The Advanced Manufacturing Revolution

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Space and Naval Warfare Systems Center Pacific
Overview

• Introduction
• AM in the Spotlight
• JAMR
• EXMAN
Midwest Tough
Information Dominance through research, development, delivery, and support of integrated C4ISR, cyber, and space systems across all warfighting domains

Source: Generic Command Overview 25JAN16
AM in the International Spotlight

Increased public awareness
“Print Me a Stradivarius”, The Economist, Feb. 2011

3D Printed Gun (confiscated)
University of Texas Law Student

Source: MakerBot® Replicator® 3D Printers

Source: Science Museum UK

Source: The Economist
Feb 12-18, 2011

Source: americamakes.us

National and International Focus | Presidential Initiative
America Makes mentioned in State of the Union 2012
AM: A Perfect Storm

• Revolutions in Production Technology
  – Material Science:
    • Alloys, cements, composites, nano, macro
  – Digital Design and supply chain
    • 3D Multi-media digital workflow
  – Remote and embedded sensing
    • High fidelity, low cost, networked
  – Manufacturing Tools and Techniques
    • Additive
    • Advanced Subtractive
    • Batch
    • Hybrid

• A Convergence of IT and OT
  – Information Technology
    • On-demand computing:
    • Cloud – Apps – Big Data – Analytics
  – Control Technology
    • Industrial Control Systems, SCADA

Outcome: What can be made today, could never be made before ... and we are at the beginning of this megatrend
Advanced Manufacturing
Diversified Portfolio

Mechanical

AM Technology Development
Advanced Manufacturing Applications
3D Structural Electronics

Electrical

Engineered & Structured Materials

Materials
AM Technology
ASTM F42 Categories

• Vat Photopolymerization
  – Process in which liquid photopolymer in a vat is selectively cured by light-activated polymerization

• Material Extrusion
  – Process in which thermoplastic is selectively dispensed through a nozzle

• Powder Bed Fusion
  – Process in which thermal energy selectively fuses regions of a powder bed

• Material Jetting
  – Process in which inkjet droplets of build material are selectively deposited and UV cured

• Binder Jetting
  – Process in which a bonding agent is selectively deposited (ceramics, metals, sand)

• Sheet Lamination
  – Process in which sheets of material are bonded to form an object and subtractively removed

• Directed Energy Deposition
  – Process in which focused thermal energy is used to fuse materials by melting as deposited

Source: Keck Center for 3D Innovation | University of Texas at El Paso
Importance of AM

• AM presents a previously unobtainable design space
  – Enables new ‘material – geometric – functional’ combinations that were previously un-manufacturable

Source: Ashby M F, Cebon D, Materials selection in mechanical design, Le Journal de Physique IV 3, C7 (1993)
Composites

- Fiber Reinforced Composites
  - Advantages
    - High stiffness/density
    - High strength/density
  - Limitations
    - Dynamic response

- Periodic Composites
  - *Extraordinary dynamic behavior*
    - Band-gap
    - Negative effective properties
    - Negative energy refraction
  - Previous limitations
    - Manufacturability
Periodic Composites

ABS Gradient Bending Resonator design for SONAR stealth in 0.5 – 5 kHz range for submarine coating.
(Source: Prof Amirkhizi of University of Massachusetts at Lowell)

3D phononic crystal composed of steel and epoxy for large all-angle stopband.
(Source: Prof Srivastava of Illinois Institute of Technology)

Out of the Box

Polymers/Elastomers
- Polyester Foam
- Polyurea
- PMMA

Metals/Alloys
- Lead
- Steel
- Magnesium
- Aluminum

Structural Composites
- CFS
- CFRP
- GFRP

In-plane Stiffness/Density ($m^2/s^2$)

Attenuation per unit length (dB/m)

$10^{-4}$ $10^{-2}$ $1$ $10^2$ $10^4$ $10^6$ $10^7$
National Security Linkages

- Mobilization
  - Defense Industrial Base Surge Capacity

- Defend the Homeland
  - Critical Infrastructure Protection

- Cybersecurity Readiness
  - Industrial Control Systems
  - Cyber-Physical Outcomes

- Innovation
  - Automation, Efficiency, Effectiveness
• Develop an integrated and detailed implementation plan that will achieve the following:
  – Increase development and integration of additive manufacturing systems
  – Develop the ability to qualify and certify AM parts
  – Standardize the digital AM framework and tools and enable end to end process integration
  – Establish DON advanced integrated digital manufacturing grid
  – Formalize access to AM education, training, and certifications for the DON workforce

