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Additive Manufacturing Mission Assurance Considerations Product Overview

May 5, 2016

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Abstract

Additive Manufacturing is driving an industry evolution at an accelerated rate and has been identified as a new technology with multiple mission assurance gaps in regards to qualified space hardware, including lack of released material, process and inspection specifications. A team was chartered to survey the multiple activities and capture mission assurance considerations that should be understood when faced with incorporating additively manufactured parts. This presentation was given at the 2016 Mission Assurance Improvement Workshop and provides an overview of the full document, *Additive Manufacturing Mission Assurance Considerations* (Aerospace Report No. TOR-2016-02152).

Additive Manufacturing Mission Assurance Considerations

Product Overview

Jim Nokes, The Aerospace Corporation
Talbot Thrasher, Orbital ATK

May 5, 2016

Agenda

- Aerospace Industry Approach for New Technology Insertion
- How Additive Manufacturing (AM) is Different
  - *What is AM*
  - *Details of Eccentricity*
- NASA Pathfinder Standard for Human Spaceflight AM Parts
- Sub-Committee Topic Questions and Answers
- Topic Follow-on Recommendations
- Team Membership and Recognition

What Is Additive Manufacturing (AM)

AM is a manufacturing process that:

1) takes an electronic model of a part and slices it into layers as a new "sliced" file;
2) employs a laser or electron beam (for metal parts) to fuse, sinter, or melt metal powder material to
3) create an object by fusing successive layers of material into a single configuration.

The additive process is different from subtractive machining processes as subtractive processes start with a piece of material and remove excess material instead of incrementally adding only that which is needed to make the part.

Motivation for Additive Manufacturing Review

- AM is driving an industry evolution at an accelerated rate. There is a need to monitor industry and government MA organizations that are responding to this new technology regarding materials, design, process, and inspection methods
  - *Target audience:*
    - M&P communities
    - Mission assurance professionals
    - Scientific and academic communities
    - Industry coordinated efforts
    - Non-SME technical staff
- AM has been identified as a new technology with multiple MA gaps in regards to qualified space hardware, including lack of released material, process, and inspection specifications.
- AM is a non-traditional mini-topic of a very broad subject. AM is a rapidly evolving technology with many evolving associated technologies—this is a survey of AM topics and concerns.

Additive Manufacturing Sub-Committee Charter

- Provide a technology overview to MAIW of the technological advances, methods, materials, capabilities, and specific applications of interest to this community, including sub-area focus if necessary.
- Assess and document related activities, known qualification needs, and considerations for accepting AM parts for flight.
- Evaluate and document what qualification/certification and suitability means for AM. Review and summarize NASA Marshall draft standard as a starting point.

Additive Manufacturing Sub-Committee Products

- The workshop briefing charts provide a deliverable presentation that contains:
  - *AM process explanation and examination*
  - *Top level view of NASA Marshall draft standard*
  - *Technology questions and topic reviews*
  - *Provide recommendations for future activities and industry certification effort.*

NASA MSFC Technical Standard

National Aeronautics and Space Administration

MSFC-STD-xxxx
REVISION: DRAFT 1
EFFECTIVE DATE: Not Released

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

EM20

MSFC TECHNICAL STANDARD

Engineering and Quality Standard for Additively Manufactured Spaceflight Hardware

DRAFT 1 – JULY 7, 2015

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VERIFY THAT THIS IS THE CORRECT VERSION BEFORE USE

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THIS DRAFT IS CURRENTLY IN ACTIVE REVISION. THIS VERSION IS FOR REVIEW ONLY

The draft AM NASA Standard provides a detailed discussion and effective requirements for AM spaceflight hardware including AM design and process control.

Regarding qualification:

"*For the current maturity of the AM process, there is need for experimental certification evidence for the design performance of the part through the qualification test series and for the integrity of each individual part through acceptance testing with proof test, NDE, and other AM build-related controls.*"

What process specifications (e.g., laser sintering or electron beam melting of powder, etc.) are in place and approved?

Background:	Criticality
Additive Manufacturing is highly process dependent. The user must control dozens of parameters to ensure stable, reproducible structures. This is further complicated by the proprietary nature of many of the instruments' functions.	✓ High ❑ Med ❑ Low ❑ Best Practice

Discussion: Category:	MA Focus
Industry is currently developing aerospace-grade specifications for general use and in the meantime, most companies have internal specifications for qualifying processes. The ASTM-released specification is a minimum template with additional in-house requirements as determined by each company. As a rule, each company produces process specifications to be approved by a Quality Review Board for process control of flight hardware.	❑ Contracts ✓ Inspection ✓ M&P ✓ Purchasing ✓ Requirements ❑ Source selection ❑ Statement of Work

How is the process controlled (Machine, Settings, Qualification, Specification, Environment, Training, etc.)?

