



Lessons Learned in Implementing the NASA 6030 AM Standard-based Qualification for Spaceflight

Alison Park
Deputy Tech Fellow
NASA Engineering and Safety Center

APICAM, June 30, 2025
Virtual

Public Release





What are NASA's roles in "doing Additive Manufacturing things"

What does "doing AM Qualification and Certification" (QnC) mean at NASA?

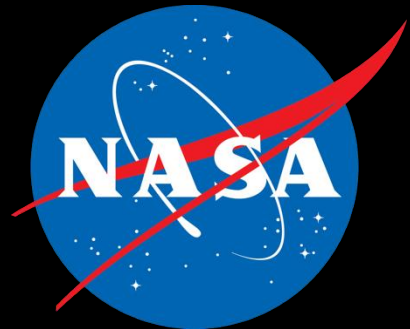
Examples of AM QnC activities at NASA

Findings and Observations

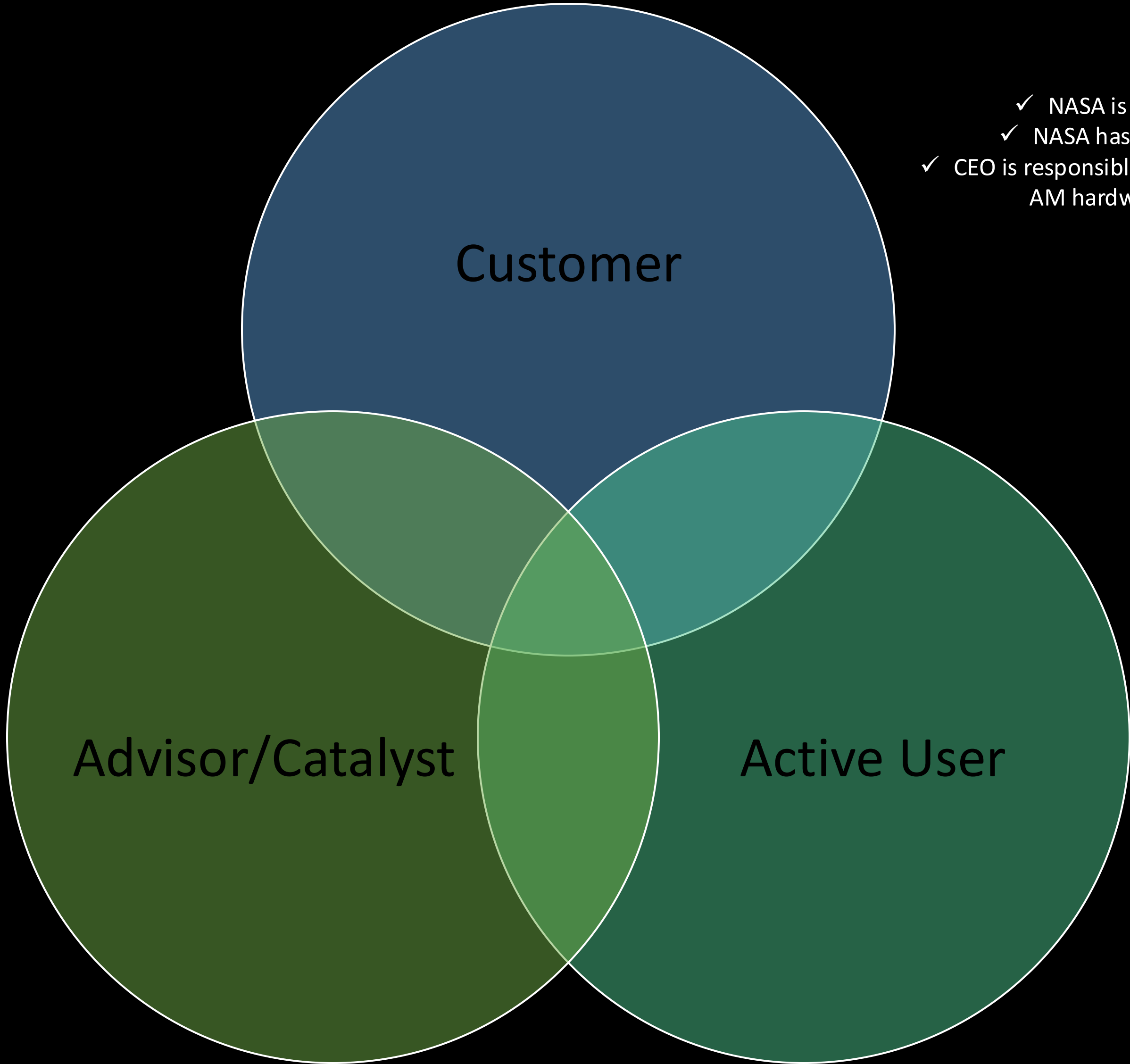
Lessons Learned in doing NASA AM QnC

What's next for NASA-STD-6030 and NASA AM QnC Group?

