A Framework to Establish Additive Manufacturing Certification

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What are the key ingredients?

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

- **Most of the traditional certification framework remains consistent**
- **Only a few items are unique to additive manufacturing certification**
- **Some roles and responsibilities are transitioned**
  - **Production facilities now largely responsible for material integrity**
  - **Statistical process controls required in environments unaccustomed to it**

Overview of Cert Framework

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

What are “Qualification” and “Certification”?

- **Answer varies by industry and even by culture within industries**
- **The following interpretations are fairly common:**
  - ***Qualification* applies to**
    - **Parts and components**
    - **Processes**
  - ***Certification* applies to**
    - **Design (e.g. status following Design Certification Review)**
    - **Subsystems (e.g. engine level certification test series)**
    - **Integrated system (Collective certification)**

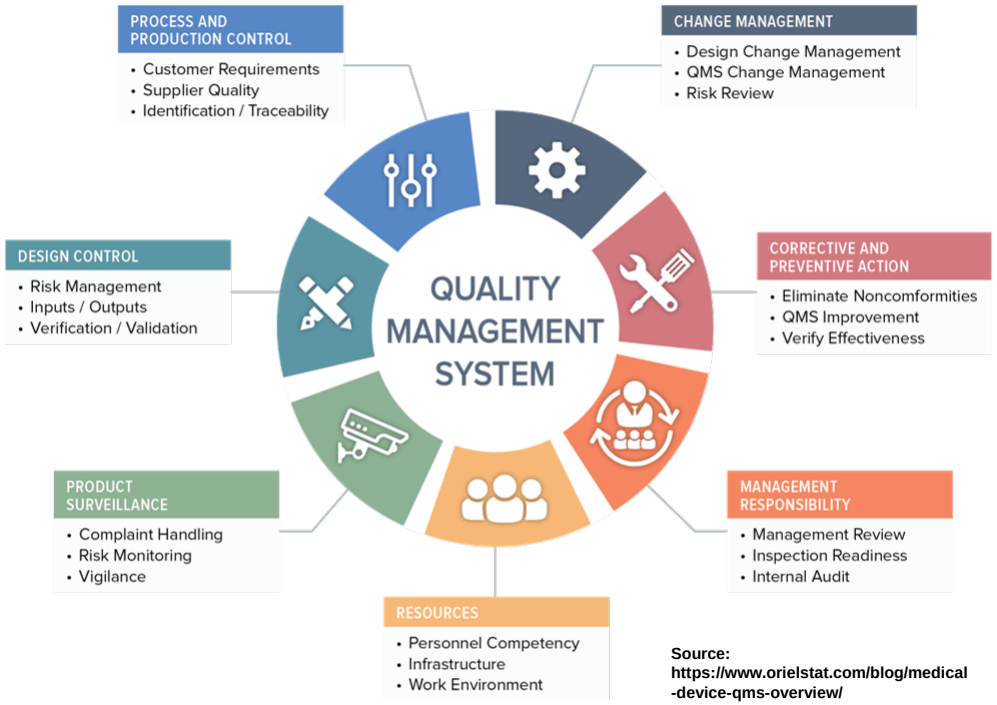
Certification is granted by the responsible reviewing authority when the verification process is complete, assuring both design and as-built hardware will meet the established requirements to safely and reliably complete the intended mission.

Have a Plan

- Start with a “Big Picture” plan for handling AM
- AM Control Plan
  - Write it down – Communicate it.
  - Authored by the Cognizant Engineering Organization, CEO (The Buck Stops Here)
- Plan should establish practice and policy for all aspects of AM design, production, and part acceptance – tailors policy relative to risk acceptance of the company, organization, or project
- Ensures everyone is on the same page
  - Provides for consistency – particularly important in off-nominal situations
  - Heightened importance when design and production entities are not the same
  - Delineates roles and responsibilities

Integrate a Quality Management System

- The Quality Management System (QMS) must be pervasive
- Long, perilous chain of controls needed
  - Design documentation
  - Feedstock
  - Facility control
  - Machine calibration
  - Digital Thread
  - Inspection
  - Statistical process controls…



