Additive Manufacturing

— FOR DEFENSE AND GOVERNMENT —

Washington DC – May 13-14, 2015

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Additive Manufacturing Perspective and R&D at NAVSEA

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Presentation at the Symposium on Additive Manufacturing For Defense and Government

13-14 May 2015

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AM supports “Culture of Affordability” & “It’s All About the Ships”!

- Enabling technology to provide critical capability to support the Navy Mission.
- Numerous initiatives to apply AM. Collaboration and coordination of initiatives required to ensure effective use of resources.
- AM can result in new unique innovative designs, improved response to Fleet and Shipyard issues, reduced acquisition and life cycle costs, and improved readiness.
- Numerous technical and business challenges exist (intellectual property rights, material properties, process controls, data controls, cyber security, quality assurance, etc).
- Must face and resolve challenges to seize the opportunities to implement AM.

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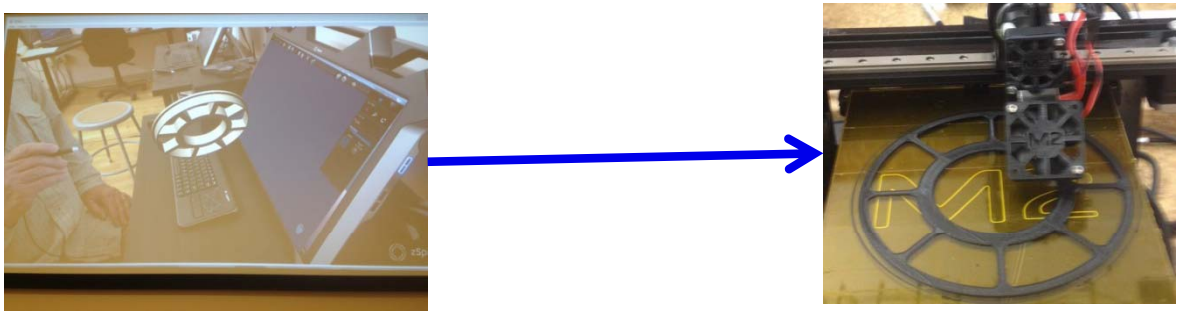
NAVSEA AM – Vision & Goals

- Establish the processes, specifications and standards for use of AM for ship acquisition, design, maintenance, and operational support.
- Collaborate and partner with other Government activities, Fleet, industry and academia to:
  - Build process, material, and design confidence in AM.
  - Ensure that AM ship and weapon system components are safe, reliable and effective for the intended application.
  - Expand the current use of AM for rapid design development, prototyping & tooling.
  - Employ AM in maintenance & repair.
  - Identify and forecast necessary S&T investments to provide enabling capabilities for the NAVSEA enterprise**.**



Operationalize AM in support of the Fleet where it makes sense.

NAVSEA AM Current Applications

- Involved in Additive Manufacturing for over a decade
- Additive Manufacturing is currently used throughout the NAVSEA enterprise in Warfare Centers and Shipyards for:
  - Rapid Prototyping
  - Models (functional/demonstration)
  - Fit checks
  - Visualization of work execution
  - Custom jigs and fixtures
  - Support traditional manufacturing methods: tooling development, injection molding, casting, hydroforming and welding
  - End use parts (limited)
  - STEM outreach
  - Workforce Development

Prototyping new capabilities

Custom Fixtures

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Naval Shipyards - AM Files

- **Objective:** Design once, use many (across shipyards).
- **How:** Sharing of completed projects via the Naval Shipyard Intranet.
- **What:** Each Shipyard post their AM project list to their site so that the other shipyards can access and request files be sent.
- **Why:** Saving time and money executing ship maintenance across the Naval Shipyards!

	Project Description
2	PS-1 4" gate valve bypass half valve body mock up 2nd half, upper bonnet large items to go along with bypass half
3	P74 Am-Clyde Swing lock coil housing prototype
4	938-60-14NT Vib Reducer dummy thrust pad to fulfill shop request QTY of 4ea
5	30deg and 60deg toolbit holder setting gage for Climax VM9000 Hull valve cutting machine MSW/ASW
6	Vib reducer special wrench with captivation screws prototype
7	Freeze seal supercooling head for 4" pipe 2ea more sets to fulfill requester QTY
8	938-60-14NT Vib Reducer dummy thrust pad
9	Freeze seal supercooling head for 4" pipe
10	PS-1 90 deg elbow sleeve fixture PC 20 for auto welder fit up
11	PS-1 90 deg elbow sleeve fixture PC 1 for auto welder fit up
12	PS-1 4" gate valve bypass half valve body mock up
13	938-60-14NT Vib Reducer dummy thrust pad
14	VH Flapper valve hinge bore protective inserts
15	RPFW GO-NO-GO Gage prototype
16	Hull valve locating plate to center Climax VM-9000 hull valve cutting machine MSW/ASW
17	2320-48-14NT PS-1 leak off adapter drill fixture
18	2320-48-14NT PS-1 leak off adapter drill fixture hanging bar PN 1
19	"F" clamp modified foot to prototype holddown clamp PS-1 leak off adpater drill fixture
20	Grinding wheel guard to prototype for cutting machine for PS-1 stud removal
21	Expandable Collet to replace broken AHP sanding fixture
22	2320-48-14NT PS-1 Drill fixture pn 1 prototype
23	938-60-14NT Vib Reducer dummy thrust pad prototype
24	930-51-14NT PH16242 MBT bearing surface protective blanks PN 1 (9ea)
25	Hold down 1 plate for drilling of weld repair holes for DDS "turtle back" foundation pads
26	Hold down 2 plate for drilling of weld repair holes for DDS "turtle back" foundation pads
27	Climax VH flapper bore line boring machine manual drive
28	930-51-14NT PH16242 MBT bearing surface protective blanks PN 1
29	938-106-12NT Modified 3 "spider" to drill cover holes for use with MBT Valve installed
30	938-106-12NT Modified 2 "spider" to drill cover holes for use with MBT Valve installed
31	938-54-14NT Fixture drilling for FDN hydrophone MBT FWD 6-5D
32	938-106-12NT Modified "spider" to drill cover holes for use with MBT Valve installed
33	SA cover template mod bushing
34	SA-7 Cover template PN3 270-57-14NT for hole repair
35	Sanding Fixture

Example - PHNSY&IMF List of AM Products

NAVSEA AM - Opportunities

- **New Capabilities** – Potential to increase performance/reliability of new platforms:
  - Rapid design development and optimization.
  - Reduced part assembly.
  - Increased quality/reliability of components.
  - Reduce weight.
  - Engineering design for AM.
  - Part obsolescence prevention – model based enterprise.
- **Support Existing Design** – Improve support of existing platforms
  - Part obsolescence mitigation.
  - Make parts not readily available.
  - Address time-criticality issues.
- **Cradle to Grave Overall Benefit**
  - Reduction in total ownership cost of system/platform.
  - Increased operational availability.

