Break for Lunch

Workshop will resume at 1300 Eastern time

Additive Manufacturing
A Virtual Workshop

NCMS
NATIONAL CENTER FOR MANUFACTURING SCIENCES

Approaches to Stimulating & Accelerating Adoption

Dr. William Frazier
NAVAIR

Additive Manufacturing
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Body of Knowledge

Matt Donovan
Senior Engineer
Additive Manufacturing/Advanced Technologies
UTC Aerospace Systems

Additive Manufacturing (AM) Body of Knowledge

13 November 2013

Matt Donovan
Senior Engineer
Additive Manufacturing / Advanced Technologies
UTC Aerospace Systems

"Have you heard about 3D Printing?"

AM Capabilities and Technologies

What can we do with Additive, and what key tools and technologies are in use?

- ***Everything!!!****
  - ❖ With some caveats of course

Technologies Focus

- **Directed Energy Deposition**
- **Powder Bed Fusion**
- **Rapid Targeted Additive Repair of High Value/ Long Lead Time Components**

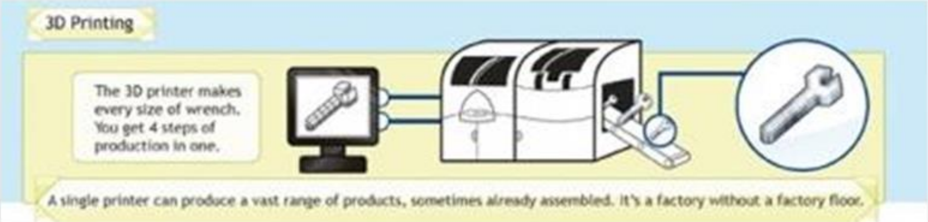
Metal AM- Fabrication of New Parts

- Metal AM processes, such as PBF-L (DMLS®, SLM, EBM) have tremendous potential to lean out supply chain
- DDM of obsolete parts will enable substantial savings for supply chain and sustainability
- Metal AM processes allow more complex, unibody components with no internal joints or welds, yielding substantial savings in time and NDE
- Metal AM enables part replication for cases where legacy supplier is no longer in business
- DDM enables substantially reduced waste and buy-to-fly ratio

Legacy Supply Chain


Start:
Depot Needs Part

Finish: Finally
Receive Part



Source: IndustryWeek Jan 31, 2013

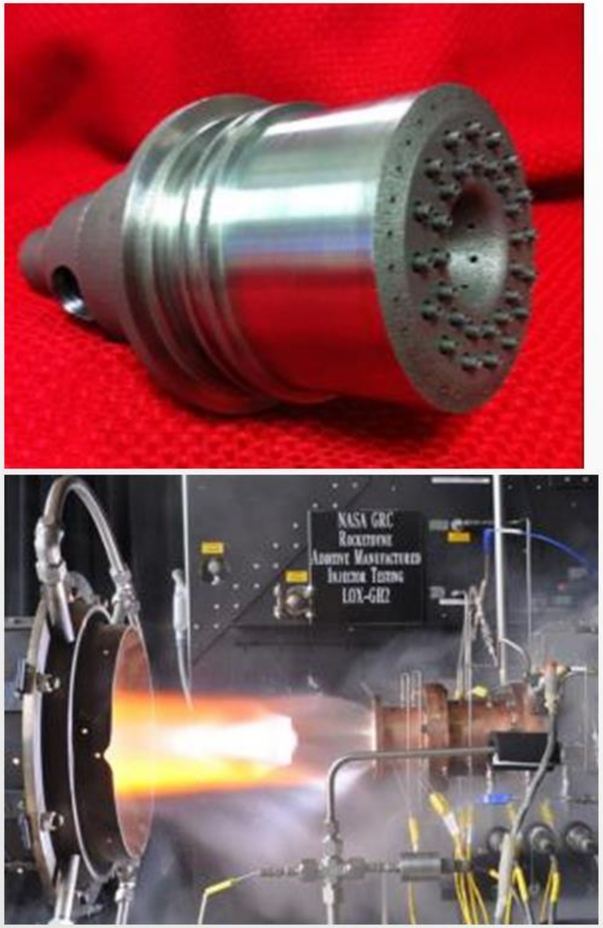
Additive Success Stories- OEM AM Components

Large Titanium structure
using EBDM for JSF

GE LEAP AM Fuel injector

Photo: GE

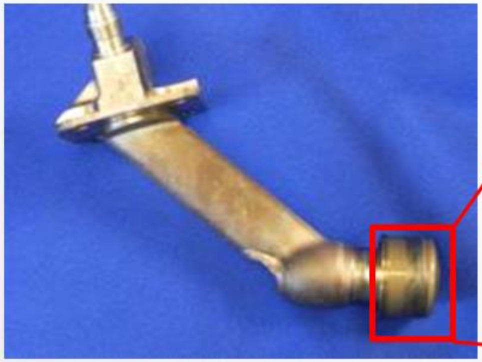
NASA SLM fuel injector for J-2X



Photos: NASA MSFC

Success Story Repair -Laser Additive Deposition - Repair

- Laser Additive Deposition and 3D Laser Scanning enables rapid repairs.
- Worn parts can be scanned and repaired using laser deposition to restore worn features
- Repair can be done in minutes or hours instead of weeks and months
- Raw material usage is substantially reduced
- No need to manufacture replacement parts.



Fuel injector from gas turbine engine with worn air shroud

Worn Air Shroud before Laser Additive Repair

The same shroud after Laser Additive Repair and finish machine

Source: UTC Aerospace Systems © 2013

If this technology is such a magic bullet, why aren't we doing more AM?

One word:

QUALIFICATION

Barriers to Implementation

- No standard process (No fixed process, like castings)
- No readily available design allowables
- Each AM process is unique; each AM machine may be unique
- Material properties vary not just with process/machine, but also build orientation of component

- SO MANY VARIABLES!

- So… How do we get there from here?

Why is a database necessary?

- **Design engineers need material performance data in order to implement AM-enabled designs.**
- **If new designs aren't implemented, benefits won't be realized.**
- **Materials produced are sensitive to the process.**
    - Evident in literature for AM 625
    - A standard way to build and test is necessary
- **Materials produced do not always perform like conventional alloys…or by other similar AM processes.**
- **Testing required for statistically significant data.**
    - >800 Tests for A-Basis Design Allowables

Proposed methodology

- Establish a framework for testing, and crowdsource the data capture
- As individual sites we may have incomplete data, but if we establish a framework and all contribute to it as a cohesive whole, the results could yield much more comprehensive data.
- Goal: A-Basis allowables for widely needed alloys such as Inconels, Titanium, Stainless steels, etc.
- Once framework is in place, and testing/data capture begin, assign a pedigree to data through trusted source (NASA MSAT) and start to build statistical confidence

Example "Gold Standard" Material Characterization Study

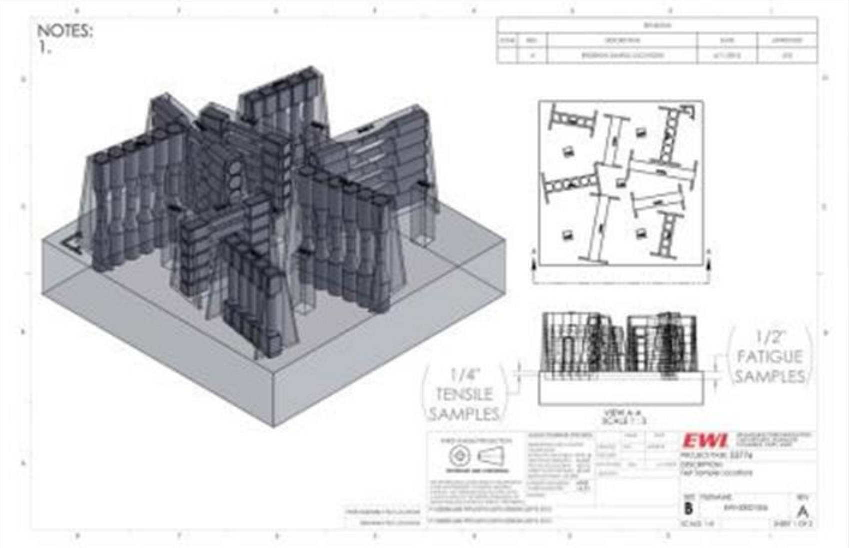
- **Objective:**
  - Generate material property data for DMLS nickel alloy 625 according to a Fixed Process Agreement. Data will feed a dataset that can be used for MMPDS S- and A-Basis design allowable properties.

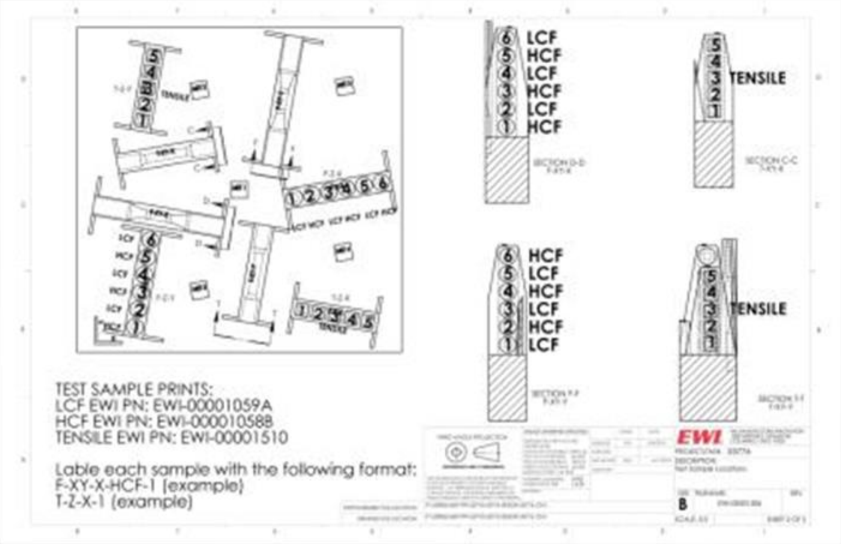
- **Current Participants:**
  - NIST
  - GEA
  - UTC Aerospace Systems
  - Rolls-Royce
  - Open to additional participation…

- **Timeline**
  - September 2012-February 2014*

PBF-L Inconel 625 Case Study

- Use peer reviewed and industry accepted test methodology, by consensus first, eventually by standard
- Determine widely accepted test methodology, build orientation and parameter set
- Develop material properties data with eye toward eventual capability of developing process based material allowables





TEST SAMPLE PRINTS:
LCF EWI PN: EWI-00001059A
HCF EWI PN: EWI-00001058B
TENSILE EWI PN: EWI-00001510

Lable each sample with the following format:
F-XY-X-HCF-1 (example)
T-Z-X-1 (example)

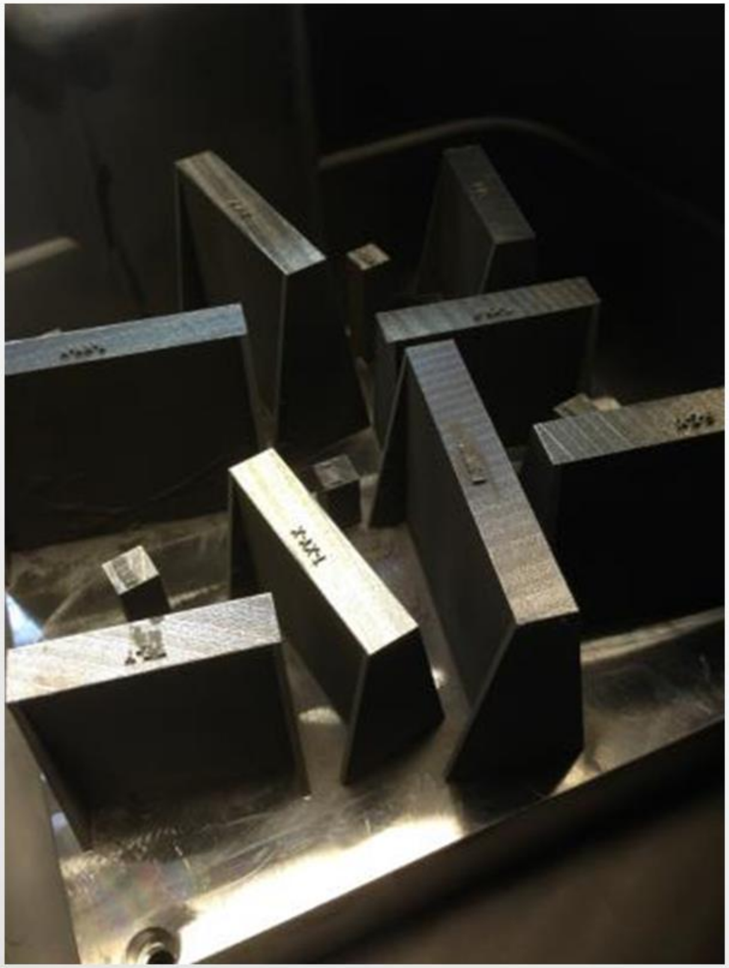
What we are testing

- **EOS DMLS M270 platforms at 200W (future testing M280-400).**
  - Nickel alloy 625 parameter set.
  - Argon and comparative nitrogen environment
  - 4 total builds
- **Full Heat Treatment: SR, HIP, SA***
- **Single blended lot of powder heats, virgin powder.**
- **Coupons are from blocks, not near net shape or individual cylinders.**
- **Machined surface finish.**
- **Properties in two orientations: X-Y and Z.**