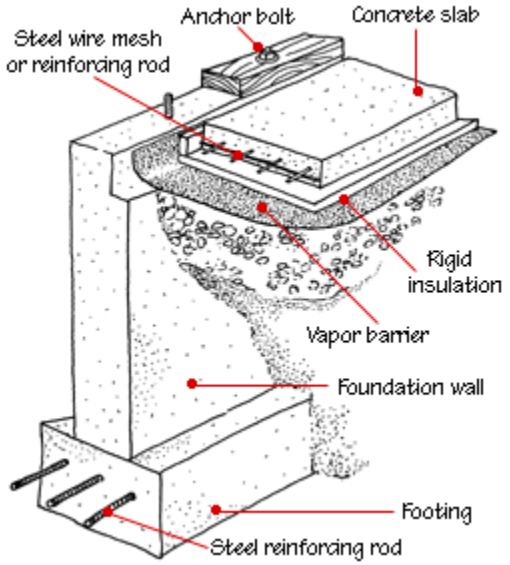
Source: https://www.orielstat.com/blog/medical-device-qms-overview/

- AM is a new process – No common-knowledge standards of practice
- Prepare for "Uh-oh, I ain't never seen that before…" (commonly heard in a North Alabama accent…)

Build a Foundation

Planning for AM certification does NOT start with a part!

- AM Control Plan should define how the foundation for certification is structured and how it operates
  - Equipment and Facility Controls
  - Personnel Training
  - Process/Machine Qualification
  - Material Properties
  - Statistical Process Controls



Foundation :: Equipment and Facility Control

- Well documented and governed by QMS
- Controls for all AM equipment and facilities
- Significant list of controls needed:
  - Tracking machine configuration status
  - Tracking machine qualification status
  - Maintenance intervals, or unplanned
  - Calibration intervals
  - Feedstock storage and handling
  - Contamination controls
  - Computer security / cybersecurity
  - Standard operating procedures/checklists
  - Handling of Nonconformance in equipment

Concept Laser/GE

http://vac-u-max.com/view_product.cfm?prod=39

Foundation :: Training

Training program to be defined, maintained, and implemented to provide:

- A consistent framework for training and certification requirements
- Content regarding the importance, purpose, and use of the QMS for all certifications.
- Operators with all necessary skills, knowledge, and experience to execute the responsibilities of their certification safely and reliably
- Operator evaluations that demonstrate adequacy in skills, knowledge, and experience to grant certifications to personnel, ensuring only properly trained and experienced personnel have appropriate certifications
- Clear delineations of abilities and responsibilities associated with granted certifications
- Records of all training and certifications

Foundation :: Process/Machine Qualification

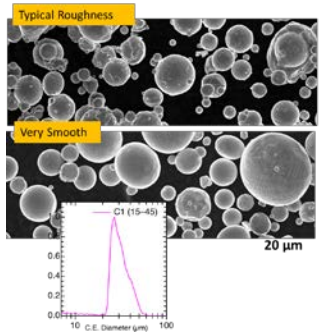
Currently in AM, machine and process are indelibly linked

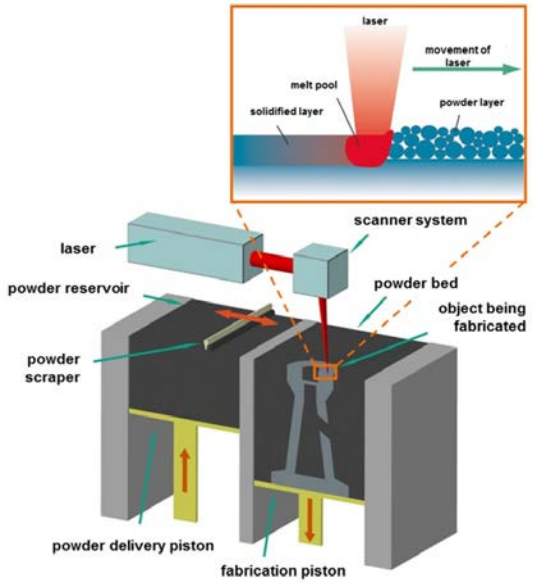
Step 1. Define a candidate process

a) Material feedstock controls

b) AM process conditions and machine configuration

c) Post-processing that influences material performance





Step 2. Qualify the candidate process to well-defined metrics, for example:

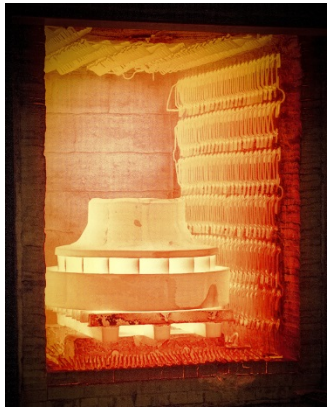
a) As-built material quality (fill and interfaces)

b) Consistency throughout build envelope

c) Appropriate detail and surface quality

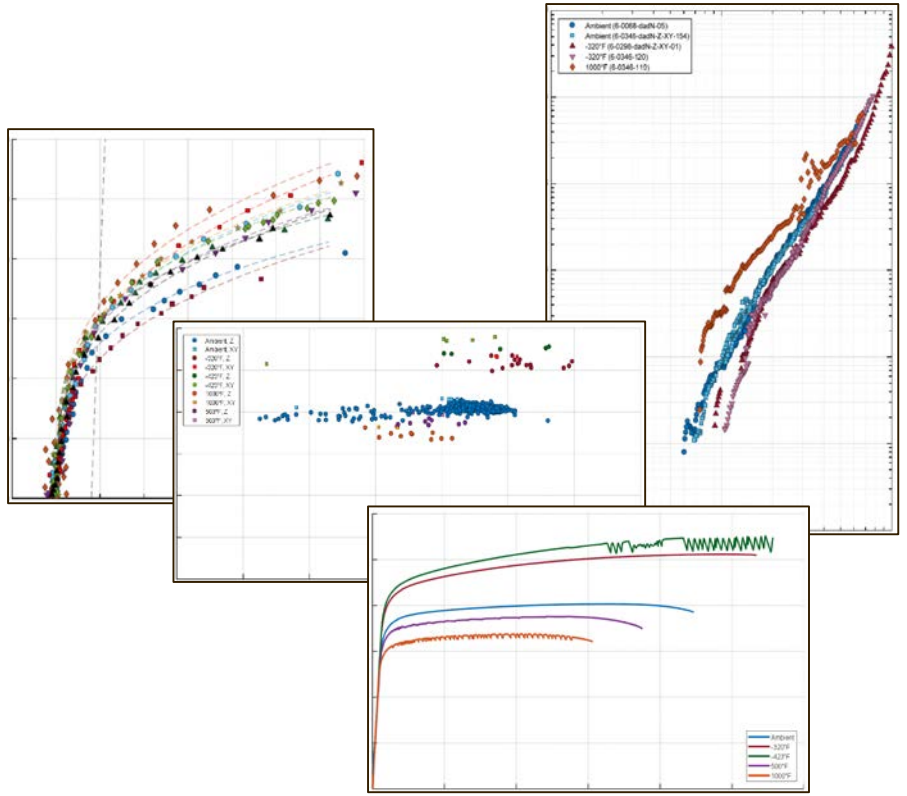
d) Tolerance to inherent process perturbations (thermal or otherwise)

