
# Additive Manufacturing @ NASA

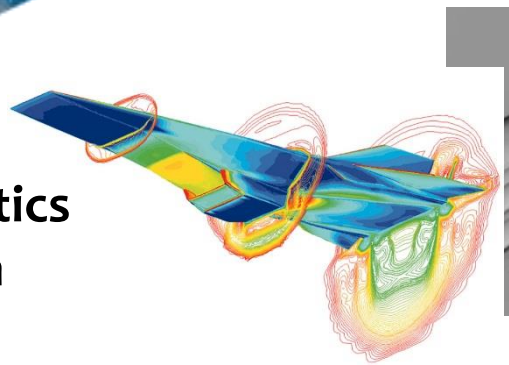
**A Summary of NASA 's Efforts in the Development of Additively Manufactured Metallic Hardware**

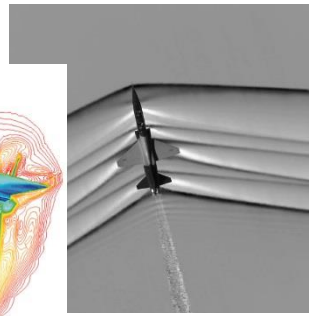
Aircraft Airworthiness and Sustainment 2019, Brisbane, Australia | July 26 2019

Douglas Wells, Technical Specialist

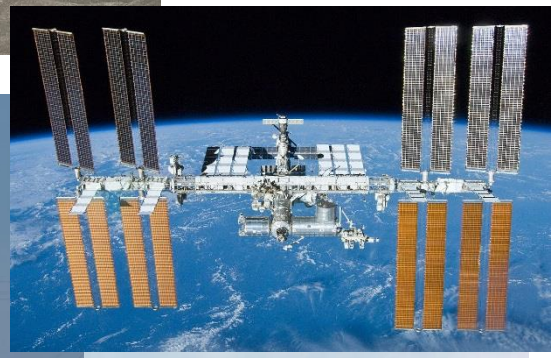
# The NASA Mission Directorates

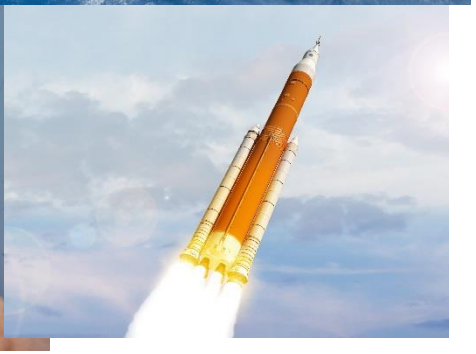
## Aeronautics Research



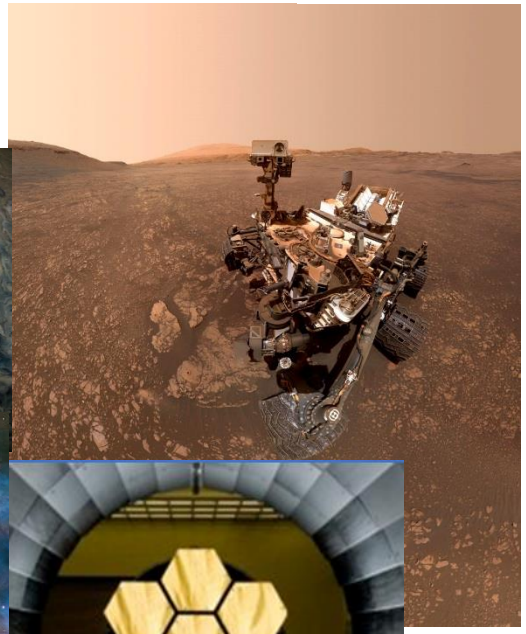


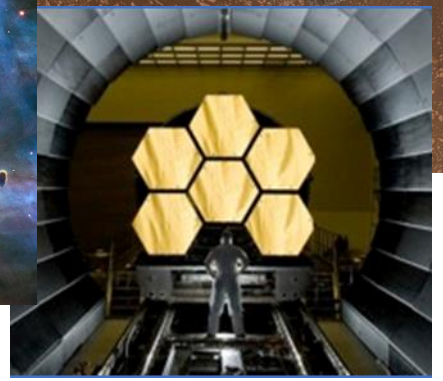
## Human Exploration and Operations (HEO)

