Data Packages and Data Sets: Using Standards to Support Part Provenance in AM

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National Institute of Standards and Technology
U.S. Department of Commerce

April 8, 2025

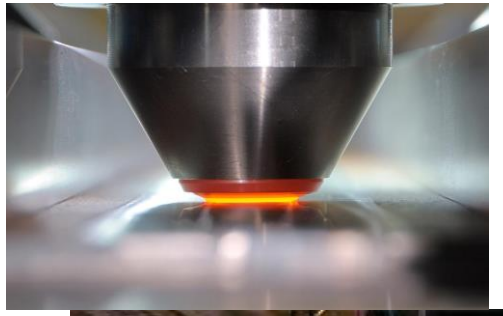
Outline

- Motivation: Building Trust in AM Parts
- Acknowledging Challenges with AM Parts
- Establishing Foundations by Maturing Processes and Environments
- Emerging Guidance for AM Adoption
- Standards Towards Establishing Part Provenance
- Moving Towards a Digital Twin for Part Acceptance
- ASME AM Efforts
- NIST AM Efforts

Motivation: Building Trust In Additive Manufacturing Parts

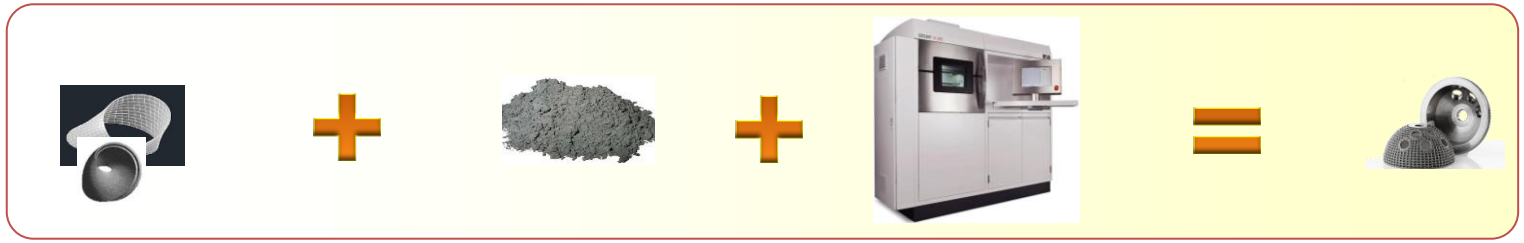
- Parts fabricated with AM processes have proven difficult to incorporate into supply chains
  - AM processes do not yet benefit from the same familiarity as more traditional manufacturing processes
  - Traditional qualification methods have proven difficult to adopt

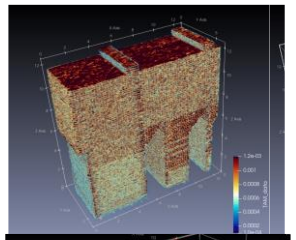
In absence of established process comfort and familiarity, can new data and analytics approaches instill the same confidence?

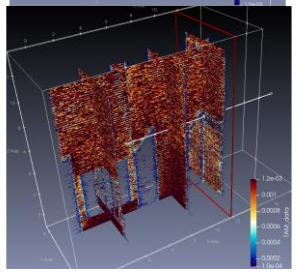


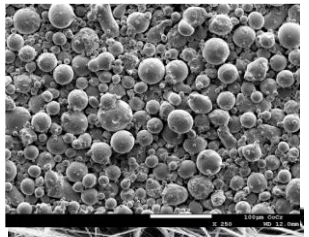
Acknowledging Challenges in Additive Manufacturing

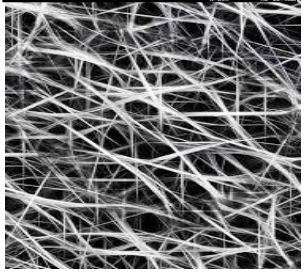
- Process novelty comes with new uncertainties
  - Creates challenges when repeatability and reliability are essential
- Increased capabilities are accompanied by increased parameters
  - Large flexibility can lead to large variability
  - Less robust to disturbances
  - Processes and parts may not benefit from established norms

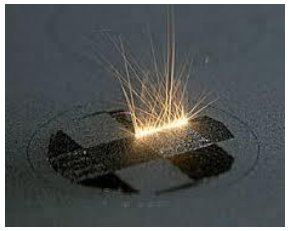


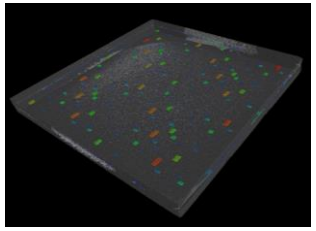


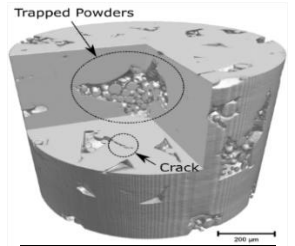


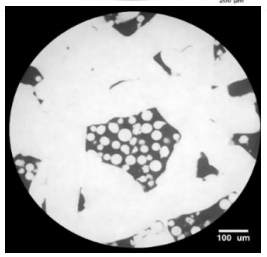






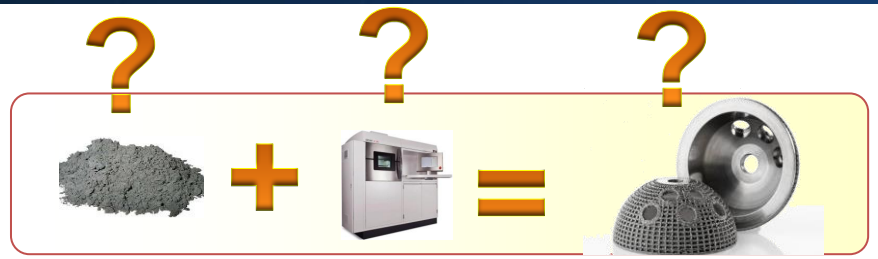




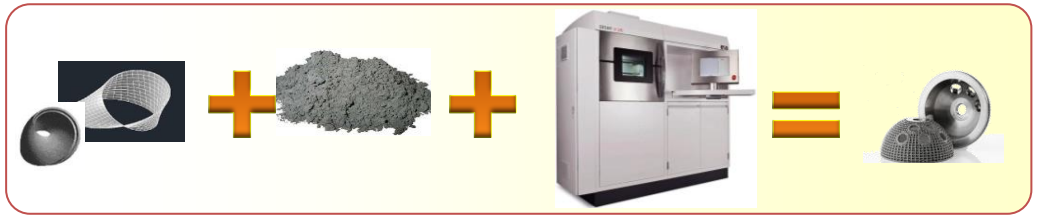


AM processes are inherently different enough that established acceptance processes cannot be readily followed