NAVSEA Advantages and Applications

Additive manufacturing is generally suited for applications that meet the following criteria:

- Low production volume
- Complex part geometry
- Expensive materials

Advantages

- Rapid part turnaround
- Shortened design time
- Inexpensively obtain geometric complexity
- Reduction in material waste
- Limited tooling required
- Reduced labor costs

Category of Applications

1. Rapid prototyping
2. Rapid tooling
3. Repair
4. Electronics
5. Rapid manufacturing

Examples

1. Rapid prototyping
   - Design iterations
   - Geometric fit-checks
   - Scale models/Mockups
   - Working prototypes
   - Accelerated Learning Centers

Design comparison

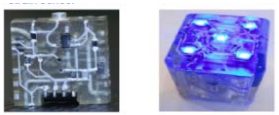
2. Rapid tooling
   - Custom fixtures/templates
   - Injection molds
   - Sand casts
   - Tools/ Go/No Gages

Custom trim tools

3. Repair
   - Machining errors
   - Casting errors
   - Worn parts & surfaces

Laser Engineered Net Shaping/Cold Spray

4. Electronics
   - Embedded sensors
   - Structural health monitoring
   - Printed electronics



Circuits and electronics

5. Rapid manufacturing
   - In-house manufacture
   - Printed assemblies
   - Legacy part development

Installed parts

Long term - Designs optimized with AM Engineering. Obsolescence is a major issue. ***Make Obsolescence Obsolete***

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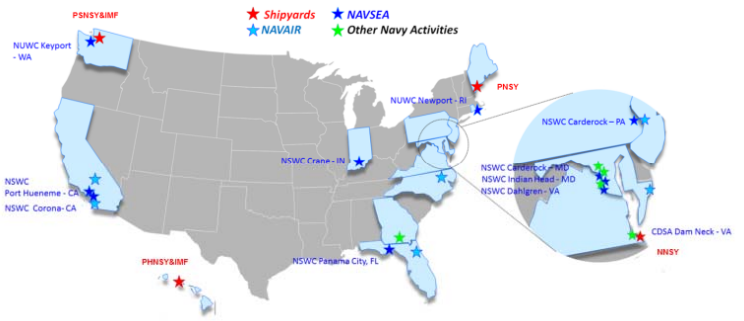
NAVSEA AM - Actions

- NAVSEA DWO/TDM for Additive Manufacturing. Complete
- Subject Matter Expert position to support AM. ECD: May 2015
- Workforce Education & Training Module for NAVSEA on AM. Apr 2015
- NAVSEA 3 year roadmap to establish the plan for operational application, qualification/certification, facilities/capabilities, information systems management, workforce development, and supply chain management. ECD: Oct 2015
- List of S&T priorities for presentation at the Quality Made Industry Day. ECD: May 2015
- Expand the use of AM among the Warfare Centers and Naval Shipyards by sharing AM application examples and digital data. ECD: Ongoing
- Establish an AM decision tree which will be a list of attributes to be considered before using AM. ECD: Aug 2015



Independent Technical Authority

SEA 05 Chief Engineer (CHENG)
Deputy CHENGs & Engineering Leadership Council

40 Total Civ

NAVSEA 05 NAVAL SEA SYSTEMS COMMAND

Workload Drivers

	New Construction	Fleet Support
CVN	CVN-78 CVN-79	CVN 72 RCOH CVN 73 RCOH Plan CVN 69 / 74 DPIA
SUB	Ohio Replacement	LA Class – 5 avails Ohio Class – 2 avails Seawolf Class – 2 avails Virginia Class – 1 avail
SURF	LX (R) LHA (R) Flt 1 DDG 51 Flt 3 TAO (X) Small Surf Combatant	DDG LPD MLP JHSV LCS
OTHER	Cyber Energy	Cyber Energy

612 Total Civilians
Includes SEA 05 SES, SL, Civilian Mission-Funded, Other Mission-Funded, Reimbursable. Excludes SEA 05X.

Excludes SEA 00C, 00VW, 04R.

Technical Domain Manager (TDM)

- Cost Engineering & Industrial Analysis (SEA 05C) (79)
- Explosive Ordnance Engineering (SEA 05E) (3)
- Warfare Systems - Littoral & Mine Warfare (SEA 05M) (3)
- Warfare Systems – Undersea (SEA 05N) (11)
- Ship Integrity & Performance Engineering (SEA 05P) (73)
- Warfare Systems – Surface (SEA 05W) (15)
- Marine Engineering (SEA 05Z) (82)
- Ocean Engineering (SEA 00C)
- Weapons, Ordnance & Explosives Safety (SEA 00VW)
- Industrial Engineering & Additive Manu. (SEA 05G) (5)
- Technical Policy & Standards (SEA 05S) (14)
- Technology Office (SEA 05T) (15)

ONR, Etc.

Capability & Certification

Output

Chief Systems Engineer (CSE)

- Surface Ship Design & Systems Engineering (SEA 05D) (69)
- Integrated Warfare Systems Engineering (SEA 05H) (56)
- Littoral Mine Warfare Design & Systems Eng (SEA 05L) (8)
- Submarine / Submerse Design & Sys Eng (SEA 05U) (114)
- Aircraft Carrier Design & Systems Eng (SEA 05V) (30)

Systems Integration Leadership

Customer Demand

Certified Products Meeting Requirements

PM Authority

- TEAM SHIPS / LCS
- PEO IWS / LCS
- PEO LCS
- TEAM SUB
- PEO CARRIERS

Blue Boxes: Focused on Ship Types / Classes
Deputy Warranting Officers = Chief Systems Engineers & Technical Domain Managers
Ship & System Design / Integration Managers (SDM / SIMs)
- New Construction
- In-Service Maintenance & Modernization

277 Total Civ

51% New Construct
49% In-Service

Red Boxes: Focused on Major Systems / Components
Deputy Warranting Officers = Technical Domain Managers
Technical Warrant Holders (TWHs), Warfare Systems Engineers (WSEs), Technical Area Experts (TAEs), Cost Engineering Managers (CEMs)
- Cost Engineering, Surface, Undersea, Munitions, etc.
- Naval Architects & Engineers

