Additive Manufacturing in Materials

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Additive Manufacturing (at MSFC)

- Extensive experience in Additive Manufacturing (AM) technologies and have been involved in about 30 different AM systems in the past 26 years.
- Over $11.5M capital investments in metallic powder bed systems in the past 5 years, and have committed significant engineering manpower resources
- NASA AM Objectives
  - Decrease production lead time & costs
  - Develop Flight Certification Standards
    - Released MSFC-STD-3716 and MSFC-SPEC-3717, 10-18-17
    - NASA-STD-6030 and NASA-STD-6033 Released in April 2021!
  - Process development and characterization
  - Share knowledge and data in pursuit of smart vendor base
  - Design optimized components & test at relevant conditions
  - Appropriate Application
    - High complexity & difficult to manufacture
    - Low production rate
    - Long lead time & high cost

EOS M100
Ø100x100 mm

DM3D LP-DED
12 ft X 8 ft X 10 ft

In House Capability:
- 6 Laser Powder Bed Fusion Machine in multiple alloys
- 4 Polymer Machines using multiple materials
- 1 Directed Energy Deposition System

•Advancing Technology and Industry•

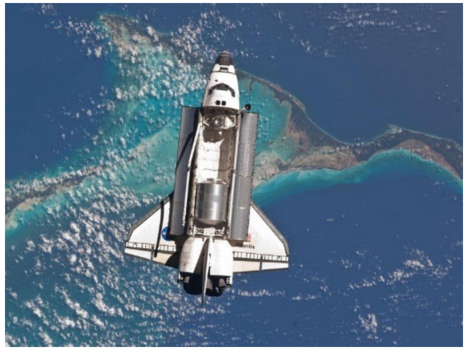
Facilitating Widespread Additive Manufacturing Development by Pushing Knowledge to Industry and NASA Partners

Big-Picture Take-Away Points

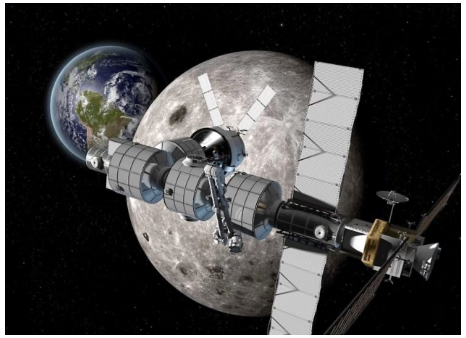
1. AM is likely one of the biggest opportunities for enabling the mission, and conserving cost and schedule
2. AM technology will continue to be a moving target.
   - It is on a pace similar to Moore's Law.
   - Adds to hype surrounding the technology
3. AM is likely one of the biggest risks in hardware reliability in the program
   - AM implementation is local, <u>each machine is like a foundry, with independent failure modes</u>.
   - A project without AM requirements holds a largely unchecked risk in hardware implementation
   - AM implementations and associated risk postures vary widely based on culture and personalities involved
   - AM has yet to reach a stage of proper "institutionalization" at many places (over-reliance on individuals)
4. There is no accepted common engineering practice for AM, as exists for other material and manufacturing processes
   - 6030 is intended as a basis to understand AM risk and to provide a common standard by which to judge AM implementations
   - 6030 is an aid for programs to control risk, with tailoring for efficiency, yet nothing is free
5. Continuous investment and work is needed by NASA to remain a smart-buyer of AM technology (critical to separate hype from reality)

NASA's motivation for AM Standards

- AM parts are already being use for NASA programs in critical applications
- Human exploration of space, especially deep space, requires <u>extreme</u> reliability



Low Earth		Deep Space
400 km	vs	400,000 - 400,000,000+ km
15-30 year life	vs	50 to 100+ years
Replacement Parts	vs	Limited Replacement
Nearby Safe Haven	vs	Largely on your own