NASA's Roles in Additive Manufacturing



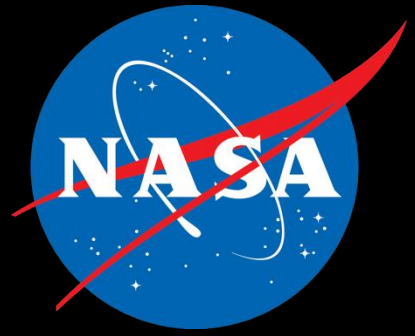
- ✓ NASA does fundamental research
- ✓ NASA infuses and transfers AM techs
- ✓ NASA is active in public standard dev activities
- ✓ NASA advises externally funded AM projects
- ✓ NASA participates in Inter-Agency initiatives



- ✓ NASA is not the CEO nor has the design authority
- ✓ NASA has authority to define AM qual requirements
- ✓ CEO is responsible to establish the certified design state and deliver AM hardware compliant with all levied requirements

- ✓ NASA is the CEO and has the design authority
- ✓ NASA has authority to define AM qual requirements
- ✓ NASA is responsible to certify AM hardware for flight

Qualification and Certification – “NASA Definition”



Answer varies by industry and even by culture within industries

The following interpretations are common within NASA, in context of AM:

- Qualification applies to

- Parts
- Materials
- Processes

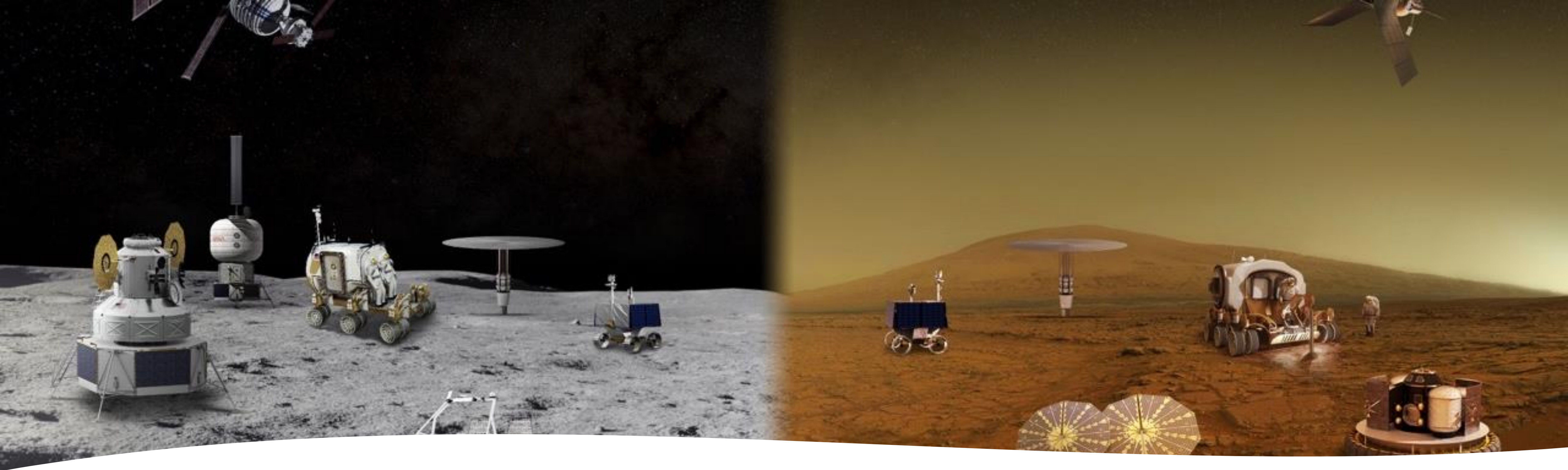
*"I am qualifying **LPBF 718** material on **X platform/Y serial** number to Material Spec #Z and LPBF Spec #ZZ to manufacture this component"*

- Certification applies to

"I'm certifying this design of propulsion system for this crewed-spaceflight and it's good to fly"

- Design (e.g., status following Design Certification Review)
- Subsystems (e.g., engine level certification test series)
- Integrated system (e.g., collective certification for flight for launch vehicle)