295 Total Civ

New Construct = Demand
In-Service = Supported

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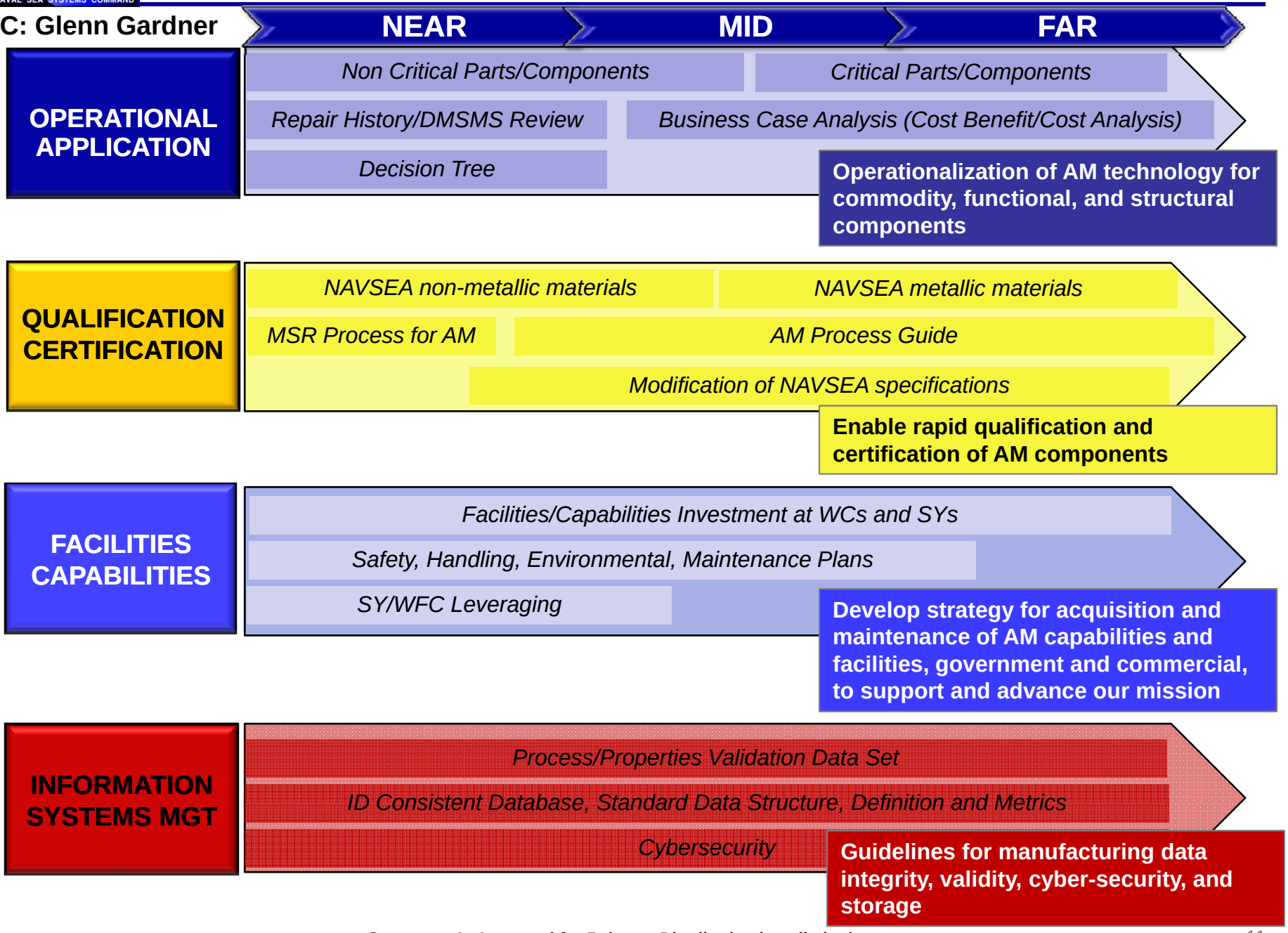
Live Additive Manufacturing Roadmap – Apr 2015

POC: Glenn Gardner

ADDITIVE MANUFACTURUING TARGETS



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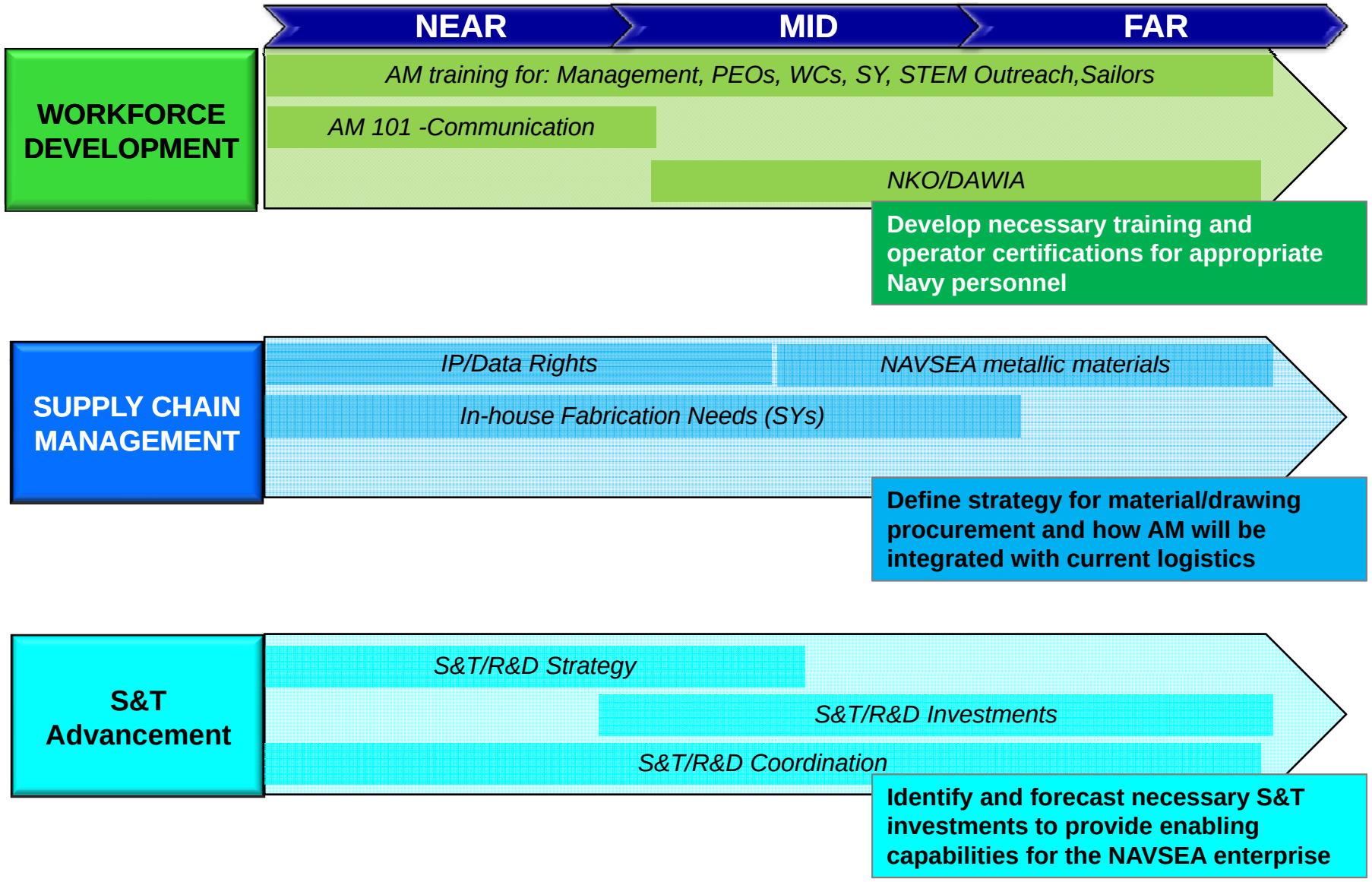
Live Additive Manufacturing Roadmap Apr 2015

