A Frank Discussion on Lessons Learned from Adopting and Applying NASA-STD-6030 for Spaceflight Systems

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Agenda and Objectives

- Tailoring NASA-STD-6030 Additive Manufacturing Requirements (AMR)
- Additive Manufacturing Control Plan (AMCP) and Part Production Plan (PPP)
- Observations from early adopters of NASA-STD-6030 and common issues with requirement interpretation
- Initial thoughts on qualification and certification of multi-laser and directed energy deposition (DED) systems not directly addressed in NASA-STD-6030

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- Fully embraces advantages of AM…
  - Cost/lead time/part count reduction
  - New design and performance opportunities
  - Rapid design-fail-fix cycles
- …while fully understanding the challenges
  - Multi-laser systems
  - Complex, opaque scan strategies
- *"NASA is a user of AM"* means…
  - NASA engineers utilizing AM processes to make hardware = NASA has the design authority
  - NASA procuring a service, sub-system, or system from a commercial provider
    - Design authority varies

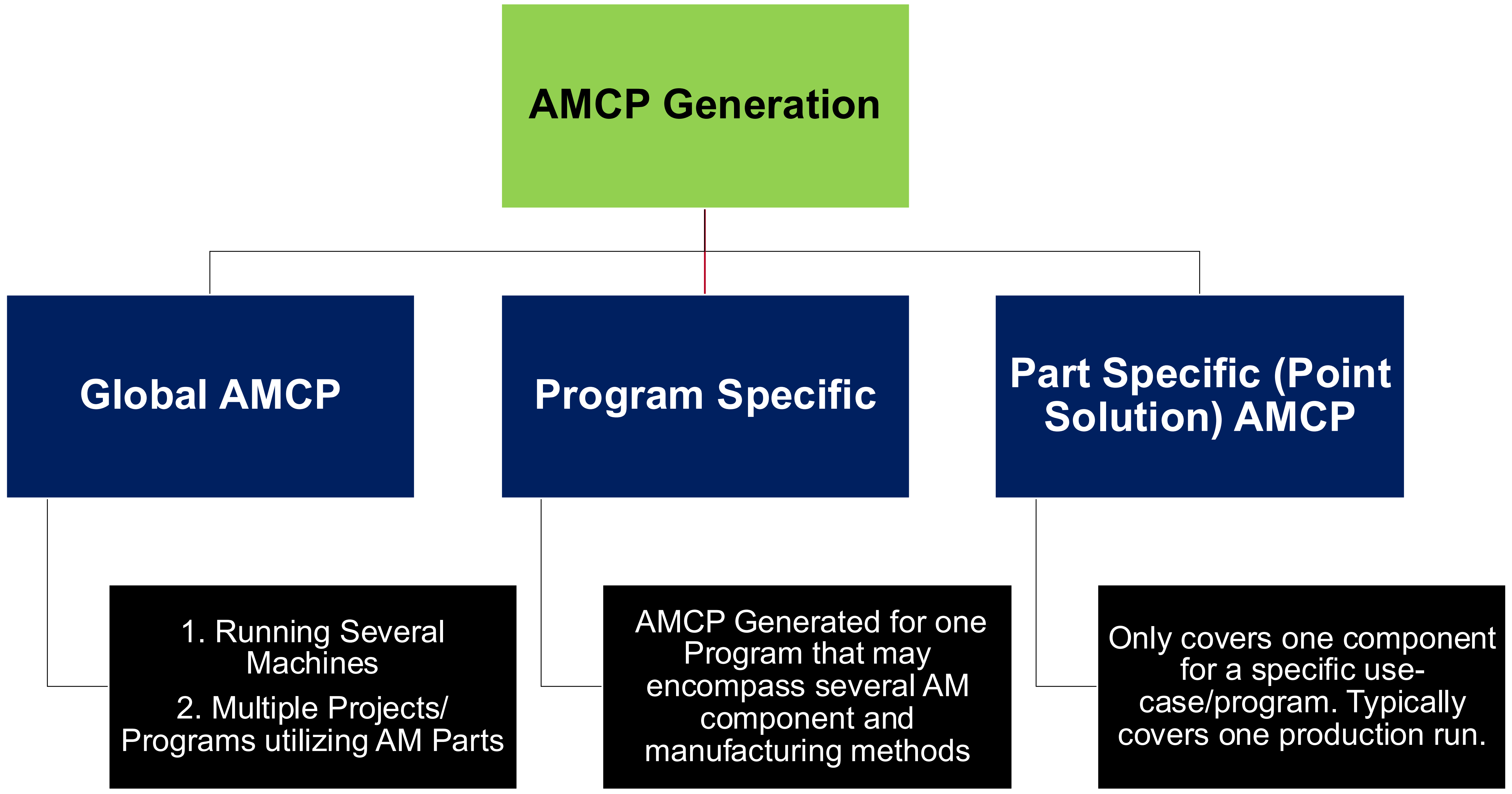
Centers involved in AM

End goal → **Safe and successful missions**

AMCP Generation for Global vs Program vs Part Specific AMCPs

AMCP Generation can be broken into three (3) categories

- Global: Enterprise level AMCP covering all AM Materials and Process
- Program Specific: AMCP covers the use of AM Materials and Process for a single program only
- Part Specific (Point Solution): AMCP covers one (1) material and AM component only



NASA AM Qualification and Certification Subject Matter Experts (SME) are available to provide guidance's on AMCP generation, <u>note that does not mean an endorsement of the AMCP by NASA</u>.

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Introduction to Tailoring an AMR

What is Tailoring an AMR?

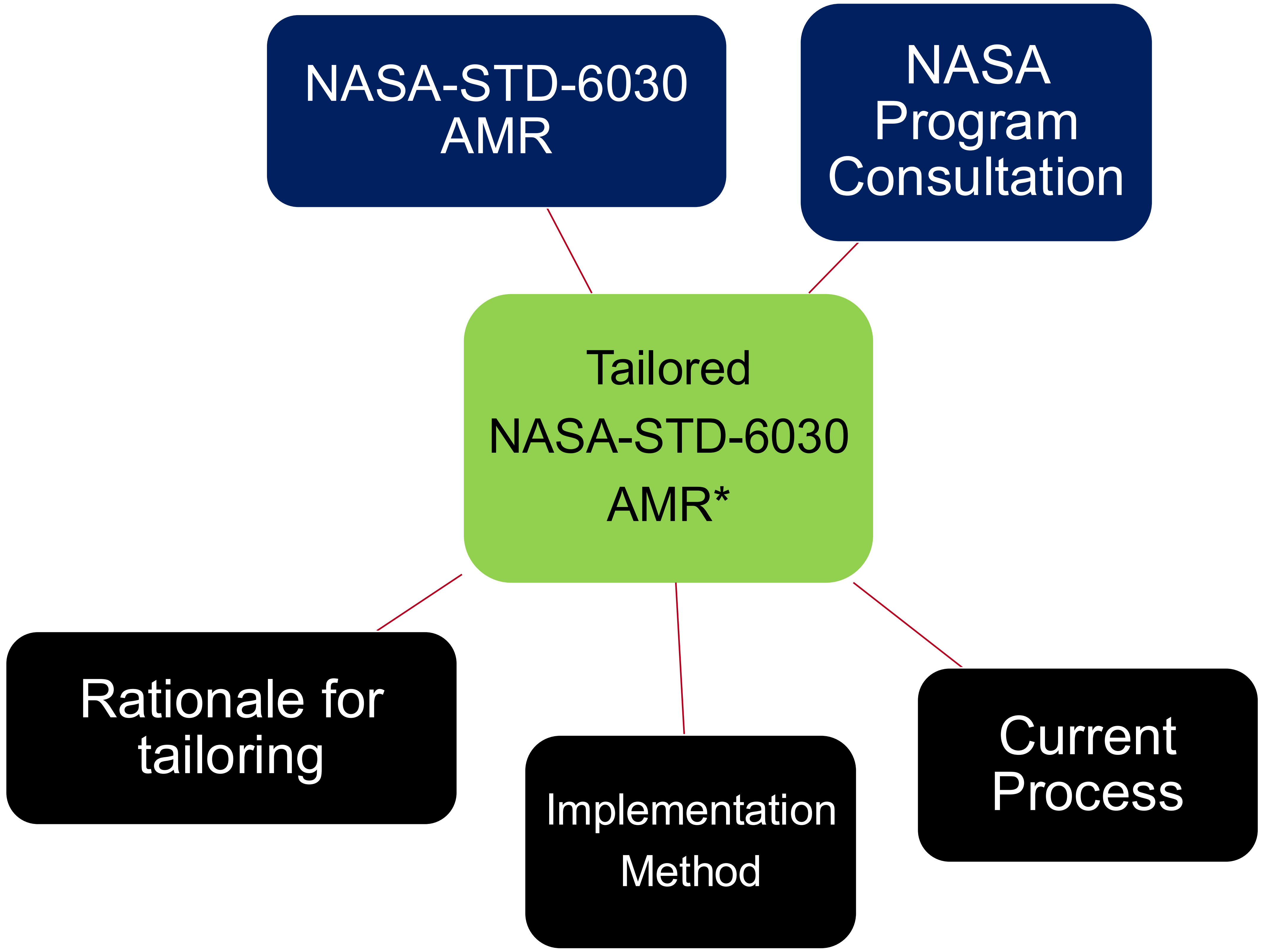
- **Tailoring Definition:** The process of revising a shall statement to a NASA-STD-6030 AMR that is accepted by the reviewing authority.