e) Mechanical and/or physical properties



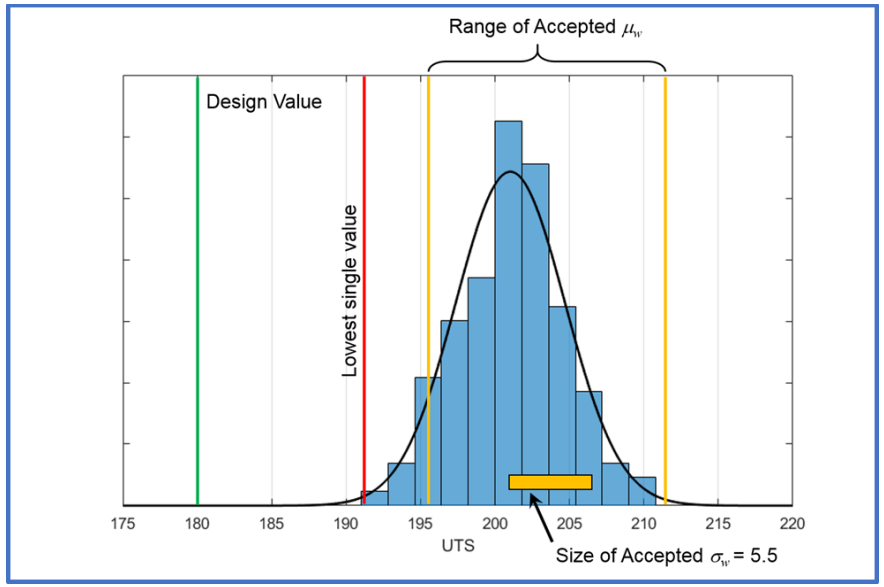
Foundation :: Material Properties

- Material properties and design values in additive manufacturing require modifications to the approach typical of traditional metallic materials, with requirements more similar to that used in composites
- Important distinctions arise due to the sensitive nature of the process and individualistic aspect of AM machines
- Traditional supplier roles and responsibilities shift with the AM machine making the final material product form and part. (Casting analogy)
  - **AM Process Vendor responsible for material integrity**



Foundation :: Material Properties

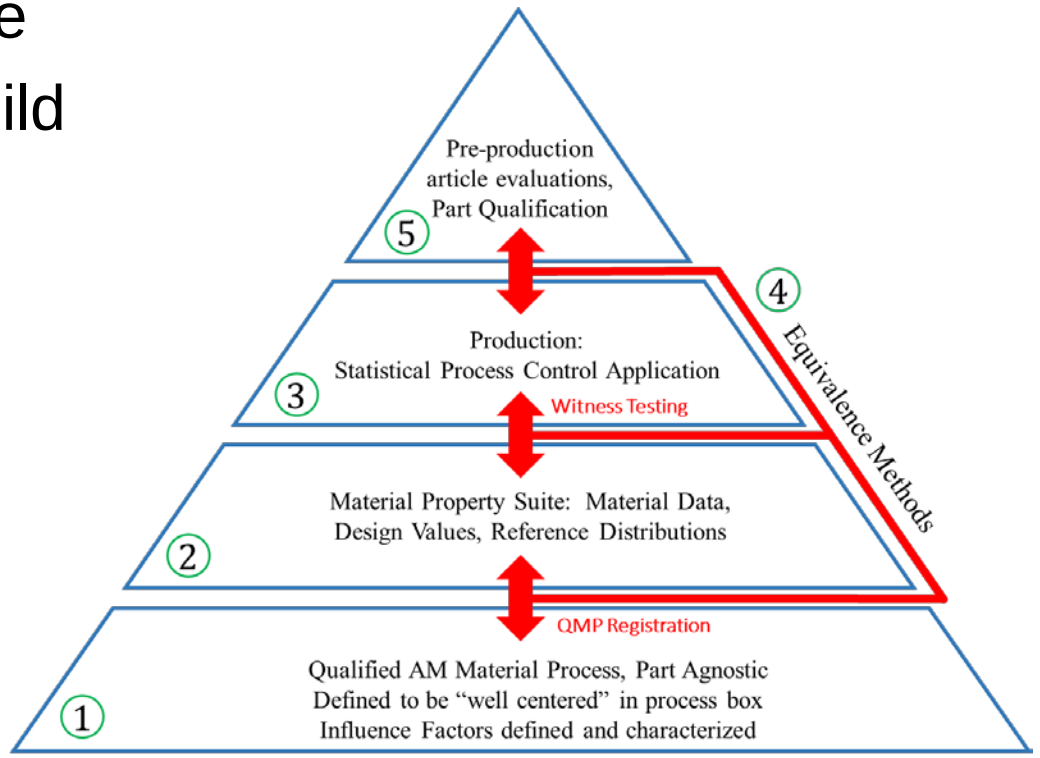
- When design and production are not within the same entity, agreements must be reached regarding design value assumptions and associated qualification and monitoring requirements of the AM hardware
- Design values must be continuously substantiated through process qualification and witness requirements
- Material property evaluations are complicated by the AM process, leading to new considerations
  - Feedstock lot variability
  - Build-to-build and machine-to-machine variability
  - Coupon to part transferability of properties
  - AM process-specific influence factors
    - Anisotropy, Surface finish effects, Thin walls, Build history effects on material structure, etc.