POC: Glenn Gardner

ADDITIVE MANUFACTURUING TARGETS



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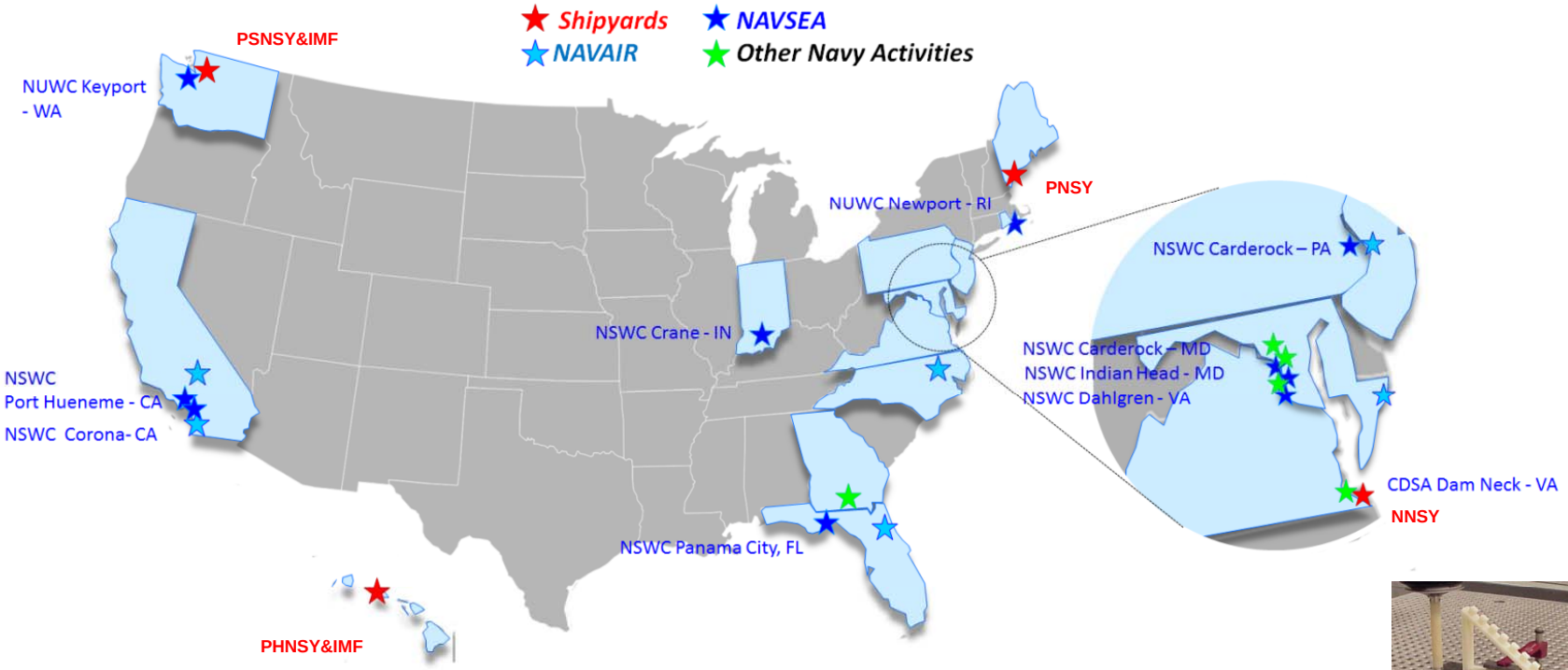
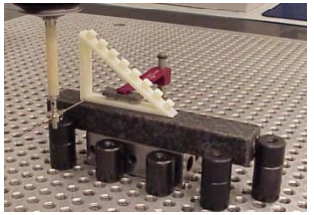
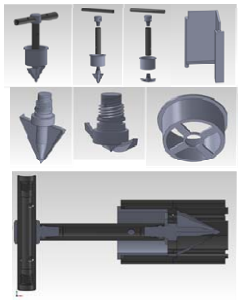
WFC/Shipyards with AM Capability







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R&D at NAVSEA

April 2015

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NAVSEA Warfare Center Overview

- Warfare Centers (WFCs) consist of seven Naval Surface Warfare Centers (NSWC) and two Naval Undersea Warfare Centers (NUWC)
- Supplies technical operations, people, technology, engineering services, and products needed to equip and support the fleet and meet the warfighters' needs
- Principle RDT&E assessment activity for surface ships, submarines, and subsystems
- Provides depot maintenance and in-service engineering support to ensure system reliability
- 2012 ASN RDA Memo: Importance of "DoN Scientists and Engineers perform or participate significantly in these functions in the early stages of research and development (R&D). Examples include: engineering work in support of AoAs, in-house prototyping. . ."