Provides a solid foundation for the dataset. Future testing should include effect of thickness, surface finish, recycled powder, other layer thickness, PBF platforms

Status

- Developed a Manufacturing Plan to capture 50+variable in process and control the production of test articles.
- Four 200+ hour builds successfully completed.
- Currently developing heat treatment conditions.
- Affirmative framework from major users of AM to implement and test towards a common standard
- Suggested as a route for implementation for future materials and processes



Participants to date

NIST
National Institute of Standards and Technology
U.S. Department of Commerce

Kevin Jurrens, John Slotwinski, Shawn Moylan

NIST funding through Cooperative Agreement 70NANB12H264 with EWI.

GE Aviation

Dave Abbott
Todd Rockstroh

UTC Aerospace Systems

Matt Donovan
Bob Bianco
Sergey Mironets

Rolls-Royce

Ray Xu

CARPENTER
Powder Products

John Hunter

EWI
We Manufacture Innovation

Additive Manufacturing Consortium

Shawn Kelly
Ian Harris
Ed Hederick

DIRECTED MANUFACTURING

Alex Fima

So Far….

- AM is not the answer to everything
- AM has many challenges, and is showing early stage possibilities

LIKE…

- There are many, many applications right now where AM offers immediate solutions to save time and money, and to sustain the warfighters and maintain operational readiness
- There are current sustainment and budget challenges that can be overcome now through the use of AM

What next….?

- Concerted effort needed to use limited resources intelligently
- Assemble a credible and experienced group of AM users and charge with task of designing the framework for "crowd-sourced" data.
- Assemble this same or different group of AM users to examine data for pedigree compliance.
- Utilize similar group of engineering and technical advisers to work on a streamlined approval process, to establish early "wins" using AM. Use to analyze proposed solutions and be able to leverage body of work already done and approve by similarity.

Questions?

Thank you for your time

**Any further questions,
please feel free to call or email.
matt.donovan@utas.utc.com
515.633.3120**

Additive Manufacturing

A Virtual Workshop

DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

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NATIONAL CENTER FOR MANUFACTURING SCIENCES

Practitioner's Guidance

Robert Kestler

Science & Technology Lead
Fleet Readiness Center East

NAVAL AIR SYSTEMS COMMAND

Practitioner's Guide to Additive Manufacturing

Lessons Learned

13 November 2013

Presented by:

Robert Kestler

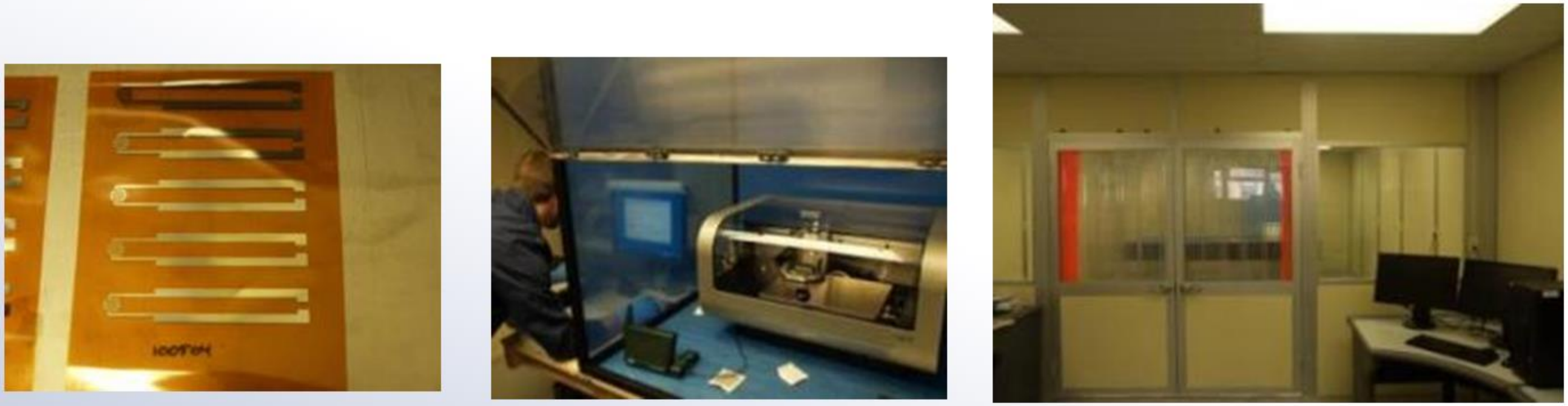
Science & Technology Lead ; AIR-4.0T

Fleet Readiness Center East

NAVAIR

Discussion Points

- Developing a Strategy
- Issues to Consider for Implementation
- Acquisition and Installation of Equipment
- Workforce Development
- Applications
- Operational Considerations



AM Technology Integration

- Adoption based on demonstrated & shared
  - Cost savings; cost avoidance
  - Improved MRO efficiencies
    - Flexible
    - CAD-based solutions
    - Readiness improvements
    - Rapid response capability in event of supply chain deficiency/disruption
    - Capability to replicate, redesign & print obsolete but critical parts
    - Capability to create improved part designs

FRC East Background

- Manufacture low volume, legacy parts no longer in the supply system, or individual aircraft structural repair parts needed to support our aircraft lines or the Fleet
- Significant man-hours to develop tooling
- Need to significantly reduce the tooling development turnaround time
- Increased requirements to manufacture hard to acquire parts

Why Additive Manufacturing?

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

Applications

- Rapid prototyping
- Rapid tooling
- Rapid manufacturing
- Repair
- Electronics

Examples

Rapid prototyping

- Design iterations
- Geometric fit-checks
- Scale models
- Working prototypes


Design comparison

Rapid tooling

- Custom fixtures
- Injection molds
- Sand casts
- Trimming tools


Custom trim tools

Rapid manufacturing

- In-house manufacture
- Printed assemblies
- Legacy part development

Prosthetic foot

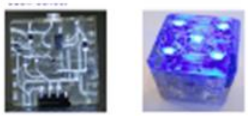
Repair

- Machining errors
- Casting errors
- Worn parts

Over-machining repair

Electronics

- Embedded sensors
- Structural health monitoring
- Printed electronics


Circuits and dice

Courtesy of NAVSEA Warfare Centers Carderock Division

Develop a Strategy

- Understand the benefits of additive manufacturing technologies
- Research potential options
  - Technology magazines
  - Internet
  - Learn about the technologies
- Identify target applications
- Network and ask questions
- Funding considerations
- Socialize the idea(s)

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Communication

- Socialize the information on AM within the organization
  - Meet with everyone from management to artisans
  - Provide information and data on how the AM technology benefits your organization
  - Explain the benefits & issues
    - (always pros & cons)
- Involve all concerned competencies early in the discussion and acquisition phases
- Change management is crucial!!
  - Be sensitive to artisans and management concerns
    - Artisans concerned about change in job status

Acquisition and Installation of Equipment

- Develop a comprehensive budget
  - Based on worst case scenario
  - Consider facility required & desired upgrades
  - Consult with others who have installed the same or similar equipment
- Identify potential funding sources
  - Securing large capital investment funding can take 2-3 years
  - Capitol Improvement Program (CIP)
  - Special funding
  - Funding from Program Offices

Acquisition and Installation of Equipment

- Additional integration costs
  - work cell design/layout
  - environmental impact analysis
  - job safety analysis (JSA)
  - rigging
- Ancillary equipment procurement & installation
  - dissolving station
  - breakout station
  - computer workstation
  - material storage & staging
  - blast media cabinet
  - unique post-fabrication processes
    - (assembly, sealing, bonding, painting, etc.)

Acquisition and Installation of Equipment

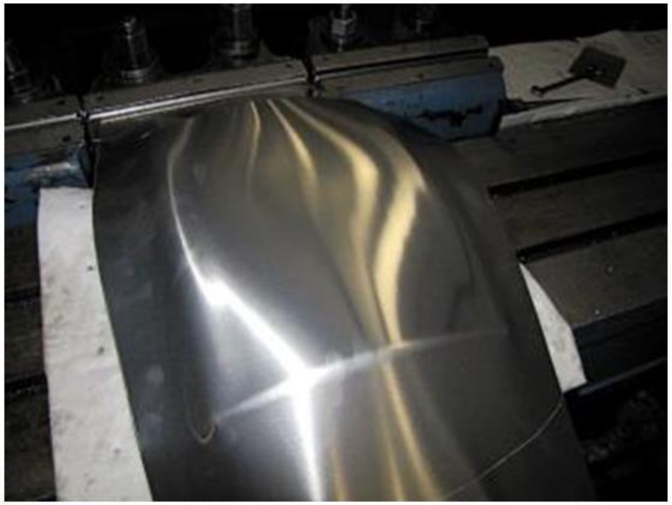
- Facility modifications
  - ventilation may be required
  - electrical / air / plumbing
  - eyewash station
  - sink / rinsing station
- Network & IT considerations
  - Computer(s) for the AM equipment and applications
  - Network considerations (i.e. NMCI)
- Post-fabrication processing
  - Sealing
  - Electroforming
  - Bonding
  - Painting
  - Assembly techniques
- “Turn Key” installation best

Choosing Applications

- Identify target applications for the chosen AM technology
  - Rapid Prototyping
  - Concept models
  - End-use parts
  - Repair
  - Tooling & fixtures
- AM technologies not 100% replacement conventional fabrication processes
  - AM technologies complement existing processes
- Endless possibilities for AM in Maintenance facilities
  - expedite manufacturing processes
  - test & evaluation fixtures
- Consider applications that have complex geometries
- Identify areas that AM technologies can improve efficiencies
- Applications that don’t require certification acceptance are easy ‘targets.’