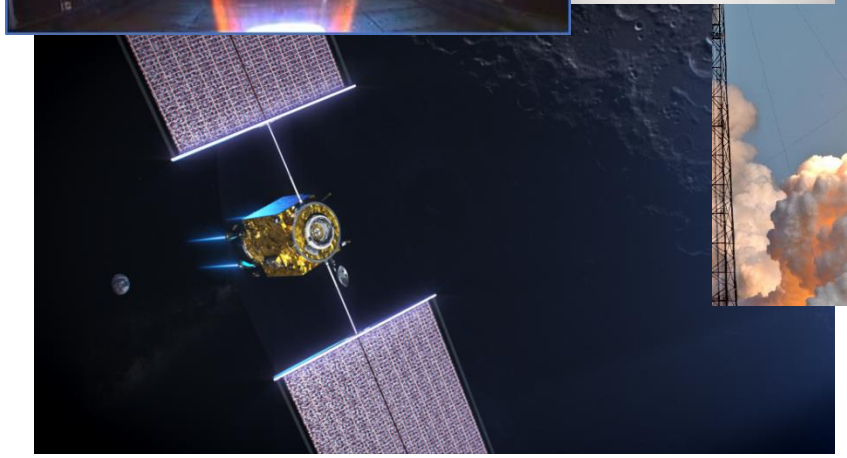




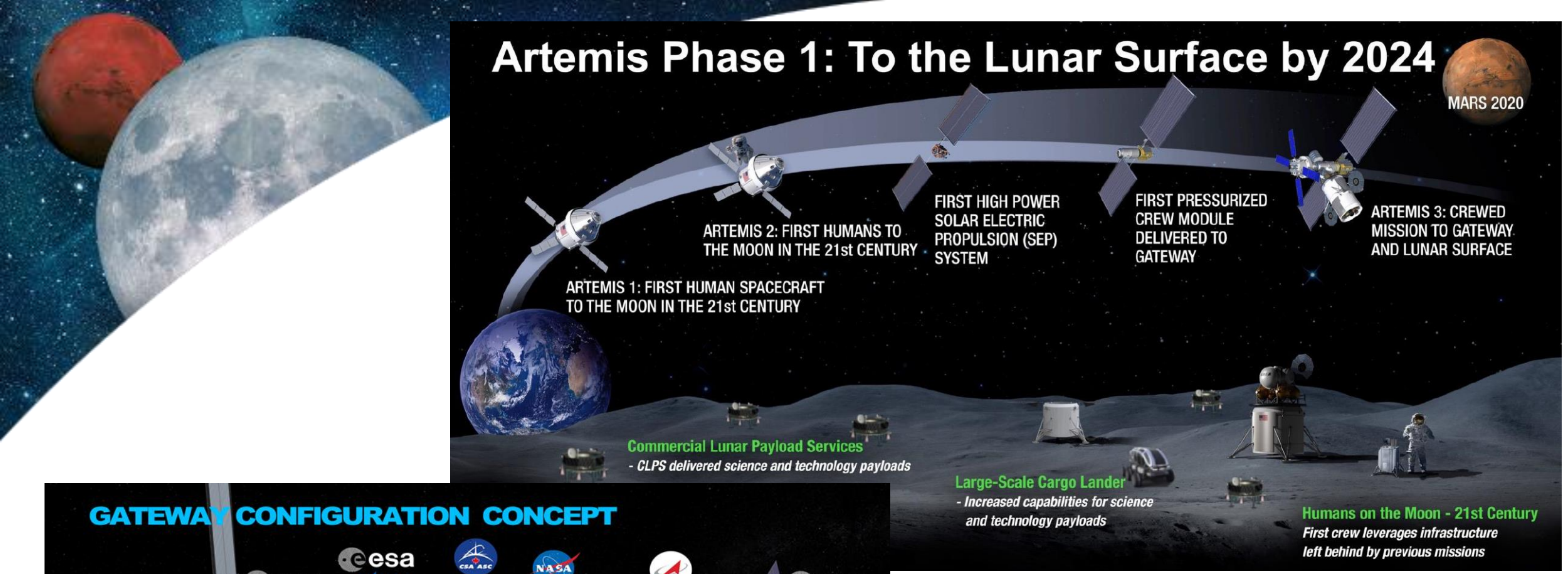
## Science

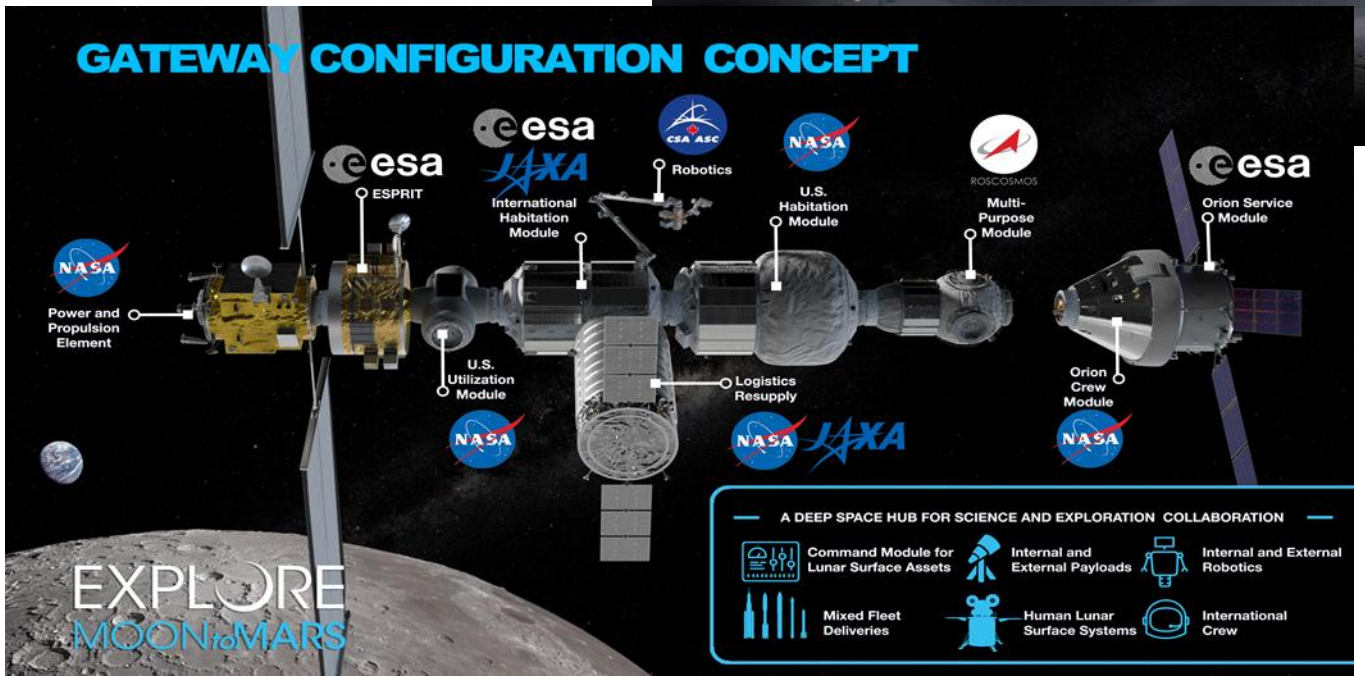






## Space Technology




# The Latest Challenges

# Additive Manufacturing at NASA

**AM is a subset of NASA's Advanced Manufacturing projects**

**Across missions, NASA's AM involvement covers all Technology Readiness Levels**

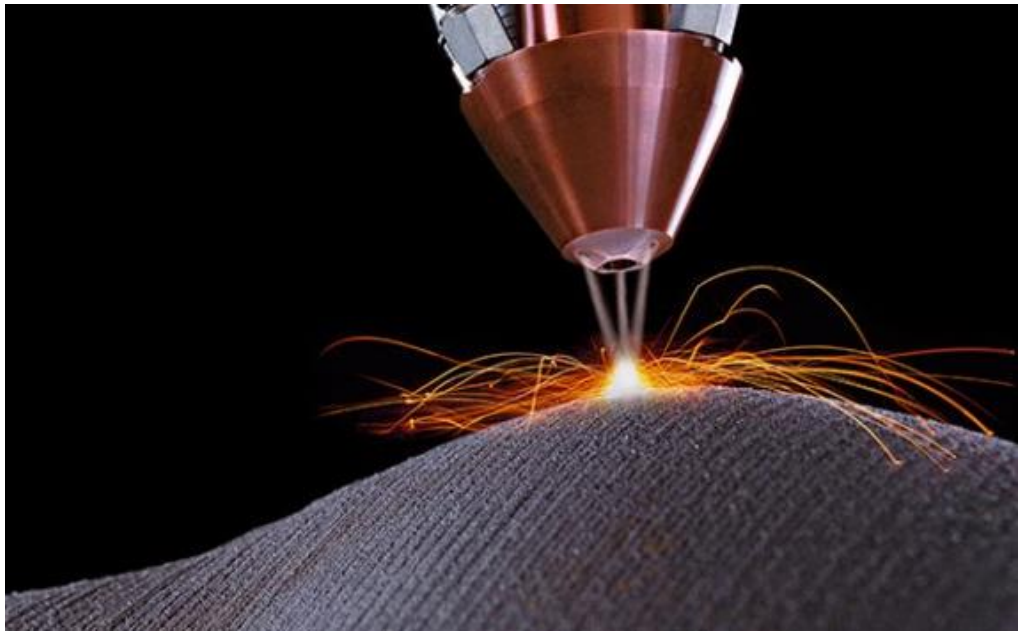
**Space applications include Earth-to-Space transportation and In-Space sustainment**

## NASA's motivations in AM are common:

- We see AM as an enabling technology
  - Design innovation
  - Cost reduction
  - Time savings

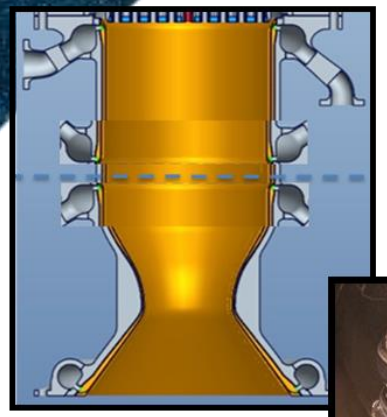
For high-TRL applications,
the primary focus is *SAFE IMPLIMENTATION*

- Attention to Standardization
- Development of qualification and certification methodologies