Building Trust by Addressing Uncertainty of AM Processes

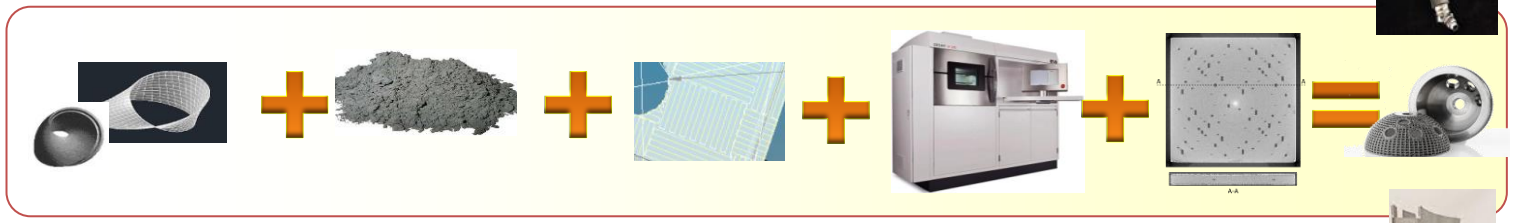


2012



2014

2016



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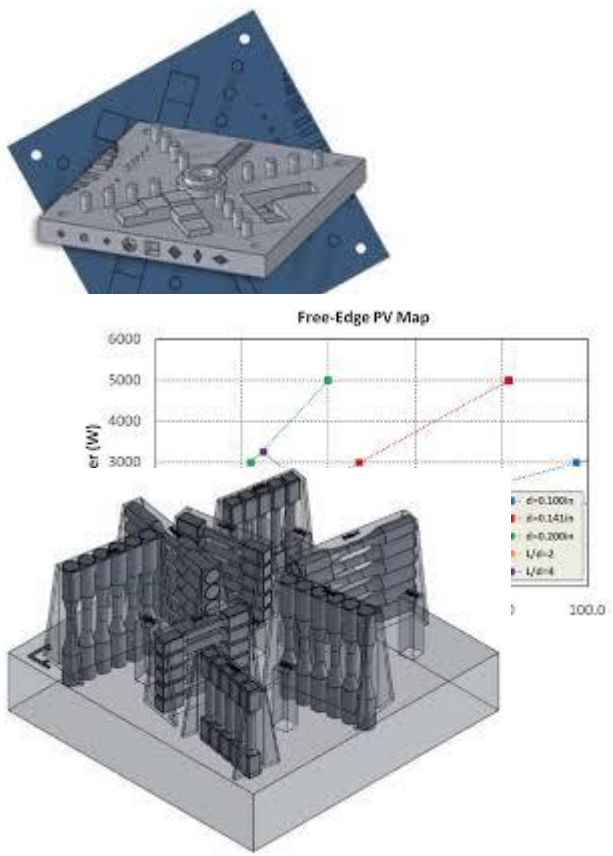
Process variability remains a challenge, though our studying and understanding of it has substantially evolved in the past decade plus.

Maturing the Process and Its Environment

Foundations are being established on which guidance can be developed…

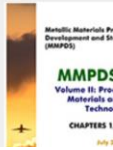
Through Research Literature



Through Standards

2024-07-01

Metallic Materials Properties Development and Standardization (MMPDS) Handbook - 2024 - Volume II B-992_VOLUME2



This first edition of Volume II publishes the framework for generating and analyzing the data so that material sponsors can generate the right data, knowing how it will be analyzed by the Battelle Memorial Institute.

MMPDS-2024 Volume II Process Intensive Materials and Joining Technologies does not currently have any material properties, focusing on additive manufacturing of metallic materials.

MMPDS-2024 Volume II is brand new and will be focused on non-conventional processes and will g forward.

ials and Joint Allowables.

AWS D20.1/D20.1M:2019
An American National Standard

Specification for Fabrication of Metal Components using Additive Manufacturing

Read sample

ISO/ASTM TS 52930:2021

Additive manufacturing — Qualification principles — Installation, operation and performance (IQ/OQ/PQ) of PBF-LB equipment

SAE AIR 7352-2019

CURRENT ISSUED 2022-08-17

Machine Qualification for Fusion-Based Metal Additive Manufacturing AMS7032

Additively Manufactured Component Substantiation

Through Focused Efforts

EASA European Union Aviation Safety Agency

Joint FAA – EASA Workshop

Qualification / Certification of Additively Manufactured Parts

America Makes

Qualification Requirements for Additive Manufacturing Processes – Phase 1 of 3

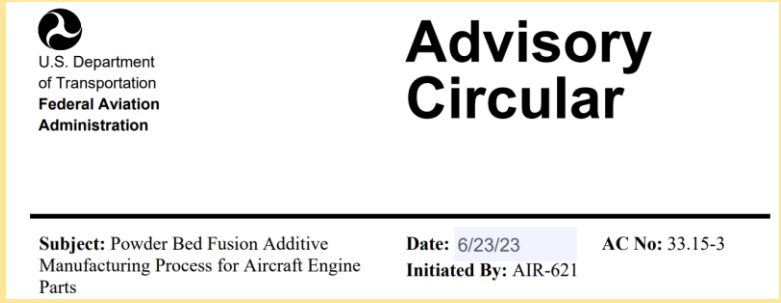
AM FORWARD

Building Supply Chain Resilience Through Partnerships in 3D Printing and Business Support

Developing Guidance Continues to Emerge

Technical Considerations for Additive Manufactured Medical Devices

Guidance for Industry and Food and Drug Administration Staff


U.S. Department of Transportation
Federal Aviation Administration

Advisory Circular

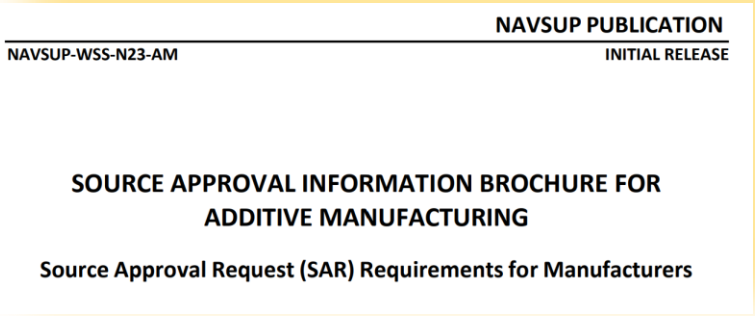
Subject: Powder Bed Fusion Additive Manufacturing Process for Aircraft Engine Parts