How to Start the Tailoring Process?

- Understand the project requirements and the maturity of the process you are planning to use
  - May require gap assessment with part agnostic requirements (e.g., process, post-process, maintenance)
- When does tailoring occur?
  - Programmatic Tailoring
  - Cognizant Engineering Organization (CEO) Tailoring
  - Any tailoring should be finalized and/or approved within the timeframe of the first major programmatic design review

How are tailored AMRs documented?

- The AMCP documents the as-tailored requirement with rationale and implementation methods for each AMR listed in NASA-STD-6030.
- Note that NASA AM Certification SMEs have found that most mature aerospace AM programs can meet the intent of most NASA-STD-6030 AMRs as written without the need for tailoring



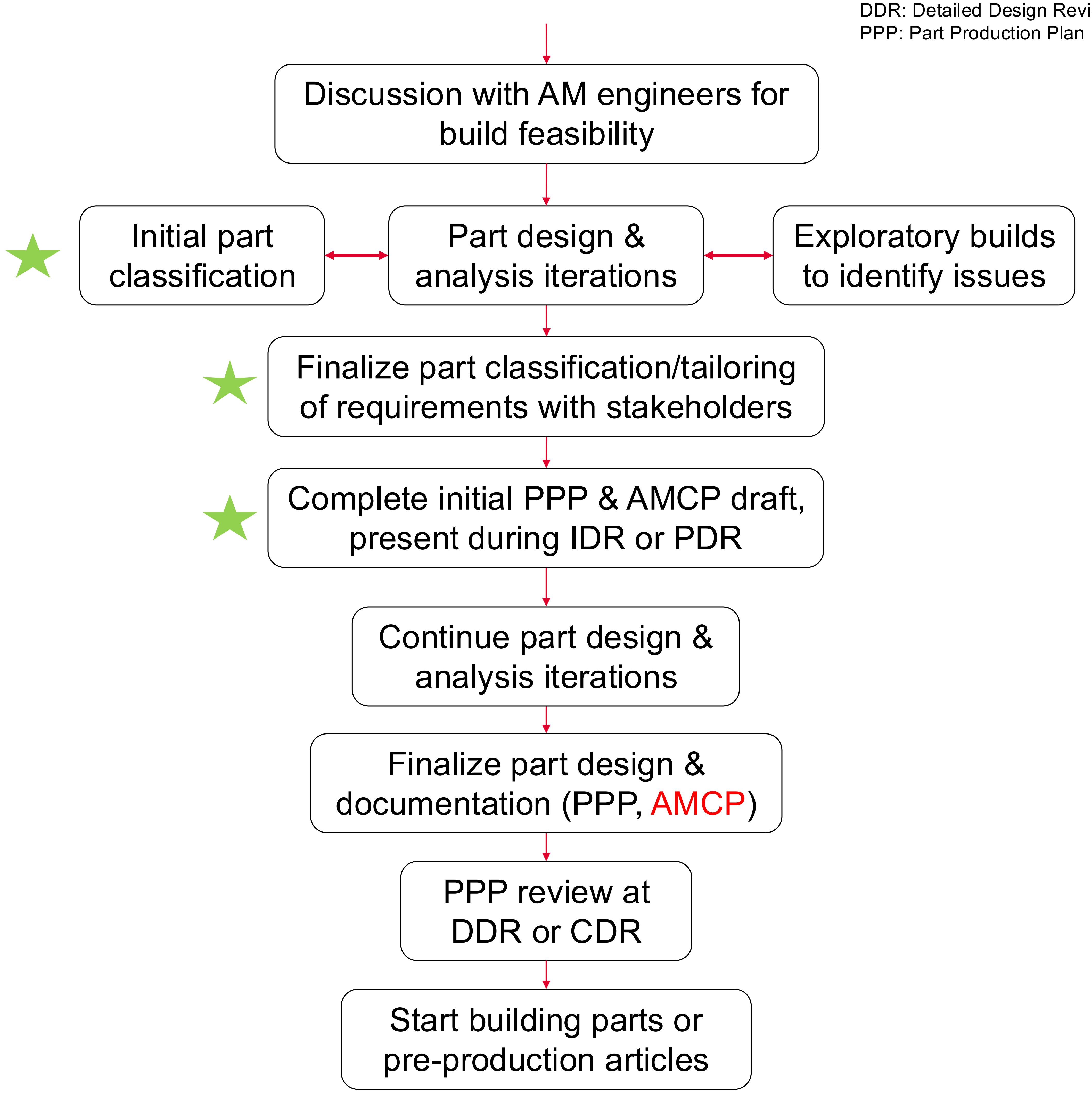
The AMCP is the foundation of successful additive manufacturing implementation