Certification is granted by the responsible reviewing authority when the verification process is complete, assuring both design and as-built hardware will meet the established requirements to safely and reliably complete the intended mission



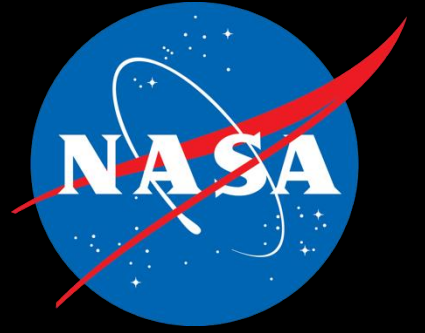
What does “doing AM Qualification and Certification” (QnC) mean at NASA?

A space company receives a contract from NASA to build a spacecraft

Mission-critical hardware is designed specifically for AM and will be manufactured using AM processes

Company either adopts NASA-STD-6030 directly or creates an alternate standard that meets its intent

Company establishes and maintains the certified design state of the AM hardware and delivers components compliant with all levied requirements

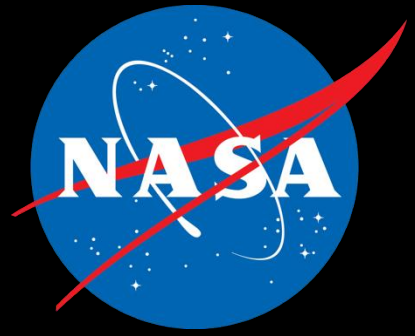


NASA Observations

Challenges encountered during AM Qualification and Certification can be categorized into the following topics:

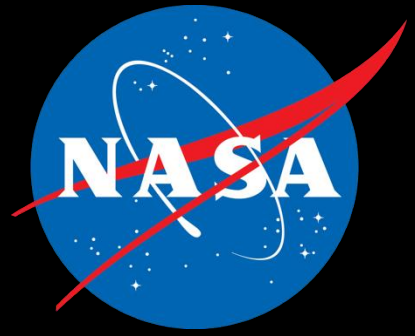
- *AM Technology Maturation*
- *Programmatic and Schedule Considerations*
- *Organizational and Cultural Factors*
- *Supply Chain and Industrial Base Readiness*
- *Mission Assurance and Safety based on Risks*

NASA Observations – *AM Technology Maturation*



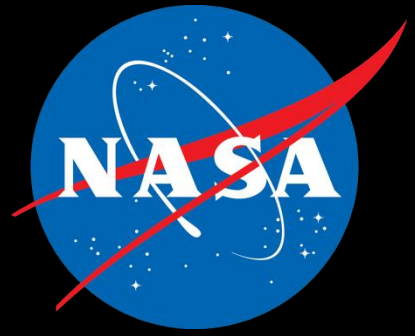
- **Inadequate Preparation (for Qualification)**
 - Skipping the homework: Bypassing initial process and material development while expecting successful qualification outcomes
 - Impediment during Standard Adjudication: Unprepared for requirement tailoring discussions with NASA when requirements remain undefined
 - Requirement do-loop: Facing difficulties during AM qualification when "writing requirements while implementing them"
- **Slow response to rapid AM tech advancements**
 - Mission capability gaps: NASA missions may lack access to state-of-the-art capabilities that could enhance science return or mission safety
 - Technology obsolescence before deployment: Technologies may not meet NASA's required Technology Readiness Level (TRL) for implementation
 - Technical Risk Management challenges: Difficulty quantifying unknowns and potential failure modes
 - Standards Currency Issues: NASA-STD-6030 (released in 2021) has not kept pace with latest AM technological advancements

NASA Observations – *Organization and Cultural*



- **Immature Engineering and Manufacturing Practice**
 - New space companies with underdeveloped engineering excellence frameworks
 - Inadequate Quality Systems: Absence or lack of focus of robust Quality Management Systems (QMS)
- **Risk Management Disparities**
 - Varying appetite for technological risk across companies, NASA programs, and centers
 - Heritage Bias: Over-reliance on flight-proven history limiting innovation adoption
 - Misaligned Implementation Strategies: Attempting to apply standard commercial approaches to NASA projects without appropriate tailoring
- **Knowledge Continuity Issues**
 - High workforce turnover creating challenges in transferring expertise from technology developers to implementers

NASA Observations – *Programmatic and Schedule*



- **Production Strategy Extremes**

- Navigating between large-scale in-house production (large quantity of printers in vertically integrated factories) versus complete reliance on external suppliers

