Additive Manufacturing
Opportunities within DoD Maintenance

Moderator
CAPT Frank Futcher
Director, Navy Business Operations Office, Navy Staff, OPNAV N415
Mr. Chris Root
Lead for Advanced Aircraft Technologies and Office of Research and Technology Applications (ORTA), NAVAIR In Service Support Center, Fleet Readiness Center Southwest

Mr. Tom Naguy
Division Chief, Life Cycle Management Division, Directorate of Logistics, Headquarters Air Force Material Command, Wright Patterson AFB

Ms. Stacey Clark Kerwien
Deputy Division Chief, Materials, Manufacturing and Prototype Technology, US Army Armament Research, Development and Engineering Center (ARDEC)
Examples of Navy Involvement in AM

Additive Manufacturing in the Navy

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**NUWC Keyport**
- Sand casting molds
- Rapid prototyping
- Metal repair
- End use parts

**NSWC Carderock**
- Ship models
- Seakeeping prototypes
- Working prototypes

**NAVAIR FRC East**
- Rapid prototyping
- Rapid tooling

**NAVAIR FRC SouthEast**
- Rapid prototyping
- Rapid tooling

**NAVAIR FRC Southwest**
- Custom parts
- Rapid tooling

**NAVAIR FRC SouthEast**
- Rapid prototyping

Naval Research Lab
- Micro-fabrication of electronic components
- Sensor/build integration
- New material research
- Microwave sintering
- In-situ characterization

Office of Naval Research
- STEM outreach
- Research programs

Walter Reed National Medical Center
- Custom medical tooling
- Prosthetic
- Cranial implants
- Surgical guides

Approved for public release, distribution is unlimited.
Case Study: Casting Cores
Cost & Time Savings: $4k & 4 weeks

Problem/Challenge:
– Providing low quantity castings for fleet needs

Solutions/Results:
– System for printing sand casting molds and cores – skips cost and lead time associated with making a pattern to pack sand around

Benefit/Impact:
Costs – Slight cost decrease  
Time – Substantially reduces lead time  
Weapon System – Any system that uses castings

Contacts/Learn More About It:
Kyle Morris  NUWC-Keyport  360-396-1939
RARE Parts Program
Case Study Part ___Vacuum Rotor_______
Weapon System___Submarines__________
Cost & Time Savings _$20k & 30 weeks_____
Fleet Readiness Center AM Capabilities

- Selective Laser Sintering (SLS)
- Fused Deposition Modeling (FDM)
- Stereo Lithography Apparatus (SLA)
Rapid Prototyping and Testing

Custom Engineering Investigation Test Apparatus Parts.

- Form and fit check
- High impact to mission readiness – quick response
- Machining / manufacturing guide
- Turn-around time after CAD modeling: 1-2 days
Trim Tools and Drill Templates

• Types
  – Scribe Tool
    • Edge of tool is net
    • Scribe is used to transfer EOP
  – Off Set Tool
    • Tool edge is inset
    • Provides guide surface for cutting tool
    • Prevents inadvertent removal
  – Drill templates
    • Precision location

• When to use FDM
  – Complex shapes
  – Ergonomic light weight
  – More stable than fiberglass in high humidity environments
Sheet Metal Press Form Tooling

- **Demonstrated Applications**
  - Hydro forming
  - Rubber pad forming

- **Demonstrated Tooling**
  - Male & female, blow down tools
  - Pressure Intensifiers
  - Matched male & female tools
  - Backfilled tools

- **Demonstrated Conditions**
  - Range of alloys and thickness tested
  - Demonstrated forming pressures up to 10KSI
  - Variety of tools >100 cycles, some >500 cycles
  - Large jointed tools have been tested

- **Tooling Example**
  - $200 material, 8-hour build
Rapid Composite Tooling

- 3D model generated from laser scan of actual component.

- Tool printed with polyphenylsulfone (PPSF), covered with a layer of paste adhesive to fill in inconsistencies and wrapped with Teflon tape (for a sealed releasable surface).

- Part removal from tool was relatively easy.
  - Tool was intact, not damaged, and could be re-used.

- Hat inner surface was smooth from Teflon tape and part surface.
AV-8B Hard Landing and Repair

LANDING APPROACH

3D SOLID CAD MODELING AND AM MADE THE ONE WEEK TURN AROUND POSSIBLE.
The Navy sponsored technical group promotes the accelerated introduction of additive manufacturing into Navy weapon systems in order to reduce total ownership cost, enhance operational availability, and promote rapid response to the warfighter.