Recommended Programmatic AM Workflow

- The recommended AM workflow was designed to pair AM review milestones with existing program reviews (PDRs, CDRs, etc.)
  - Reduce the number of additional meetings
  - Capitalize on review authority gathering
  - Every program differs and may require different approach
  - Discussing requirements as early as possible in the AM workflow will reduce issues with compliance
  - Recognize that design and analysis iterations are an important part of the new AM part development process
- NASA acknowledges this work is not always how programs run. NASA AM SMEs are available provide input throughout the program's life.

A critical best practice is to engage with NASA additive manufacturing subject matter experts early and often during the design and part classification phase.

PDR: Preliminary Design Review
IDR: Interim Design Review
CDR: Critical Design Review
DDR: Detailed Design Review
PPP: Part Production Plan



★ - Tailoring opportunity

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Proposed Tailoring NASA-STD-6030 Example: Multi-Laser for Witness Testing for Continuous Production

NASA-STD-6030 AMR

*[AMR-24] Governs witness test sample requirements by part class and material…**

*Note this is a brief excerpt NASA-STD-6030 AMR see NASA-STD-6030 for full AMR text

Rationale for Tailoring

[Company] uses a robust statistical process control to monitor the health of the printer for production components. With the use of a [multi-laser system] [Company] has identified the known defects, effect of stitch lines, and completed a Qualified Material Process ensure each laser is generating data the buys into the the Material Process Suite. [Company] is going to reduce the the sample quantity per laser listed in Table 7 of NASA-STD-6030.

Tailored Requirement

[Company] shall comply with with AMR-24 with a reduced witness specimen count per laser source.

Implementation

[Company] will continue to test witness specimens on the large fleet of multi-laser printers and add to the SPC data based, if a test show suspect a Sub-QMP will be preformed upon successful root cause and correction event. Data will be made available to NASA upon request.

Table 7 from NASA-STD-6030 Metals Witness Testing Quantities and Acceptance Results for Continuous Builds

a. Minimum Quantities of Witness Specimen Types by Part Class

Class	A1	A2	A3	A4	B1	B2	B3	B4	C
Tensile	4	4	4	4	4	4	4	4	2
FH Contingency*	1	1	1	1	1	1	1	1	-
Post-build Tensile**	4	4	4	4	4	4	4	4	2
Microstructure	1	1	1	1	-	-	-	-	-
Post-build Microstructure†	1	1	1	1	-	-	-	-	-
Chemistry	1	1	-	-	-	-	-	-	-
HCF	-	-	-	-	-	-	-	-	-
Low Margin Point	A/R	A/R	-	-	-	-	-	-	-
Witness Sub-article	A/R	-	A/R	-	A/R	-	-	-	-
Witness Article	1 for 6	-	-	-	-	-	-	-	-
Customized QMP	A/R	A/R	A/R	A/R	A/R	A/R	-	-	-

Notes:

*FH contingency = Full-height contingency specimen for PBF only

**Post-build tensile = Post-build witness tensile specimens required for DED only

†Post-build microstructure = Post build microstructure specimens required for DED only

A/R = As required when specified in the PPP/QPP

Sample direction should be chosen from the most process-sensitive orientation (typically the Z-direction)

See Tables 13 through 16 in section 5.5.3.5 for recommended test specifications

Document the Tailored AMR, rationale and Implementation in the AMCP to be presented to NASA Program for approval.

Proposed Tailoring NASA-STD-6030 Example: LP-DED for Witness Testing for Continuous Production

NASA-STD-6030 AMR

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Rationale for Tailoring

[Company] uses a robust statistical process control to monitor the health of the printer for production components. With the use of a [LP-DED] system co-witnessing is not feasible. [Company] has adopted the approach of performing witness sample builds at three set points during a production build (Pre-Build, Mid Point of Build, Post-Build).