- **Schedule Vulnerability**

- Critical path dependencies creating cascading impacts when technology uncertainties affect overall program timelines

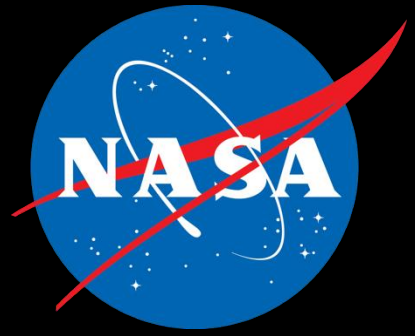
- **Development-Program Misalignment**

- Technology development cycles rarely synchronizing naturally with program milestone requirements

- **Resource Limitations**

- Insufficient budget allocation for comprehensive technology development, testing, and qualification activities

NASA Observations – *Supply Chain/Industrial Base Readiness*



- **Capability-Demand Mismatches**

- Powder suppliers, printer OEMs, and heat treatment facilities often unable to meet required quality/quantity demands for aerospace applications
- Difficulties ensuring long-term availability of specialized feedstocks, equipment, and technical expertise
- Many suppliers optimized for prototyping unable to effectively transition to production volumes

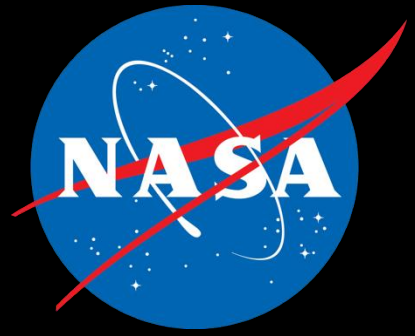
- **Qualification Variance**

- Inconsistent qualification processes across supplier network creating validation challenges and potential bottlenecks
- Varying levels of compliance with industry standards among different tiers of suppliers

- **Intellectual Property Constraints**

- Complex IP arrangements restricting knowledge sharing and process improvements across the supply chain

NASA Observations – *Mission Assurance and Insight*



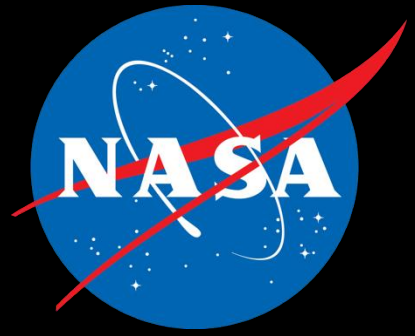
- **Process Characterization & Control**

- **Process Parameter Sensitivity:** Minor variations in AM process parameters can significantly impact part quality, requiring more sophisticated monitoring and control strategies
- **Non-Traditional Defect Modes:** Unique defect types requiring new detection and risk assessment methodologies
- **Process Monitoring Integration:** Challenges incorporating in-situ monitoring data into formal risk assessment and acceptance rationales

- **Data & Statistical Limitations**

- **Statistical Basis Limitations:** Insufficient flight heritage data to establish statistically meaningful reliability predictions for AM components
- **Risk Quantification Challenges:** Difficulty applying traditional risk assessment tools to processes with limited historical performance data
- **Qualification Transportability:** Uncertainty in how qualification data from one machine/facility applies to another nominally identical setup

NASA Observations – *Mission Assurance and Insight*



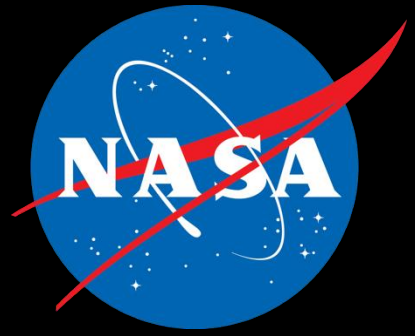
- **Verification & Acceptance Methodologies**

- **Inspection Technology Constraints:** Conventional NDT methods often inadequate for detecting AM-specific defects, especially in complex internal geometries
- **Lot Acceptance Paradigm Shifts:** Need for new approaches to lot definition and acceptance when each build plate may represent unique processing conditions
- **Configuration Control Complexity:** Maintaining rigorous configuration management across digital design files, build parameters, and post-processing specifications

- **Organizational & Cross-Functional Challenges**

- **Multi-Disciplinary Risk Assessment:** Need for integrated risk evaluation across materials, manufacturing, and structural discipline
- **Insight Access Limitations:** Balancing proprietary process protection with necessary government insight into critical quality factors