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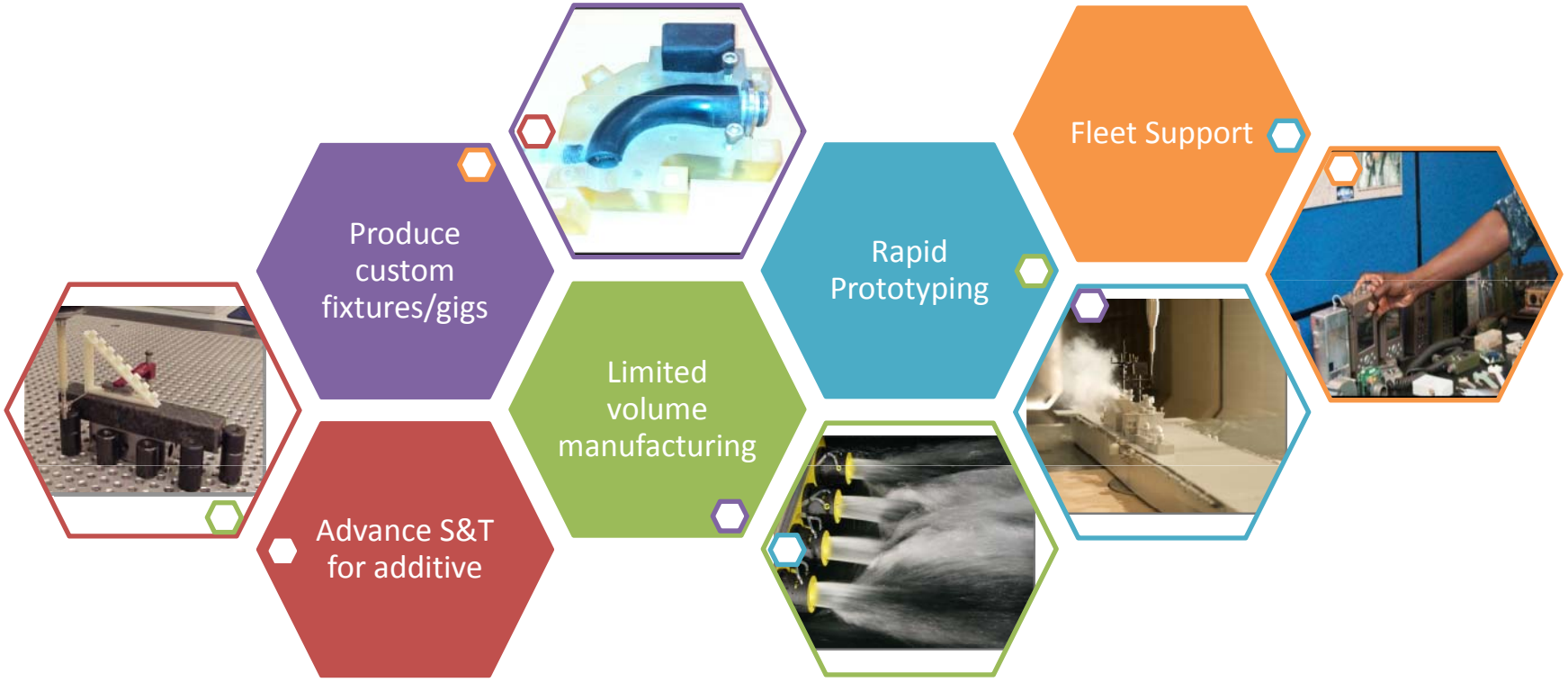
Additive Manufacturing at the NAVSEA Warfare Centers

Involved in Additive Manufacturing for over a decade. . .



". . .'Prototyping not necessarily leading to programs of record.' It gives us the chance to take risk and hopefully fail and not be hauled out onto the carpet for failing." - Ben Riley, Deputy Assistant Secretary of Defense for Emerging Capability and Prototyping. "

Prototyping Chief Sees New Emphasis, Though Not Necessarily New Money
By Tony Bertuca, Posted on InsideDefense.com, 7 Nov 14

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WCs AM Supporting Readiness

NUWC Keyport uses:

- ProMetal S15 to print sand casting molds and cores for short lead time, low quantity, complex castings meeting original design specifications and materials.
- FDM and SLS systems support manufacturing, testing & evaluation, and repair processes with quick-turnaround thermoplastic prototypes and tools.

NSWC Panama City supports Fleet Readiness by fabricating wings and fairings for the Q-24 Underwater Mine Detection Device. Also supporting Modular Integrated Display System (MIDDS) for Full Facemasks.

NSWC Crane uses AM to validate plastic enclosure designs/ custom requirements for development of new electronics/ system designs. As an organic DoD Printed Circuit Technology capability, AM can be a bridge solution to mission critical needs.

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AM and the Warfighter

NSWC Dahlgren (CDSA) is a part of the CNO's Rapid Innovation Cell (CRIC) Print the Fleet project dedicated to introducing AM to the Fleet. Accomplishments:

- Conducted a series of workshops, including the Navy's first "Maker Event"
- Built non-critical parts for Fleet at shore and shipboard
- Collected user feedback to develop requirements
- Worked with NAVSUP to develop a AM data repository (in development)
- USS ESSEX (LHD-2): uPrint installation and training of sailors to design and build non critical components for fit checks

NSWC Port Hueneme, participating in the CNO's Rapid Innovation Cell (CRIC), employs two Stratasys AM machines to print ABS plastic based parts for a myriad of purposes including

- Academic aids
- Tomahawk Form, Fit and Function tests
- Intra-assembly piece-part replacement; and rapid prototyping.

NSWC Carderock supports the Warfighter through understanding the impact of ship motion on AM. Experiments were performed on JHSV-2 CHOCTAW COUNTY and supported the CRIC effort on USS ESSEX (LHD-2) during calm-water powering trials June 2014 (NPS Dental/ NSWCCD/NSWC Corona).

- Visual/property variation in build quality when specimens fabricated underway on CHOCTAW COUNTY and USS ESSEX.
- Ongoing work in coupled/decoupled motion and environmental effects in FY 14.

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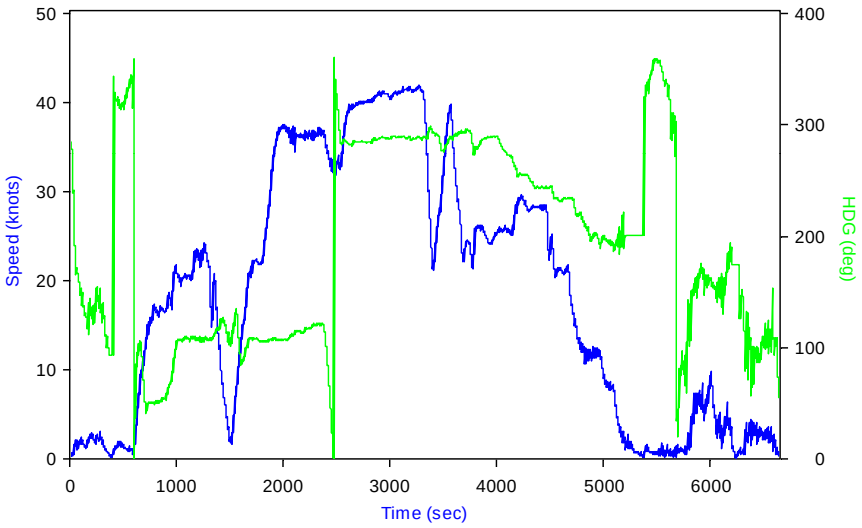
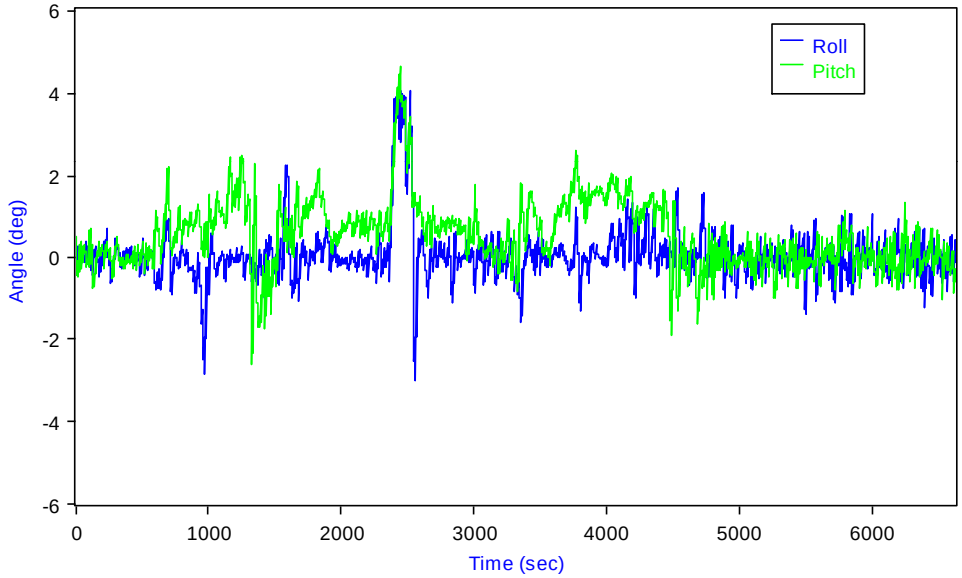
Inertial Motion Data (Dogbone Tensile Data)