**AM Technical Objective:**
- Identify opportunities for AM that will enhance operational fleet readiness, reduce energy consumption, and enable parts on demand manufacturing by defining the Warfighter Payoff and enhanced naval capabilities.
- Facilitate the exchange of expertise in additive manufacturing to promote collaboration and leveraging of Navy resources by identifying existing AM Naval applications and organizational capabilities. The current state of the technology will be assessed through technology cost-benefit analysis and case studies.
- Identify AM science and technology challenges, and define the approaches needed to address these challenges. Results will be used to develop a Navy roadmap and S&T investment strategy designed to accelerate the introduction of innovative, high impact AM technology into Navy weapon systems.

**Current Focus Areas**
Delivering a Naval AM Roadmap that
- Design Innovations
- Rapid Response and Fielding to Warfighter through AM
- Advanced Materials
- Qualification and Certification of Technology and Materials
- Life Cycle Sustainment

**Future Focus**
- Navy foundation will build a collaborative program to advance the science and use of additive manufacturing for Navy applications
- Generate an official COI Charter

**Benefit to the Warfighter**
- Reduced Total Ownership Costs
- Reduced parts cost (approx 45-55%)
- Infrastructure, time, labor savings (89% time)
- Conservation of strategic material (>86% savings)
NAVAIR AM ROADMAP Overview

**Goals**

**NAVAIR Transformative Goals**

1. Execute change necessary to rapidly leverage additive manufacturing for delivery of warfighter capability.
2. Manufacture and qualify a flight critical, non-proprietary component at an FRC with minimal “touch” labor using additive manufacturing.
3. Manufacture explosive train using additive manufacturing.

**Tactical Focus Areas**

1. **#1 - Field AM Parts**
2. **#2 – Demonstrate Rapid Qualification/Certification**
3. **# 3 – Utilize “Digital Thread” across NAE**
4. **# 4 – Update Business and Acquisition Processes**

**Projects**

- ALRE Release Element
- LEX Fitting
- Bathtub Repair
- CH-53K Gearbox
- Spike Canard
- EMAM
- Digital Thread
- Cost Model*
- Supply Integration*

*Still in work
NAVAIR Additive Manufacturing Tactical Focus Areas

#1 - Field AM Parts

**Initiative #1 Projects**
- Casting Replacements
- Structural Repair/Replacement
- ALRE/SE Components
- AM Tooling Process Standard
- Weapons and Energetics
- Complex Engine Components
- Industry/DoD/Other

**Candidate Parts**

#2 – Demonstrate Rapid Qualification/Certification

**Initiative #2 Projects**
- Material and Process Qualification
- Structural Analysis and Structural Certification
- Non-Destructive Inspection Methods
- Innovative Process Models
- Industry/DoD/Other

[Diagram showing candidate parts and initiatives]
Initiative #3 Projects

- 3D/Model Based Environment
- 3D Modeling and AM Digital Environment
- AM Data Architecture/Standards
- AM Build Package Development

Industry/DoD/Other

# 3 – Utilize “Digital Thread” across NAE

# 4 – Update Business and Acquisition Processes

Initiative #4 Projects

- NAVSUP and DLA Supply Chain
- Cost Modeling and ROI

Industry/DoD/Other
Closing Comments

• DoD Maintenance faces unique challenges
  • Aging infrastructure, Obsolescence issues, Service Life Extensions, Accelerated OPTEMPO
  • Mandate to reduce Total Operating Costs of existing platforms while at the same time introducing new platforms

• New technologies (AM and others) will:
  • Improve maintenance processes & procedures
  • Positively impact availability, reliability, & maintainability

• Expanded AM build volumes, lower cost materials and faster through-put needed for expanded use in the manufacture of large air vehicle parts
  • BAAM (ORNL)
  • Sheet metal tooling applications
  • Composite tooling applications

• Efforts today prepares DoD Sustainment Community for a future of weapon systems built with increasing AM technology

• Encourage collaboration within DoD services and with academia & industry to move sustainment technologies forward
  • Increased exposure to new technologies in the DoD workforce creates new innovative opportunities and ideas

• AM, 3D digital data, PLM enterprise software and connectivity will increase collaboration across FRC’s, competencies and disciplines
Additive Manufacturing Defined

• Additive Manufacturing (AM)
  - cost savings / reduction of depot costs
  - readiness improvements

AM - Processes in which successive layers of materials are laid down under computer control...

