon previous AM workshop results and actively pursue solutions in seven foundational topic areas critical to our ability to scale additive manufacturing adoption and execution across DoD. The 2020 AM Workshop had 275 registrants divided into the following work groups: addressing AM cyber challenges, AM data management, workforce development for AM, AM metrics,

AM part risk categorization and relation to part criticality, AM TDP for procurement in sustainment, and framing the DoD-level AM guidebook.

Appendix A provides more detailed information on the previous AM wargames and workshops and contains links to the final reports.

Participant Demographics

The 2021 AM Workshop had 280 people register amongst the seven workgroups. Participants were composed of representatives from government, the military services, academia, and industry, with disciplines in contracts administration, engineering, enterprise IT, legal, logistics, and program management. Figure 1 shows the demographics of the AM Workshop 2021 registrants.

Figure 1. AM Workshop 2021 Registration Demographics

AM Workshop 2021 Concept Development

The concept of this workshop was to assemble seven working groups of subject matter experts (SMEs) composed of key disciplines, and then focus their efforts on key integral areas of additive manufacturing necessary for DoD's wide adoption of this game-changing capability. The working groups were selected from a combination of last year's AM workshop and ongoing efforts at the JAMWG and America Makes. Four additional topics were identified as breakout topics to be presented informationally vs a working group.

Seven Workgroups

The 2021 AM Workshop Workgroups and co-leaders are listed in Table 1.

Table 1. 2021 AM Workshop Workgroups

No.	Work Group Name	Co-Leaders / Facilitators
1	Research & Development to Advance AM Qualification and Certification	• Mark Benedict, Jennifer Wolk, Jeffrey Gaddes, Brandon Ribic
2	Cybersecurity	• Jon Powvens, Greg Shannon, Larry Lynch, Adwoa Amofa
3	Common AM Data Package Approach / Joint Additive Manufacturing Acceptability (JAMA)	• Edilia Correa, Tony Delgado, Michael Ridgway, Chris Babcock, David Wittes
4	Education and AM Workforce Development	• Josh Cramer
5	AM Standards – Defense industry priorities and addressing the Research and Development gaps	• Jesse Chambers, Jim McCabe
6	Integrated AM Network Response – How industry and government can work together to respond to urgent and important needs	• John Wilczynski, Federico Sciammarella
7	AM Decision Making – Business Case Analysis for AM in the defense industry	• Stephen Kuhn-Hendricks, William Peterson, Ernesto Ureta, Timothy Vorakoumane

Four Break-Out Sessions as part of "University Day"

The four break-out sessions and presenters for the educational topics are listed in Table 2.

Table 2. 2021 AM Workshop Break-Out Sessions

No.	Break-Out Name	Presenter(s)
1	One Size Doesn't Fit All: The Role for Technology in Meeting the Multiple Workforce Challenges in Manufacturing	• Dr. Ben Armstrong
2	Training: Joint Additive Manufacturing Model Exchange (JAMMEX) Introduction	• Catrina Murphy & Vikas Sharma
3	DoD Additive Manufacturing Draft Guidebook Review	• Michael Parkyn
4	Cybersecurity in the Manufacturing Workforce	• Lizabeth Stuck & Michael Gramoni

AM Workshop 2021 Workgroup Descriptions

Following are the seven AM Workgroup abstracts.

Research and Development to Advance AM Qualification and Certification

The intent of the workshop is to outline opportunities for strategic research and development (R&D) to address gaps in AM Qualification and Certification (Q&C). The workshop has historically served as an important opportunity to influence focus and prioritization for funded R&D activities. The workshop will include reference materials and presentations to aid brainstorming and understanding of AM Q&C as well as examples of ongoing relevant efforts. The goal of the workshop is to identify and develop near term and long term plans to address gaps in AM Q&C via R&D.