Date: 6/23/23 **AC No:** 33.15-3
Initiated By: AIR-621

Requirements for

Additive Manufacturing

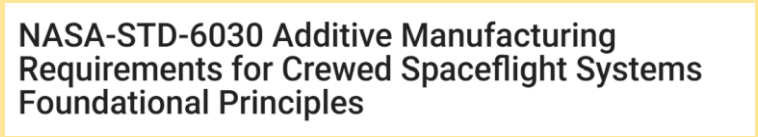
ABS

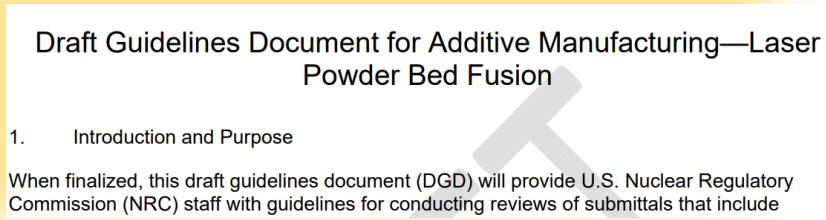

NAVSUP PUBLICATION

NAVSUP-WSS-N23-AM INITIAL RELEASE

SOURCE APPROVAL INFORMATION BROCHURE FOR ADDITIVE MANUFACTURING

Source Approval Request (SAR) Requirements for Manufacturers


NASA-STD-6030 Additive Manufacturing Requirements for Crewed Spaceflight Systems Foundational Principles


Draft Guidelines Document for Additive Manufacturing—Laser Powder Bed Fusion

1. Introduction and Purpose

When finalized, this draft guidelines document (DGD) will provide U.S. Nuclear Regulatory Commission (NRC) staff with guidelines for conducting reviews of submittals that include

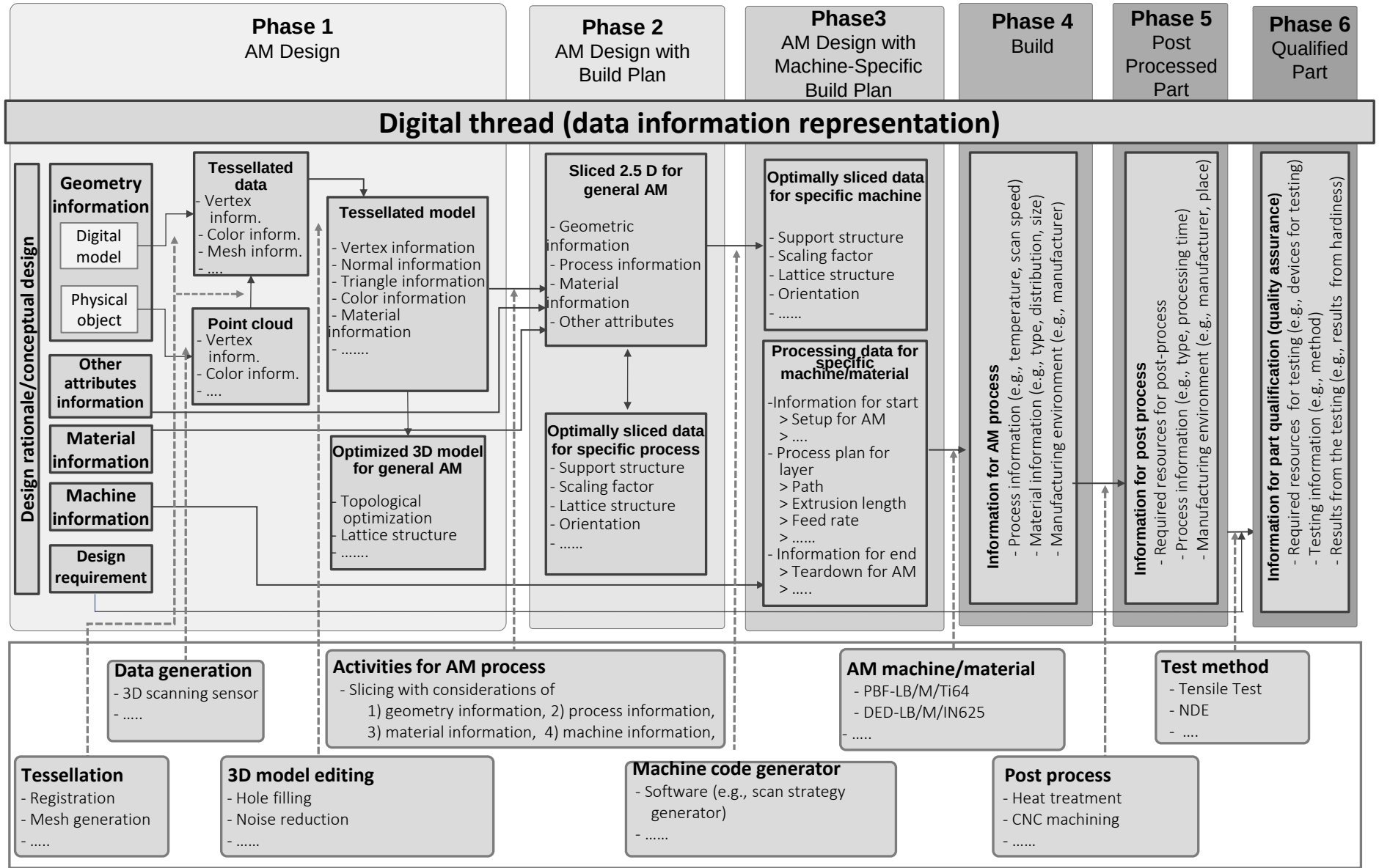
These foundations are supporting the development of guidance for AM adoption

- Qualification and Certification guidance being developed for designs, processes and feedstock
- Qualification guidance being established at machine, facility, and enterprise levels

Shout Out:

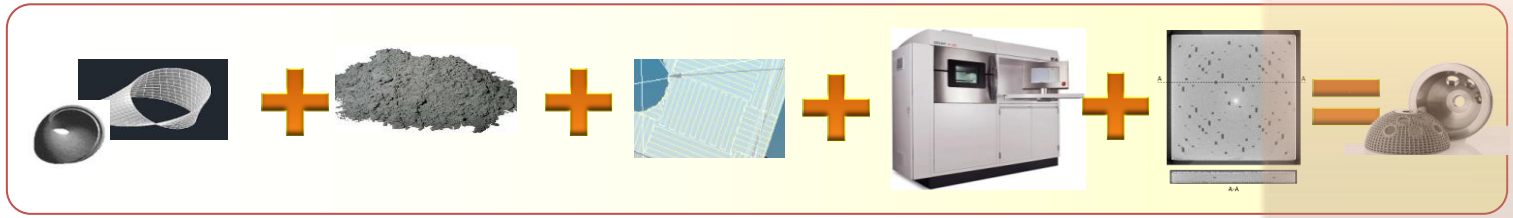
https://www.advancedmanufacturing.org/industries/aerospace-defense/standardized-qualification-frameworks-for-am/article_d0ef300c-f940-11ef-967f-1fdb948afc04.html

But Variability Persists



Demonstrating Performance

The satisfaction of performance requirements must still be demonstrated at part level!