Operational Considerations

- Consumables
  - Need material in stock
  - Material storage
  - Government purchase card
- Comprehensive Maintenance Contracts
  - Preventative maintenance
  - Reactive/Emergency repair maintenance
  - Technical support
  - Applications engineering support
  - New user training



Operational Considerations

- Workforce Development
  - Continuous learning
    - Not always a pushbutton operation
  - Lofting and pattern making
  - Reverse engineering
  - Design/prototyping engineering expertise
  - Skilled manufacturing processing engineering expertise

Summary

- Have a focused approach
- Network & research AM technologies
- Involve everyone who has a stake in the process
- Manage expectations
- Don’t forget about ancillary requirements
- Workforce development key to implementation and sustainment
- Don’t forget IT requirements

Special Thanks

Contributors:

Justin Reynolds, Mechanical Engineer, Code 4.3.3.5, FRC East

Ken Murphy, Engineering Technician, Code 4.3.3.5, FRC East

Bryce Webber, Mechanical Engineer, Applied Technology, NUWC Keyport

David Price, AMS/RE Lab Lead, Code 4.1.1, FRC Southwest


NAVAIR

AM Benefits

- Rapid manufacture of tooling from engineered approved samples
- Reduction of manufacturing turnaround times
- Reduces need for tooling logistical space
- True JIT (Just In Time) manufacture of tooling
- Supports customization
- Supports LEAN initiatives
- Increases operational efficiency
- Reduces total ownership costs

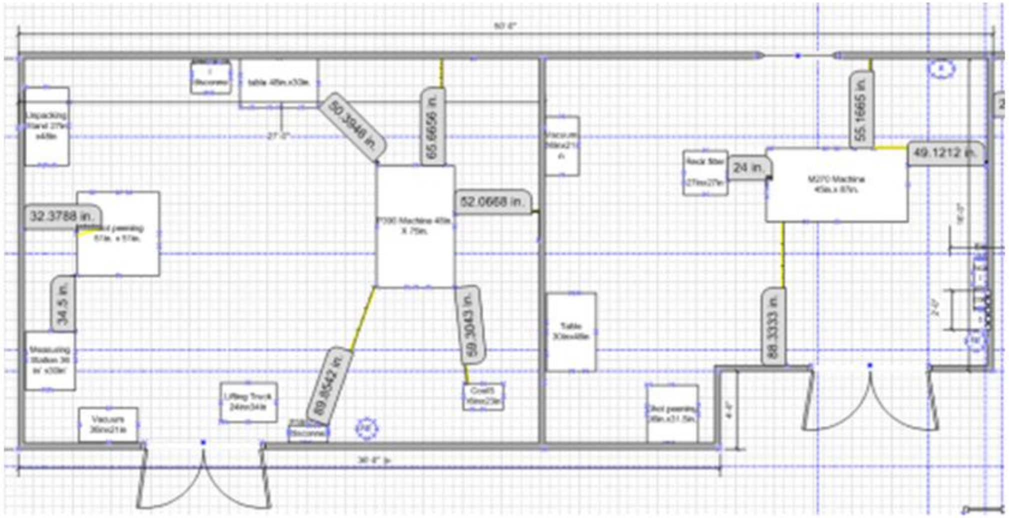
Additional Efforts

- Research/ Prototype funding
  - Purchase of materials for the tooling
  - Artisan time to prototype tooling and develop methodologies and processes
- Computer hardware and software for Production
  - Workstations for the loftsmans/patternmakers
  - Cad software for loftsmans/patternmakers
- Personnel training/development
  - Training on CAD software
- Enhance reverse engineering capabilities & process
- Network Communication between Production and Engineering

ARDEC: DMLS

- This equipment, though technically considered to be OTS has taken 1.5 years to set up.
- A variety of factors:
  - Very few electrical and mechanical contracting firms have dealt with DMLS equipment and the handbooks are inadequate.
  - Ditto the safety and health inspectors who hear the words 'laser' or 'metal powders' and quail with fear.
- Need more realistic safety and health information to combat issues with inspectors.

ARDEC: DMLS



There were several draft plans for the modular room to house the equipment.

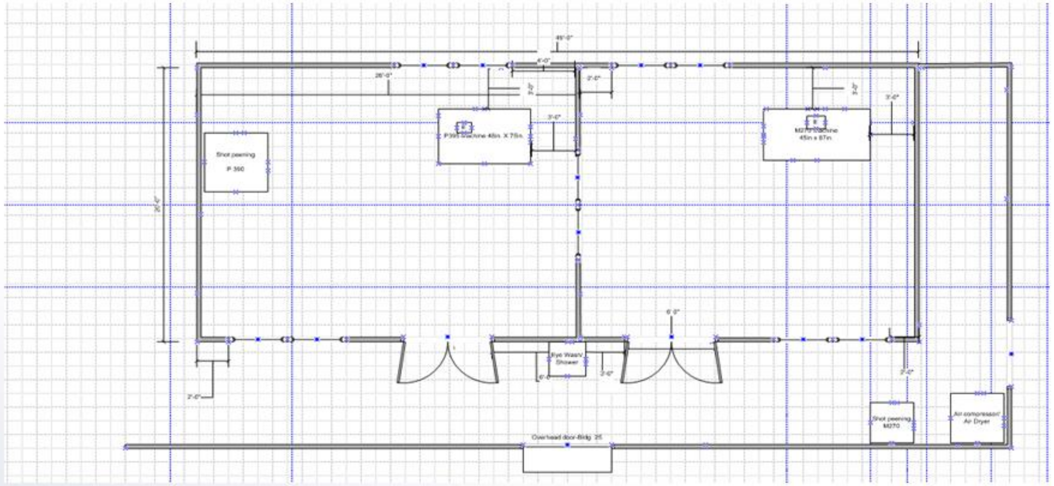
Using the manual, this took several months because we needed to consider several things.

- A. accessory equipment location
- B. main disconnect location

Finally, received the revised layout a year after submitting our initial layout.

Obtaining this information would have saved time and made the process easier.

The final configuration was determined after a visit from an EOS technician in March 2012.



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Materials & Processes – Data Development & Sharing

Wayne Ziegler
U.S. Army Research Lab

US ARMY RDECOM

U.S. Army Research, Development and Engineering Command

Additive Manufacturing Data Infrastructure

Additive Manufacturing in Support of DoD Maintenance

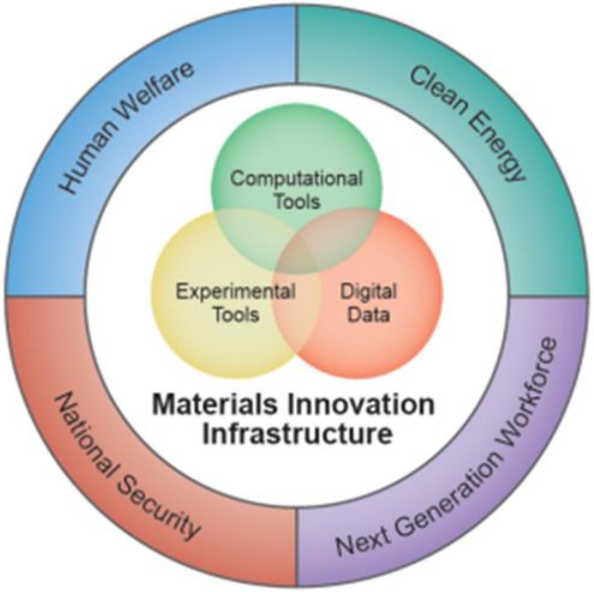
13 November 2013

ARL

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Wayne Ziegler
U.S. Army Research Lab

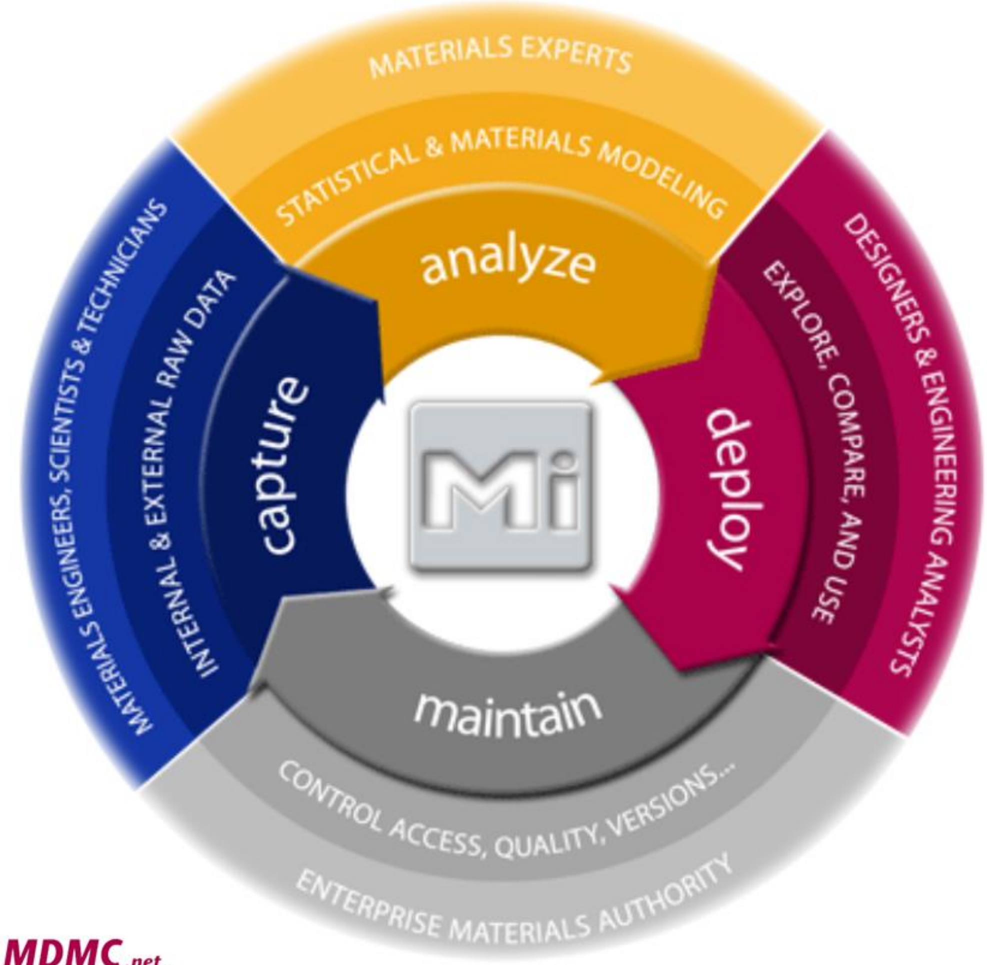
Why have a Material Information System



- To work smarter and faster
- Reduces duplication of testing
- Electronic notebook
- Faster dissemination and retrieval of data
- Stop data loss - Ensures data is available to next generation
- Improved data consistency and quality
- Improved work processes and throughput
- ***Accelerates implementation***

Data management plans are vital to remain relevant

Successful plans use systems engineering approach.

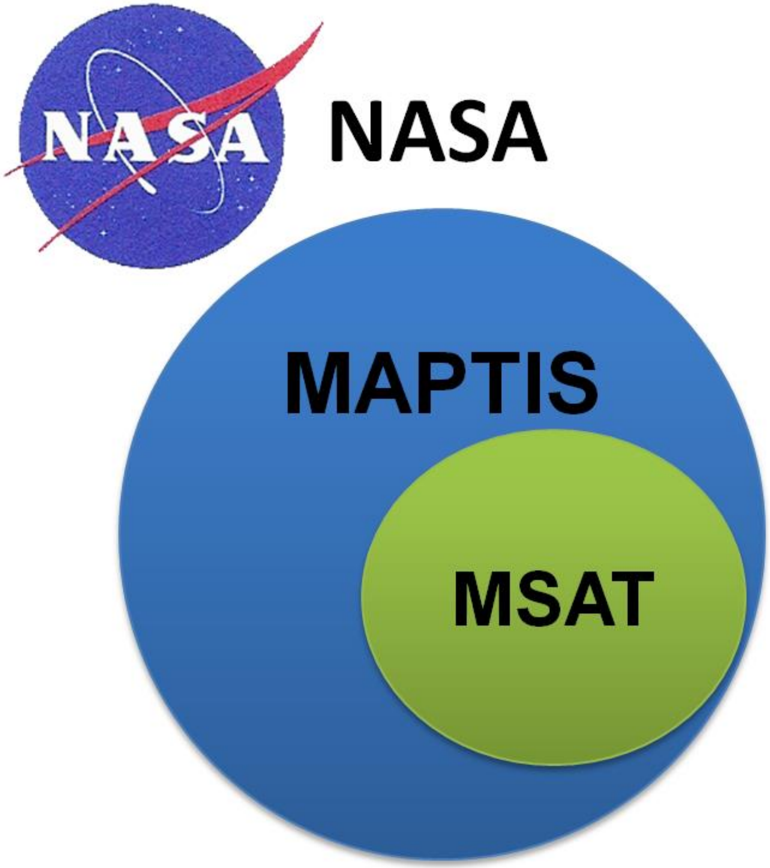


<u>Challenges?</u>

- Lack of unified directive
- Requires investment of resources
- Culture
- Misinformation