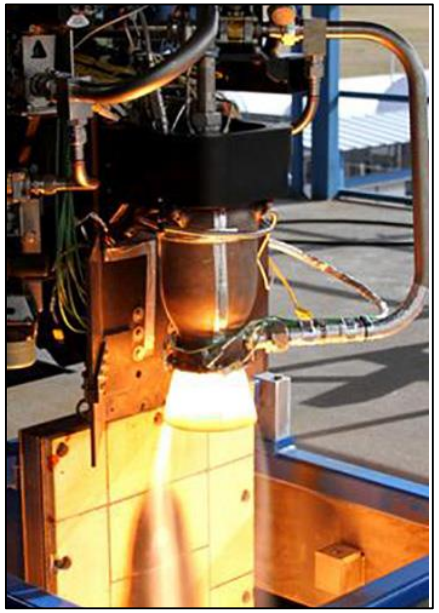
# Additive Manufacturing at NASA
# HEO Applications

## For-Space Applications



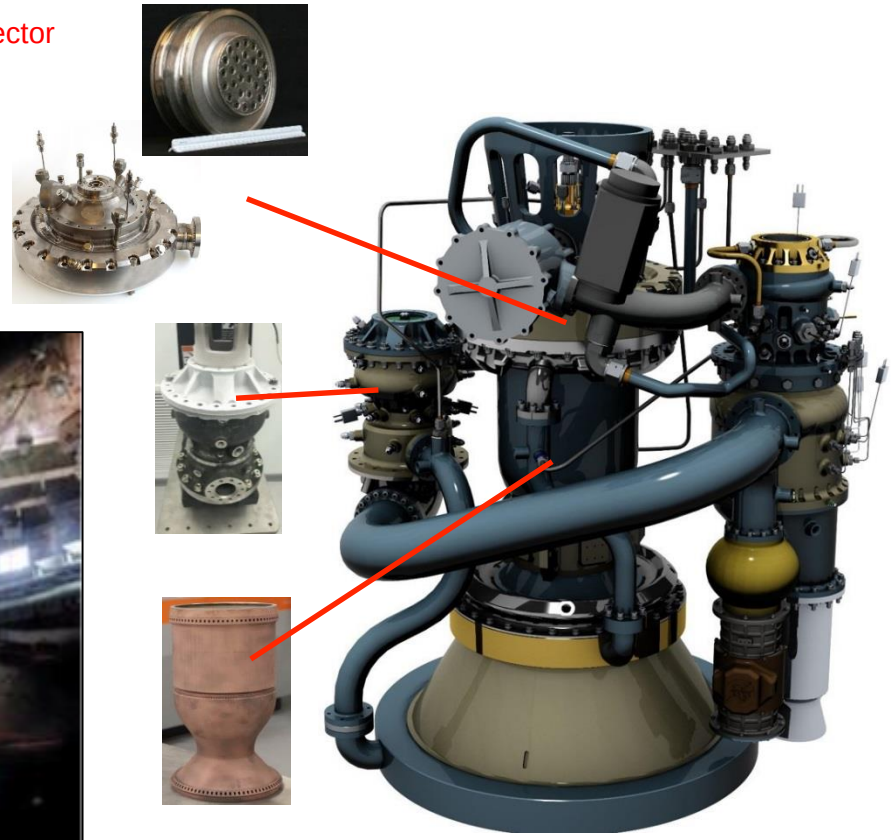
Schematic of integrated SLM copper/EBF$^3$ Inconel nozzle

Nozzle after completion of EBF$^3$ deposition of Inconel onto SLM copper liner



**SpaceX SuperDraco**

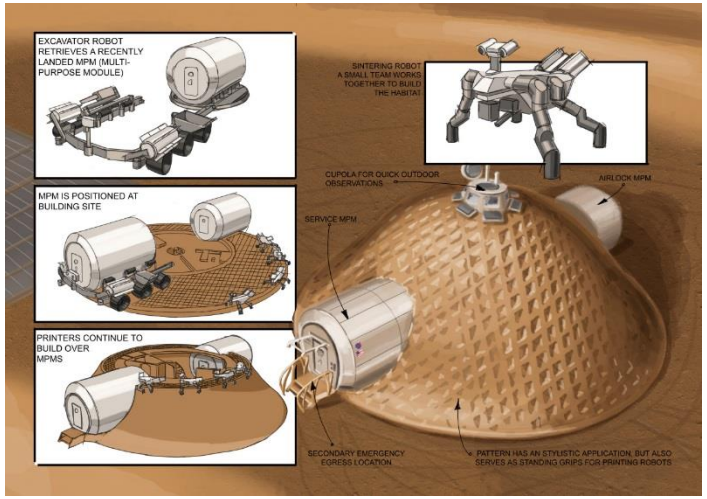
**Aerojet-Rocketdyne RS-25**



# Additive Manufacturing at NASA
# HEO Applications

## In-Space Manufacturing


### Regolith



# AM Certification: Standardization Activities

## *Avoiding ad hoc implementations of AM*

- NASA Standards and Specifications
- Industry consensus standards
  - ASTM F42 Committee on Additive Manufacturing
  - ISO TC261 Additive Manufacturing
  - ASTM Center of Excellence in Additive Manufacturing
  - SAE Technical Committee, AMS AM Additive Manufacturing