Additive Manufacturing Certification

NASA-STD-6030

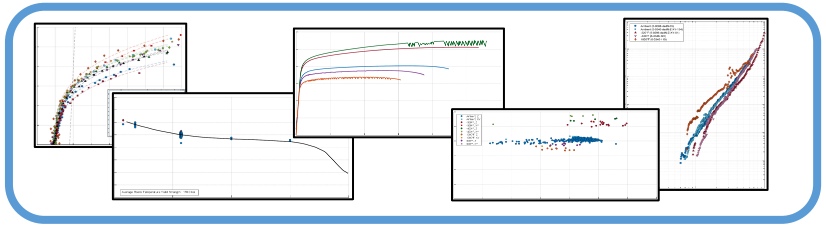
AM Standard for Crewed

NASA-STD-6033

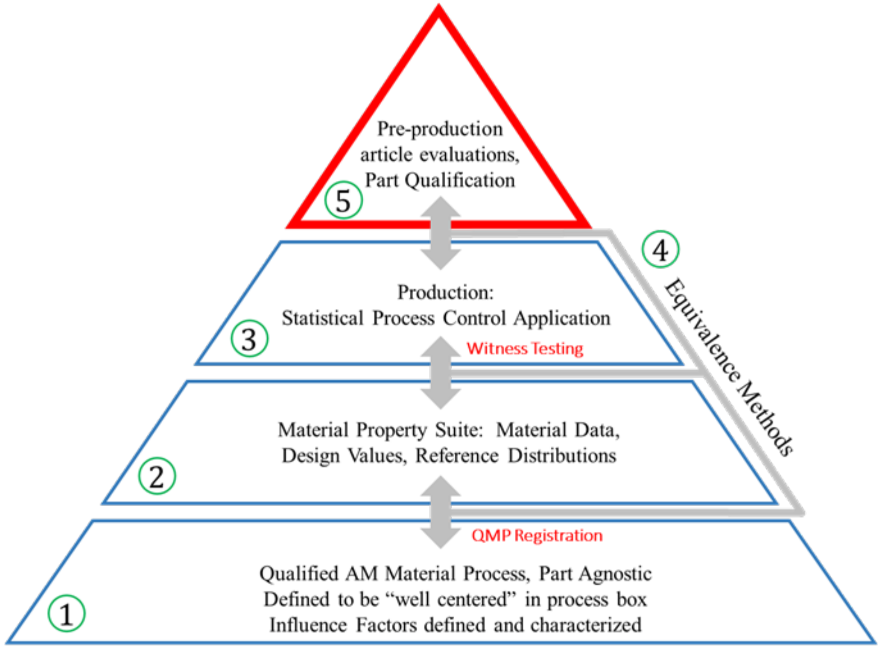
AM Spec for Equipment and Facilities

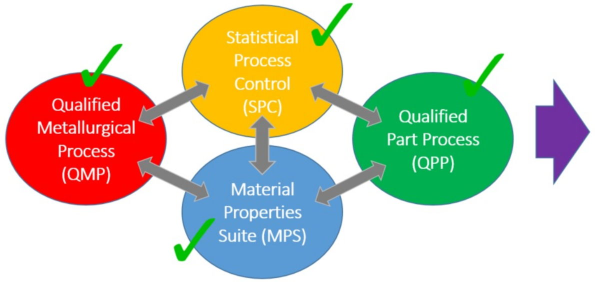
- MSFC Standard and Specification
  Release Date: October 18, 2017

- NASA-STD-6030 and NASA-STD-6033 Released in April 2021!