Tailored Requirement

[Company] shall comply with with AMR-24 with three (3) builds to of Table 7 at the following build points, Pre-Build, Mid. Point of Build, and Post-Build.

Implementation

[Company] will continue to test witness specimens on the [LP-DED] system and add to the SPC data based, if a test show suspect a Sub-QMP will be preformed upon successful root cause and correction event. Data will be made available to NASA upon request.

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Chemistry	1	1	-	-	-	-	-	-	-
HCF	-	-	-	-	-	-	-	-	-
Low Margin Point	A/R	A/R	-	-	-	-	-	-	-
Witness Sub-article	A/R	-	A/R	-	A/R	-	-	-	-
Witness Article	1 for 6	-	-	-	-	-	-	-	-
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LP-DED: Laser Powder Directed Energy Deposition

Document the Tailored AMR, rationale and Implementation in the AMCP to be presented to NASA Program for approval.

AMCP Revision Control and Child Document Management

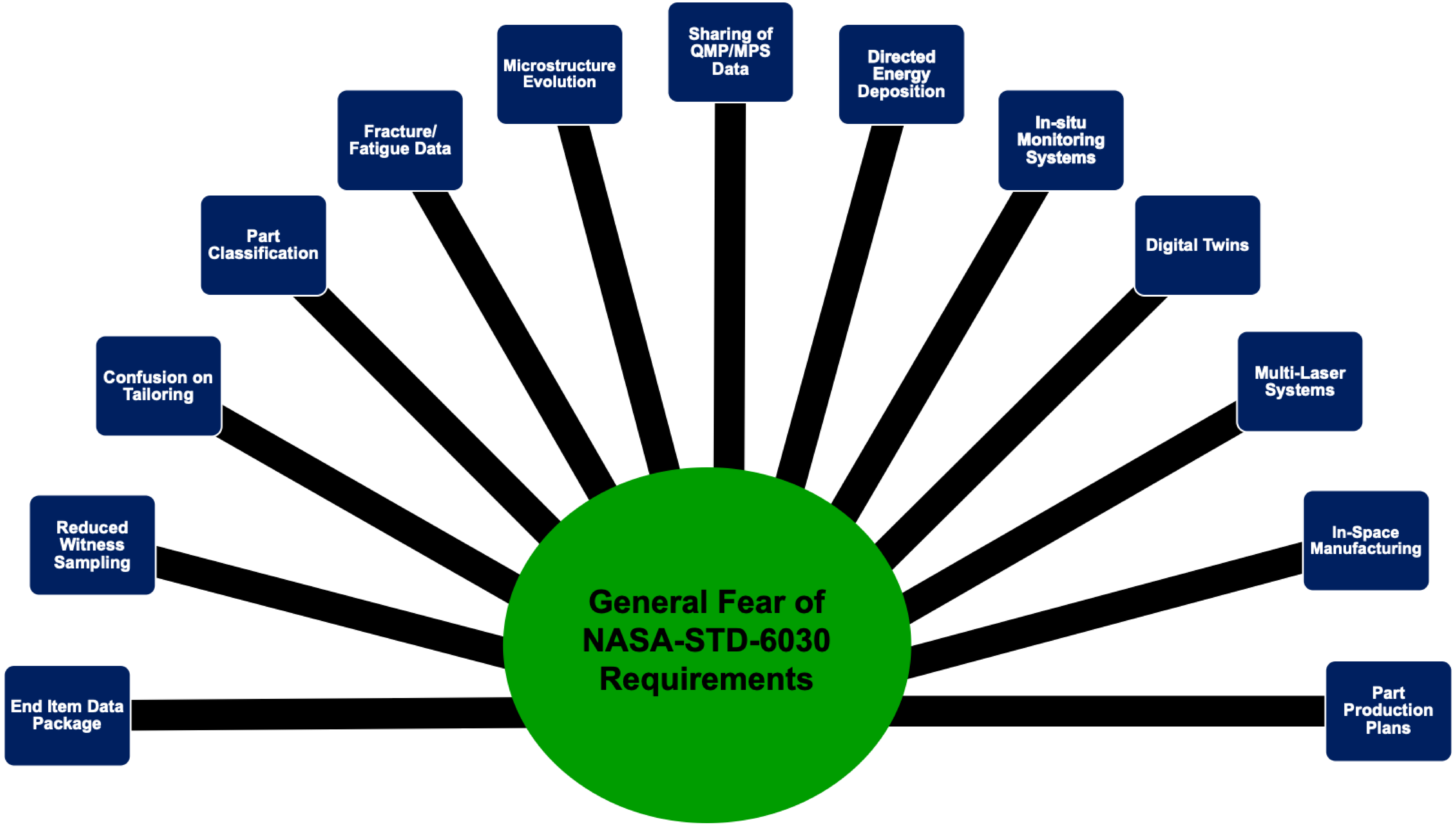
AMCP Revision Control vs Speed of the AM industry:

- An AMCP should always follow your current AM practices: “Write down what you are doing”
- NASA recommends a quarterly status check for any updates for a released AMCP.
- AMCP revisions shall be sent to NASA for review.