Foundation :: Statistical Process Controls

Statistical process controls are important in sustaining certification rationale

- *Statistical equivalency evaluations* substantiate design values and process stability build-to-build
  a) Process qualification
  b) Witness testing
  c) Integration to existing material data sets
  d) Pre-production article evaluations
- Equivalency of material performance is an anchor to the structural integrity rationale for additively manufactured parts

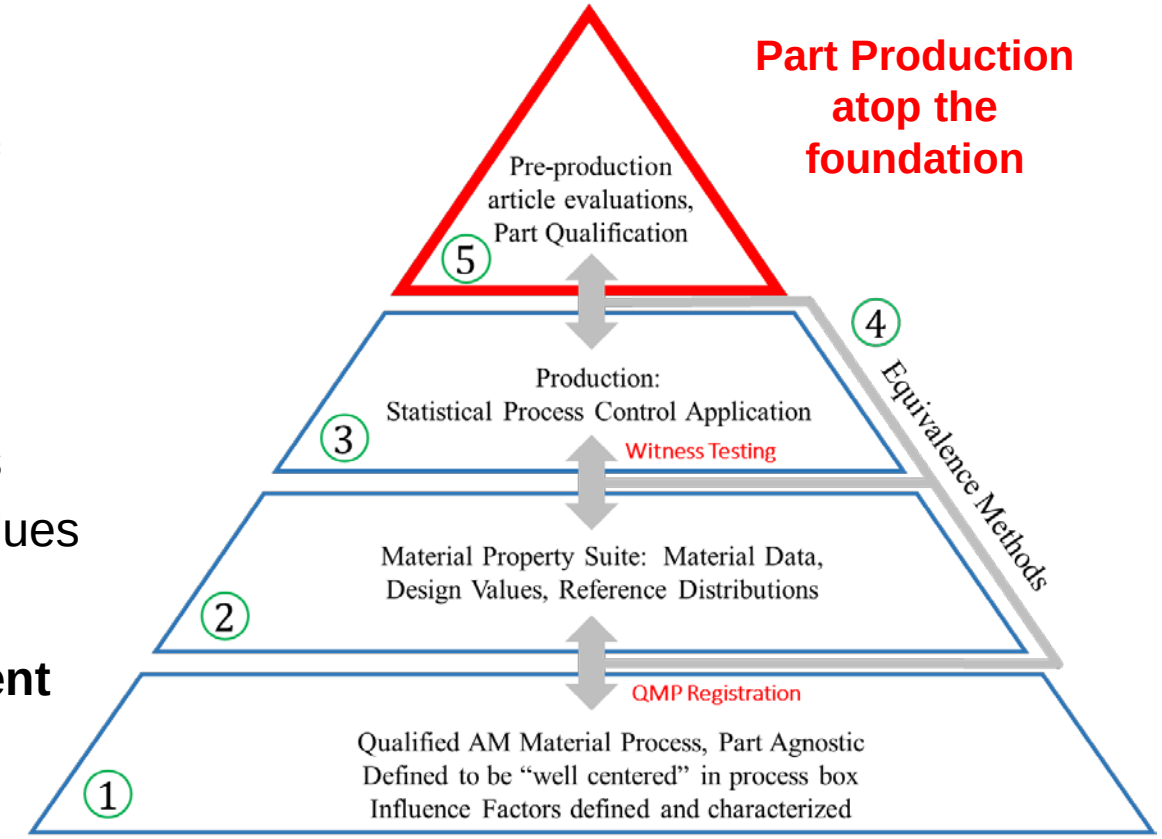


Foundation Complete

A basis to begin designing AM parts with certification intent is feasible once the foundation is laid.

- Equipment and facility understood and controlled
- Well-trained personnel who understand the importance of their role
- Properly qualified machines and processes consistently producing material of known quality
- Understood material capability characterized and process controls established to substantiate the rigor of design values for materials from all qualified machines