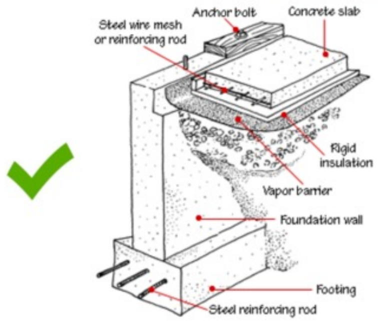


Part Production Sits on Top of a Solid Process Foundation

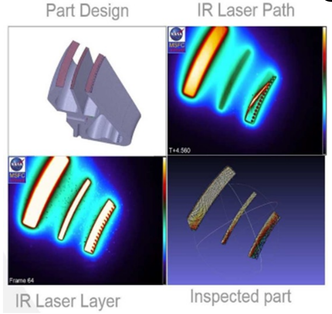




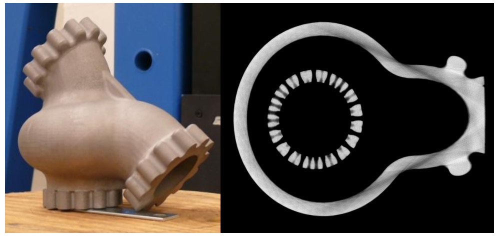
Rationale for Qualified AM parts



In-Situ Monitoring



NDE



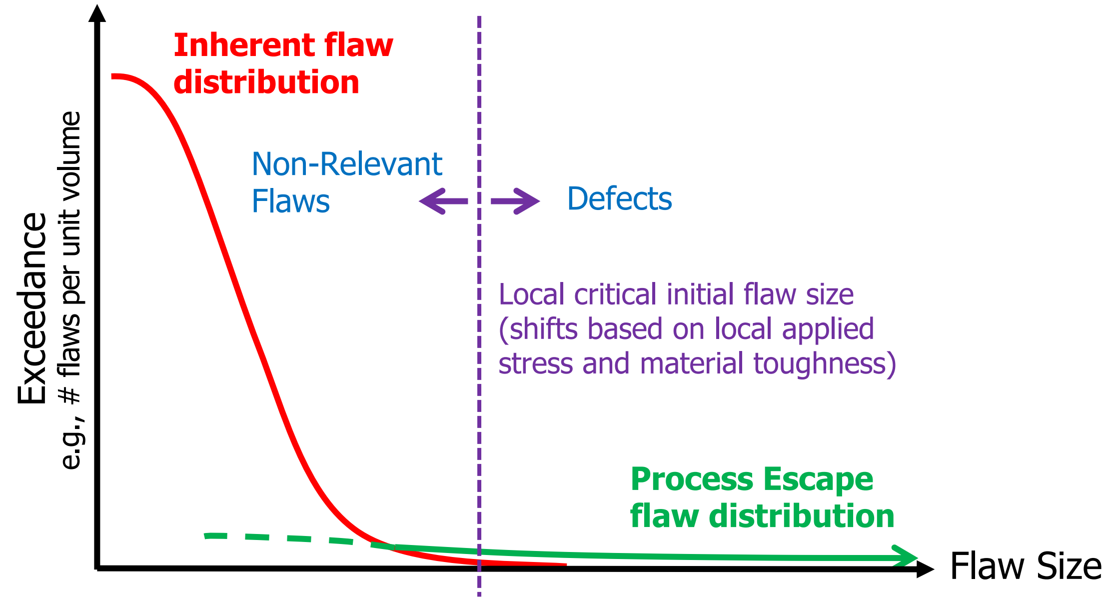
Challenges: Un-inspectable Hardware

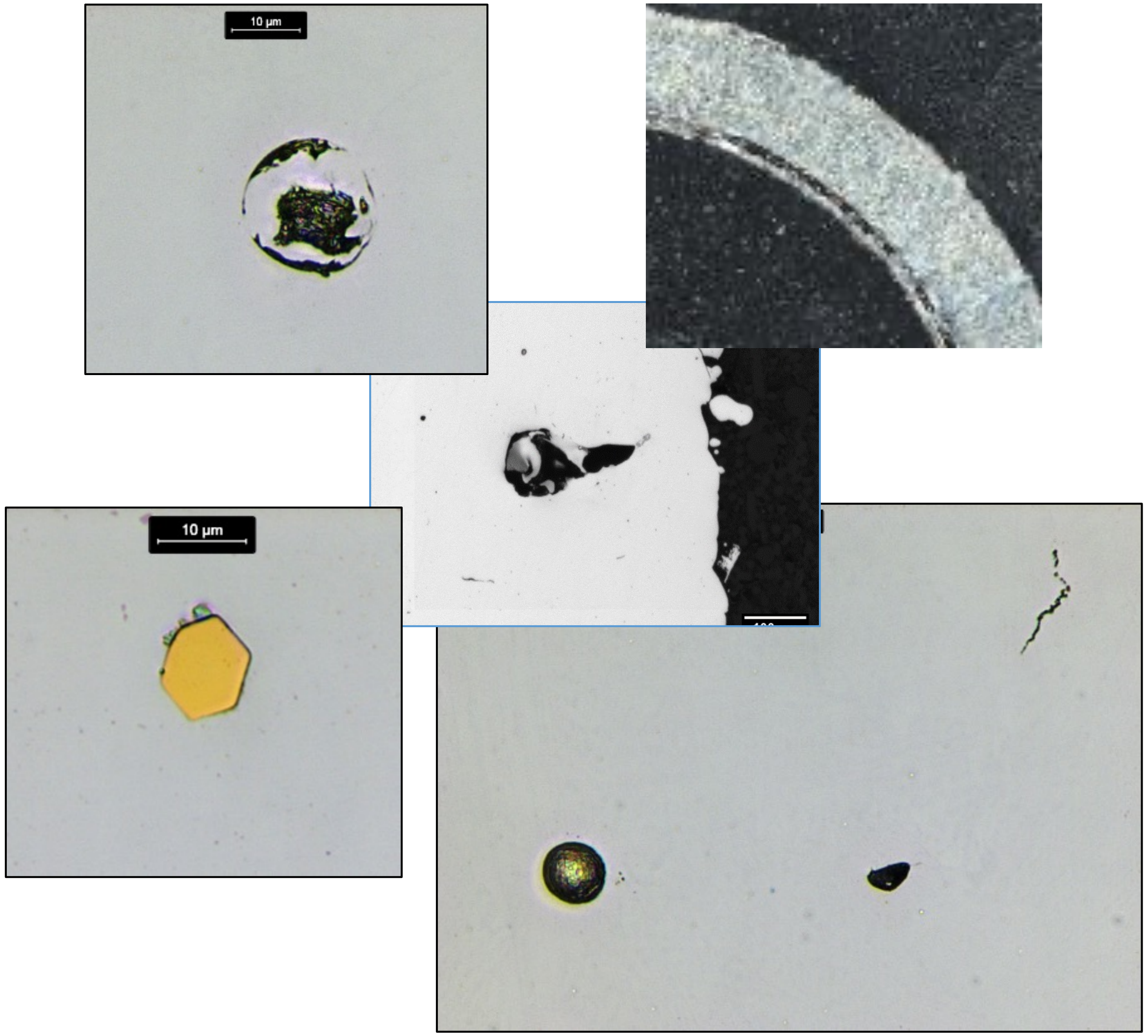
Complexity is Not Free

Problem: Fracture critical AM components with limited or no inspectability will be used for NASA programs.

Need: Develop a governing philosophy for a systematic and consistent approach for fracture control for AM parts without full inspectability.

- **Flaw** – an imperfection or discontinuity that may be detectable by nondestructive testing and is not necessarily rejectable. (Inherent flaws, Rogue flaws)
- **Defects** – one or more flaws whose aggregate size, shape, orientation, location, or properties do not meet specified acceptance criteria and are rejectable.





Challenges: Coming Reliance on In-Situ Monitoring

How to approach in-situ monitoring of AM processes?

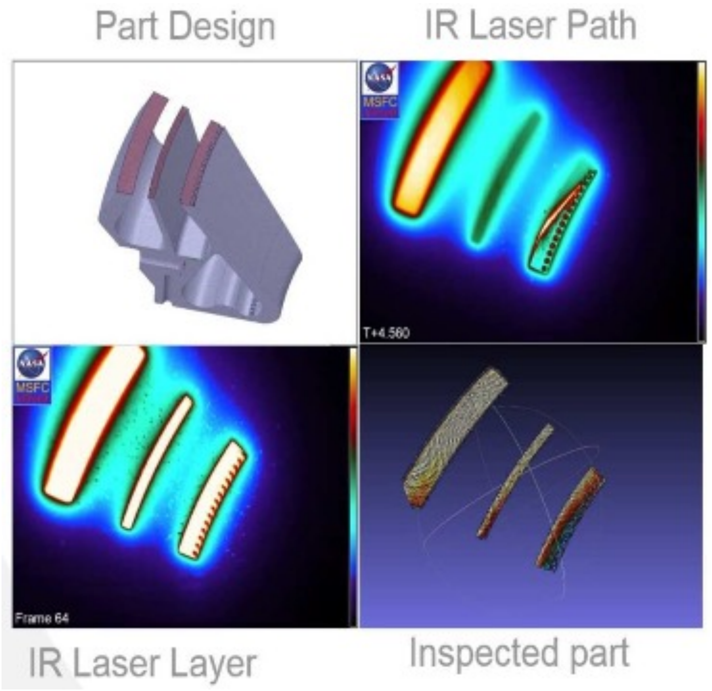
- Harnessing the technology is only half the battle
    - Detectors, data stream, data storage, computations