NOT MEASUREMENT SENSITIVE

MSFC-STD-3716
REVISION: DRAFT 1
EFFECTIVE DATE: Not Released

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

EM20
MSFC TECHNICAL STANDARD

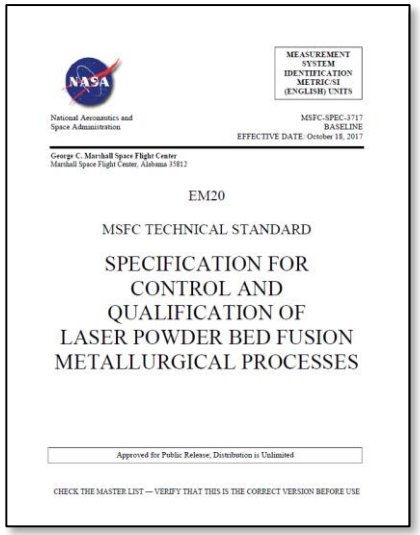
Standard for Additively Manufactured Spaceflight Hardware by Laser Powder Bed Fusion in Metals

DRAFT 1 – April 10, 2017

This official draft has not been approved and is subject to modification.
DO NOT USE PRIOR TO APPROVAL

CHECK THE MASTER LIST — VERIFY THAT THIS IS THE CORRECT VERSION BEFORE USE

THIS STANDARD HAS NOT BEEN REVIEWED FOR EXPORT CONTROL RESTRICTIONS
DRAFT VERSIONS DISTRIBUTED FOR REVIEW ARE NOT TO BE DISSEMINATED


MEASUREMENT SYSTEM IDENTIFICATION METRIC/SI (ENGLISH) UNITS

National Aeronautics and Space Administration

MSFC-SPEC-3717
BASELINE
EFFECTIVE DATE: October 18, 2017

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

EM20

MSFC TECHNICAL STANDARD

SPECIFICATION FOR CONTROL AND QUALIFICATION OF LASER POWDER BED FUSION METALLURGICAL PROCESSES

Approved for Public Release; Distribution is Unlimited

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# NASA Standards and Specifications in AM

MSFC-STD-3716


MSFC-SPEC-3717


Governing Requirements

Requirements:
Process definition
Qualification

Requirements:
Equipment and facility process control

NASA-STD-603X

AM Standard for Crewed

NASA-STD-603X

AM Standard for Non-Crewed

NASA-STD-603X

AM Standard for Aero

NASA-SPEC-603X

AM Spec for Equipment and Facilities

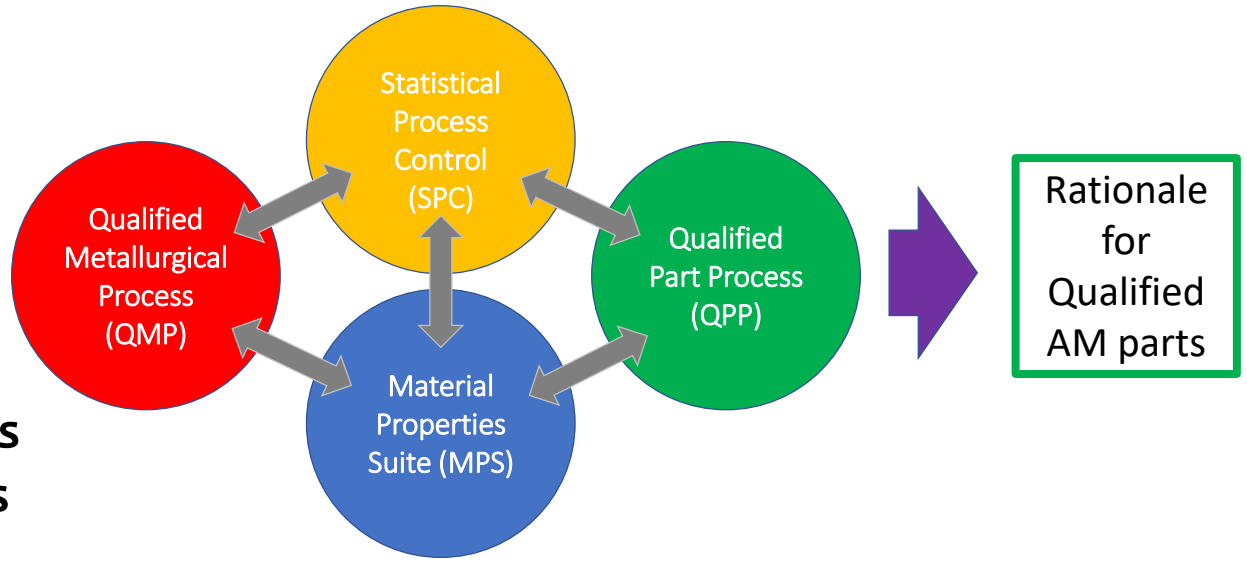
NASA-HDBK-603X

Handbook to AM Standards

# AM Certification: Governing Principles

- ***Understanding*** and ***Appreciation*** of the AM process
- ***Integration*** across disciplines and throughout the process
- ***Discipline*** to define and follow the plan