<u>Current Strategy:</u>

- Don’t reinvent the wheel-” trick it out” to maximize impact.
- Build a DoD resource: Material Selection and Analysis Tool (MSAT)



NASA

MAPTIS

MSAT

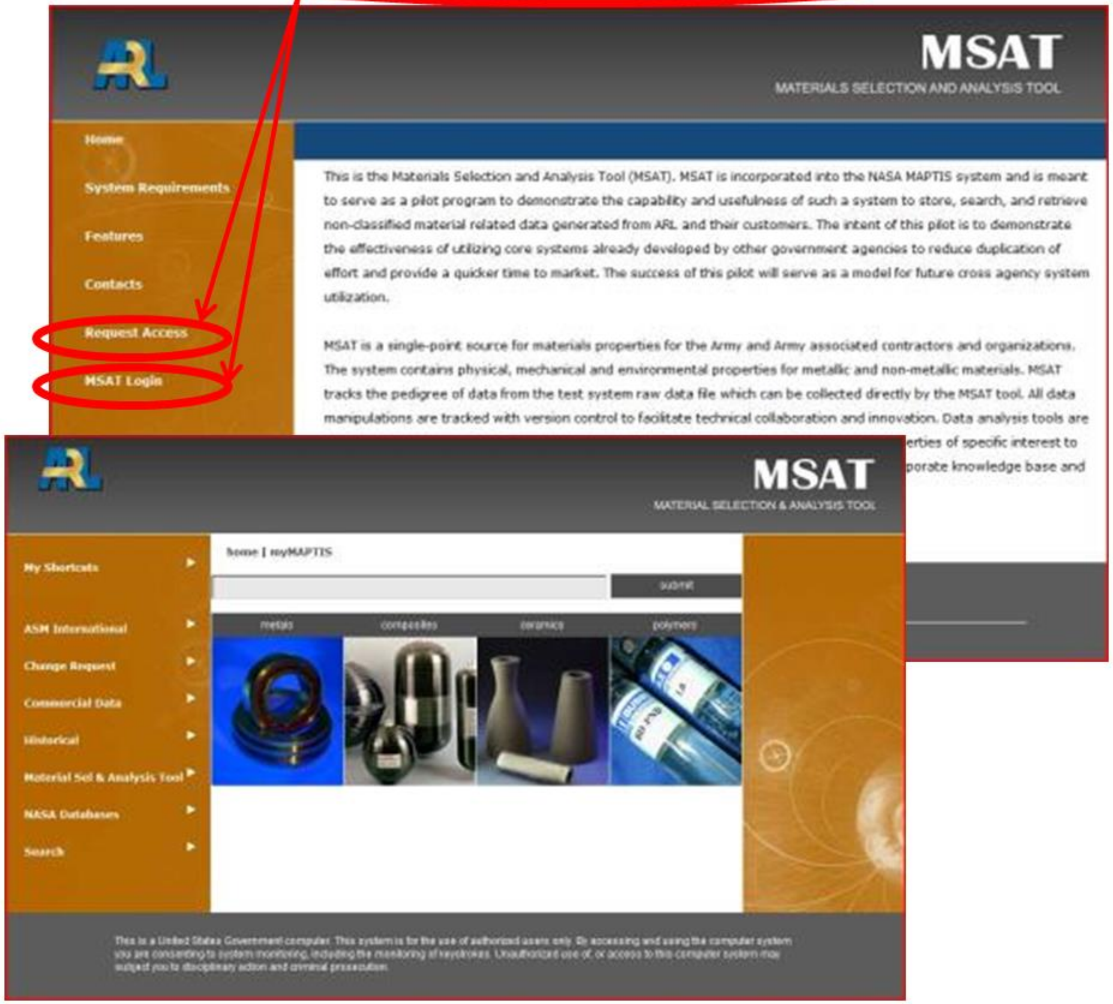
ARL

System Details

- Automated Data Quality tool
- Analysis tools
- Report tools
- Database
- and more…

MSAT:
Material Selection & Analysis Tool

http://maptis.nasa.gov/homemsat.aspx



This is the Materials Selection and Analysis Tool (MSAT). MSAT is incorporated into the NASA MAPTIS system and is meant to serve as a pilot program to demonstrate the capability and usefulness of such a system to store, search, and retrieve non-classified material related data generated from ARL and their customers. The intent of this pilot is to demonstrate the effectiveness of utilizing core systems already developed by other government agencies to reduce duplication of effort and provide a quicker time to market. The success of this pilot will serve as a model for future cross agency system utilization.

MSAT is a single-point source for materials properties for the Army and Army associated contractors and organizations. The system contains physical, mechanical and environmental properties for metallic and non-metallic materials. MSAT tracks the pedigree of data from the test system raw data file which can be collected directly by the MSAT tool. All data manipulations are tracked with version control to facilitate technical collaboration and innovation. Data analysis tools are

erties of specific interest to

porate knowledge base and

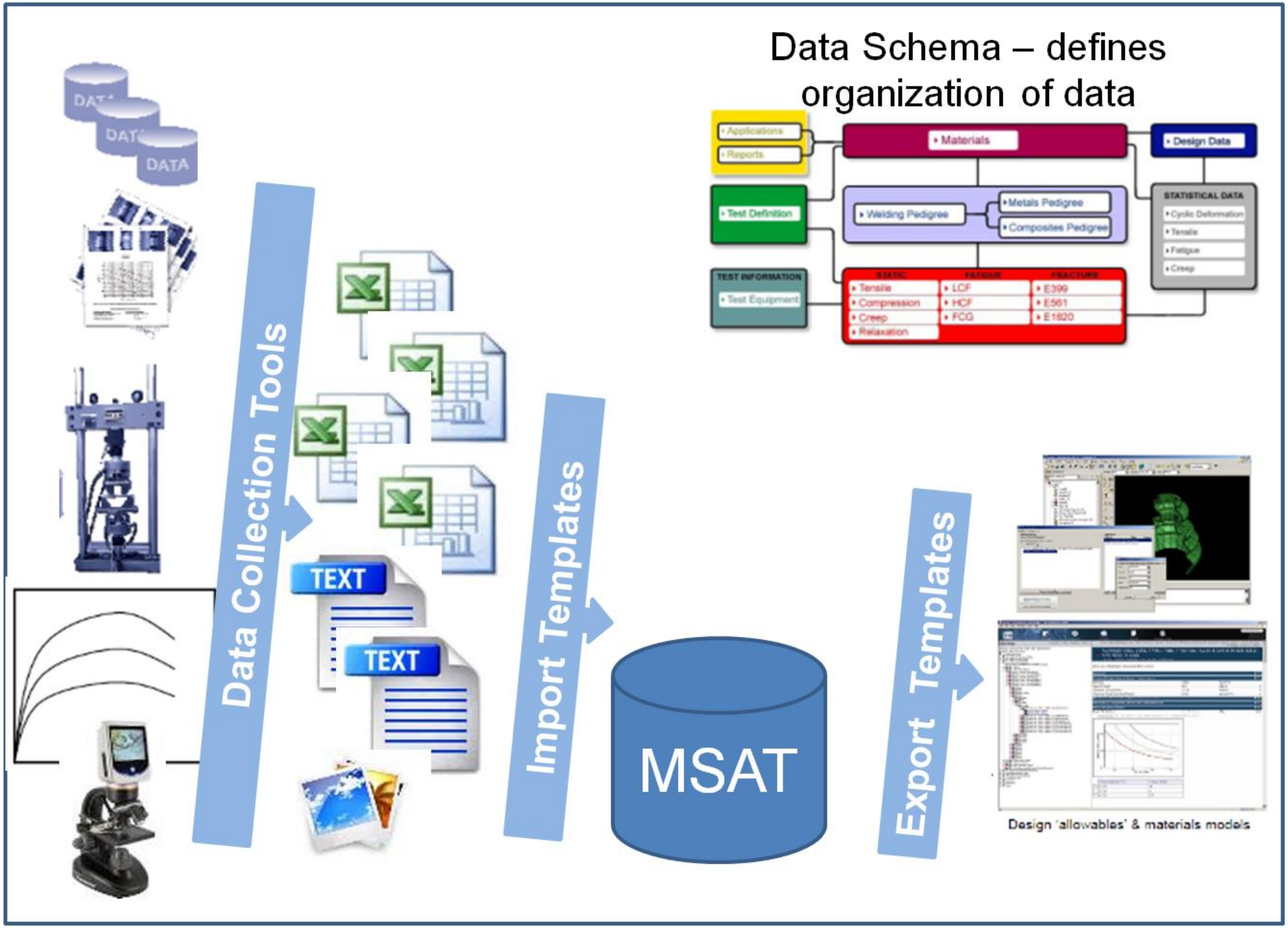
This is a United States Government computer. This system is for the use of authorized users only. By accessing and using the computer system you are consenting to system monitoring, including the monitoring of keystrokes. Unauthorized use of, or access to this computer system may subject you to disciplinary action and criminal prosecution.

What is MSAT?
- Single point source for materials properties, testing protocols, selection & analysis tools.
- Repository for high fidelity, pedigreed material datasets
- Web based platform with portals to extensive database resources

For who?
- DoD organizations & select contractors

Why should I use this?
- Controlled access to data
- Aids work flow efficiencies
- Customized it to fit program needs
- Automated data analysis; standard & custom
- Reporting and Documentation tools

Anything Else?
- ARL's MSAT is based upon NASA's 20+ yrs experience in materials data management
- Material Data Management Consortium (MDMC) 20+ members