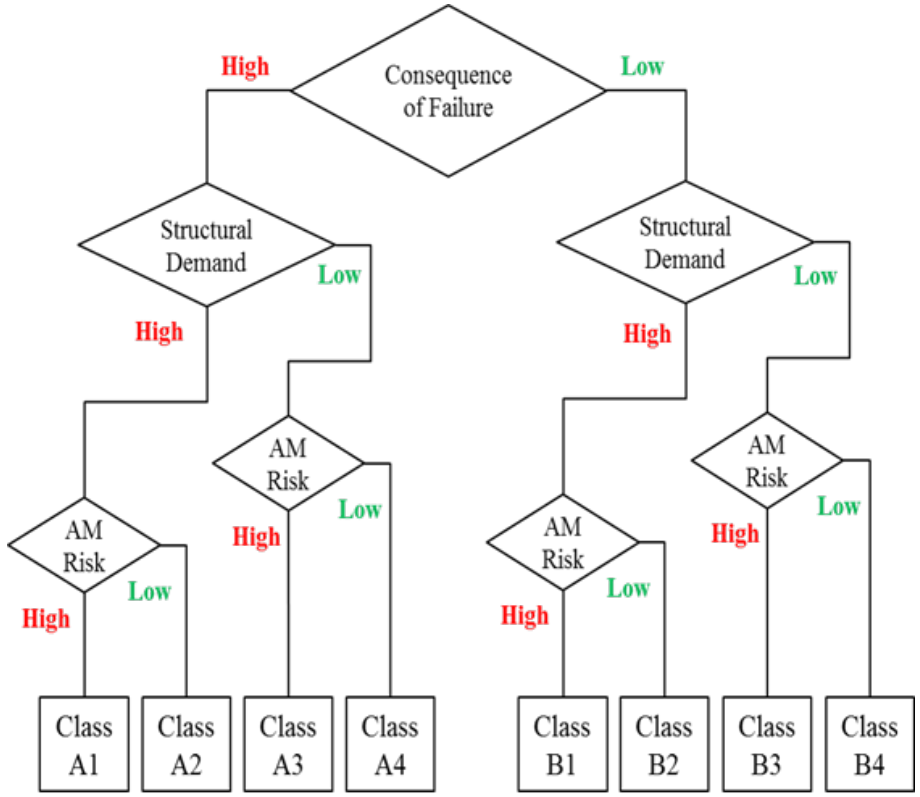
Foundation is now ready to support AM part development in an environment with suitable rigor to establish certification.



Part Planning

AM Part Design

- *Requires integration* across disciplines
  - Manufacturing, Material properties, Inspection
- AM design for manufacturability
  - Ease of build, self supporting, cost effective
  - For certification, NO awards given for most complicated, organic-looking part
  - Prized certification characteristics are ease of *access for verification* and *ability to inspect*
- Classification of parts for risk
  - Consistent ranking and handling of parts based on risk