Background:	Criticality
Controlling the process is critical to attain a repeatable, long-term, cost-effective process. Not all critical aspects required for control are publicly understood. Practices vary significantly by each user. Different systems/settings work best with different raw material characteristics; therefore, it is not possible to write a one-size-fits-all standard practice.	✓ High ❑ Med ❑ Low ✓ Best Practice

Discussion: Category: C1	MA Focus
Standard processing technologies and critical parameters, characteristic performance, typical defects, inspection techniques. Compliance is demonstrated with pre-process testing, in-situ measurements, post-process testing, and inspection. It is critical to verify that performance requirements are met when changes are made to settings; new machines; and standardize practices, and train personnel to those practices. Still very human intensive, not plug-n-play. Process shall be controlled per spec; machine parameters on additive manufacturing equipment shall be locked down; periodic validation of machine parameters shall be performed, e.g., tests on printed samples. Technologies are constantly changing, need to work to stay on top of these changes and how they affect the ability to control the processes. Not economical to lock everything down, difficult to control a continually evolving process. Need to strike a balance through basic qualification criteria. Comparable approach for traditional fabrication techniques, critical welding operations, composites.	❑ Contracts ✓ Inspection ✓ M&P ❑ Purchasing ✓ Requirements ❑ Source selection ❑ Statement of Work

How do you inspect and accept/reject parts?

Background:	Criticality
Non-destructive part inspection versus acceptance testing is the industry standard for quality assurance of production parts. As AM fabrication produces a rough surface finish while allowing for, and implicitly increasing, contours, cavities, and internal feature complexity; traditional CMM, handheld tool, and visual inspection techniques are insufficient to inspect configuration and internal part integrity. As such, acceptance criteria and techniques are borderline insufficient or prohibitively expensive for some AM parts.	✓ High ❑ Med ❑ Low ✓ Best Practice
Discussion: **Category:**	**MA Focus**
Inspection capabilities and accepted industry standards for appropriate capabilities need to be developed and defined for degrees of criticality. CT, X-ray, white/blue/structured light grades as well as traditional methods need to be assessed for their applicability to AM part with regard to surface roughness and internal inspection. FAI of sectioned parts will only be reliable when process repeatability for surface control (finish, tolerance, cracks, etc.) is defined and understood. Current QA processes shall be used. Develop QA processes for additive parts as required.	❑ Contracts ✓ Inspection ✓ M&P ❑ Purchasing ✓ Requirements ❑ Source selection ❑ Statement of Work

Additive Manufacturing Quandary

- AM is an emerging and evolving technology with a large potential to replace many current fabrication techniques on a select array of parts for satellites.
- The standard quality control and mission assurance approaches that are mature for most technologies have not been developed or are not appropriate for all aspects of AM. Specifically:
  - *Material specifications, properties, and powder re-use*
  - *Process specifications, control parameter refinement, and repeatability*
  - *Inspection criteria and method definition for all part varieties*
- Certification and qualification procedures, methods, and criteria are still in work for industry and regulating agencies.
- How do we get to “repeatable and reliable?”

Intended Product Use

- Target audience:
  - *M&P communities*
  - *Mission assurance professionals*
  - *Scientific and academic communities*
  - *Industry coordinated efforts*
- Information about AM for those needing to understand the detail issues of AM in regard to qualification efforts
  - *These charts will need to be updated as the technology matures*
- ASTM, SAE, SWE, NIST, AMUG, EWI, America Makes
  - *AM-specific conferences already address these societies and topics*
- The government needs to continue fostering AM science efforts and promote information sharing and material testing

Topic Follow-on Recommendations

- MAIW Follow-on recommendations:
  - *Quarterly/bi-annual updates of new technology and specification development for another year*

- Recommendation for all
  - *Currently no one is developing an industry-accepted certification method*
  - *Industry needs help establishing a broadly accepted method for government/agency/DOD for certification and qualification of AM parts*
  - *It is going to be used soon if it is not already in space*

Team Introductions

Company	Core Team	Additional SMEs	
The Aerospace Corporation	**Jim Nokes*** **Mike O'Brien***	**Emanuel Bucur*** **John Chobany** **William Endres** **Jennifer Lee**	**Woonsup Park** **Kara Schmitt** **Dave Witkin**
Ball Aerospace & Technologies Corp		**David French**	
The Boeing Company	**Carlos Torres***	**David Dietrich** **Kevin Slattery**	
Harris	**Carlyn Smith***	**Mu-Jen Yang**	
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JHU/APL		**Edmond Mitchell***	
MIT LL		**Michael Glynn***	
Northrop Grumman Aerospace Systems	**Kevin Meehan**	**Larry Pfafflin** **Ed Savage**	
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*Denotes workshop participant

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