Data Schema – defines organization of data

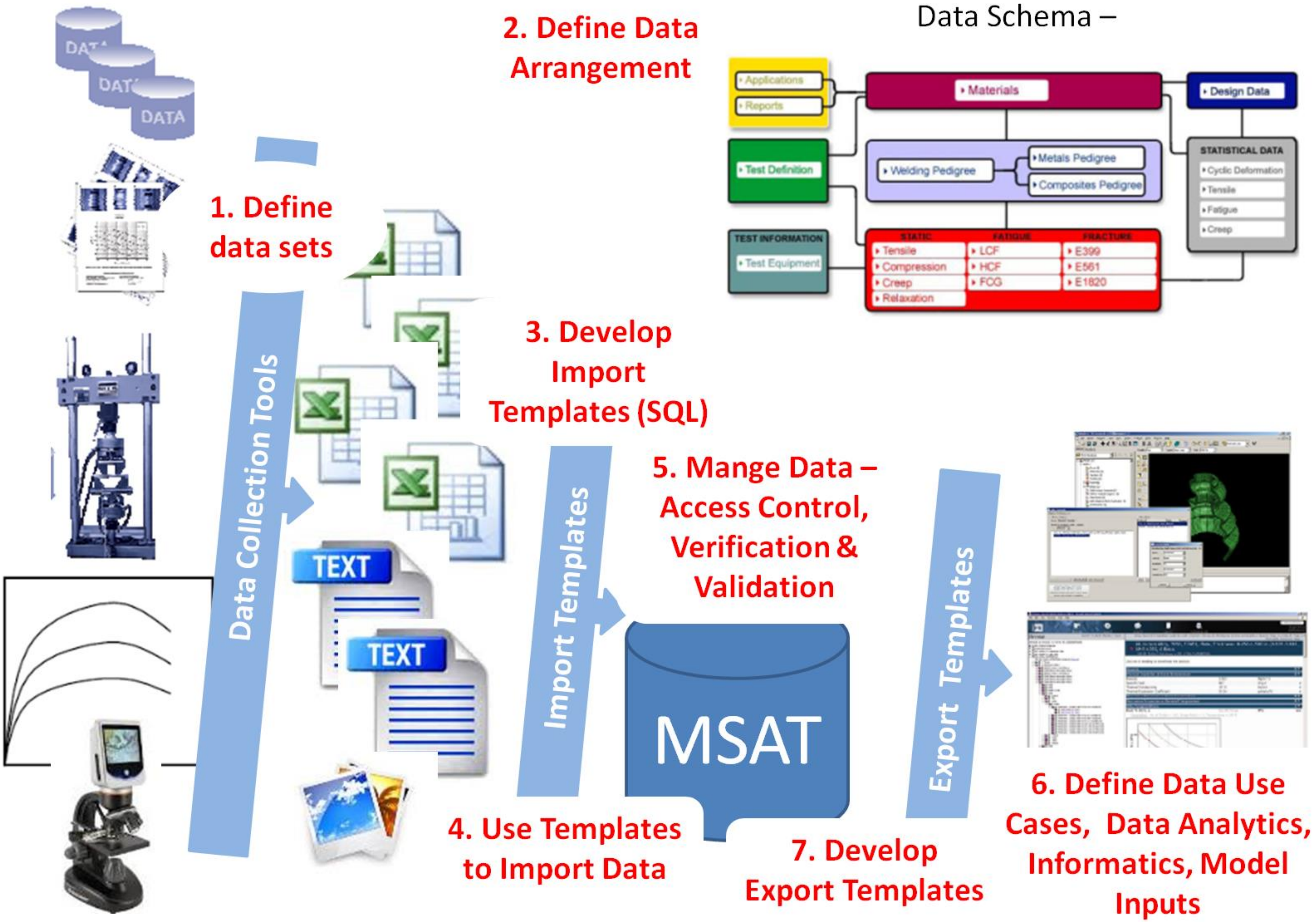
Data Collection Tools

Import Templates

MSAT

Export Templates

Design 'allowables' & materials models



1. Define data sets

2. Define Data Arrangement

Data Schema –

3. Develop Import Templates (SQL)

4. Use Templates to Import Data

5. Mange Data – Access Control, Verification & Validation

6. Define Data Use Cases, Data Analytics, Informatics, Model Inputs

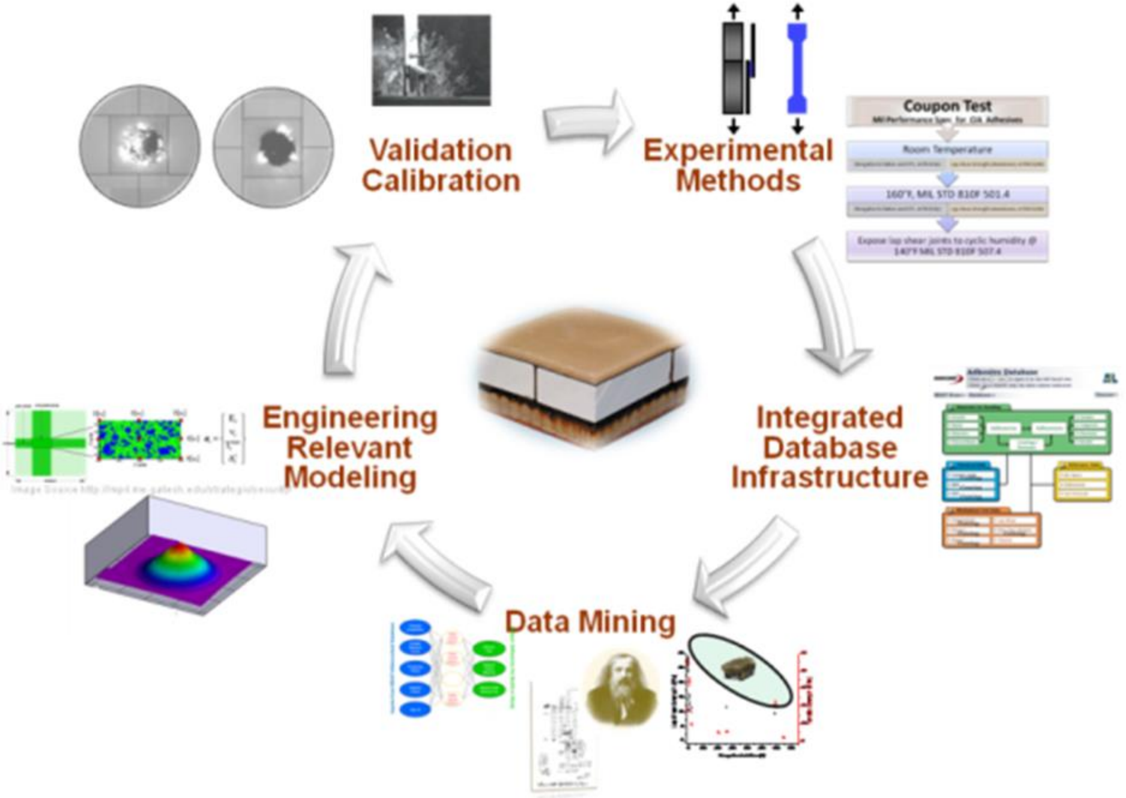
7. Develop Export Templates

Considerations

- Definition of the main function of the system
- How the system will fit in with existing systems and workplace practices
- Who will use the system, and how
- How data flows through the system
- What type of information will be handled
- How the system will be setup, deployed and maintained
- Who is responsible for, and owns, the various system components

Current AM Efforts

Material Informatics Vision



Validation Calibration

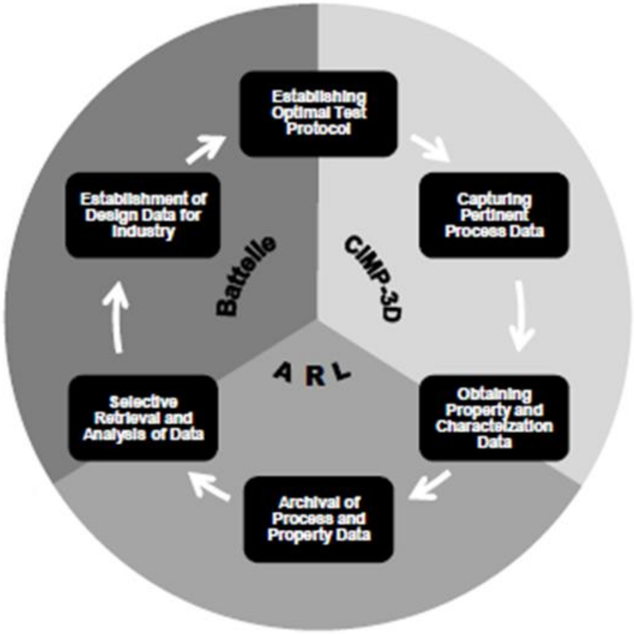
Experimental Methods

Integrated Database Infrastructure

Data Mining

Engineering Relevant Modeling

DARPA Open Manufacturing Program



Establishing Optimal Test Protocol

Capturing Pertinent Process Data

Obtaining Property and Characterization Data

Archival of Process and Property Data

Selective Retrieval and Analysis of Data

Establishment of Design Data for Industry

Source: Richard Martukanitz, Director CIMP-3D

Contacts

Materials Selection & Analysis Tool (MSAT)

- Wayne Ziegler, ARL
- Wayne.W.Ziegler.civ@mail.mil

Materials and Processes Technical Information System (MAPTIS)

- Ben Henrie, NASA MSFC
- Benjamin.L.Henrie@nasa.gov

Standards Generation

Kevin Jurrens

NIST Engineering Laboratory
Intelligent Systems Division

NIST Role in Additive Manufacturing Standards

Kevin Jurrens
NIST Engineering Laboratory
Intelligent Systems Division
kevin.jurrens@nist.gov

Virtual Workshop: Additive Manufacturing in Support of DOD Maintenance and Sustainment
November 13, 2013

Unique Role of NIST Research Laboratories

- Emphasis on infrastructural metrology and non-proprietary, standardized metrology methods that address a broad class of measurement challenges
- Emphasis on rigorous and generic procedures to characterize measurement uncertainty that comply with international standards
- Long-term commitment, expertise, and neutrality essential for harmonized and unbiased national and international standards
- Leverage NIST core competences in measurement science, rigorous traceability, and development and use of standards -- as well as specific expertise in measurements and standards for manufacturing systems, processes, and equipment

➢ **Measurements and Standards**

Primary Outputs of NIST Research Laboratories

- Measurement methods
- Performance test methods and metrics
- Documentary standards
- Standard reference data
- Standard reference materials
- Calibration services
- Technology transfer: technical publications, industry workshops, collaborations

Barriers that Prevent Broad Adoption of Additive Manufacturing

- Material Types and Properties
- Process Repeatability and Performance
- Part Accuracy
- Surface Finish of Contoured Surfaces
- Fabrication Speed
- Build Volumes / Part Size
- Need for Qualification and Certification
- Data Formats
- Lack of AM Standards

Uncertainties in Additive Manufacturing

Powder

Uncertainties in the Input Materials

+

Process

Uncertainties in Equipment and Process Performance

=

Part

Uncertainties in the Final Parts

Measurement Science and Standards Reduce Risk of Adoption

NIST Project:
Materials Standards for Additive Manufacturing

Deliver enhanced measurement techniques that support new, standardized methods for quantifying the material properties of both the metal ***powders*** *used for additive manufacturing and the resulting manufactured* ***parts***

- *Technical Focus:*
  - Standard test methods for metal powder characterization
  - Standard test methods to obtain material properties of AM parts
  - Test protocols, procedures, and analysis methods for industry round robin testing of AM materials for consensus material property data

Powder Characterization

Current Emphasis:

- Variability of nominally identical powder, effects of recycling (e.g., exposure of powder to multiple builds), documented properties of round robin powder (for potential future correlation with mechanical properties)

Characteristics of Interest:

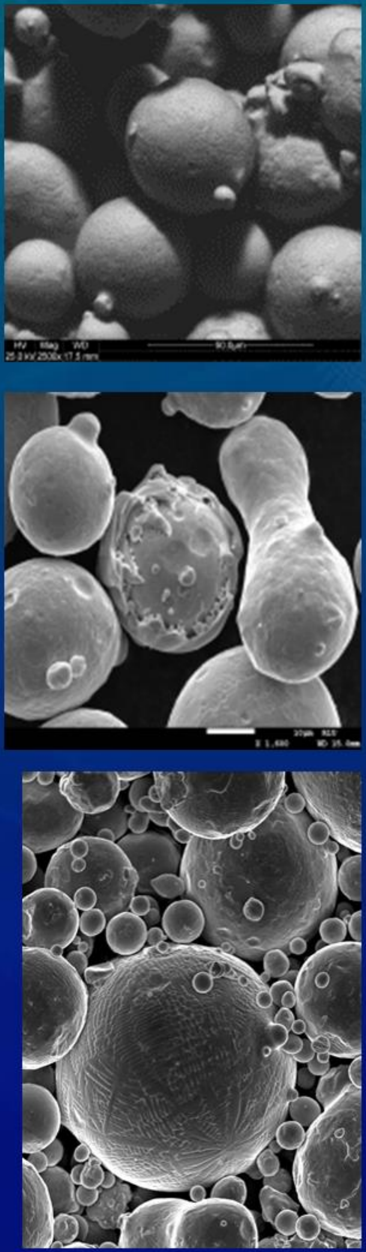
- Size (and size distribution), morphology, chemical composition, flow, thermal properties…

Measurement Methods:

- SEM (size, morphology), Quantitative X-Ray Diffraction (chemical composition), Laser Diffraction (size distribution), X-Ray Computed Tomography (morphology), X-Ray Photoelectron Spectroscopy (gives photoelectron energy characteristic of elemental chemical states)

Results:

- Recycling reduces austenite, increases ferrite content in Stainless Steel (QXRD), but does not change surface chemistry/atomic concentration (XRPS)
- Nominally identical Stain Steel and Round Robin CoCr powder lots have same base chemical composition (QXRD)
- CoCr and Stainless Steel powder morphology is “quasi-spherical”
- Laser diffraction measurements and analysis are currently underway.



Material Properties Round Robins

- Two NIST-funded round robin tests in-process (one internally led, one externally led)
- Mainly focused on laser-based DMLS powder bed systems, but internal study also includes two e-beam (ARCAM) AM systems for comparison
- Preparation of test protocols, procedures, test specimens, powder specifications, and analysis methods
- NIST statistical and material science expertise for design of experiments and analysis of internally led round robin
- Both have careful controls and procedures on powder, build parameters, post processing, and material property measurements
- “Tests to develop the test”

NIST Project: Fundamental Measurement Science for Additive Processes

Develop first-ever standard test methods and validated models that allow industry to evaluate and improve the performance of additive manufacturing (AM) systems to make better parts more quickly and more economically.