AM enables new design in which geometric complexity is not a constraint and material can be located by choice

- Directed Energy Deposition
- Powder Bed Fusion
- Materials Extrusion
- Materials Jetting
- Binder Jetting
- Sheet Lamination
Expanded Component Geometries

Current Issues:
• Long Tooling Lead Times
• Low Production Volumes
• Material Substitution Re-certification

Potential for
• Part Consolidation
• Lead-Time Improvements
• Performance Benefits

Component Repair

Current Issues:
• Current components NOT designed FOR repair
• Unvalidated repair processes and inspection requirements

Potential for
• Repair-able components
• Reduced Sustainment Burden

Unintended Spares and Obsolescence

Current Issues:
• Improved Lead Times
• Reduced Cost

Potential for
• Material Substitution

Multiple component families geometries are constrained by conventional manufacturing capabilities, including ducting, fuel nozzles, heat exchangers and turbine airfoils
Air Force AM Implementation Strategy

Immediate Value

- Tools, fixtures, prototypes, non-critical parts
- Hybrid tooling/ fixtures integrated with metal subcomponents
- Rapid prototyping for form, fit, and function

Mid - Long Term Outlook

- Manufacture of metal fixtures, masks, and jigs for repair process
- Manufacture of DMSMS components
- Manufacture of non-rotating and structural aircraft components

Game-Changers

- Effective dimensional metallic restoration of propulsion items
- Better microstructural control
- Manufacture of parts On-Demand
- Near Net Form Castings & Extrusions
Why AM Implementation Is a Challenge

- Considerations for Implementation of AM
  - Demonstrated Process Controls
  - Nondestructive Evaluation & Quality Assurance
  - Post-Deposit Processing & Residual Stress Management
  - Statistically-Based Mechanical Property Database

- Constrains
  - Lack of property databases, inadequate design tools
  - Lack of constrained process controls
  - Continually-changing, local processing environment with changes in geometry and process parameters
  - Post-deposit distortion and residual stress
  - Undefined post-processing requirements
  - State of maturity for successful transition
    - Stabilized material and/or material process
    - Producibility
    - Characterized mechanical properties
    - Predictability of structural performance
    - Supportability

- Qualification Process
  - Airworthiness (AW) approach across Enterprise for deploying New or Substitute Materials, Processes, and Product
Purpose

✓ Formal process for Materials & Processes (M&P) changes is needed for aircraft applications

AW: Why to use it

✓ Many new M&P changes are cross-cutting and present unique challenges that must be characterized for the intended service environment, usage, and duration

✓ Approval or disapproval should be documented by the appropriate authority, recognized by all AFMC and DLA personnel as a minimum, and implemented in each application

AW: Benefits

✓ Ensure M&P changes are fully qualified prior to implementation

✓ Encourage implementation of M&P changes when business case is favorable

Implementation through Airworthiness Approach
AM Qualification Process

AM Technology (materials/process/product form) has been properly evaluated

5 primary factors entrance criteria are met:
• Stability
• Producibility
• Characterized Mechanical & Physical Properties
• Predictability of Performance
• Supportability

AW Process for Deploying New or Substitute Materials, Processes, and Product Forms

A • Preliminary Evaluation
   • Define enterprise new/substitute materials, processes, and product forms
   • Identify applicable weapon systems

B • Airworthiness Plan and Certification Basis Development
   • Identify AW and Qualification Plan (existing and additional testing)

C • Business Case Development/Endorsement
   • Endorsement by Key Senior Stakeholder(s)

D • Compliance Review
   • Determine Certification Compliance

E • Implementation
   • SPM submits Implementation Plan

Technology Deployment
Additive Manufacturing for DoD Maintenance Activities

November 19, 2014

Stacey Clark Kerwien
Deputy Division Chief, Materials, Manufacturing & Prototype Technology
US Army RDECOM-ARDEC
Additive manufacturing technologies bring the promise of enhanced performance with the flexibility of manufacture at the point-of-use.

While this technology is powerful, there are also important considerations and limitations:

– Each part is unique, therefore certification/qualification of the material and process are paramount
  • Because industry views AM process data as proprietary, the product data needed to guarantee part performance is not available and is closely held as IP
– There are very limited published standards and much of the work is still in progress
– There are a limited number of machines, additive processes and materials available from the equipment manufacturers
– Material performance is not “as advertised” on the OEM data sheets and not fully characterized for all use cases
– No full materiel released – no systems in the field using additive parts

To ensure that Additive Manufacturing delivers on the promise, it is important to manage expectations and develop the proper foundation necessary to ensure reproducibility of AM components.
• What are the Goals for using AM in maintenance activities?

• What are the Challenges?

• What are we doing / What do we need to get there?
• The goal is to make Additive Manufacturing as accessible to use as machining, welding, etc.