Cybersecurity

This working group will focus on what industry, academia and manufacturing USA institutes are doing to help solve the current issues facing DoD today and what will need to be done to ensure a more secure tomorrow. Presentations/ Discussions/Tabletop scenarios will help shape the dialogue over the two days with action items to ensure continued progress towards the common goal of securing America's supply chains and the Defense Industrial base. Participants will engage with MxD and CyManII to inform national roadmaps for cybersecurity in manufacturing.

Common AM Data Package Approach / Joint Additive Manufacturing Acceptability (JAMA)

This working group will provide participants a review of the JAMA project and seek feedback on the project's approach. The JAMA effort was a collaboration between the Military Departments (MILDEPS) and the Defense Logistics Agency (DLA) to meet the Office of the Secretary of Defense's mandate to integrate AM into the supply chain. The

DLA and MILDEP partners developed a common AM Data Package approach which will be discussed in depth during the workshop.

Education and AM Workforce Development

This two-part training/workshop first offers participants a highly interactive, virtual learning experience where the instructor will demonstrate effective approaches in communicating to decision-makers how additive manufacturing technologies can streamline the manufacturing process, improve product life cycles, allow for flexible mass customization, and lead to increased productivity and profitability. In the second part, participants will apply this new knowledge and write their own business case. Coaches are available to help participants hone their messages into a solid, compelling business case. Participants will also have access to America Makes technical business cases. At the workshop's conclusion, students will present their business cases to the group and receive feedback and ideas for improvement.

AM Standards – Defense Industry Priorities and Addressing the Research and Development Gaps

During this session, the 93 additive manufacturing standards gaps of the American National Standards Institute (ANSI) Additive Manufacturing Standardization Collaborative (AMSC) and America Makes Standardization Roadmap for Additive Manufacturing will be reviewed to prioritize the open gaps based on defense industry needs. Group members will then develop Statement of Objective for the top gaps and how they can best be addressed through R&D projects.

Integrated AM Network Response – How industry and government can work together to respond to urgent and important needs

This working group will discuss and document areas where additional investment and development is required to ensure a resilient supply chain. The working group will investigate and provide recommendations for the following areas to focus around scaling and exercising capabilities:

- Platform Improvement & Sustainment -- Evolve the enabling technology platform
- Capability Expansion – Expand AM technologies and develop program capabilities
- Ecosystem Cultivation -- Empower, grow, and mobilize stakeholders
- Regulation & Policy Management
- Workforce Development

AM Decision Making – Business Case Analysis for AM in the Defense Industry

Decision making for AM in the DOD is a balance between the engineering feasibility of producing a part via AM ("can we") and the business case for AM production ("should

we"). In this working group, we will attempt to formally define (i.e. equations) the AM business case by considering the potential ramifications of AM across the supply chain. After critically evaluating draft definitions, we will discuss opportunities and challenges for quantifying each component. Specifically, we will identify critical pieces of data and address how various AM use cases will influence the business case. Next, we will present views on the AM business case from representatives across the Military Services and commercial partners in regard to their current view of the AM business case, considerations specific to their organization, and vision of the AM business case in a full AM capable DOD. Lastly, the group will discuss next steps to establishing a standardized DOD perspective of the AM business case.

AM Workshop 2021 Break-Out Session Descriptions

Following are the four break-out session abstracts.

One Size Doesn't Fit All: The Role for Technology in Meeting the Multiple Workforce Challenges in Manufacturing

U.S. manufacturers continue to be challenged in finding the right workers with the right skills. Today, research from MIT's Initiative for Knowledge and Innovation in Manufacturing argues that manufacturers are facing not one, but a set of related workforce challenges: a "skills shortage", a "skills gap", and a "wage gap." In this presentation, MIT Research Scientist Dr. Ben Armstrong will detail these workforce challenges, provide a roadmap to creating scalable and sustained solutions, and describe the role that policy and acquisition strategy plays in moving forward. Dr. Armstrong will provide examples of what some of the most advanced factories have done to address these challenges as evidence to the viability of his proposed approaches.