- October 7, 2013 – JHSV-2 UW from Little Creek to Norfolk Naval Station **0942-1133 EST**



Max Speed = 41.9 knots



Max Roll Angle = 4.1 degrees
Min Roll Angle = -3.0 degrees

Max Pitch Angle = 4.6 degrees
Min Pitch Angle = -2.6 degrees

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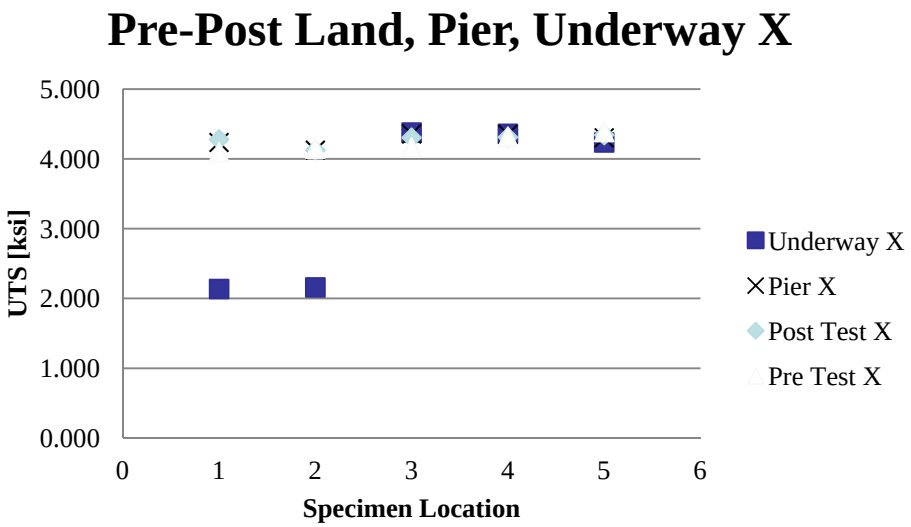
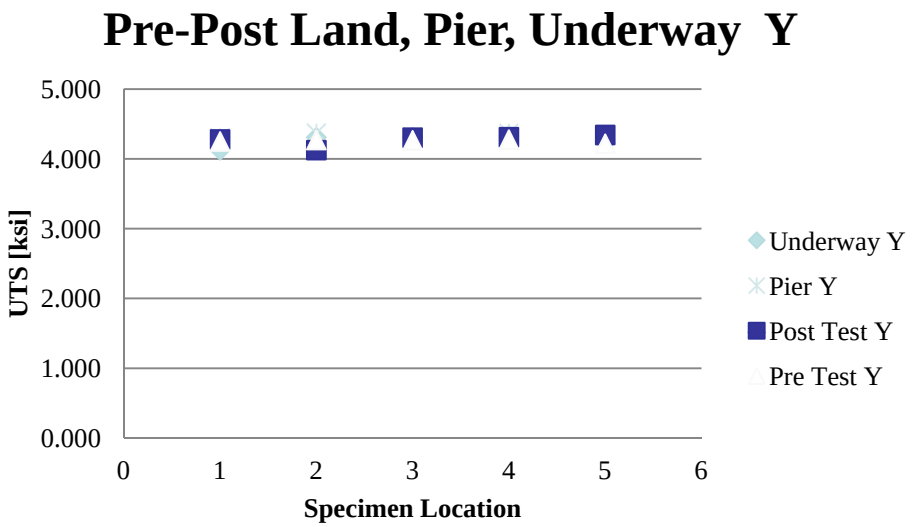
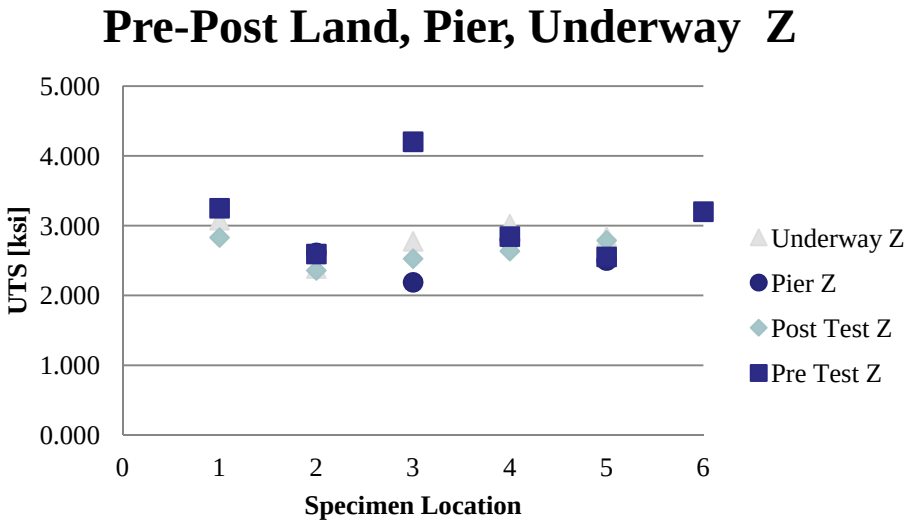
Tensile Data







- Underway Little Creek to Norfolk Naval 10/7/2013 Specimen ID: 1-3-1139
- ASTM D638 Specimens As-built in x, y, and z orientations at five locations on the build plate
- Material specification mechanical properties for ABSplus plastic: UTS 5.3ksi (36.5MPa) (www.stratasys.com)