• Develop standards that are substantive

• Use digital product data!!

• Populate materials databases with AM materials and processes

• Manage expectations regarding the use of AM.
Agenda

• What are the Goals for using AM in maintenance activities?

• What are the Challenges?

• What are we doing / What do we need to get there?
Summary of Major Technology Challenges

- **Each part is unique, therefore certification/qualification of the material and process are paramount**
  - Part quality is tied closely to process parameters, therefore processing conditions must be defined to ensure a quality part
  - Because industry views AM process data as proprietary, the process data needed to guarantee part performance is not available and is held as IP

- **AM standards are not available – much of work is still in progress**
  - The relationships between materials, process and performance have not been established, so standards development is slow
  - In specific cases, companies have established their own standards, which they retain as proprietary

- **There are a limited number of machines, additive processes and materials available from the equipment manufacturers**
  - Material performance is not always “as advertised” on the equipment mfr. Data sheets and not fully characterized for all use cases

- **No full materiel release – no systems in the field using additive parts**
  - The few cases where additive has been used to produce a part are on an exception basis: SOCOM, REF for spares, repairs and/or tooling

The goal is to make Additive Manufacturing as “available” as traditional manufacturing techniques.
• Additive Manufacturing, like all manufacturing requires CAD model data to make a part
  – Traditional processes require models, but these are often generated as part of the manufacturing process – standards are in-place to assure part quality
  – Additive manufacturing requires a 3-D model and is highly dependent on process data to make a quality part, so both geometry data (CAD) and machine process data are essential

• The Army does not regard digital models as “official data” and does not typically store or provide 3-D part data or process information in its product data libraries
  – The official data record is .pdf, models are for reference only
  – Process data is almost never stored, as companies view it as proprietary
  – Companies typically re-master product data by creating 3-D data from government provided .pdf’s and developing company specific CAM data – part quality comes through final inspection and the use of standards through the manufacturing process

Until Standards and Machine Technology Mature, the Army must store both product and process data for AM – to inform standards and make quality parts.
Agenda

- What are the Goals for using AM in maintenance activities?
- What are the Challenges?
- What are we doing / What do we need to get there?
How are we “getting there” currently: one NSN at a time…until we address the issues of qualification and certification

An Army investment strategy is based upon looking at the common needs between Army systems and value proposition to customers – an analysis of alternative and customer input to maximize transition potential and minimize the current “part-by-part” demonstrations

With ~186,000+ items (managed by DLA) in Army inventory, the goal is to demonstrate the use of AM for 1% of them within 5 years

– Need to assess good candidates for AM (long lead time items, items that need to be forged or cast, items made with expensive materials, complex geometries
Concept

- Establish a data repository where additive process are recognized as known alternative methods for manufacture of parts
  - REF Parts Library, DLA
- Build data repository using processes consistent with government product data storage methods
  - JDMTP Effort to store information in MSAT
- Make part information (geometry) and process (manufacturing) data available so parts can be made using known additive processes
  - Army AM Community of Practice to perform Round Robin builds
- Establish business rules for using product data information to make acceptable parts
  - Army ManTech Program
- Provide guidance to buyers and manufacturers on parts that can be made using additive processes
Notional Architecture

- COTS Parts Definitions
- Digital Product Definition
- Library of Components, Product CM
- Custom Web Portal
- Process Definition Accessible Via Net
- Product Structure Per Component
- WindChill10.1, Forward Facing on the DREN
- Final Product Produced in Field

Digital Product Definition
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Additive for Rapid Fielding and Spare Parts:

- Additive manufacturing can provide point-of-use manufacturing for non-critical parts
- Supporting REF and CASCOM to establish library of parts “Digital Catalogue” of Additive Manufactured Parts for field sustainment
- Reduces logistics burden and lead-time for spare parts
- Capability envisioned: additive processes in field forward environment supported by digital parts library

**Cost to implement:** Working with REF/CASCOM on scope and resources to implement

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**Mini Track Bot**

Designed as an ultra portable bot for camera surveillance in any terrain. Operated by a small touch screen controller with adequate range for the soldier to standoff at a safe distance.

- **Weight:** 2 pounds
- **Dimensions:** 8” x 7” x 5”
- **Status:** Approved for printing
• Additive Manufacturing is an enabling technology that has the potential to provide a step function increase in cost reduction and functionality

• Additive Manufacturing directly aligns with the Army’s goals to support of novel designs, rapid fielding, prototyping and reducing sustainment costs

• Army must develop and resource an enterprise-wide Additive Manufacturing strategy to ensure Army systems can take advantage of this technology
Thank you