National Aeronautics and Space Administration


# Observations from Initial Implementation of NASA MSFC AM Standards

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# Summary of Presentation

- The challenge of integration in the implementation of AM
- Brief overview of unique concepts in NASA MSFC AM standards
  - MSFC-STD-3716 "*Standard of Additively Manufactured Spaceflight Hardware by Laser Powder Bed Fusion in Metals*"
  - MSFC-SPEC-3717 "*Specification for Control and Qualification of Laser Powder Bed Fusion Metallurgical Processes*"
- Observations on experience in the early implementation of these AM requirements at various scales
- Forward direction of these documents and related Agency efforts

# The challenge of integration in the implementation of AM


The NASA MSFC AM standards require integration across disciplines

- Design
- Qualification of Metallurgical Processes
- Qualification of Part Processes and Part Production Plans
- Substantiation of AM Material Property Design Values
  - Statistical Process Control
  - Equivalency arguments
- Structural Integrity Rationale
  - Fracture Control / NDE
  - Process controls

Successful integration requires

- Cross-discipline communication
- Proper organization products and information for certification
- Ownership of these integration responsibilities

# Overview of key topics requiring integration

The following slides are intended to briefly reintroduce a limited set of attributes of the standards that are important to this integrated approach and provide the basis for observations that follow.

Assumption: The AM standard with the most cryptic acronyms wins the prize.

**AMCP**

## Additive Manufacturing Control Plan

Defines the methods of implementation and any tailoring of requirements

Typically the AMCP becomes the governing document.

QMS

## Quality Management System

The standard is explicit in the need for a Quality Management System in place regarding all aspects of AM production.

# Qualified Metallurgical Process

A methodology to confirm and document the integrity of the AM process as implemented by each AM machine.

**QMP**

The QMP is an enabling concept for evaluating consistency of the AM process, machine requalification, design values, and other key aspects of integration in the production of critical AM parts.

## Qualified Part Process

A methodology to confirm and document the integrity of AM parts produced to a QMP, and then control the future production of those parts.

**QPP**

# Material Property Suite

A methodology to establish and maintain AM material property design values. Requires integration of statistical process controls and the concept of establishing "equivalency" in properties of qualified processes. An MPS consists of

- Material property data
- Design Values
- Descriptors of nominal material performance
- Statistical process control criteria for evaluation of processes

**MPS**

## Integrated Structural Integrity Rationale

A required, brief statement describing the rationale for the safety of the AM part.

Content and specificity of the ISIR depends upon the criticality and complexity of the AM part.

**ISIR**

# Statistical Process Control

In this context, SPC represents a variety of measures used to continuously monitor the health of the AM process.

- Currently, SPC typically only provides information on the systemic health of the AM process.
- SPC is an enabler for AM design values and structural integrity rationale.

**SPC**

# Part Production Plan

The Part Production Plan provides and integrated review of the design and production of each AM part or family of parts.

Provides NASA insight into risks with AM parts.

**PPP**

# Pre-Production Article

The Pre-Production Article provides evidence of successful QMP implementation and other controls and operations required for a successful part, essential to establish a QPP

The PPA serves the "first article" role in the classic materials and processes sense (dissections) as well as the production sense per SAE AS9102.

**PPA**

# Non-Destructive Evaluation

NDE remains the primary challenge to AM part integrity assurance.

The growing desired reliance on Computed Tomography (CT) presents anticipated challenges.