Training: Joint Additive Manufacturing Model Exchange (JAMMEX) Introduction

JAMMEX is the collaborative system for the exchange and sharing of 3D AM models across the DoD community. JAMMEX fulfills the requirement of the OSD DTM-19-006 to provide an interoperable capability enabling DoD entities to procure, securely access, and share AM technical data. This workshop session will provide participants with a demonstration of the current functionalities of JAMMEX. Participants will hear highlights about some of the system enhancements that are currently being worked. The discussion will also involve an exchange of ideas and feedback from the participants on lessons learned from working with AM repository systems and further suggested enhancements for JAMMEX.

DoD Additive Manufacturing Draft Guidebook Review

In this session on the draft DoD AM Guidebook, a discussion started at the 2020 workshop, participants will have an opportunity to learn more about the status and plans of this intended guide as well as how to contribute to its development. The guidebook is

intended to be a resource to assist with holistically implementing AM across the DoD in acquisition, technology development and application, engineering, and logistics.

Cybersecurity in the Manufacturing Workforce

With the COVID-19 pandemic in 2020 came a blitz of new and urgent concerns over cybersecurity. Manufacturing's growing reliance on automation, advanced control systems, and remote work only expands the attack surface for cyber criminals. The Hiring Guide: Cybersecurity in Manufacturing is a playbook for building that urgently needed workforce. It describes 247 job roles; recommends how to train and upskill workers to handle these jobs; and breaks out detailed descriptions for three specific roles crucial to the future of cybersecurity. This presentation will highlight some of the most critical pathways and opportunities described in this detailed document with examples of execution (i.e. CyMOT). Participants should review documents. The goal is to determine what are the critical roles to ensure AM has a ready workforce as it relates to cybersecurity.

AM Workshop 2021 Workgroup Objectives and Deliverables

The seven AM Working Groups briefed their objectives and deliverables during the opening plenary on 14 June. Though these are generally stated within the abstracts above, you can view them in bullet form on the attached slides briefed during the opening plenary. (Appendix B)

AM Workshop 2021 Workgroup Key Takeaways and Recommendations

On the final day of the workshop, the workgroups presented their out-briefs of findings. Each team's entire brief can be found in Appendix C. The subsections that follow detail the key takeaways and next steps that each team presented.

Research and Development to Advance AM Qualification and Certification Working Group

<u>Key Takeaways / Accomplishments:</u>

- Greatest number of gaps observed were in Inspection and testing (28) and AM processes (29)
- Inspection and machining gaps correlated with weeks of time savings
- Modeling/Integrated Computational Materials Engineering (ICME), process-structure-properties (effect of defects, design allowables, materials data), standards, and in-situ process monitoring gaps correlated with largest time savings (months)
- Addressing gaps identified tended to offer weeks of time savings or better (76 out of 95)
- Longer term efforts provided more opportunities for qualification time savings

- Prioritized Near Term Gaps (out of 38):
    - Materials data for dynamic applications including process-structure-property relationships
    - E.g. Fatigue data, effect of defects, design allowables
    - Improved inspection throughput and techniques
    - Machine calibration
    - ICME tools/Distortion prediction/residual stress measurement
    - In-situ monitoring and data registration with inspection data
- Prioritized Long Term Gaps (out of 57):
    - ICME methods for qualification, including dynamic property (fatigue life) prediction
    - AM equipment equivalency for qualification and vender to vendor validation
    - AM material specific acceptance criteria
    - AM system designs which promote reliability and repeatability (ex. sensors)
    - Use of industry standards compared to proprietary standards to enable vendor certification/approval

Recommendations / Next Steps:

- OUSD(R&E) will task the JAMWG Qualification and Certification Council to partner with America Makes to detail out the five near term high priority areas – to look at what projects are out there already (e.g. University of Maine large scale polymer AM) and what gaps remain that could be new project calls under America Makes or where else if and how appropriate.
- Focused on time savings as the metric to prioritize these.