- *Technical Focus:*
  - Standard test methods to evaluate and improve AM equipment performance
  - Standard test methods to evaluate fundamental process characteristics
  - Standard test artifacts to determine the accuracy and capabilities of AM processes
  - Physics-based modeling of AM processes and material transformation
  - *In-situ* measurements of AM parts

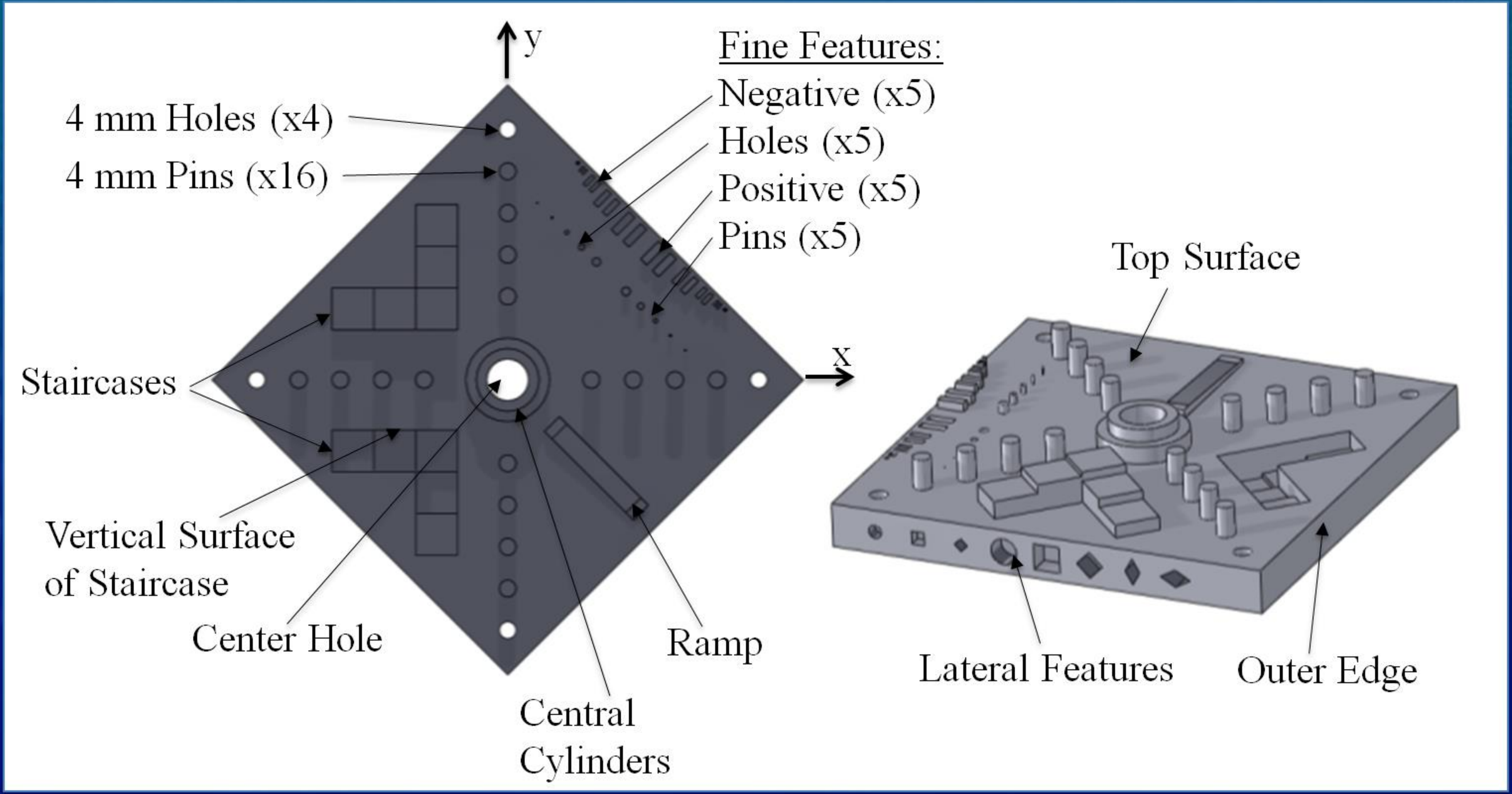
Metrology and Modeling for Improved Product Quality Assurance

- Real-time measurements of additive processes
  - High-speed thermal
  - High-speed vision
  - *In-situ* porosity sensor
- Physics-based models of metal additive processes
  - Collaborations with Univ. of Louisville and Carnegie Mellon University
  - Initial focus:
    - EOS direct metal laser sintering (DMLS) process
    - Modeling of material transformation in the laser melt pool
    - Parameters: material type and properties, powder characteristics, laser power, laser speed, temperatures, melt pool geometry, etc.
  - Preliminary results so far, validation experiments and additional modeling planned

Standard Test Artifact for AM

- Reviewed more than 40 test artifacts previously described in literature
- Prior AM test artifacts typically fall into one of two categories:
  - Designed to highlight capabilities of a process
  - Designed to measure process accuracy and allow for process optimization
    - NIST Internal Report 7858: *A Review of Test Artifacts for Additive Manufacturing*, May 2012
- Ideally one standardized test artifact would address both
  - So that AM processes can be optimized by correlating specific errors in the test artifact with specific errors in the process
- Ideally could be built via any AM process

Description of Proposed Artifact



http://www.nist.gov/el/isd/sbm/amtestartifact.cfm

NIST Roadmapping Workshop: Measurement Science for Metal-Based Additive Manufacturing

- Held at NIST on December 4-5, 2012, with 88 AM experts
  - In-depth coverage of measurement science barriers, challenges, and gaps
- Workshop Final Report and Measurement Science Roadmap
  - Summary of results, including recommendations, presentation slides, white papers, break-out group results, etc.
  - Actionable plans: beyond a list of research needs
  - Addresses one slice of overall AM roadmap
  - Integrated with NAMII national AM roadmap
- Foundation for ASTM F42 Strategic Plan
- Consensus needs and priorities to influence the national research agenda for metal-based additive manufacturing

http://events.energetics.com/NIST-AdditiveMfgWorkshop/index.html

AM Materials

- Characterization Data and Standards for Post Processing
- Robust In Situ Process Monitoring Techniques
- Metals Design Allowables Database

AM Process and Equipment

- Non-Destructive Evaluation Techniques Optimized for Metals AM
- Fast In-Situ Measurements
- Performance Capability Database for AM Technologies
- Sensors for Measuring and Monitoring AM Processes and Products

AM Qualification and Certification

- Closed Loop Process Control
- Standard Guidelines and Methods for Qualification and Certification
- Shared/ Standardized Third-Party Data Repository
- Standards and Protocols for Round-Robin Build and MaterialTesting

AM Modeling and Simulation

- Expert System for AM Design
- Validated Physics- and Properties-Based Models for AM
- Standard Data Structures, Definitions, and Metrics for AM Models

Figure E-2. Important Technology and Measurement Challenges for Additive Manufacturing

ASTM Standards Committee F42

- Established in January 2009 to address high-priority needs for standards in Additive Manufacturing Technologies
- Initiated with Society of Manufacturing Engineers (SME), Rapid Technologies & Additive Manufacturing community
- F42 subcommittees formed for :
  - *Terminology*
  - *Test Methods*
  - *Materials and Processes*
  - *Design (including data formats)*
  - *U.S. TAG to ISO TC 261*
- Current F42 roster: 144 individuals and organizations; 13 countries represented (23% of roster from outside the U.S.)
- Status: 5 approved standards; 16+ work items under development
- Formal collaboration with ISO TC 261 committee on Additive Manufacturing (first of its kind!)

ASTM INTERNATIONAL
Standards Worldwide - Home

NIST Role in ASTM F42 Standards Development

- Substantial NIST technical presence and contributions to ASTM F42
  - Chair of Test Methods Subcommittee
  - Leadership of task groups
  - Executive Committee member, tasked to lead the strategic planning for F42
  - U.S. Technical Advisory Group to ISO TC261
- Developed and presented “Future Vision of AM Standards” at January 2012 meeting
  - Strategic approach and vision; focused on maximizing impact of F42 standards

Strategic Approach for Development of AM Standards

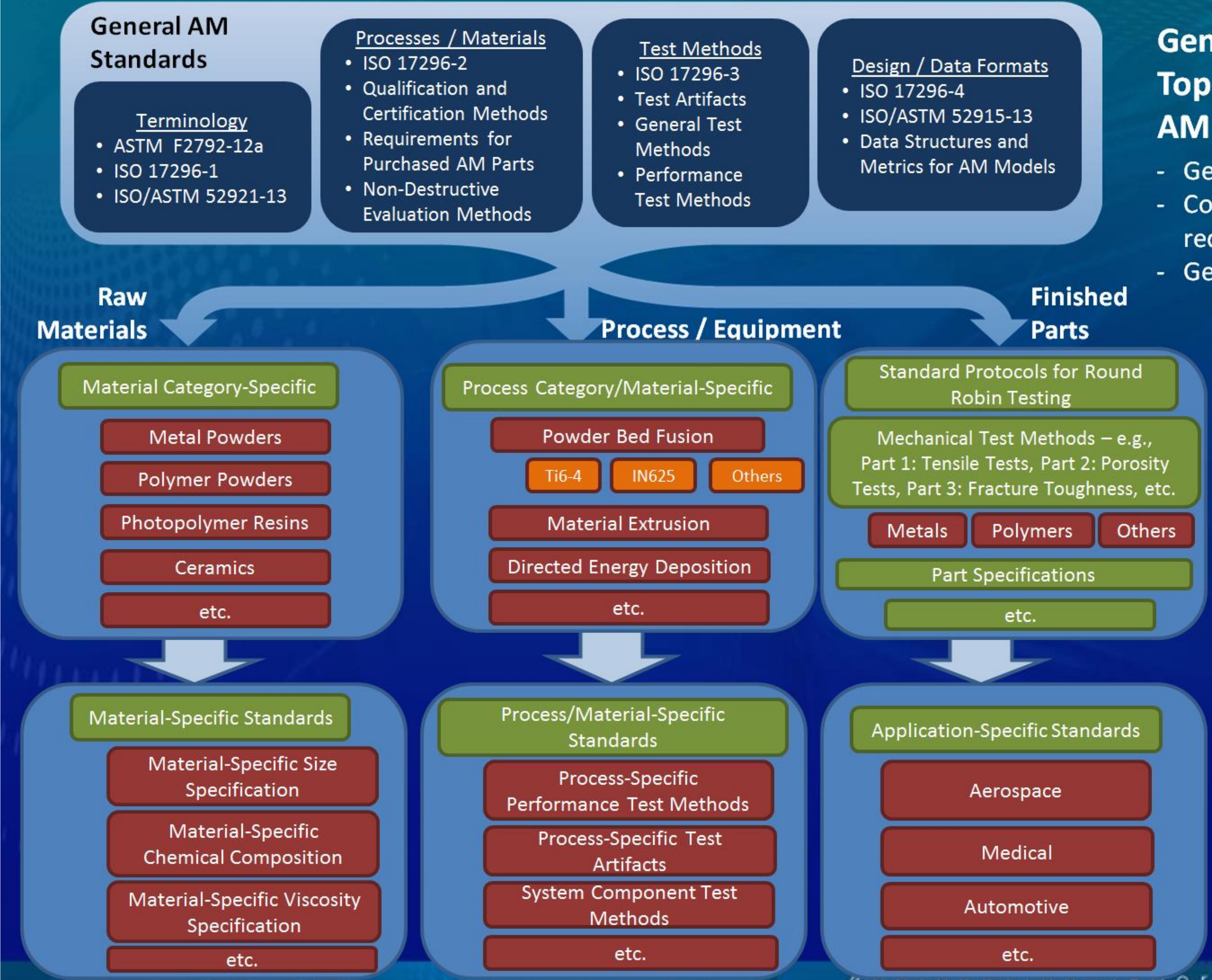
- Needed to establish the overall structure and give guidance to the task teams, helping with planning and prioritization
  - Where do we want to be in 5 years? What standards are needed to get there? What steps can be taken now to maximize future impact?
- Will maximize the impact of the standards by:
  - Preventing overlap and contradiction among F42 standards
  - Ensuring that future F42 standards work together as an integrated and cohesive set
  - Improving usability and acceptance for future users of all types

ASTM F42 / ISO TC 261: Agreement on Guiding Principles

- **One Set of AM Standards** – to be used all over the world
- Common roadmap and organizational structure for AM standards
- Use and build upon existing standards, modified for AM when necessary
- For efficiency and effectiveness, ISO TC 261 and ASTM F42 should **begin** the work together and in the same direction
  - Emphasis on **joint** standards development

➢ Joint Plan for AM Standards Development

Proposed Structure of AM Standards



General AM Standards

Terminology
- ASTM F2792-12a
- ISO 17296-1
- ISO/ASTM 52921-13

Processes / Materials
- ISO 17296-2
- Qualification and Certification Methods
- Requirements for Purchased AM Parts
- Non-Destructive Evaluation Methods

Test Methods
- ISO 17296-3
- Test Artifacts
- General Test Methods
- Performance Test Methods

Design / Data Formats
- ISO 17296-4
- ISO/ASTM 52915-13
- Data Structures and Metrics for AM Models

General Top-Level AM Standards
- General concepts
- Common requirements
- Generally applicable

Raw Materials

Material Category-Specific
- Metal Powders
- Polymer Powders
- Photopolymer Resins
- Ceramics
- etc.