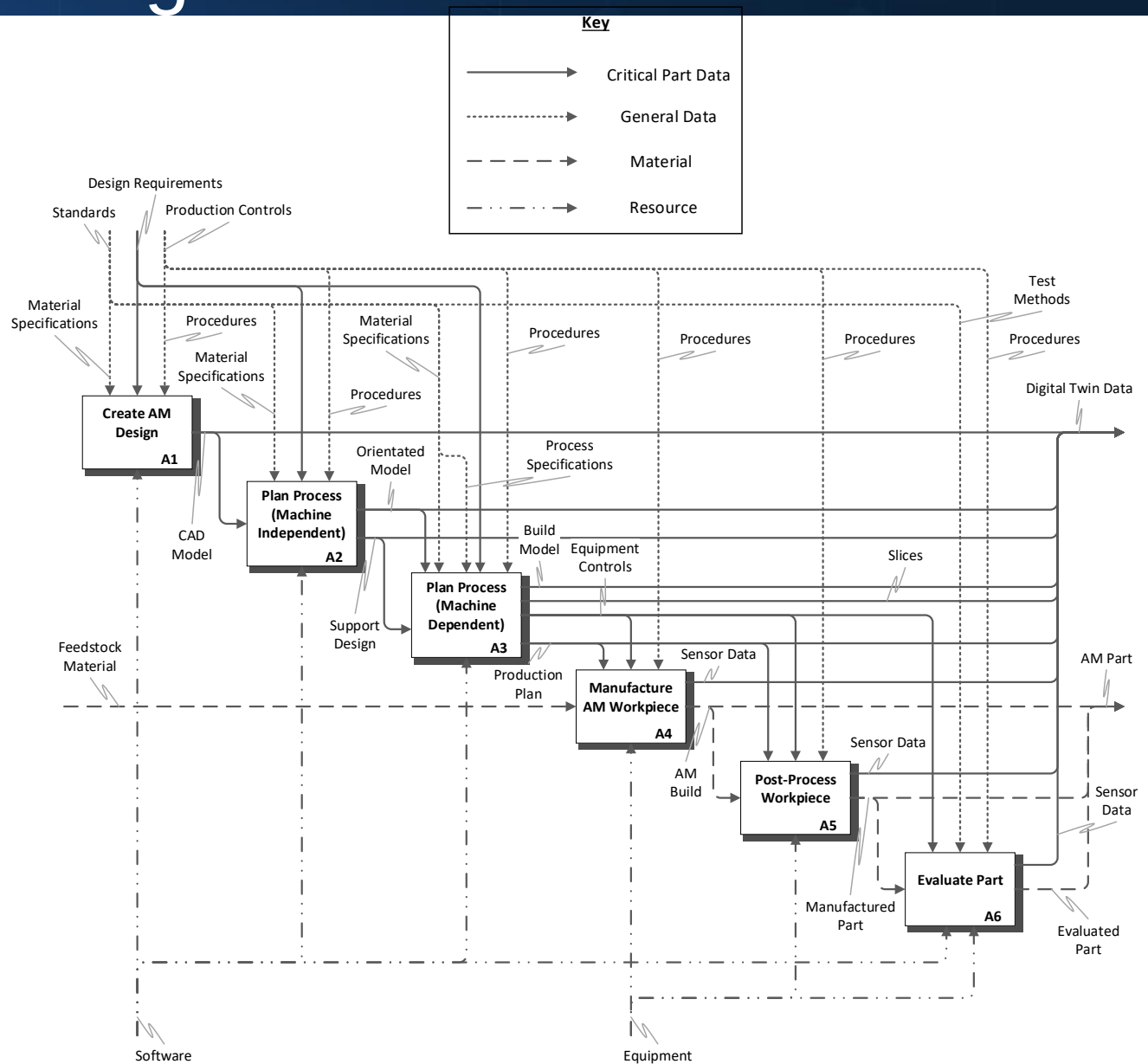


- Whether we are referring to qualification, certification, acceptance, in general, the aim is to:
  - Provide repeatable, standardized means of observing/measuring/recording quality in parts, processes, etc
  - Establish confidence that the part will repeatedly perform as designed
  - Build confidence/trust into part

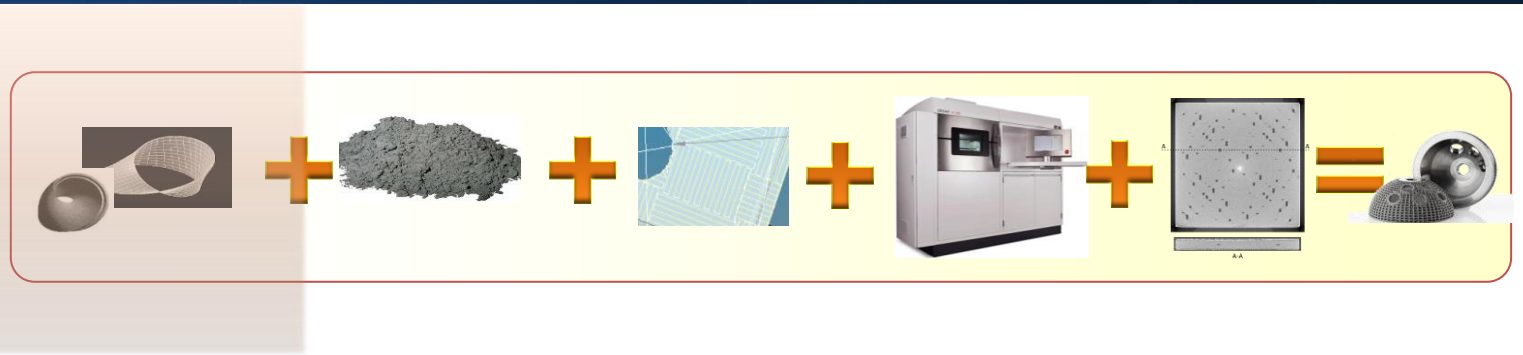
- How the part is communicated for acceptance is evolving
  - Performance has been demonstrated through one-off efforts to meet guidance
  - New standards are emerging that will facilitate this process