Advanced Manufacturing is the Cornerstone of both Economic Security & Naval Modernization
Importance of AM

- Augments and extends existing manufacturing processes
  - Better, faster, cheaper in some cases

Dorsey Rust Buster
“Rust Never Sleeps and Neither Do I”
<table>
<thead>
<tr>
<th><strong>Public</strong></th>
<th><strong>Private</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Develop</strong></td>
<td><strong>Understand</strong></td>
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<tr>
<td>- Design Considerations for notional Smart Manufacturing Grid</td>
<td>- Emerging technical trends, threat drivers, fiscal environment and perceived needs of DoD</td>
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<td><strong>Define</strong></td>
<td><strong>Influence</strong></td>
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<tr>
<td>- Security, Safety, Privacy and IP “needs” for Digital Thread</td>
<td>- Standards, specifications, implementation patterns and secure, strategic architecture to improve Infrastructure resilience</td>
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<td><strong>Collaborate</strong></td>
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<td>- Across Agencies, Commands and Manufacturing Communities of Practice</td>
<td>- By sector, value-chain, PPP, region or discipline</td>
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<td><strong>Expand</strong></td>
<td><strong>Respond</strong></td>
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<td>- Reduce the barrier to entry for non-traditional suppliers to DoD</td>
<td>- Provide profitable, executable, proposals to solicitations coming from DoD / Public sector</td>
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<td><strong>Advise</strong></td>
<td><strong>Grow</strong></td>
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<td>- Naval and DOD leadership on findings and recommendations</td>
<td>- Get a piece of the expanding industrial pie</td>
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<td>- Take advantage of the reshoring phenomenon</td>
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**Critical Manufacturing Independence by 2025**

**Advanced Manufacturing Cluster by 2020**
### Smart Manufacturing Grid

**Digital Manufacturing Network**
- Information Technology
- Operational Technology
- Cyber-Physical Systems

**Distributed Manufacturing Topology**
- Node Location
- Physical Logistics
- Capacity / Mix Optimization

**On-Demand Value Chain Management**
- eProcurement
- eCommerce
- ERP / SCM / PLM

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*Source: Committee on National Security Systems Instruction (CNSSI) No. 1253*

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*Source: http://www.gsa.gov/portal/category/25574*

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Smart Manufacturing Grid provides the resilient, secure, digital and physical critical infrastructure that will support the "reshoring" of emerging advanced manufacturing capabilities back to the United States.
Smart Manufacturing Scope

Part of the "New Defense Industrial Base"

Smart Manufacturing Protocol Stack

Notional Naval / Joint Grid Nodes

Titanium Alloy Printer: EOS 290

Cyber-Physical Supply Chain

Manufacturing Readiness Levels

Open Standards

Product Lifecycle Management (PLM)

Model Based Engineering Process

Digital Work Instructions

Workforce Collaboration
Economics of Manufacturing are Changing

Most of a product's costs (80 to 90%) are locked in, or committed at the end of the design stage.

A dollar spent on design and development can reduce costs in the later stages of the product's life cycle by $8 - $10 according to Shields and Young.

Adapted from the CAM-I conceptual design p. 140. Original source, Blanchard, Design and Manage to Life Cycle.
Smart Maintenance, Repair & Operations

- Combines advanced control and information technologies with new production tools, methods and materials
- Augments existing manual processes that are reducing the profitability and competitiveness of manufacturers
- Creates a new hybrid supply chain of complimentary digital and physical components
AM as a Process, Product, and Service is Complex and Still Emerging
Continuous experimentation under actual operational conditions is essential
Virtual Secure Manufacturing Cloud

Mobile Manufacturing
- VDI Stations
- 3D-Scanner
- 3D-Printer
- HCI Servers
- VSE Cyber Suite

Industry Manufacturing Partners
- VDI Stations
- Large Scale 3D-Printer
- HCI Servers
- VSE Cyber Suite

Secure Encrypted VPN Core

Joint Manufacturing Operations Center
- Quality Assurance
- Technology Evaluation
- Logistics
- Integration
- Cyber Security
- Process Management and Control

Network / Cyber Monitoring
- VSE Cyber Suite
- HCI Servers
- Central Data Repository
Print to Fleet
UxV

Source: Universitat Politecnica De Catalunya
Out of the Box

Connected World

- Is a popular case study representing broader megatrends
  - Distributed, Digital, Smart Manufacturing
  - Connected World: Industrial Internet of Things

Libelium Smart World

Source: © Libelium Comunicaciones Distribuidas S.L
Thank You

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