Cybersecurity Working Group

Key Takeaways / Accomplishments:

- Top Five Needs:
    - Make security more invisible and unobtrusive
    - Make key security properties or controls “built in”
    - Additive Manufacturing machine providers provide secure machine environments
    - Case studies of where security improvements paid off in ways that matter to manufacturer/different messaging
    - Keeping the security posture up to date so it doesn’t get stale/ vulnerable
- Small manufacturers are leasing equipment with no control abilities so they aren’t able to make security improvements

- Statement by NIST that small manufacturers can implement cybersecurity easier than large manufacturers and the dependence of small manufacturers implementing cybersecurity rests with the Chief Executive Officer
    - Small manufacturers have flatter organizations that allow quicker actions when the choice is made

Recommendations / Next Steps:

- Getting experts on what we need to do differently to get effective messages
- Kick offs meetings discussing methods and research on disciplinary areas
- Cyber case studies and multiple outreach efforts that include demos

Common AM Data Package Approach / Joint Additive Manufacturing Acceptability (JAMA) Working Group

Key Takeaways / Accomplishments:

- Presented our AM Data Package approach to the Common JAMA AM Data Package risk categorization, content requirements, structure, and formatting
- Gathered feedback from industry peers through workgroup surveys and open dialogue
- Developed recommendations based on our feedback to refine our approach to AM Data Package risk categorization, content requirements, structure and formatting

Recommendations / Next Steps:

- The JAMA team recommends the modular approach based on overall AM data package goals and current system capabilities
- Based on the risk category different types of information are needed, 3 modules with different types of data
    - TDP Module
    - Manufacturing Module
    - Testing Module
- Looking to incorporate this approach into the AM Guidebook.

Education and AM Workforce Development (EWD) Working Group

Key Takeaways / Accomplishments:

- Deployed a pilot of the “Optimizing for AM” Instructor Led Training
- Deployed a pilot of the “Optimizing for AM” Instructor Led Training

Recommendations / Next Steps:

- Further engagement with core team subject matter experts to review and assess feedback

- Deploy suggested amendments through continuous improvement for full scale deployment
- The team would be open to working with interested groups in future deployments
- Pursue Manufacturing Engineering Education Program support for this program
- Continue support of EWD engagement with the Council and America Makes

AM Standards – Defense Industry Priorities and Addressing the Research and Development Gaps

Key Takeaways / Accomplishments:

- Received 66 responses to a pre-workshop survey on top defense industry standards gaps in the AMSC roadmap
- Reduced this list to 15 gaps
- Developed final list of 10 gaps:
    - AM Part Classification System for Consistent Qualification Standards
    - Machine Qualification
    - Contents of a TDP
    - Harmonization of AM Q&C Terminology
    - Design Allowables
    - Machine Calibration and Preventative Maintenance
    - Material Properties
    - Recycle & Re-Use of Materials
    - AM Process-Specific Metal Powder Specifications
    - Design of Test Coupons

Note: Descriptions and recommendations for R&D for these 10 gaps are included in the work group out brief.

Recommendations / Next Steps:

- Several items work has begun on:
    - Two of these items part classification and TDP align to the JAMA project – OSD is actively supporting this
    - Consistency in terms – working on a DoD AM guidebook and would support additional standardization
    - Design allowables – started this work with Joint Metal Additive Database Definition (JMADD) – look to see what is next on this
- Working with the JAMWG to focus these down:
    - Machine calibration and prevention – will work with OSD(A&S) on this one
    - Need to prioritize materials, something we could look to do in DoD
    - Recycle and reuse – something we can look into
    - Metal Powder specs

    - Design of test coupons – move this beyond medical and into defense applications
- Need to connect with AM Center of Excellence to get an update on these projects – to the Qual/Cert group

Integrated AM Network Response – How industry and government can work together to respond to urgent and important needs

Key Takeaways / Accomplishments:

- An integrated AM Network is important in times of crisis and normalcy, to convene, catalyze, and coordinate AM efforts across the ecosystem
- There are critical needs along two primary pathways
    - Drive Innovation & Collaboration to enable effective response and technology development
    - Be the source of truth to help the AM ecosystem navigate the regulatory complexities of a crisis response
- Educational gaps in a time of crisis – Design, Quality, Technology, Post Processing, Materials

Recommendations / Next Steps:

- Continue to:
    - identify and execute systematic and discrete crises test scenarios to continuously evaluate and improve the systems capabilities
    - grow database of designs, suppliers, and reviewers.
- Develop a distributed network of designs and response organizations.
- Establish Design Collaboration & Innovation Space
- Explore connection between access to vendor capabilities via a platform which enables order fulfillment.
- Enhance platform capability related to requirements: regulatory, quality management systems, approved suppliers, etc.
- We learned a lot through COVID, there is an opportunity to build from this to be more ready for the future and how this can support our day to day operations. Feed this back to the JDMC.
- OSD supported with the COVID response funding to initiate these and look to continue support as appropriate.
- What else would the current online Exchange need: design collaboration space, visibility to those who have printed and feedback, cost estimate in the tool
- Identified different stakeholders and mapped out different scenarios

AM Decision Making – Business Case Analysis for AM in the Defense Industry

Key Takeaways / Accomplishments:

- Drafted business case equations
- Developed mathematical frameworks for objective evaluation of business case
- Potential use cases for AM:
    - New AM designs
    - Replace or supplement traditional part supply with AM supply
    - AM lead time replacements

Recommendations / Next Steps:

- Standardize lower level equations (e.g. how to calculate AM cost, how to estimate costs) across DoD
- Standardize and require in policy the collection of data necessary to evaluate the AM business case across the DoD
- Support the JAMA project that will build off of this work and ongoing efforts across the Services to come to a common base to help coordinate our approach and share best practice for those earlier in the curve of developing tools
- Looking for this to be part of our future AM Guidebook as this matures.

AM Workshop 2021 Hot-wash

The AM Workshop 2021 planning team, co-leads, facilitators, and coordinators conducted a hot-wash on June 28, 2021 to discuss lessons learned during the 14-21 June 2021 Virtual AM Workshop. The following are some of the key discussion points.

Virtual and Attendance Specific Comments:

- Minimal issues with connecting to a platform or finding workgroup/breakout rooms
- 290 signed up 158 for plenary opening and 100 for closing.
- Participation in the working groups was approximately 50 percent lower than registrations
- Only about 20% of participants completed the survey

Agenda and Workshop Format Comments:

- Overall format worked well having it spread out, avoiding Friday was good
- Out brief quality was greatly improved by having more time to prepare them.
- Consider building more time for the out briefs into a face to face schedule or do a virtual out brief a few days later.
- Identify a way to be more specific in targeting individuals for some of the topics – e.g. standards for a “roll up your sleeves” event.

- Suggestion: Write the abstracts more specifically where those who are experienced are requested.
- Suggestion: Engage with industry in the co-leadership role to support attendance.
- Suggestion: Engage with industry in the co-leadership role.
- Suggestion: Move “University Day” before or after the “workshop” to not break up the working blocks.

Administrative Support

- Administrative support from NCMS was outstanding. Availability was never an issue.
- Only issue was folks not getting their first choice due to high registration levels.

Briefings

- Templates worked well and had sufficient time to brief.
- Not as much engagement and discussion during the out briefs.

Next Steps / Follow-on

- JAMWG leadership will be setting up one on one’s with each set of co-leads to review the outcomes.
- Brief follow up on the actions and follow ups to the AMMO group in a few months.
- Consider different future workshop formats that may include a hybrid virtual/in-person “University Day” for all registrants on the first day, followed by small working groups that may be invitation only on subsequent days.