Material-Specific Standards
- Material-Specific Size Specification
- Material-Specific Chemical Composition
- Material-Specific Viscosity Specification
- etc.

Process / Equipment

Process Category/Material-Specific
- Powder Bed Fusion
  - Ti6-4
  - IN625
  - Others
- Material Extrusion
- Directed Energy Deposition
- etc.

Process/Material-Specific Standards
- Process-Specific Performance Test Methods
- Process-Specific Test Artifacts
- System Component Test Methods
- etc.

Finished Parts

Standard Protocols for Round Robin Testing

Mechanical Test Methods – e.g., Part 1: Tensile Tests, Part 2: Porosity Tests, Part 3: Fracture Toughness, etc.
- Metals
- Polymers
- Others

Part Specifications

etc.

Application-Specific Standards
- Aerospace
- Medical
- Automotive
- etc.

Category AM Standards
- Specific to material or process category

Specialized AM Standards
- Specific to material, process, or application

Contact Info

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- Manufacturing Portal
- Building and Fire Research Portal
- Energy Efficient Buildings
- Construction Integration and Automation
- Sustainable Materials
- Fire Protection
- Disaster Resilience
- Robotics and Automation Interoperability
- Industrial Control Standards
- Robotics and Automation
- Science-Based Manufacturing
- Supply Chain Integration
- Sustainable Manufacturing

NIST Tests Afghan Language Translation Devices for U.S. Troops
1 2 3 4

News
- Fiery Video Shows Moisture is Main Ingredient for a Safe Christmas Tree
- NIST Seeks Comments on Study of Charleston Furniture Store Fire
- Opening Statement—News Media Briefing Technical Study of the Sofa Super Store Fire

Popular Links
- EL Newsletter
- Fire.Gov
- NSTC Subcommittee on Buildings Technology R&D
- World Trade Center Disaster Investigation
- Building and Fire Investigations
- XML Testbed
- PerMIS
- MOSS Project
- Urban Search and Rescue Robot Performance Standards

Products and Services
- Research Information Service
- Software Products
- Research Facilities

Kevin Jurrens
Deputy Chief
Intelligent Systems Division

(301) 975-5486
kevin.jurrens @nist.gov

National Institute of Standards and Technology (NIST)
100 Bureau Drive, MS 8230
Gaithersburg, MD 20899

www.nist.gov/el/isd

Standards Generation Cont’d

Marty McDonnell

Mechanical/Weld
TARDEC

Standards Generation and MIL-STD 3049

Marty McDonnell
Mechanical/Weld Engineer, TARDEC

13NOV13

OBJECTIVES

1. Background
2. Challenges
3. Steps taken
4. MIL-STD and methodology
5. Benefits
6. Implementation

BACKGROUND

- TARDEC Investigating new technology with great potential to:
  - Reduce lifecycle costs
  - Avoid increases in procurement and sustainment cost
- Define acceptance criteria for process and quality
  - Define good process to follow
  - Deliver usable parts
  - Finally, reduce overall manufacturing cost

CHALLENGES

- Lack of Standards, both Industrial and Military
- Industrial trend:
  - Interest from nonprofits & research organizations
    - Growing parts from seed
- Criticality of the part
  - Dimensional Accuracy
  - Qualification and Certification
  - Unknown Defects
  - Materials Selection
  - Must meet/exceed original design
  - Minimize testing and validation

STEPS TAKEN

- Reached out to nonprofit, private industry, OEMs, academia, and research institutions

- To date, TARDEC and DoD funded research:
  - FY05-11
    - > $17M from SBIR I/II/III, ManTech and Congressional Add for laser deposition
    - > $2M TARDEC core funding for laser deposition
  - FY12-13
    - ≈ $1M for Laser assisted cold spray
    - CRADA for Electron Beam (EB) deposition

DELIVERABLE

- MIL-STD 3049 to define:
  - Materials Deposition, Direct Deposition of Metal (DDM) for Remanufacture, Restoration and Recoating

- Establishes requirements for:
  - Material selection
  - Qualification
  - Inspection of parts

METRIC
MIL-STD-3049
5 September 2013

DEPARTMENT OF DEFENSE
MANUFACTURING PROCESS STANDARD

MATERIALS DEPOSITION, DDM: DIRECT DEPOSITION OF METAL FOR REMANUFACTURE, RESTORATION AND RECOATING

AMSC N/A AREA MFFP

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited.

METHODOLOGY

Material Process Development & Validation

- Lab coupons for analysis
- Inspection & testing

Part Repair Process Development

- Procedure Qualification Record (PQR)
- Part evaluation

Part Repair Process Validation

- Evaluation of part repair
- Dimensions, NDT & characterization

Production Process Monitoring

- Sampling procedures
- On-going NDT for Production/Sustainment

TESTING

TEST	APPLICATION				
	High Stress	Fatigue	Wear	Corrosion	Load Bearing
Tensile	X	X			X
Fatigue	X	X			X
X-Ray	X	X	X	X	X
Micro-Hardness	X	X	X		X
Wear Abrasion	X	X	X		X
Salt Spray				X	
Side Bend	X	X			X
Lap Shear	X	X	X		X
Cohesion	X	X	X	X	X

TESTING

MATERIAL ATTRIBUTE	RECOMMENDED STANDARDS		
Tensile	ASTM E8	ASTM B557	
Fatigue	ASTM E60		
X-Ray	ASTM E94	ASTM E1030	
Micro-Hardness	ASTM E18	ASTM E10	ASTM E384
Wear Abrasion	ASTM G65		
Corrosion	ASTM B117	GMW 14872	
Side Bend	ASTM E290		
Lap Shear	ASTM D1002	ASTM D2295	ASTM D3846
Cohesion	ASTM C633		

BENEFITS

- Advances Additive Manufacturing technology
- Meets or exceeds original design
- Reduce future increases of sustainment cost
- Increases Army Depot capability
- Improves supply chain response
- Aligns with future vision OSD: Maintenance

FUTURE

- TARDEC to receive POM DMD405 machine
  - Material and process certification and qualification
  - Build on Army Additive Manufacturing Knowledge-base
    - Materials of interest to the Army
    - Database with material property data
    - Parts where Additive Manufacturing is an alternative for repair

Questions?

Additive Manufacturing
A Virtual Workshop

NCMS
NATIONAL CENTER FOR MANUFACTURING SCIENCES

Advocacy at Command Levels

Dr. William Frazier

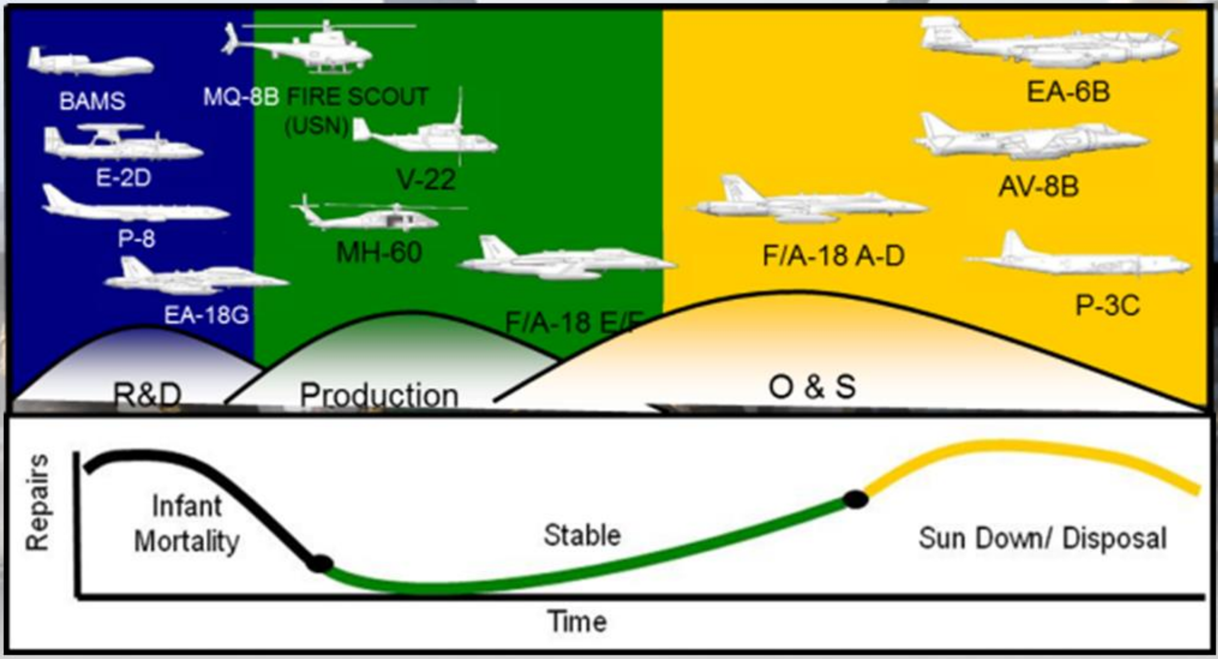
NAVAIR

Operational Challenges

Supply Chain Limitations:

Aircraft Inventory Maturing

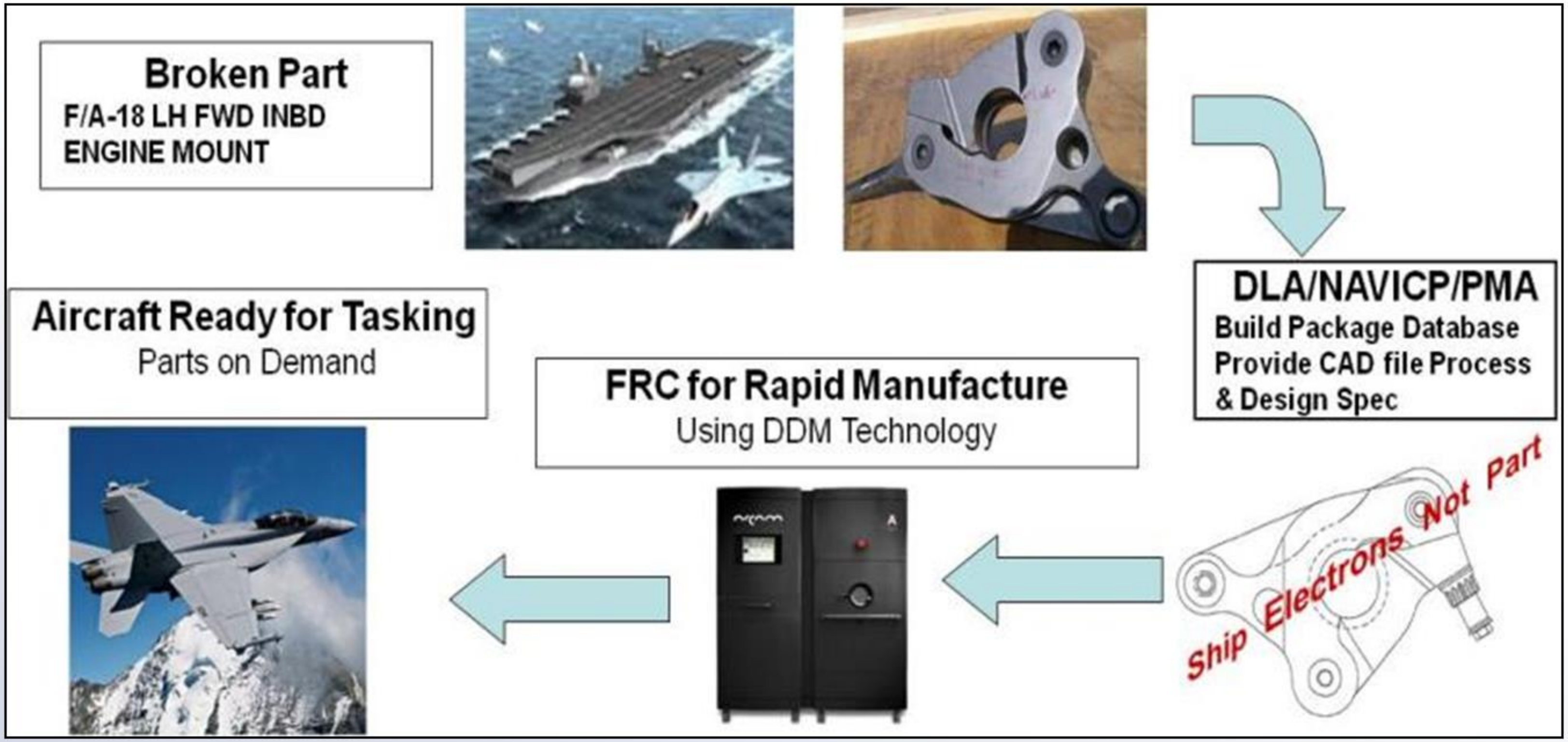
- 3828 Aircraft
- 39 Type-Model-Series
- 19.18 yrs Avg A/C age
- 3074 Operating



Problem Statement: "The Navy's inventory of aircraft is being pressed into service beyond their design life. As a result, components fail that were *never expected to be repaired or replaced*. With *no replacements available* in the supply system, long lead times develop for the repair or manufacture….." *Garry Newton, Deputy Commander, Fleet Readiness Centers (FRC)*

Vision of Parts on Demand

(Where and When They are Needed)



Broken Part
F/A-18 LH FWD INBD
ENGINE MOUNT

DLA/NAVICP/PMA
Build Package Database
Provide CAD file Process
& Design Spec

Ship Electrons Not Part

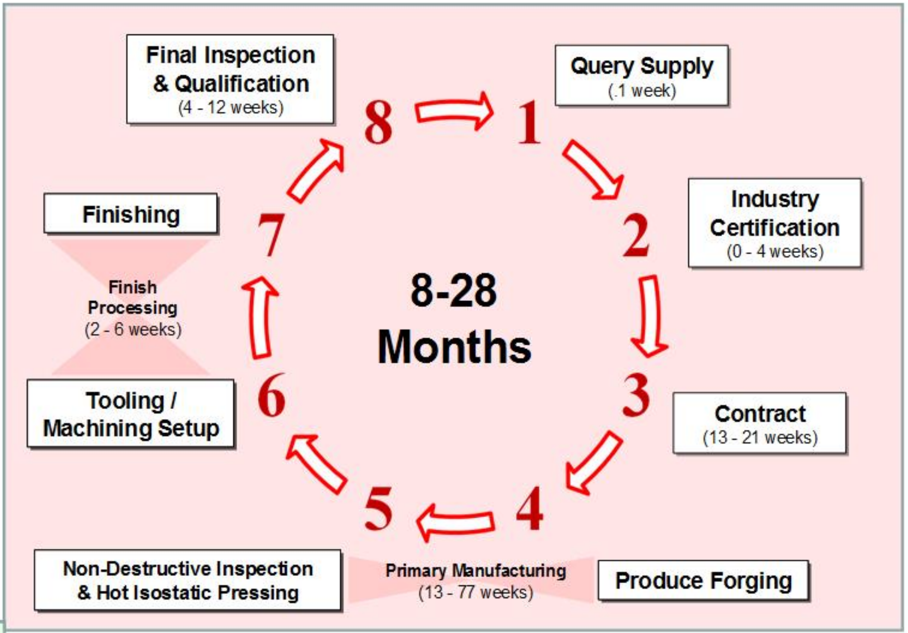
FRC for Rapid Manufacture
Using DDM Technology

Aircraft Ready for Tasking
Parts on Demand

Operational Availability

Current Process

- Long lead time especially for Titanium forgings.
- New tools and dies may be required
- Government vendor certification
- Qualification testing
- First article testing



8-28 Months

1 **Query Supply** (.1 week)

2 **Industry Certification** (0 - 4 weeks)

3 **Contract** (13 - 21 weeks)

4 **Produce Forging**

Primary Manufacturing (13 - 77 weeks)

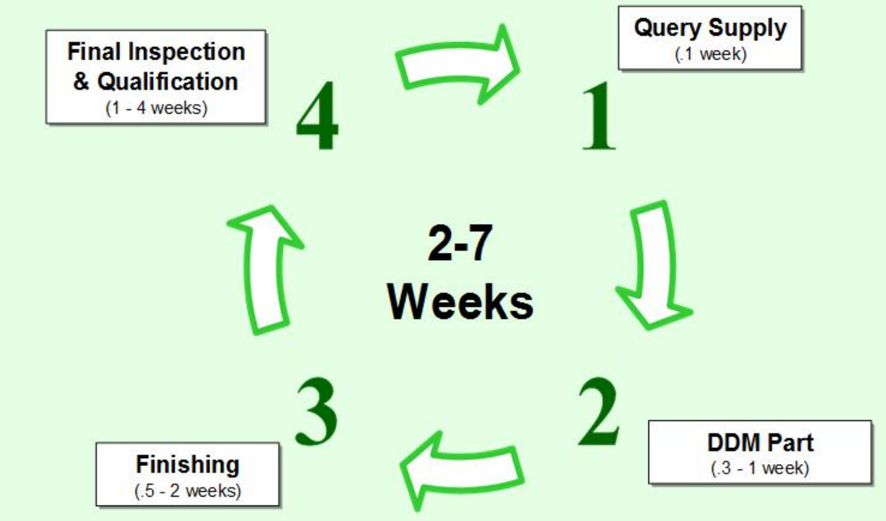
5 **Non-Destructive Inspection & Hot Isostatic Pressing**

6 **Tooling / Machining Setup**

Finish Processing (2 - 6 weeks)

7 **Finishing**

8 **Final Inspection & Qualification** (4 - 12 weeks)



2-7 Weeks

1 **Query Supply** (.1 week)

2 **DDM Part** (.3 - 1 week)

3 **Finishing** (.5 - 2 weeks)

4 **Final Inspection & Qualification** (1 - 4 weeks)

DDM is a manufacturing process that has the potential to create physical parts directly from 3D CAD files or data.

DDM On-demand (Future Process)

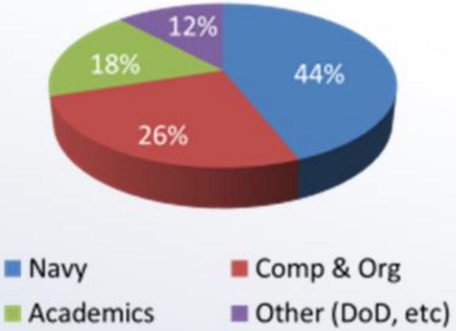
- Parts in weeks rather than months
- No Forging or Tooling
- Conserve strategic material by reducing the buy-to-fly ratio (material waste) from 20:1 to approx 1:1

AM-MMOWGLI

(Additive Manufacturing Massively Multiplayer Online Wargame Leveraging the Internet)

The AM-MMOWGLI was executed (16-30 Sept) as part of an integrated Navy AM Road mapping effort

The results of the AM-MMOWGLI will be incorporated into the Navy Additive Manufacturing Technology



A MMOWGLI may be summarized as follows: "…….is a message based game that encourages innovative thinking about some of the world's most wicked problems….."

"MMOWGLI is designed to support large number of distributed global players working together on idea generation and action planning, with an eye towards surfacing innovative outlier strategies."

Unleash the potential of AM design innovation! Click here to read today's blog.

Today's theme is DESIGN INNOVATION!

Today's Navy
How could AM be used to solve current Navy challenges?

Tomorrow's Navy
How could AM be used to transform the Navy of the future?

Today's Navy

TODAY'S NAVY 1079
How can innovative AM design concepts be used to reduce Navy costs today?
SeedCard 09/18 17:45 PDT

TODAY'S NAVY 1080
Lack of design guidelines, organizational experience, and tools impede AM design innovation.
SeedCard 09/18 17:48 PDT

TODAY'S NAVY 1081
Promising AM enabled capabilities will have great impact on Systems design. (Think multi-materials, electronics, nano structure)
SeedCard 09/18 17:49 PDT

TODAY'S NAVY 1082
Current tools in the design process will afford the Navy less than 10% reductions in weight & fuel.
SeedCard 09/18 17:50 PDT

Tomorrow's Navy

TOMORROW'S NAVY 1083
How could advanced AM designs improve a sailor's quality of life?
SeedCard 09/18 17:51 PDT

TOMORROW'S NAVY 1084
What operational capabilities will AM enable?
SeedCard 09/18 17:52 PDT

TOMORROW'S NAVY 1085
How would you change Navy designs using futuristic AM capabilities?
SeedCard 09/18 17:53 PDT

TOMORROW'S NAVY 1086
What software design toolbox improvements are needed (e.g., to get a 50% or more reduction in weight & energy)?
SeedCard 09/18 17:54 PDT

700 + participants invited to play
Over 2100 "Idea Cards" written
Over 26 Action Plans Developed

AM-MMOWGLI

(Representative Action Plan Themes)

Strategy & Approach (3 Action Plans)

Strategic Plan for the Navy Use of Additive Manufacturing; Encourage Fleet Innovation in AM; **Supply Chain Reassessment of AM**

Collaboration and Centralization (5 Action Plans)

Integrated AM Technologies and Best Practices Across DoD; Establish a Navy Central Expertise Group for AM Development; **Establish in-house AM Capability;** Develop and certify AM depot repairs; Use AM to improve sustainment

Technology (5 Action Plans)

Rapid Qualification; Advanced AM Alloys; Polymer and Polymer Composite; Computer based training & AM design software; Adoption of common CAD file format across DoD

Design & Innovation (4 Action Plans)

Increased component functionality; Design for ease of assembly and disassembly; Lattice designs for internal structures; Dynamic mold design

Applications (2 Action Plans)

Nation Building and Disaster Relief; Customize ordnance

Summary

- AM is a rapidly emerging, disruptive technology
  - It will affect every phase of the acquisition life cycle
- AM Qualification
  - A rapid, low cost approach is required
- Collaboration across DoD is essential to reduce cost, time, and duplicative work
  - Shared Data
  - Shared standards and processes
  - Share the sustainment load – get the part made by whomever is qualified & equipped to produce it, Army, Navy, AF, NASA, DOE
- How can we work together??

1530 to 1630

Active Discussion & Synthesis

Moderator – Connie Philips

2013-2014 & Beyond

Our predictions

The Future will see *evolutionary* AM process technology and materials development continue

Nov | **Dec** | **Jan** | **Feb** | **Mar** | **Going** | **Forward** →

Expanded AM technology adoption; **Collaborative** U.S. and international standardization work; **Formalized** AM knowledge-sharing across industries, DoD and Government agencies; **Expanding** AM knowledge base into multi-material, multi-process applications; **Continued** emergence and maturation of AM systems along with **development** of new material capabilities, and "**cracking the code**" of design data for design allowables.

Beyond, we will see AM and other automation / robotics systems merged into 6+DOF additive manufacturing systems. Gravity-free.

1630

Next Steps

Greg Kilchenstein

Thank You!