Child Document Management:

- NASA acknowledges that companies have internal documents that may be used to comply with NASA-STD-6030 Additive Manufacturing Requirements (AMR)
  - Best practice for using child documents a reference in an AMCP, is to provide a summary of how the child document is being applied to a specific AMR
- Child documents in a AMCP must be revision controlled and upon revision shall be sent to the Certifying Agency (e.g., NASA, ESA, etc.) for review.
  - NASA recommends regular reviews of child documents, with the cadence based on the speed of the providers development of AM practices.

NASA's Observations from Users on the adoption of NASA-STD-6030



Examples of NASA's Observations on the adoption of NASA-STD-6030

Examples of Observations and NASA's Response:

- Over/ Under classification of AM components
  - NASA has recently worked a project that had originally a higher classification based on a perceived risk, that was mitigated through containment of the hazards.
- NASA has observed attempts to build polymer AM components in a Class B part classification, using Fused Deposition Modeling for a structural component.
    - NASA-STD-6030 does not allow polymers to be Class A or SLA/FDM Class B components
- NASA has observed a several providers that will not provide a Part Production Plan in a single document format.
  - Reasons: the document is too much work to compile; all the information will be design reviews
  - This will be further addressed in the presentation.
- NASA has seen providers add new machines and did not follow the Sub-QMPs process.
  - The Sub-QMP can be used to buy in new machines to ensure that the material is in-family with the registered MPS.

NASA AM Qualification and Certification SME Recommend the following:

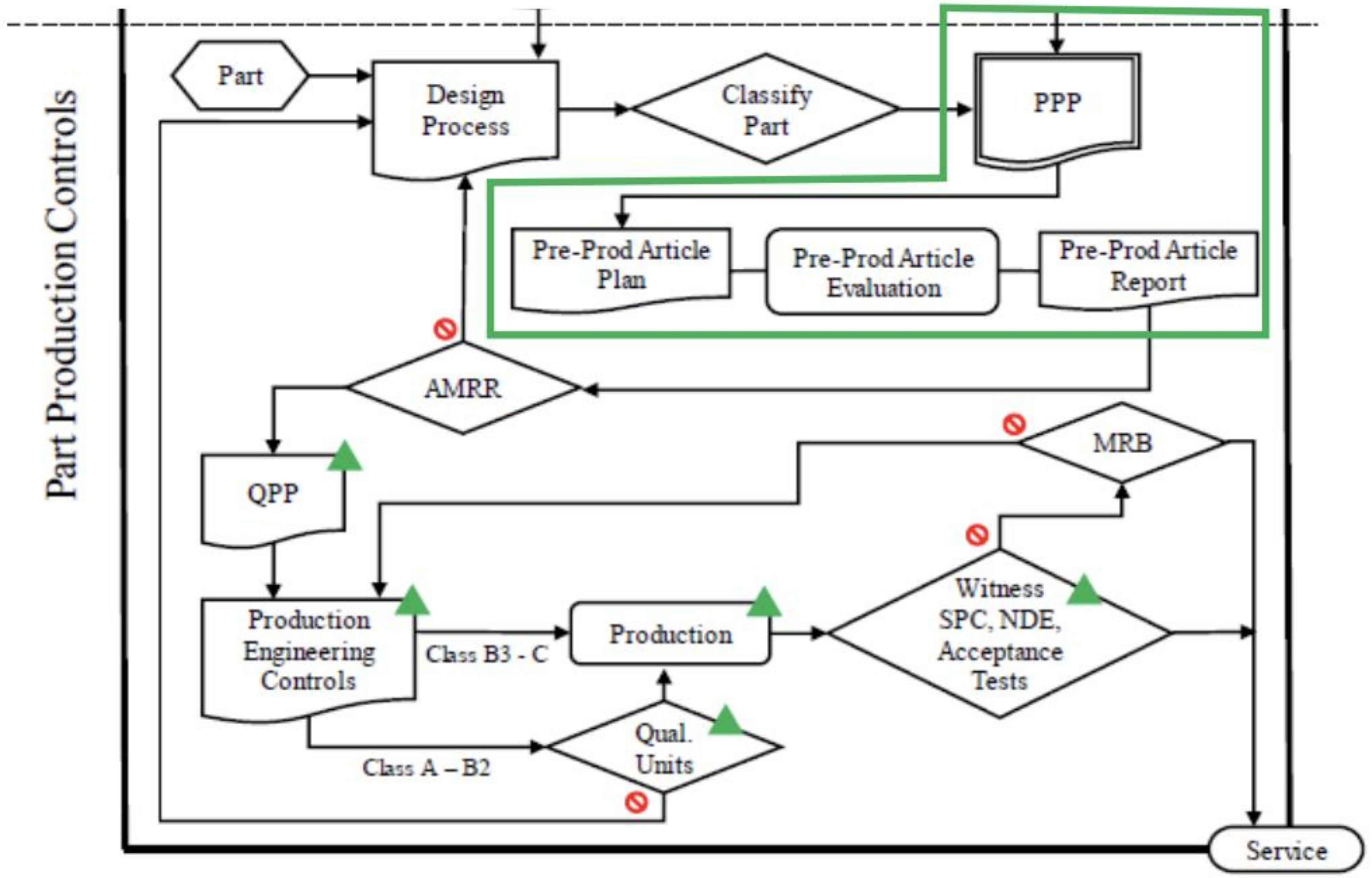
A critical best practice is to engage with NASA additive manufacturing subject matter experts early and often during the design and part classification phase.