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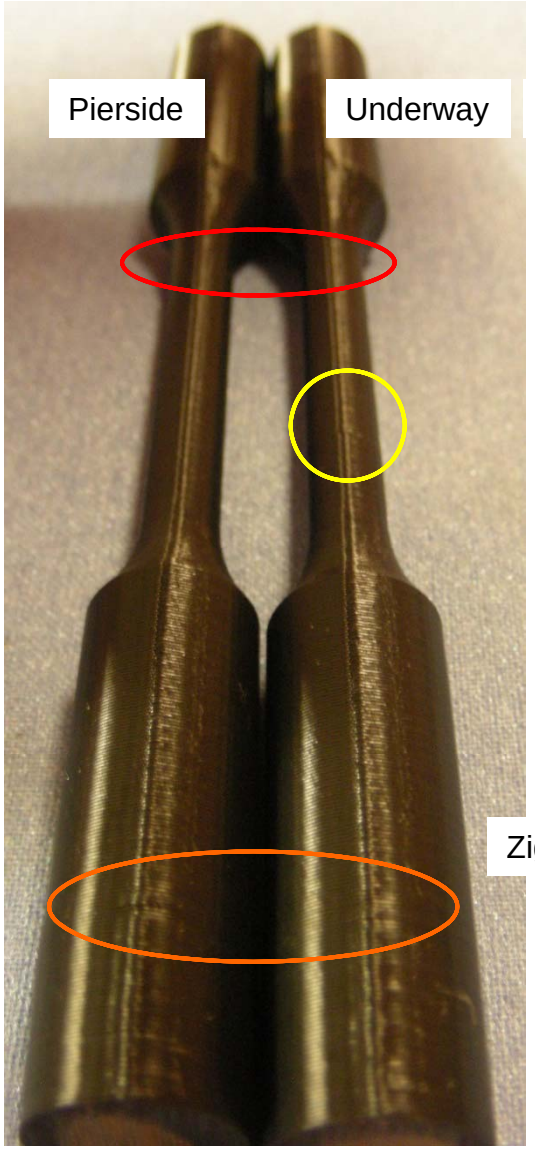
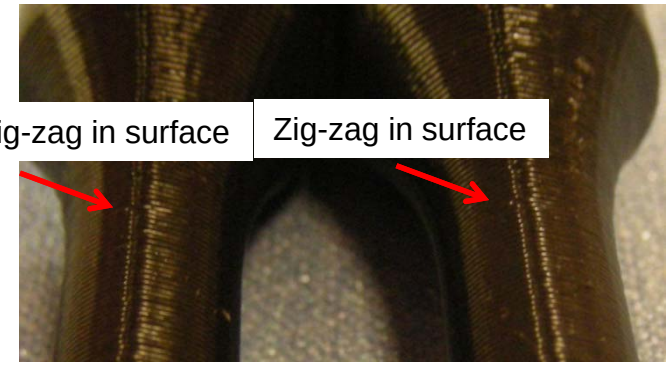
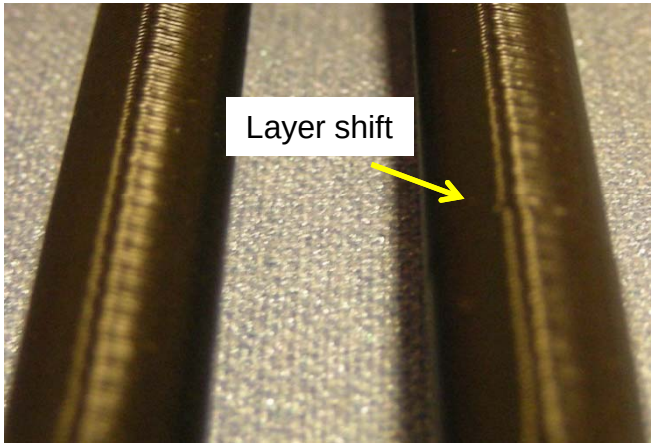
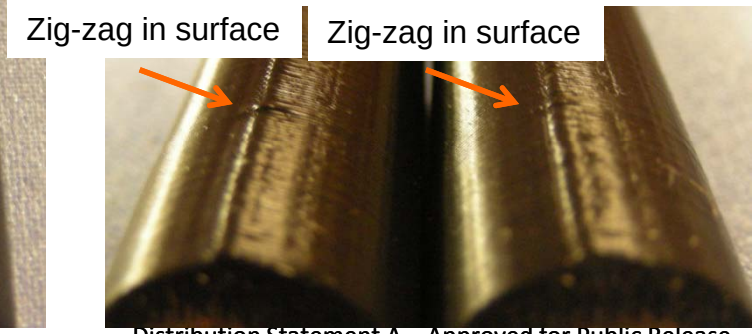
Underway and Pierside Specimen Comparison









Round tensile specimens, one printed pierside and one printed while underway, are compared. While there are multiple locations with surface indications, the majority are identical in location, size, and shape between both specimens indicating continuity in the printing process.

The underway specimen, which saw larger motions than at pierside, shows a shifted deposition layer along the x-y plane. After shifting, the build continued unhindered.

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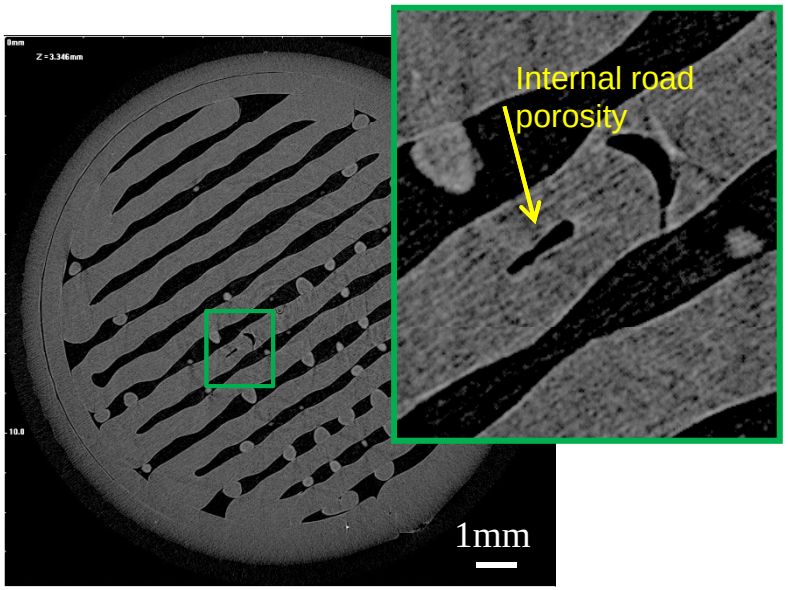
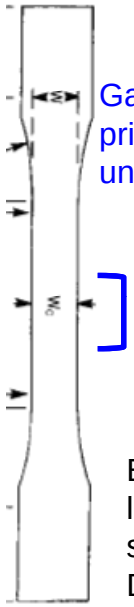
Big Questions For AM:
Variation on WHERE it is Printed