Towards Establishing Part Provenance through Added Layers of Data Management

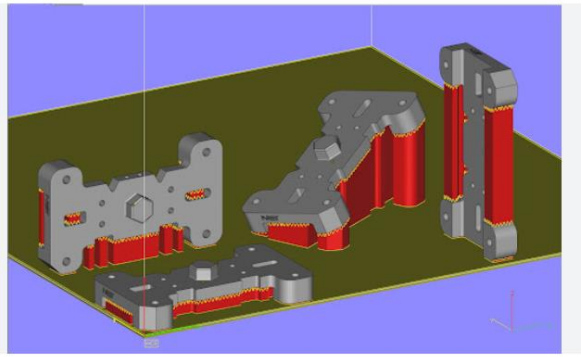
- Standards and specifications are in development that will help establish provenance across the design to product transformation
- Establishing provenance leads to establishing traceability
- Traceability allows for correlations to be made between different stages of a part lifecycle
- These correlations can be leveraged to predict (and demonstrate?) part performance
- Across the lifecycle, data management practices in
  - Design and Material are mature but evolving
  - Process Planning and Monitoring are making gains
  - Inspection is emerging
  - Data packages are here



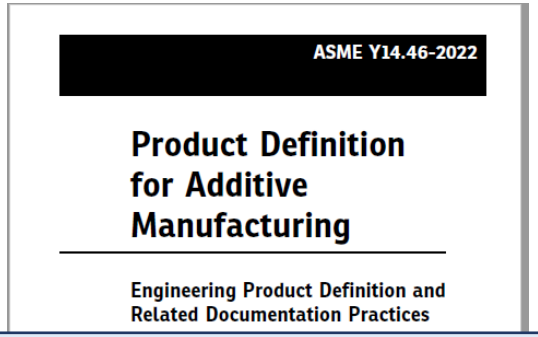
Design



www.ap242.org

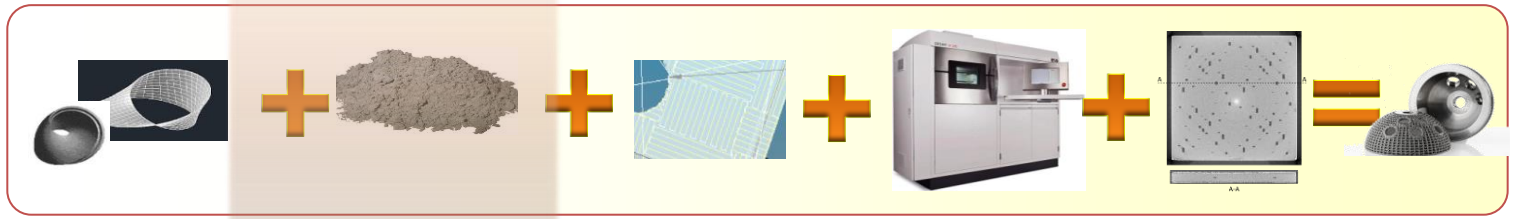


3MF CONSORTIUM



ASME Y14.46 Product Definition for Additive Manufacturing Published in 2022

Feedstock



- F2924-14(2021) Standard Specification for Additive Manufacturing Titanium-6 Aluminum-4 Vanadium with Powder Bed Fusion
- F3001-14(2021) Standard Specification for Additive Manufacturing Titanium-6 Aluminum-4 Vanadium ELI (Extra Low Interstitial) with Powder Bed Fusion
- F3049-14(2021) Standard Guide for Characterizing Properties of Metal Powders Used for Additive Manufacturing Processes
- F3055-14a(2021) Standard Specification for Additive Manufacturing Nickel Alloy (UNS N07718) with Powder Bed Fusion
- -See also WK80940 proposed Revision
- F3056-14(2021) Standard Specification for Additive Manufacturing Nickel Alloy (UNS N06625) with
- F3091/F3091M-14(2021) Standard Specification for Powder Bed Fusion of Plastic Materials
- F3184-16(2023) Standard Specification for Additive Manufacturing Stainless Steel Alloy (UNS S316(
- -See also WK89313 proposed Revision
- F3187-16(2023) Standard Guide for Directed Energy Deposition of Metals
- F3213-17 Standard for Additive Manufacturing – Finished Part Properties – Standard Specification f Powder Bed Fusion
- F3301-18a Standard for Additive Manufacturing – Post Processing Methods – Standard Specificatic Made Via Powder Bed Fusion

AMS7055 • Carburizing Steel Alloy, Powder for Additive Manufacturing, 3.5Cr - 7.5Ni - 16.3Co - 1.75Mo - 0.2W - (0.10 - 0.15 C)
January 22, 2025 • Issued

AMS7057 • Cold Spray Additive Manufacturing (CSAM) Process
December 5, 2024 • Issued

AMS7028 • Titanium Alloy, Ti-6Al-4V, Hot Isostatically Pressed (Low Temperature, High Pressure), Produced by Laser Powder Bed Fusion
December 3, 2024 • Issued

AMS7030 • Aluminum Alloy, 10.0Si - 0.35Mg Stress Relieved, Hot Isostatic Pressed (HIP), Solution Treated and Artificially Aged, Produced by Laser Powder Bed Fusion (L-PBF)
August 12, 2024 • Issued

AMS4999B • Titanium Alloy Direct Deposited Products, 6Al - 4V, Annea
July 3, 2024 • Stabilized

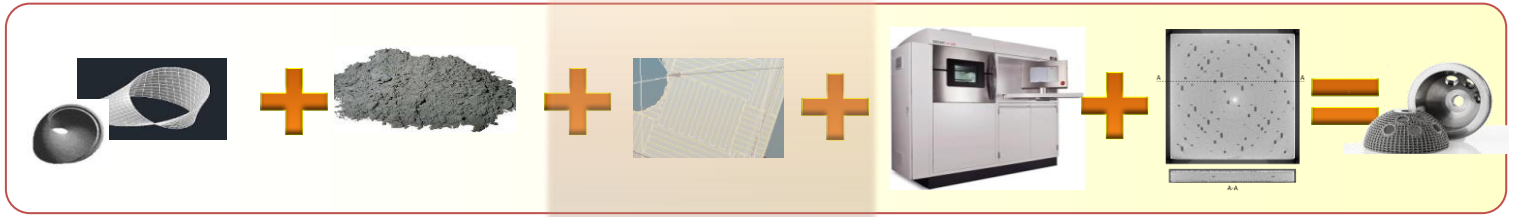
ARP7064 • Machine Requalification Considerations for Fusion-Based M
May 9, 2024 • Issued

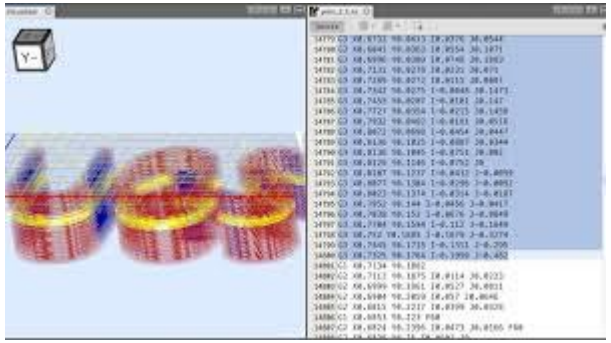
AMS7011 • Electron Beam-Powder Bed Fusion (EB-PBF) Produced Pre 4V, Hot Isostatically Pressed
November 22, 2022 • Issued