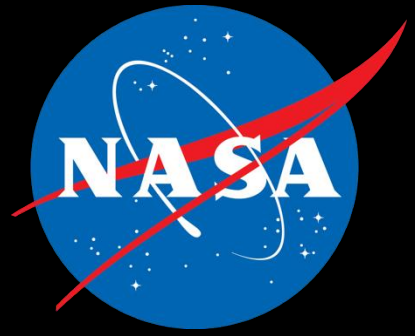
Lessons Learned in 6030-based Qualification (from the Standard Authority perspective)



Getting to know the Cognitive Engineering Organization *early*

- Understanding the business and technical case for AM, design intent, technical adequacy and form/fit/function requirements
- Part risk and classification discussion to clear establish the expectations for which qualification pathway
- IP rights and appearance of rights
- Roles and responsibilities explicitly assigned to specific individuals or functions
- Understanding supply chain definition, integration approach, and resilience strategies
- Clarification of desired state and acceptance criteria for final products

Lessons Learned in 6030-based Qualification (from the Standard Authority perspective)



Effective Communication & Systems Perspective

- Clearly communicate context and intent to 6030 users
- Recognize that AM components are elements within complex engineering systems
- Address prerequisite and auxiliary processes comprehensively (material R&D, part-specific material testing, heat treatment, NDI, machining, welding)

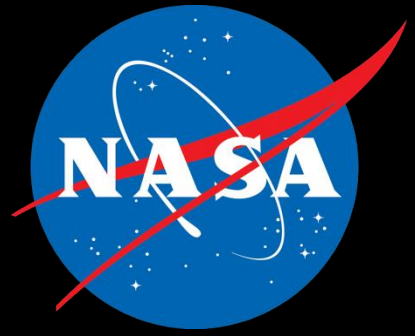
Process Control & Variables Management

- Define key process variables and understand their interdependence with part performance
- Document impacts of process variable changes, both individually and in combination
- Develop comprehensive best practices, guidelines, and standards

Integration & Approach

- Connect AM qualification processes with broader engineering and manufacturing operations
- Consider relevant suppliers in qualification approach
- Balance process-based versus performance-based qualification strategies

Lessons Learned in 6030-based Qualification (from the Standard Authority perspective)



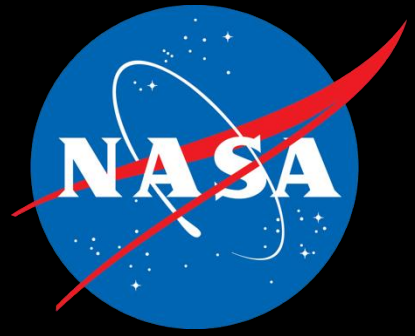
Data Utilization & Digital Transformation

- Leverage opportunities in data-rich manufacturing environments
- Implement sensors and optical data streaming to create digital threads between engineering and manufacturing
- Avoid common pitfalls: under-utilizing available data or misapplying collected data
- Design data structures that fit operational scenarios, connecting design through production
- Apply data effectively in qualification and process control activities

Shared Objectives

- Focus on common goals among stakeholders
- Emphasize reliable and consistent AM part production as the ultimate measure of success

Future Direction - NASA AM Qual and Cert Group



Standards Modernization

- Update and revise standards to reflect rapid advancements in AM technology and implementation approaches:
 - Develop qualification strategies for multi-laser systems
 - Create comprehensive guidelines for Direct Energy Deposition (DED) AM qualification
 - Establish qualification protocols leveraging in-situ monitoring systems
 - Provide practical examples and elaboration of "engineering equivalency" concepts
 - Develop specific guidance for Class C hardware qualification

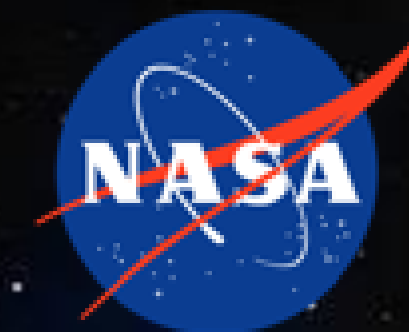
External Engagement

- Strengthen active collaboration with other U.S. Government AM Qualification group
- Increase participation in industry Standard Development Organizations
- Share expertise and align approaches across the AM Community

Knowledge Management

- Publish comprehensive Lessons Learned documentation for NASA AM Qualification and Certification
- Document diverse implementation scenarios and approaches to build institutional knowledge
- Create reference materials for future qualification activities

National Aeronautics and
Space Administration



The motivation: back to the Moon, on to Mars...