NASA-STD-6030 AMR-97 Part Production Plan

What is included in a Part Production Plans (PPP):

For Class A and Class B parts, the PPP **shall** list the following minimum general information, or may reference other configuration-controlled documentation that is available to NASA upon request [1]:

- Part Specific Information
- Part Classification and detailed rationale
- Integrated Structural Integrity Rationale
- AM part Production Summary
- Preproduction Article Requirements
- End Item Data Package Information



The PPP is the foundation of successfully communicating the means of the part production intent and the level of risk associated with the AM component.

[1] Note this is a summary of the PPP requirements, full requirements are found in NASA-STD-6030

NASA-STD-6030 AMR-97 Part Production Plan: Lessons Learned

Why are Part Production Plans (PPP) Important to NASA:

- The PPP serves as a mechanism to define process controls unique to a particular part design/build, capturing those process criteria that are not on the drawing or product definition.
- The PPP serves as the primary means of communication of the part production intent and the level of risk associated with the AM part.

Current Feedback on PPP Generation:

- Question on rationale for generating the documents for large AM Part Count programs
- All the information is provided in design reviews no need to write standalone documents
- Some information will not be provided in the PPP thus a tailoring is required.


National Aeronautics and Space Administration

Baseline
EFFECTIVE DATE: 3/19/2026

DRAFT

Program Title

Part Production Plan TITLE

Additive Manufactured (AM) Part Production Plan (PPP)

NASA commentary is listed in Italics

NASA-STD-6030 PPP Template Coming Soon!