- Have a plan
- Integrate a Quality Management System (QMS)
- Build a foundation
  - Equipment and Facility
  - Training
  - Process and machine qualification
  - Material Properties / SPC
- Plan each Part
  - Design, classification, Pre-production articles
  - Qualify and lock the part production process
- Produce to the plan – Stick to the plan

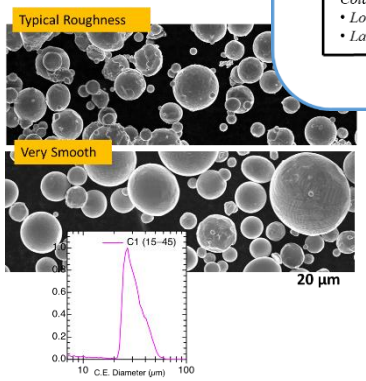


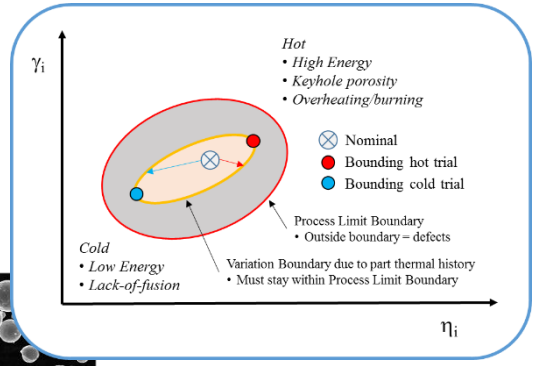
# AM Certification: Governing Principles