ASTM F3560-22

Standard Specification for Additive Manufacturing – Data – Common Exchange Format for Particle Size Analysis by Light Scattering

Process Plan





COMMON LAYER INTERFACE (CLI)

VERSION 2.0

Introduction

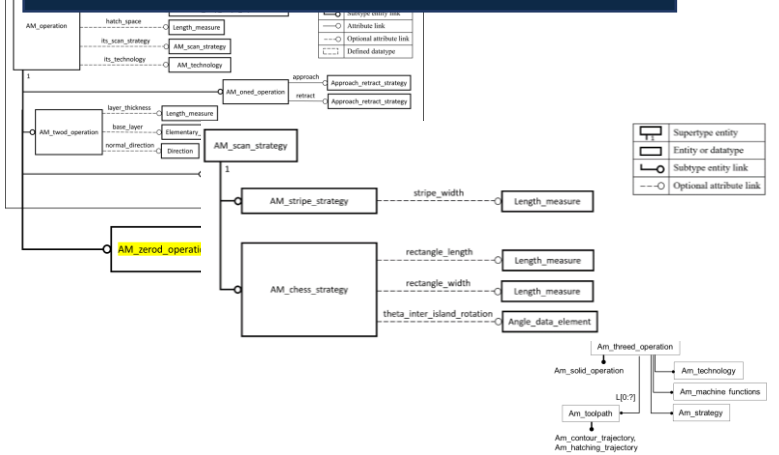
The Common Layer Interface (CLI) is a universal format for the input of geometry data to n

ISO/ASTM CD TR 52918 ed.1- id.76415 ASTM	Additive manufacturing — Data formats — File format support, ecosystem and evolutions
ISO/ASTM 52915:2020 ed.3- id.74640 ASTM CEN	Specification for additive manufacturing file format (AMF) Version 1.2

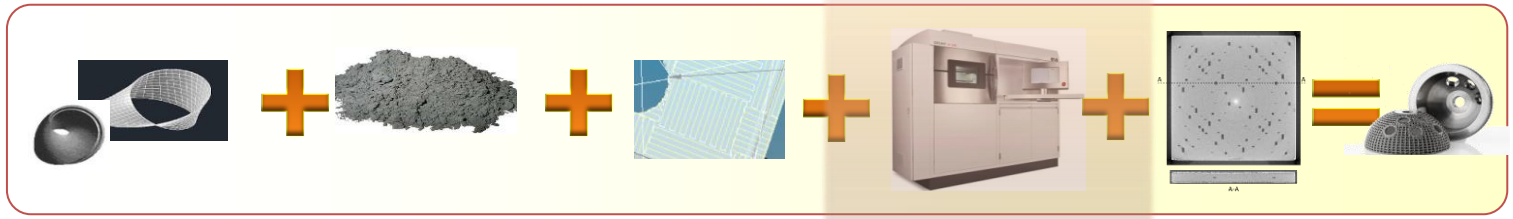
3D Manufacturing Format

Core Specification & Reference Guide

ISO TC 184 WG 15 : AP-238 E4 AP238 Extension for Powder Bed Fusion

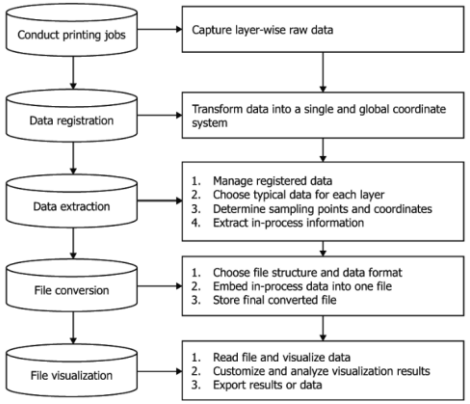


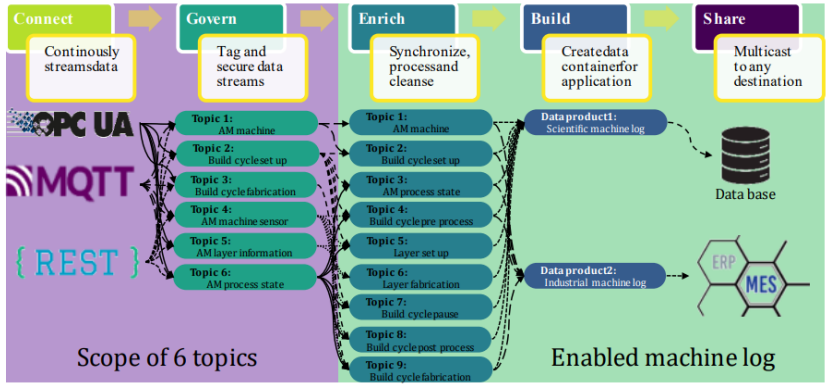
Process



Designation: F3605 – 23

Standard Guide for Additive Manufacturing of Metals — Data — File Structure for In-Process Monitoring of Powder Bed Fusion (PBF)[1]

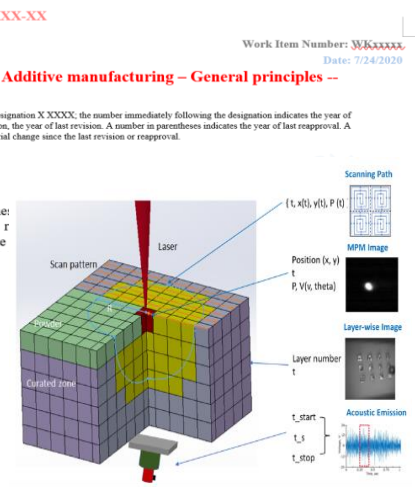




Collection	Document	Object	Endpoint OPC UA/ MQTT/ REST API	Data type	Data unit	Sampling rate	Threshold of applied filter
AM process state	AM machine	comment	-	-	-	-	-
		error	-	-	-	-	-
		maintenance	-	-	-	-	-
		oee	-	-	-	-	-
		process	-	-	-	-	-

New JG83 “Digital Quality Assurance” Additive manufacturing — Data — Data capturing and structure for PBF-LB/M machine log

ISO/ASTM DIS 52953: Registration of AM data acquired from process-monitoring and for quality control