Survey Results

A survey was distributed to all the participants after the wargame, with a variety of questions to solicit feedback and help shape future wargames. The vast majority of respondents stated that they would very likely attend an AM Workshop in the future, that the workshop met or exceeded expectations, the event was engaging and about the right duration, and that their time spent dedicated to the workshop was informative and valuable. The survey results also include numerous responses on what participants liked, suggested changes, potential future topics, and other general comments. To view these responses go to Appendix D.

Conclusion

The 2021 AM Workshop provided a venue where members from government, industry, and academia were able to collaborate and work on seven foundational aspects of additive manufacturing necessary for DOD-wide adoption of this capability. The progress achieved by the working groups in addressing these AM critical areas, whether collectively developing solutions, or better defining the problems, will support the continuous efforts that members of the DoD’s Joint Additive Manufacturing Working Group, the America Makes Additive Manufacturing for Maintenance and Sustainment Advisory

Group, and the Additive Manufacturing for Maintenance Operations Working Group perform throughout the year with the goal of enabling the successful adoption and implementation of AM within the DoD and its' industry partners.

Appendix A. Previous AM Workshops

AM Business Model Wargame I

In May 2016, the DoD AMMO WG, in collaboration with the America Makes AM for Maintenance and Sustainment Advisory Group, co-sponsored AM Business Model Wargame I in Suffolk, Virginia. The purpose was to bring together participants from DoD and industry and illuminate the required business transactions when DoD needs repair parts to be additively manufactured at a DoD depot or third-party location in support of an immediate readiness goal. The wargame also assessed gaps and challenges discovered during the simulation to begin developing the necessary environment to support the continued adoption of AM capabilities.

Final Report: https://ammo.ncms.org/resources/?drawer=Resources*AM%20Wargames*2016

AM Business Model Wargame II

In 2017 the first wargame scenario was expanded to include life cycle platform considerations relevant to the business environment required to support the continued adoption of AM capabilities. Four teams, representing four different business models, dealt with the same scenario involving a need to manufacture repair parts using AM capabilities at the point of use. The four teams were:

- #1 Team “Buy-out”: Traditional government acquisition
- #2 Team “Loaner”: Government leases the end items
- #3 Team “CLS”: Contractor provides commercial logistics support (CLS)
- #4 Team “Net-Flix”: Government and original equipment manufacturer (OEM) set-up a “pay as you go” IP arrangement to allow AM part production in the field

The 2017 AM Wargame participants concluded that future focus areas should align with gaps identified in developing the business models during the AM wargames. These gaps include AM contracting guidelines, security, technology certification, workforce training, IP protections, and establishing secure data transmissions for AM and the digital thread. The AM planning group will organize future AM workshops to develop solutions to these gaps that create improved sustainment opportunities for the warfighter.

Final Report: https://ammo.ncms.org/resources/?drawer=Resources*AM%20Wargames*2017

AM Workshop 2018

The purpose of this workshop was to address five business model aspects of AM for sustainment and production in parallel with ongoing AM technology community efforts.

- Develop an AM Contracting Guide for Navy / DoD
- Information Assurance on 3D TDPs and Blockchain
- Pathfinder Scenario Study of AM Repair Part
- 3D Model Exchange
- AM Intellectual Property Management

Key findings from the 2019 AM workshop include:

- Governance needs to be established – a Joint body of Service-level Leadership - subgroup of the JAMWG
- Implement AM-focused policy for AM to begin in acquisition and contract phase
- AM Contracting Strategy should contract for AM as a service…not a supply
- Create a Central Database for AM Tech Data, 3D Model Exchange, and IP rights
- Services are working AM technology with the current processes in place, same engineering processes, similar procurement, similar qualification and testing
- Blockchain technology itself is not a barrier, but business cases and return on investment in AM are still being defined to determine when blockchain makes sense

Final Report: https://ammo.ncms.org/resources/?drawer=Resources*AM%20Wargames*2018

AM Workshop 2019

The purpose of this workshop was to collaborate across government, industry and academia to actively pursue solutions in five foundational topic areas (and subgroups) critical to our ability to scale additive manufacturing adoption and execution across DoD.