## Process Qualification and Control

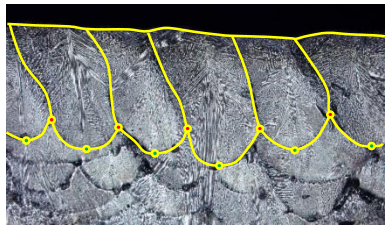
Start-to-Finish Holistic Integration

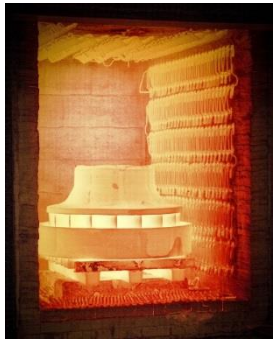
### Feedstock

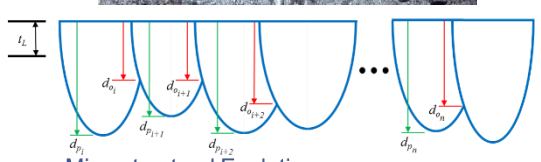



### Process Mapping

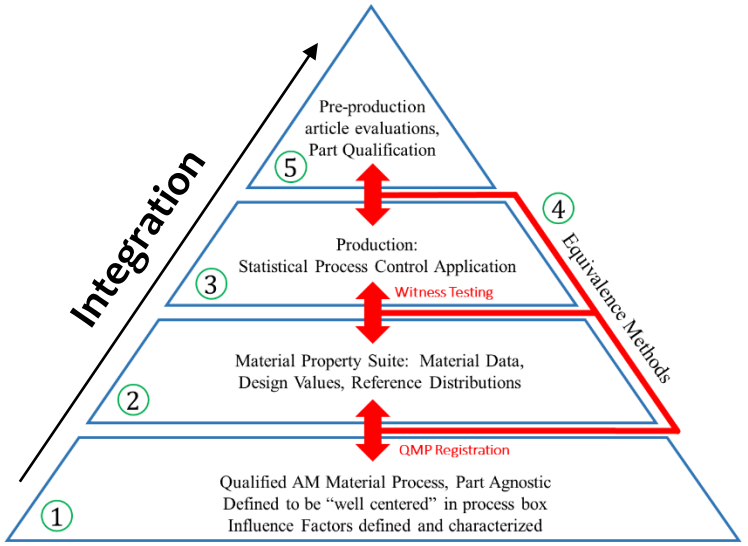




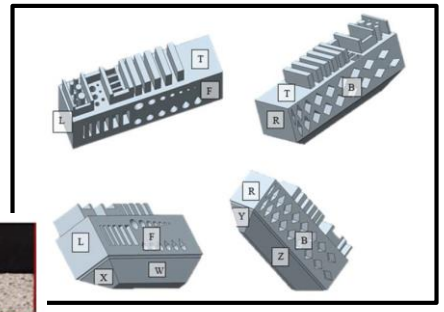


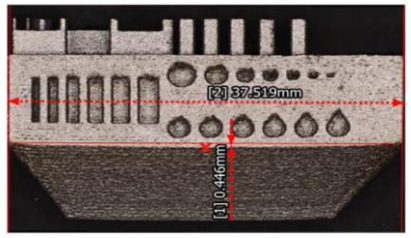


### Fusion Process/Thermal Process/Microstructure

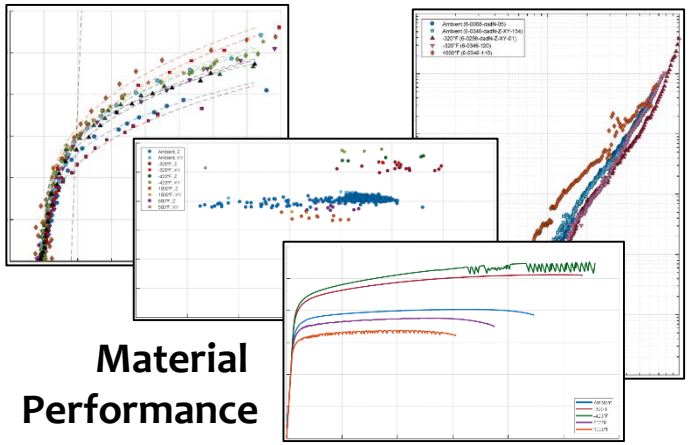



### Reference Parts

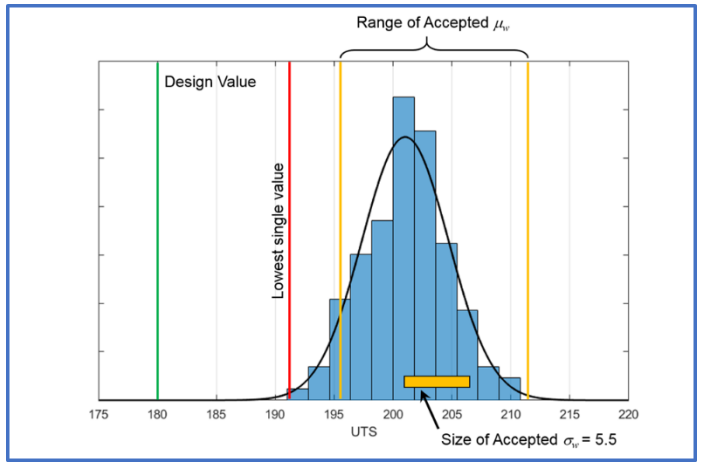





### Surface Texture & Detail Resolution



### Material Performance

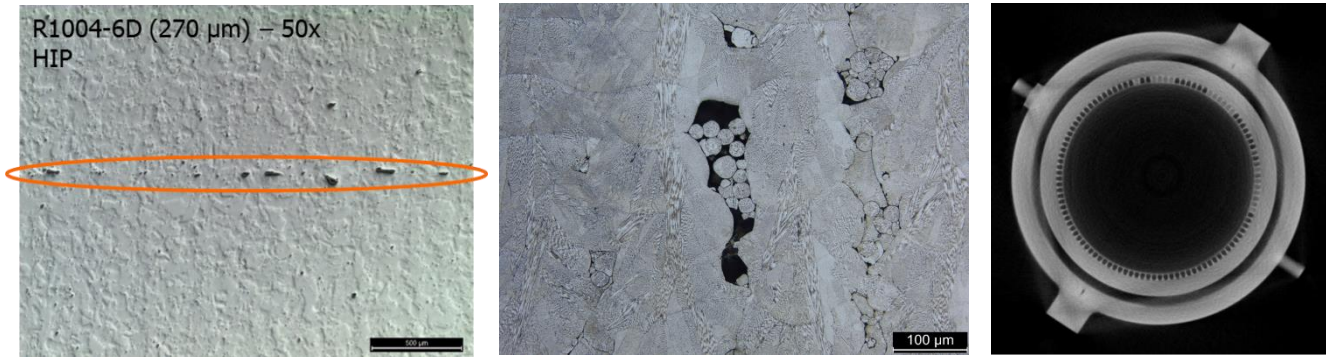


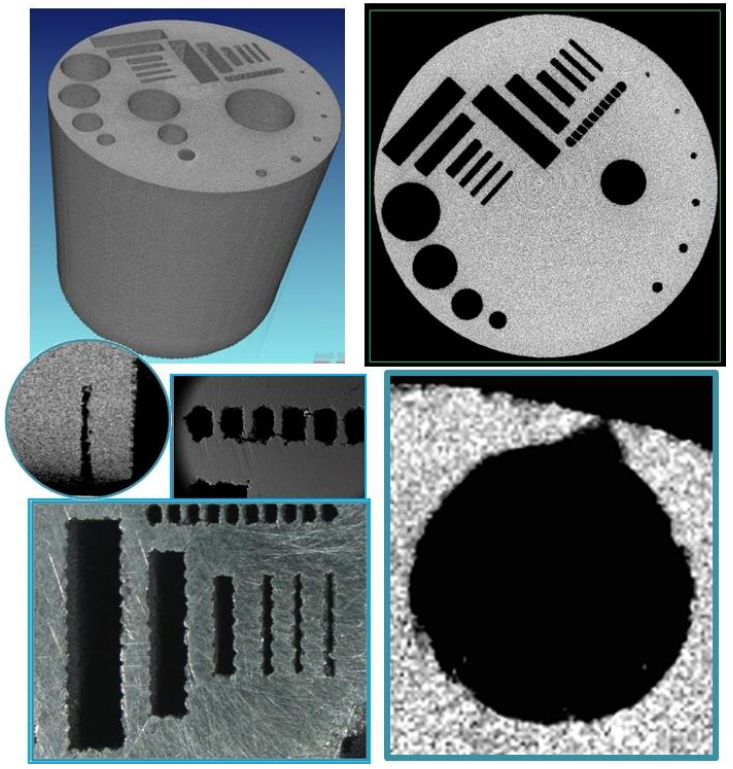

### Statistical Process Controls

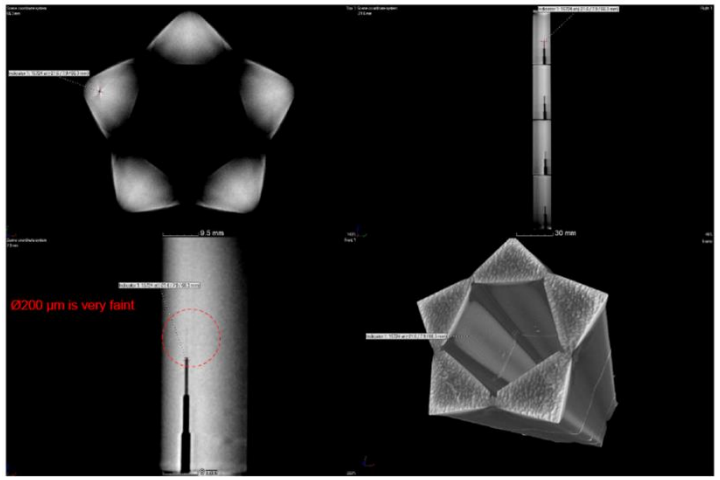
# AM Certification: Technology Challenges

## Non-destructive Evaluation

### Understanding AM defect characteristics






Moving CT from research mode to certification mode.