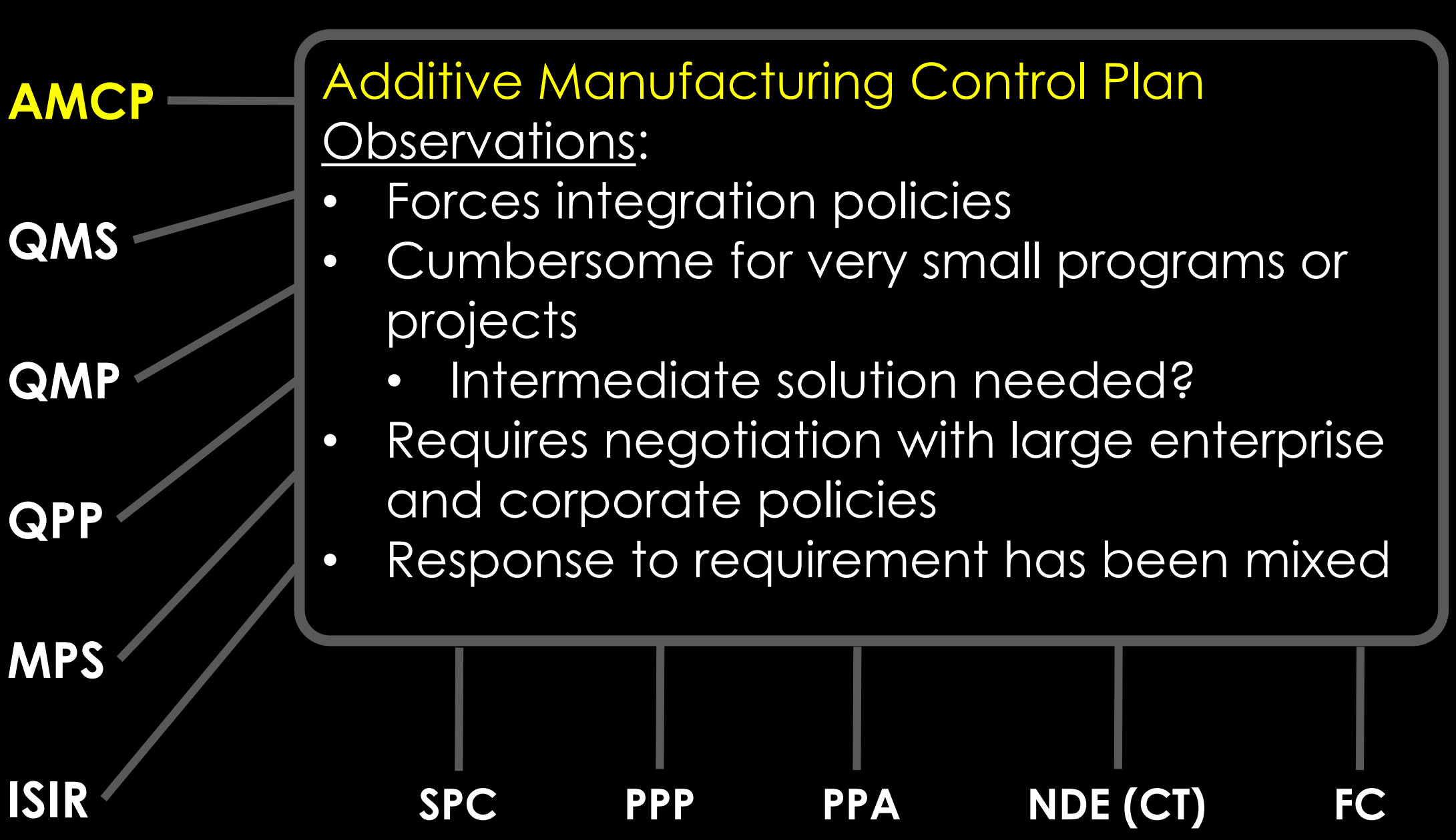
**NDE (CT)**

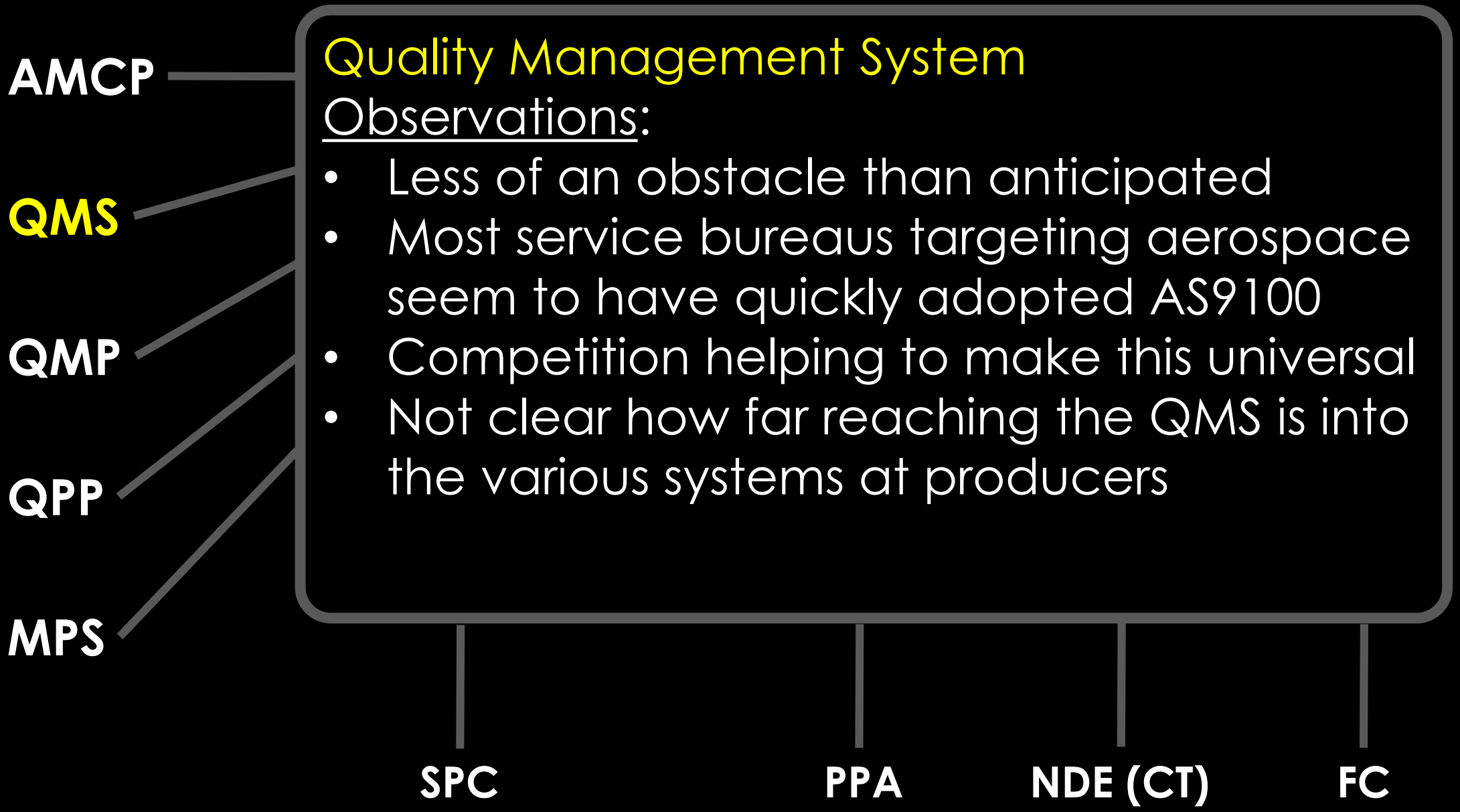
# Fracture Control

The bane of most human-rated programs.

The primary integration challenge for critical AM parts.

FC


AMCP
QMS
QMP
QPP
MPS
ISIR
Additive Manufacturing Control Plan
Observations:
• Forces integration policies
• Cumbersome for very small programs or projects
• Intermediate solution needed?
• Requires negotiation with large enterprise and corporate policies
• Response to requirement has been mixed
SPC
PPP
PPA
NDE (CT)
FC


AMCP
QMS
QMP
QPP
MPS
Quality Management System
Observations:
• Less of an obstacle than anticipated
• Most service bureaus targeting aerospace seem to have quickly adopted AS9100
• Competition helping to make this universal
• Not clear how far reaching the QMS is into the various systems at producers
SPC
PPA
NDE (CT)
FC

## Qualified Metallurgical Process

Observations:

- Remains the key enabler
  - Methodology to determine quality of AM process as implemented by a AM machine
  - Required to substantiate use of design values
- Needs standardization in methodology
- Complicated and subjective
- Exemplars
  - Find balance of prescriptive requirements versus freedom of generalization

**QMP**

**MPS**

**SPC**

# Qualified Metallurgical Process

- Needs standardization in methodology
- **ASTM Additive Manufacturing Center of Excellence**