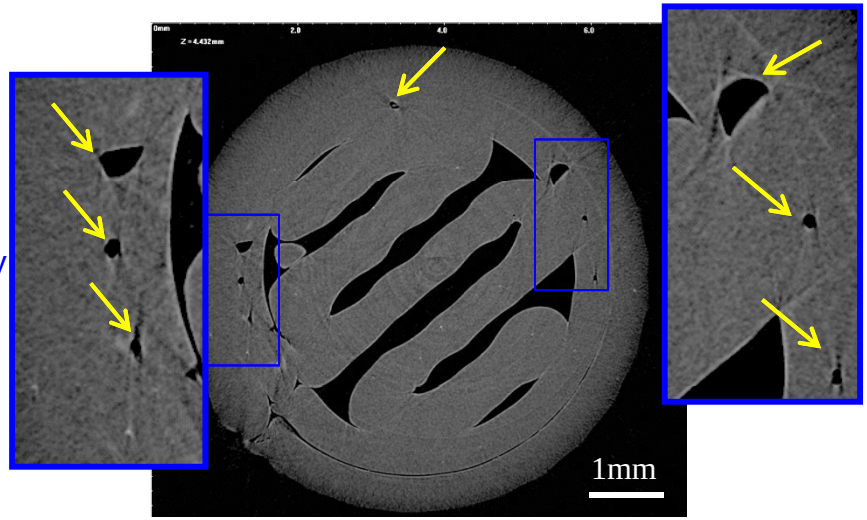
Pierside Tomography Specimen





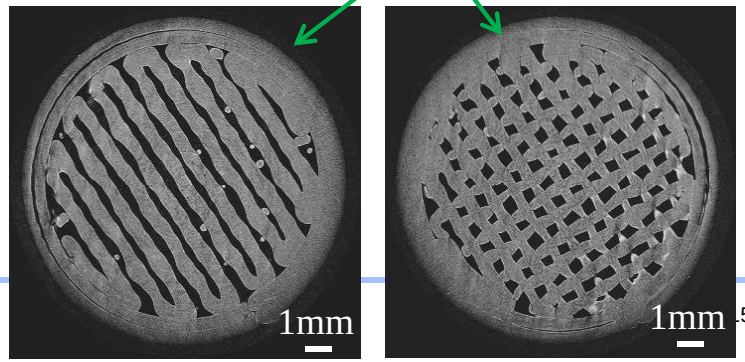
Gage: printed underway

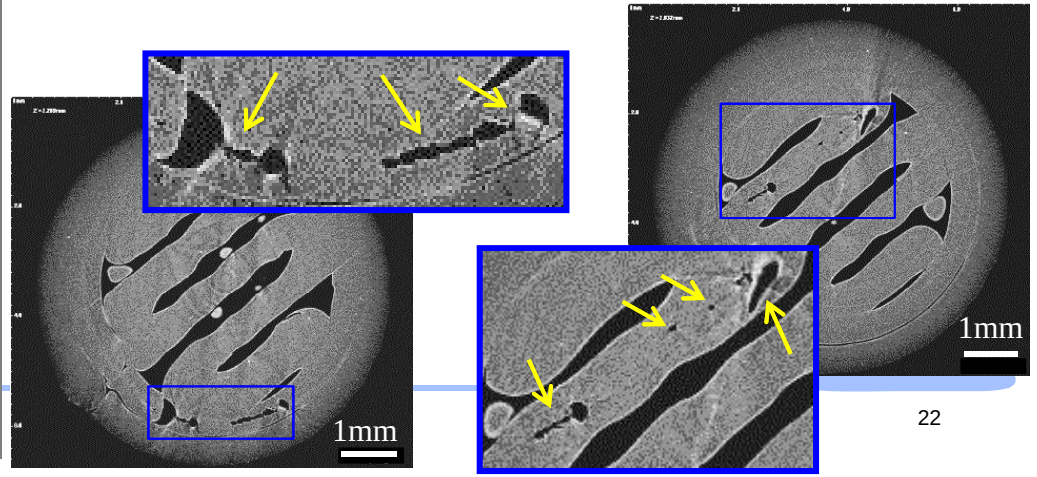
Gage: printed underway



Examples of the internal road porosity are shown. Voids are often locally grouped. When multiple porosity groups occur within the same layer, they generally occur along the same printer path. Defects are observed at both core and interior sections locations.

The majority of the observed section of the pierside specimen did not exhibit internal road porosity.





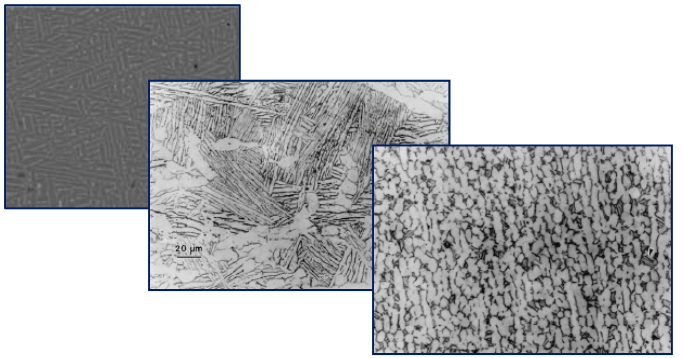
Big Questions For AM

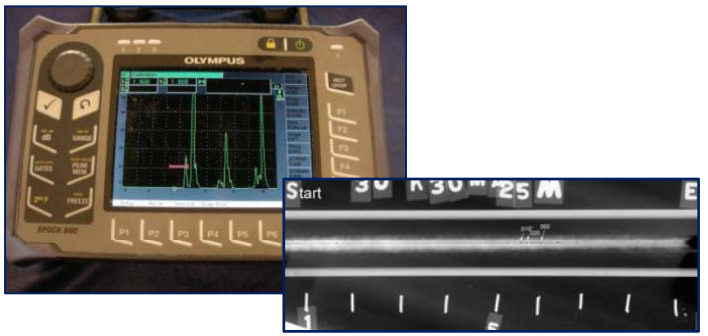
<u>Material and part characterization</u>

- How do we control the manufacturing process?
- How does the manufacturing process impact the microstructure?
- How do the mechanical properties compare to handbook values?
- How do AM parts respond to post-processing (welding, peening, heat treatment, etc.)?
- What level of distortion is seen?

<u>Non-destructive evaluation</u>

- What are the common defects and how do we identify them?
- What NDT processes are appropriate?
- What are the acceptance and rejection criteria?





Questions?

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