- Second half of the battle is quantifying in-situ process monitoring ***reliability***

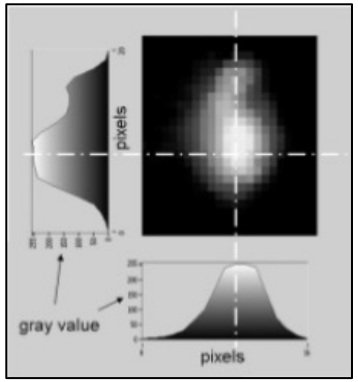
Community must realize that passive in-situ monitoring is an NDE technique

1. Understand physical basis for measured phenomena
2. Proven causal correlation from measured phenomena to a well-defined defect state
3. Proven level of reliability for detection of the defective process state
    - False negatives and false positives → understanding and balance is needed

Closed loop in-situ monitoring adds significantly to the reliability challenge

- No longer a NDE technique – *<u>may not be non-destructive</u>*
- Establishing the ***reliability of the algorithm*** used to interact and intervene in the AM process adds considerable complexity over passive systems





Concept Laser QM Meltpool

Summary

- MSFC has vast experience and investment in AM
- Extensive in-house capability, processes and alloys
- AM evolving rapidly, balance risk vs reward
- Critical mass of NASA AM certification knowledge exists in EM
- AM challenges are being worked, new ones evolve with the technology
- EM is characterizing AM to advance NASA and Industry

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