ASTM INTERNATIONAL
Helping our world work better

AUBURN UNIVERSITY

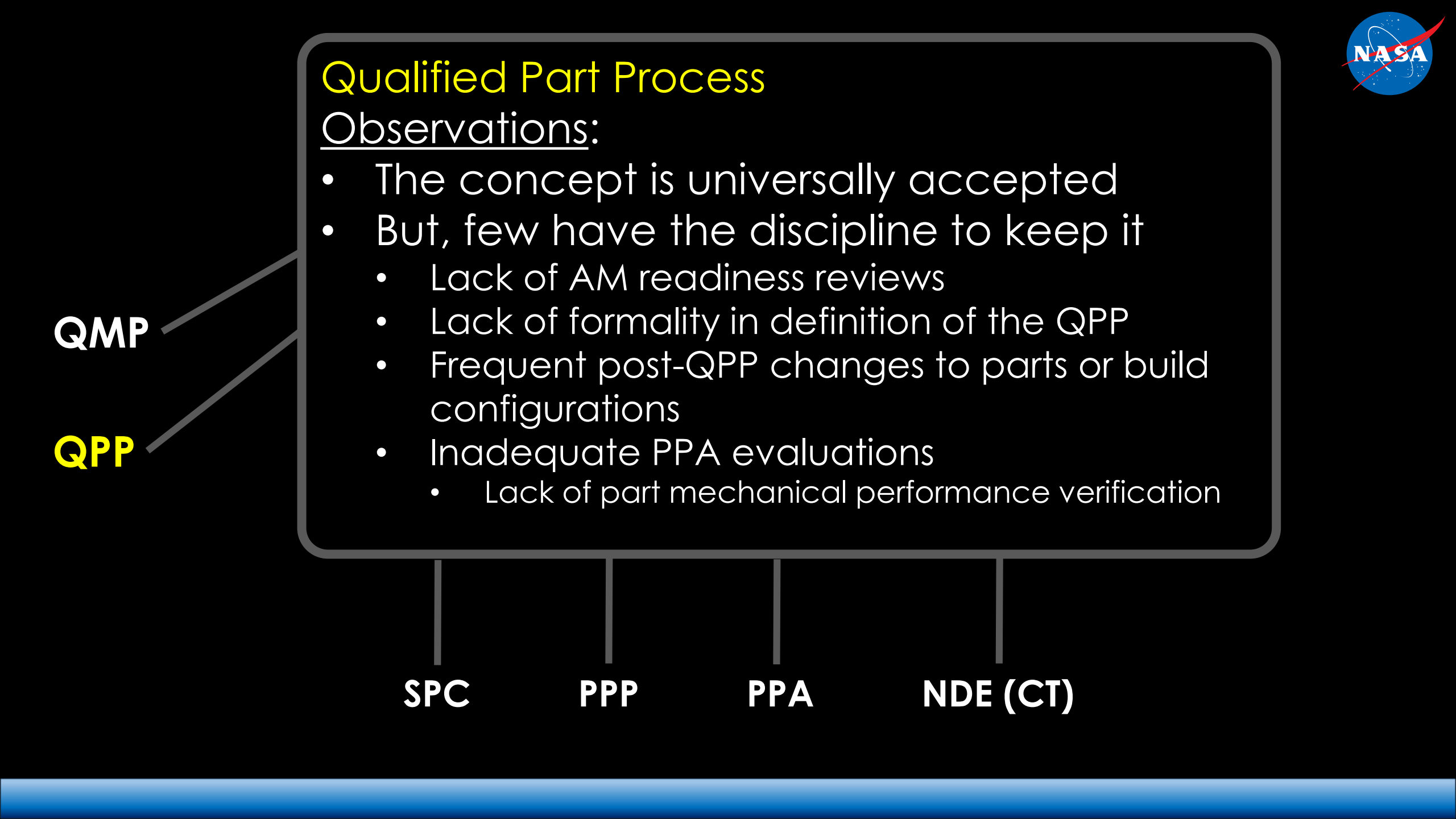
EWI
We Manufacture Innovation

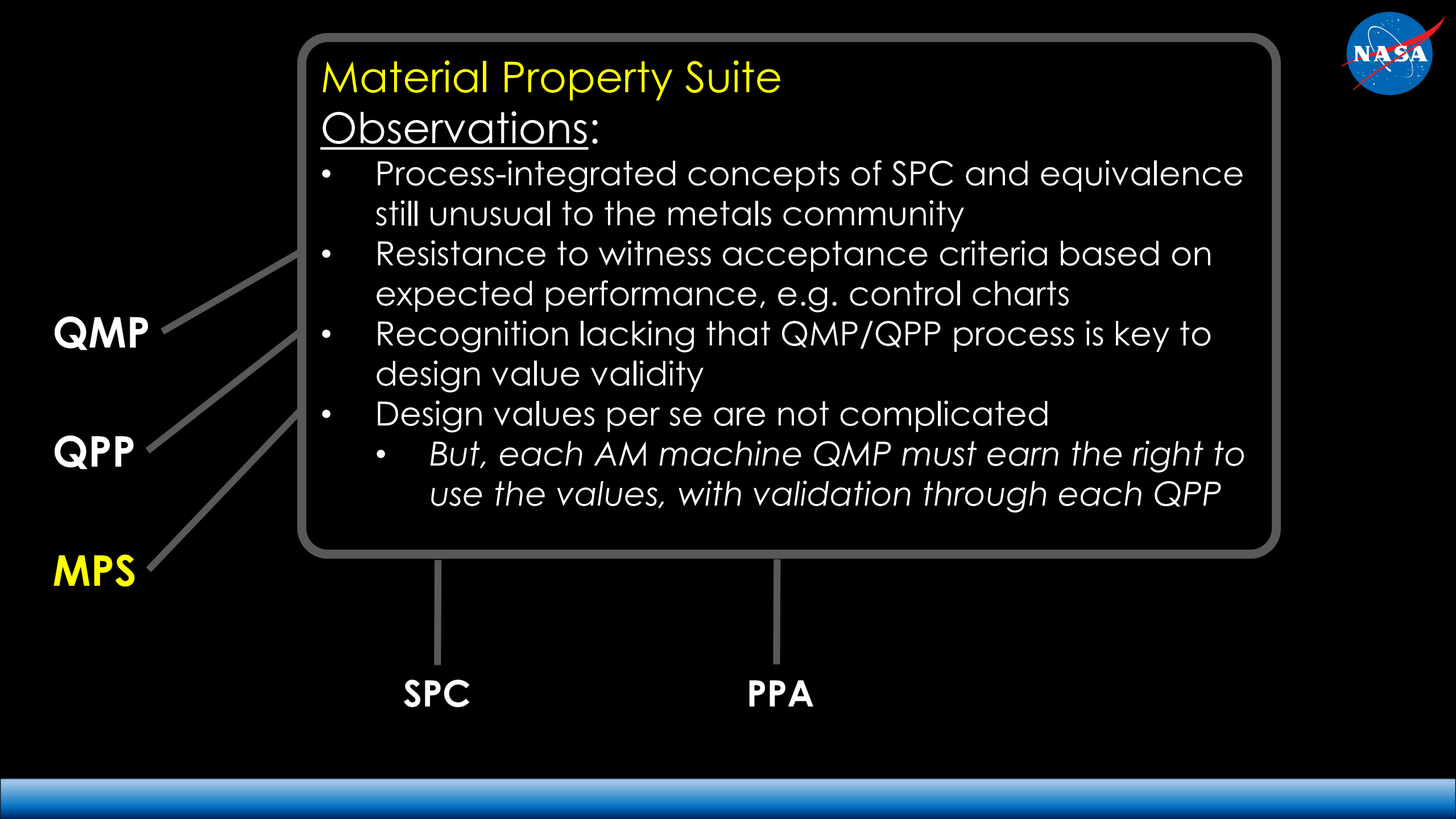
mtc
Manufacturing Technology Centre

**QMP**

**MPS**

**SPC**


Qualified Part Process
Observations:
• The concept is universally accepted
• But, few have the discipline to keep it
• Lack of AM readiness reviews
• Lack of formality in definition of the QPP
• Frequent post-QPP changes to parts or build configurations
• Inadequate PPA evaluations
• Lack of part mechanical performance verification
QMP
QPP
SPC
PPP
PPA
NDE (CT)


Material Property Suite
Observations:
• Process-integrated concepts of SPC and equivalence still unusual to the metals community
• Resistance to witness acceptance criteria based on expected performance, e.g. control charts
• Recognition lacking that QMP/QPP process is key to design value validity
• Design values per se are not complicated
• But, each AM machine QMP must earn the right to use the values, with validation through each QPP
QMP
QPP
MPS
SPC
PPA

# Integrated Structural Integrity Rationale

Observations:

- Most difficult content to make adequate in the PPP
- Requires knowledge and communication to integrate across material, structural, manufacturing, NDE and Quality disciplines
- Most valuable part of the PPP for understanding part risk as well as the capability and appreciation of the AM development team
- Growing desired reliance on CT
  - CT must move from the research mentality of "how small of a flaw can I find" toward "how big a flaw can I miss"

QMP

QPP

MPS

ISIR

SPC

PPP

NDE (CT)

FC

# Forward Direction

- MSFC-STD-3716 and MSFC-SPEC-3717
- Generally pleased with the controls the documents provide
  - No Immediate plans for major changes in direction
- Revisions underway to
  - Make corrections and improve clarity
  - Better accommodate low criticality projects
    - Non-structural, “do no harm” cases, JSC Class 1-E
- Plan to incorporate industry standards to the extent possible as they become available and considered appropriate

# Forward Direction - Agency-wide AM Standards

- NASA Engineering and Safety Center (NESC) has established a team
  - Representatives from across Agency and external entities
  - Intent to develop AM standards for all Agency uses

- Expect to develop distinct standards tailored to three Agency needs
  - Human-rated spaceflight
  - Non-human-rated spaceflight
  - Aeronautics

- Approach
  - Cover broad scope of currently used processes and materials
  - Polymers and metals
  - Concepts based on MSFC-STD-3716, MSFC-SPEC-3717


# Thank you!