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

Approved for Public Release; Distribution is Unlimited

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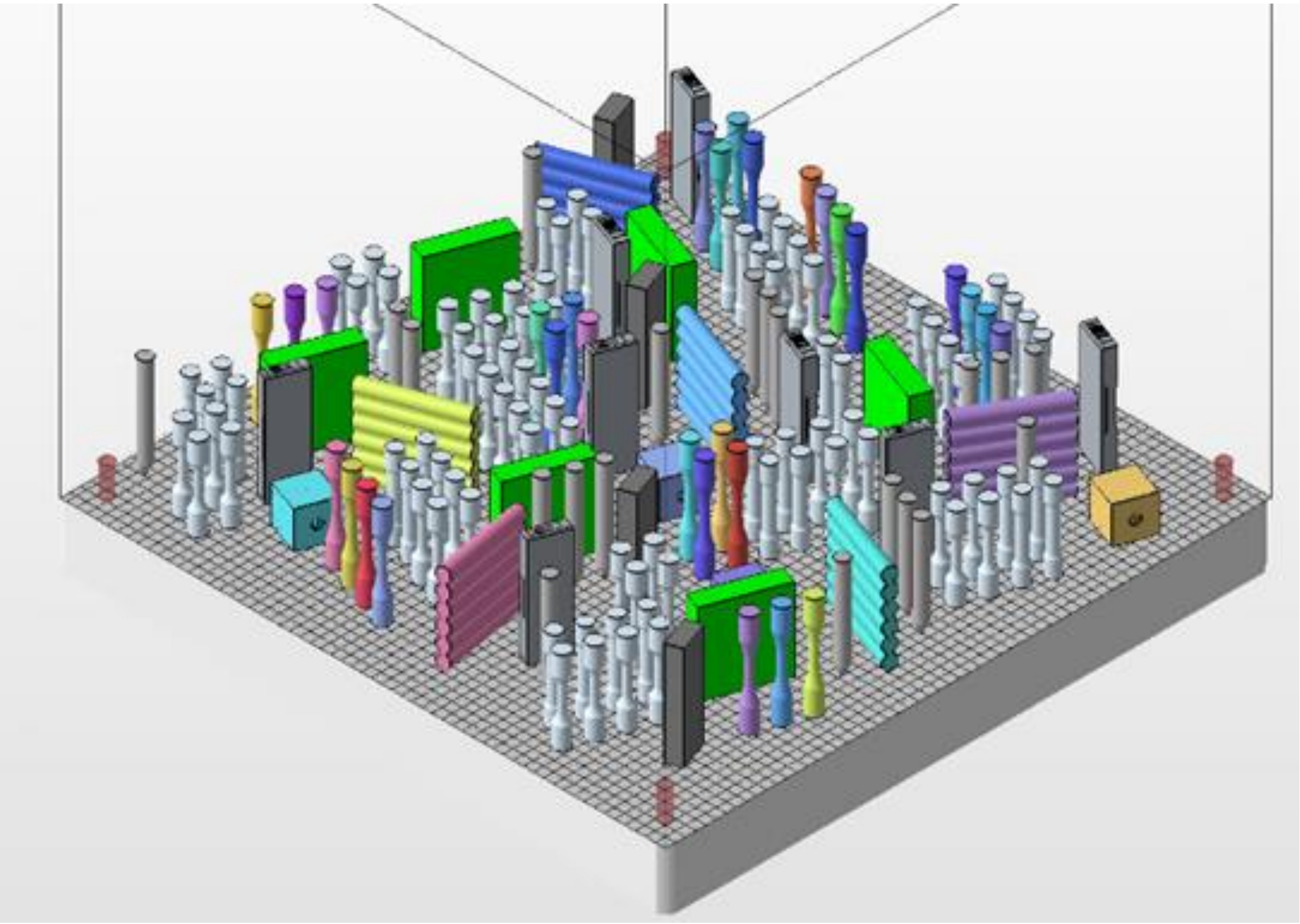
NASA initial though on NASA-STD-6030 for Multi-Laser Systems

Material Qualification Builds and the Material Process Suite should include the following at a minimum:

- Variability across the build plate of laser-to-laser interaction.
- All permutations of the laser assignments
  - Documented in the Part Production Plan

NASA will address Multi-Laser Systems in NASA-STD-6030 Rev A

- NASA has been soliciting best practices from industry to inform these requirements
  - NASA has polled SpaceX, Blue Origin, Aerojet Rocketdyne, Boeing, US Navy and more to come.
- **NASA is open to talking with anyone who is willing to share best practices (No Intellectual Property) on the use of multi-laser systems.**



Sample Multi-Laser Build Layout

Based on the current survey by NASA AM Qualification and Certification SME general direction on requirements language updates will be structed on machine type vs prescribed global requirements for all machines.

[1] Note this is not official tailoring, only guidance and requires program and NASA AM Qualification and Certification SME buy in

NASA initial thoughts on NASA-STD-6030 for DED Systems

NASA AM Qualification and Certification Subject Matter Experts have evaluated NASA-STD-6030 for DED and have the following initial guidance:

- NASA-STD-6030 potential modifications for DED include [1].
  - Witness Coupons and NDE Approach
  - Full understand of required Parameters sets
  - Laser Blown Powder DED has different challenges for qualification and certification than Wire DED processes (Other United States Government Agencies are Utilizing Wire DED Currently)

Full Scale RS-25 Nozzle Upgrades for ARTEMIS NTRS 20250009398*

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Questions and Coming Soon!

Coming Soon	Estimated Release Date
Part Production Plan Template	Q3 2026
Process Control Reference Document White Paper (PCRD)	Q4 2027
NASA-STD-6030 Revision	2027

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Below is the email to reach out for NASA-STD-6030 and NASA-STD-6033 questions:
GSFC-AMWG@nasa.onmicrosoft.com

Back-up Slides

Proposed Tailoring NASA-STD-6030 Example: Multi-Laser for Witness Testing for Continuous Production

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