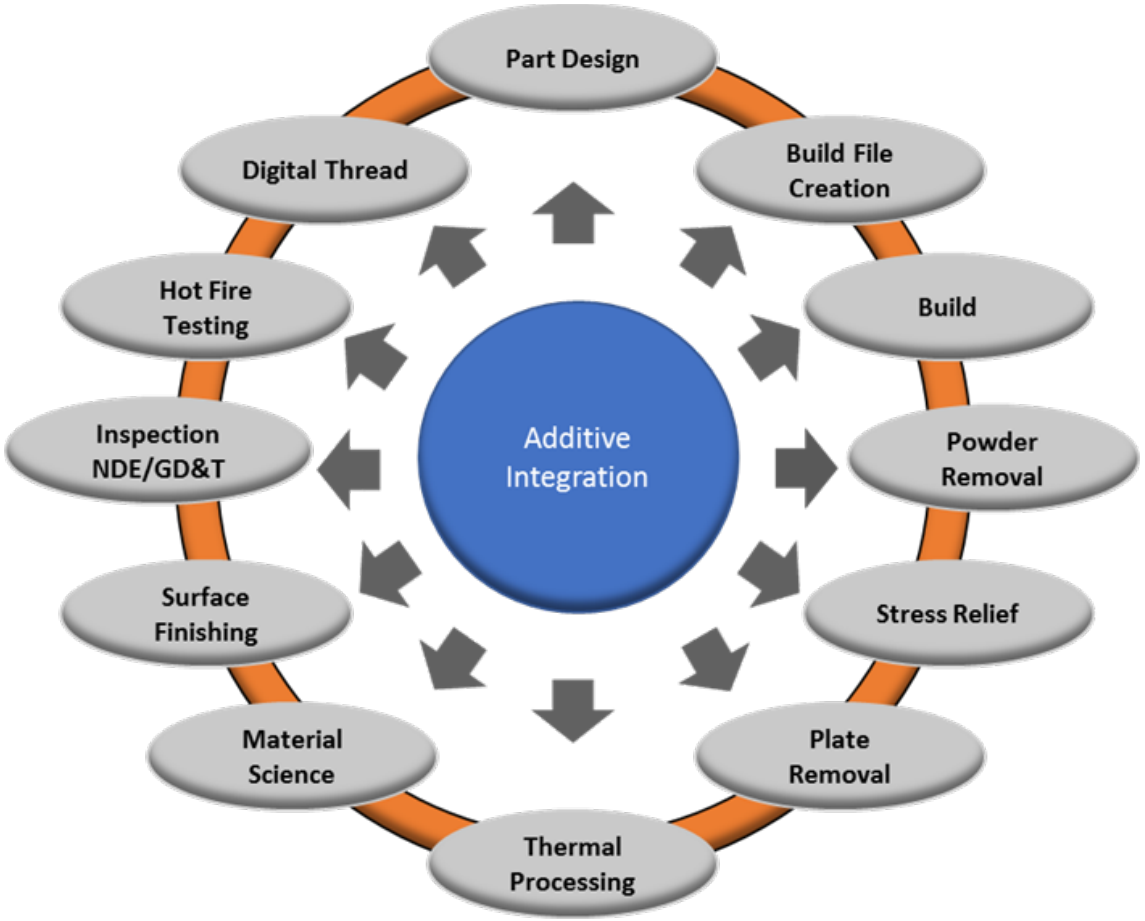


Example AM Part Classification Scheme

Part Planning

AM Part Production Plans

- AM parts do not yet have a common industry standard of practice
  - Challenge to integrate all required aspects of AM design requirements through drawing content
  - Requires many aspects to be integrated
    - Build layout
    - Specification of qualified process ID
    - Witness test and acceptance
    - Post processing details
    - ***Inspection requirements and limitations***
- Requiring a AM Part Production Plan as a drawing companion is best option currently



Qualified AM Part Process

1. Agreed upon and approved AM Part Production Plan
2. Pre-production article evaluation
   - ***Critical step to confirm established foundation successfully produces a part with full integrity and design intent***
   - Dimensional, cut-up material evaluations: microstructure and mechanical
   - Confirmation of inspection procedure and non-destructive evaluation effectivity
3. AM Manufacturing Readiness Review
   - All stakeholders agree AM part development is successful and complete for qualification or production articles to be produced
   - Demarcates the point in time when changes to AM part definition (digital files, engineering instructions, etc) are locked. NO MORE CHANGES
4. Produce to the Plan and STICK TO THE PLAN

AM Part Production

1. Follow the plan, always, with no short-cuts
2. Do not change a Qualified Part Process without re-qualification
3. Efficiency in process monitoring is critical to minimize the inevitable disruption
   - Witness tests can take considerable time to complete
   - Track the performance of each machine using all available metrics by control chart
   - In-process monitoring may provide early warning of changes in machine performance
4. Emphasize the importance of inspection for every part
   - Not just NDE, but visual inspection of as-built conditions
   - Watch for changes in part appearance – colors, support structure issues, witness lines/shifts
5. Consider systemic implications for all non-conformances

Summary

1. Certification rationale is most heavily rooted in the foundational controls
   - Having a Plan
   - Fully involved QMS
   - Equipment and Facility Controls
   - Training
   - Process/machine qualifications
   - Material properties
   - SPC
2. Part Planning must confirm the foundation produces a good part consistently
3. Part production follows a fixed process with statistical process controls

Summary

This overview was intended to demonstrate, at the most fundamental level, the primary aspects of establishing certification rationale for the implementation of AM parts. The concepts covered herein have been agnostic to material and AM process. For a detailed example of the requirements to implement this approach in laser powder bed fusion of metals, see the following documents, which may be found at the links below.

- MSFC-STD-3716 “Standard for Additively Manufactured Spaceflight Hardware by Laser Powder Bed Fusion in Metals”

  https://www.nasa.gov/sites/default/files/atoms/files/msfcstd3716baseline.pdf
- MSFC-SPEC-3717 “Specification for Control and Qualification of Laser Powder Bed Fusion Metallurgical Processes”

  https://www.nasa.gov/sites/default/files/atoms/files/msfcspec3717baseline.pdf

Questions?

Thank You!