- Data Standards and Data / Model Sharing Work Group
  - JAMMEX Sub-Group
  - TDP Standard Project Sub-Group
  - Cybersecurity Challenges and Solutions (Blockchain) Sub-Group
- Qualification and Certification Work Group
  - Database and Common Language Sub-Group
  - Quality Assurance Sub-Group

    - Standards Sub-Group
- Business Practices Work Group
    - DoD AM Acquisition Guide Sub-Group
    - AM Supply Chain Integration Sub-Group
    - IP Management Sub-Group
- Workforce Development Work Group
- DoD AM Policy Development Working Group
    - Acquisition Sub-Group
    - Engineering Sub-Group
    - Logistics Sub-Group

Key findings from the 2019 AM workshop include:

- Alignment of AM workshop working groups with the JAMWG is important to continue work
- AM-focused policy must include the entire product life cycle
- There is a need for a central database for AM tech data, 3D model exchange, and IP rights
- AM data must be in a "shareable" format across the military services and industry

Final Report: https://ammo.ncms.org/resources/?drawer=Resources*AM%20Wargames*2019

AM Workshop 2020

This workshop actively pursued solutions in seven foundational topic areas critical to our ability to scale additive manufacturing adoption and execution across DoD.

- Addressing AM Cyber Challenges
- AM Data Management
    - Standards and Data Dictionary
    - Common AM Database Experiment (CAMDEN)
- Workforce Development for AM
- AM Metrics – Measures of Effectiveness and Measures of Performance
- AM Part Risk Categorization and Relation to Part Criticality
- AM TDPs for Procurement in Sustainment
- Framing the DoD-Level AM Guidebook

Key findings from the 2020 AM workshop include:

- Cybersecurity assessors and AM leads must have awareness of respective mission requirements (secure infrastructure and produce components, respectively) and select security controls on risk evaluation, not by a checklist
- Need policy emphasis for data management at the start of acquisition
- Standardize workforce roles, language and definitions as much as possible
- Create a tiered criteria for ensuring AM systems are mature enough to handle a predefined criticality, complexity, and output
- Need to level-set AM methodology across DoD
- Current TDP focus in ensuring accuracy of design data will evolve to ensure accuracy of contracted deliverables
- Government, industry and academia must collaborate to work these critical focus areas and develop solutions that enable the successful delivery of AM technologies to both the government and its' industry partners.

Final Report: https://ammo.ncms.org/resources/?drawer=Resources*AM%20Wargames*2020

Appendix B. Abbreviations

AM	additive manufacturing
AMMO WG	additive manufacturing for maintenance operations working group
AMSC	Additive Manufacturing Standardization Collaborative
ANSI	American National Standards Institute
CAMDEN	common additive manufacturing database experiment
CLS	commercial logistics support
COVID	Coronavirus Disease
DLA	Defense Logistics Agency
DoD	Department of Defense
EWD	Education and Workforce Development
ICME	Integrated Computational Materials Engineering
IP	intellectual property
JAMA	joint additive manufacturing acceptability
JAMMEX	joint additive manufacturing model exchange
JAMWG	Joint Additive Manufacturing Working Group
JMADD	Joint Metal Additive Database Definition
MILDEPs	Military Departments
MxD	Digital Manufacturing Institute
NIST	national institute of standards and technology
OEM	original equipment manufacturer
OSD	Office of the Secretary of Defense
Q&C	qualification & certification
SMEs	subject matter experts
TDP	technical data package
WGs	working groups

Appendix C. Survey Results (Attached)

Appendix D. AM Workshop 2021 Opening Plenary and Agenda Slides (Attached)

Appendix E. AM Workshop 2021 Out-Brief Slides (Attached)

Appendix F. AM Standards Working Group Back-Up Slides (Attached)

Appendix G. 061521 Defense Industry Additive Manufacturing Standardization Gap Priorities (Attached)