**<u>Must shift the CT culture and focus</u>**

**From:**

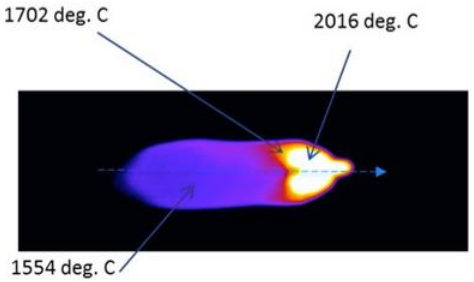
**“How small a defect can be found?”**

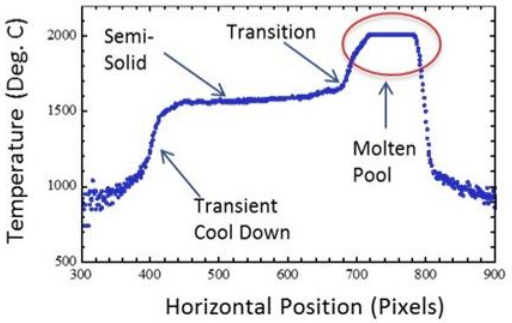
**To:**

**“How large a defect can be missed?”**

# AM Certification: Technology Challenges

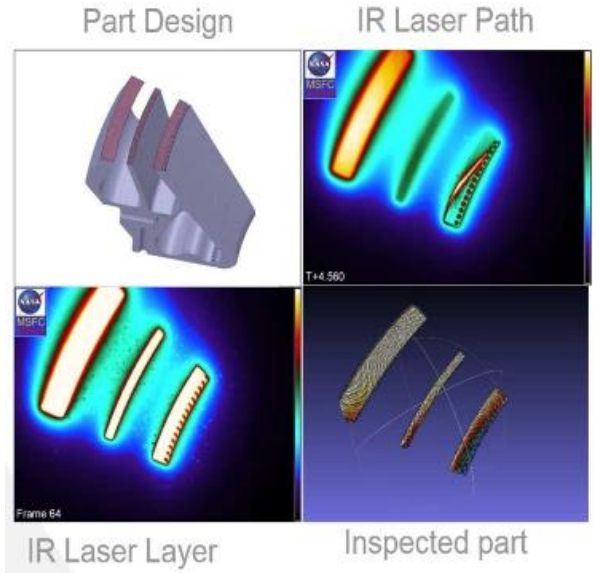
## In situ Process Monitoring




**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***




**<u>Community must realize that passive in-situ monitoring is an NDE technique</u>**

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**

**<u>Closed loop in-situ monitoring adds significantly to the reliability challenge</u>**

**No longer a NDE technique – *<u>may not be non-destructive</u>***

**Establishing the *<u>reliability of the algorithm</u>* used to interact and intervene in the AM process adds considerable complexity over passive systems**

# Thank You

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