Designation: X XXXX-XX

Work Item Number: WKxxxxx

Date: 7/24/2020

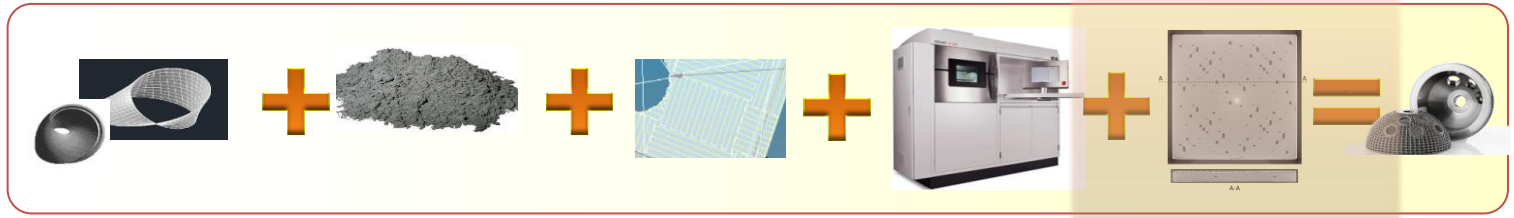
Standard Practice for Additive manufacturing – General principles -- Data Registration[1]

This standard is issued under the fixed designation X XXXX; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice establishes Manufacturing (AM) data r nondestructive sensors. The

Inspection

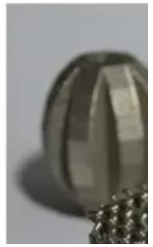


ASME B46.1-2019
(Revision of ASME B46.1-2009)

Surface Texture
(Surface Roughness, Waviness, and Lay)

All contained in Appendix B-5:

- References to standard AM terminology, characterization best practices, and other relevant standards are provided
- Handling issues from cracks and porosity (similar to casting)
- Cautionary statements on limited knowledge base and wide range of AM systems and materials



ASME B89.4.23-2020

X-Ray Computed Tomography (CT) Performance Evaluation

AN AMERICAN NATIONAL STANDARD

The American Society of Mechanical Engineers

TECHNICAL REPORT
RAPPORT TECHNIQUE
TECHNISCHER BERICHT

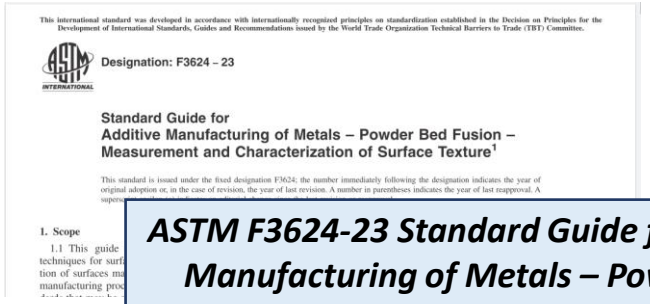
CEN ISO/ASTM/TR 52916

February 2022

ICS 25.030

English Version

Additive manufacturing for medical - Data - Optimized medical image data (ISO/ASTM TR 52916:2022)



Designation: F3624 – 23

Standard Guide for
Additive Manufacturing of Metals – Powder Bed Fusion – Measurement and Characterization of Surface Texture[1]

1. Scope

ASTM F3624-23 Standard Guide for Additive Manufacturing of Metals – Powder Bed Fusion – Measurement and Characterization of Surface Texture

Designation: E3166 – 20

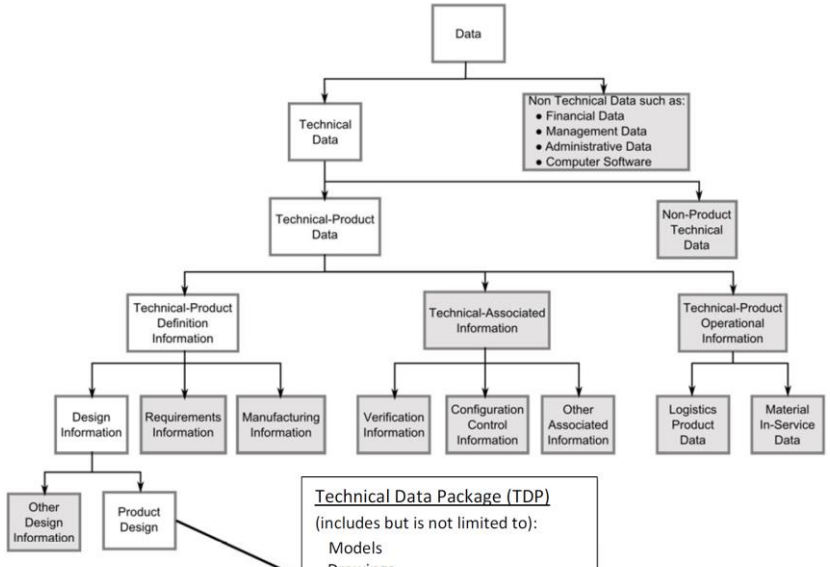
Standard Guide for
Nondestructive Examination of Metal Additively Manufactured Aerospace Parts After Build[1]

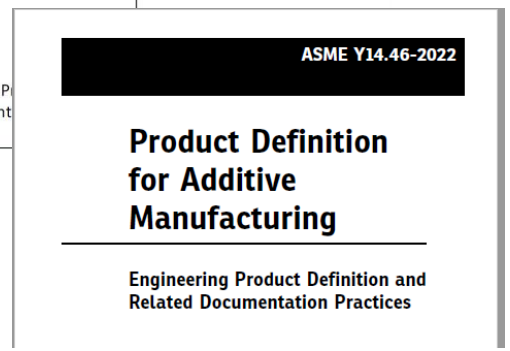
ASTM E3166-20

Standard Guide For Nondestructive Examination Of Metal Additively Manufactured Aerospace Parts After Build

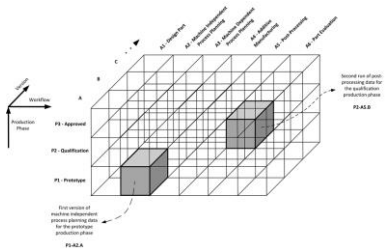
Configuration/ Data Package Management

MIL-STD-31000 Technical Data Packages in Acquisition

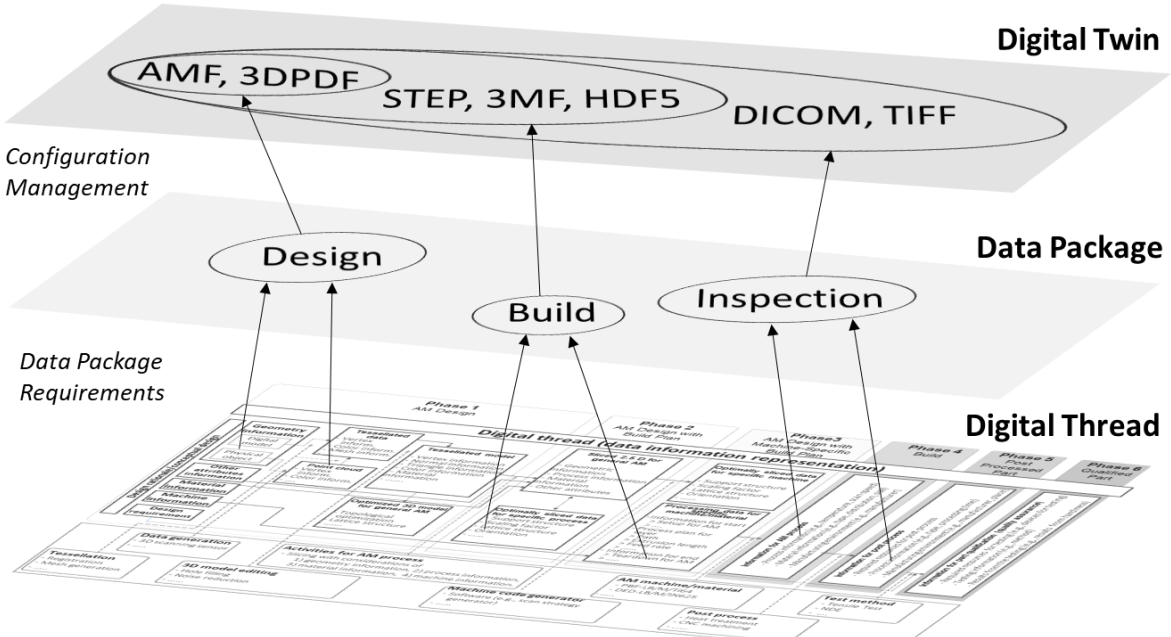




ISO CD 52951 Additive Manufacturing—Data – Data Packages for AM Parts



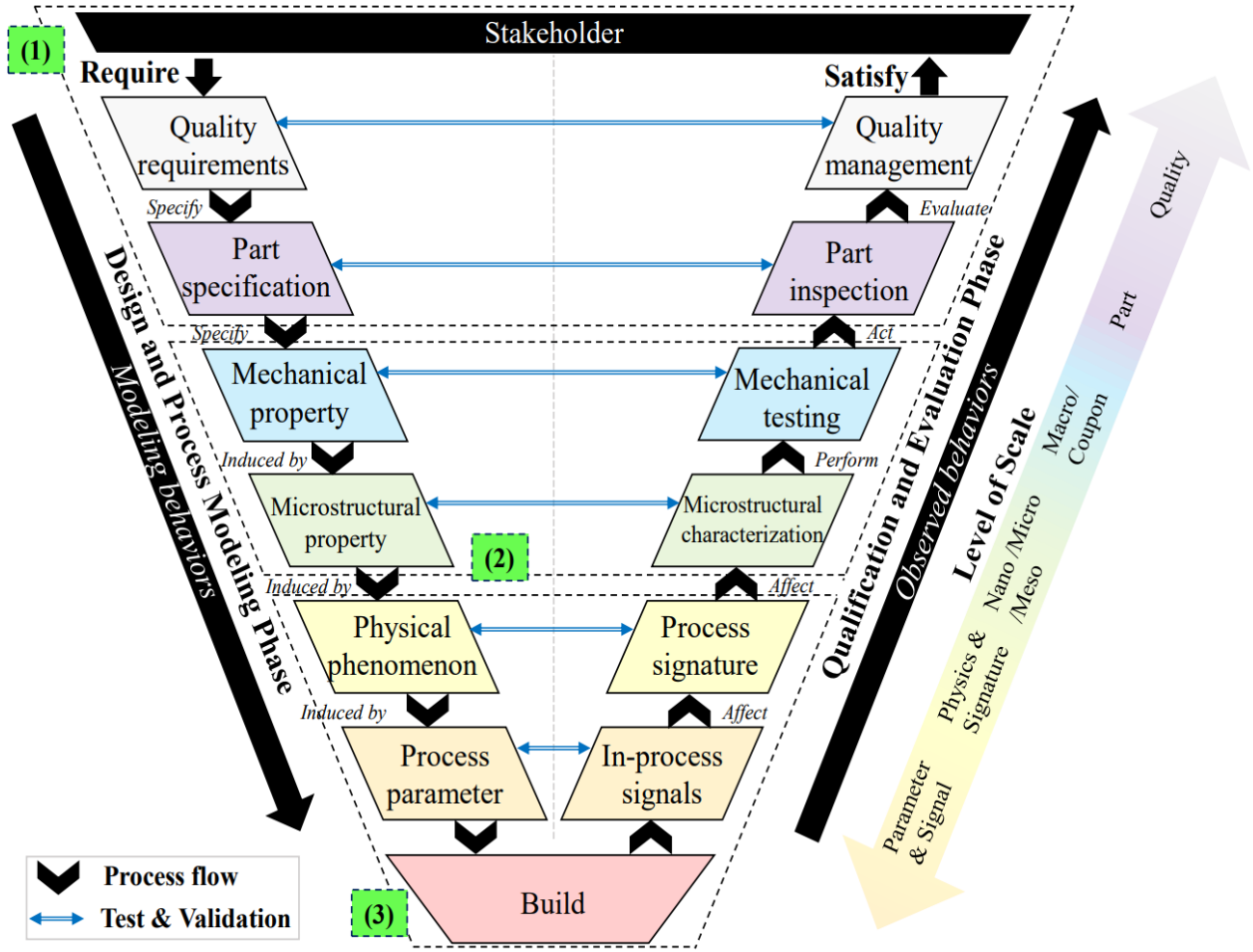
	High Capability	More Capability	Medium Capability	Less Capability	Low Capability
High Critical	Medium Control	Medium to High Control	High Control	Not Recommended	Not Recommended
More Critical	Medium to Low Control	Medium Control	Medium to High Control	High Control	Not Recommended
Medium	Low Control	Medium to Low Control	Medium Control	Medium to High Control	High Control
Less Critical	Low Control	Low Control	Medium to Low Control	Medium Control	Medium to High Control
Low Critical	Low Control	Low Control	Low Control	Medium to Low Control	Medium Control



Mapping Part Provenance to Performance Requirements

- Part acceptance requires transparency throughout this V-Model, which in turn requires:
  - Accounting for specifications at all stages
  - Ability to traverse different scales
  - Ability to test and validate at all stages

This necessary transparency cannot be readily achieved through part or process observations alone, and reconciliation between physics-based and data driven models is necessary.



Ensuring Quality in Metal Additive Manufacturing through a V-Model Framework | IEEE Journals & Magazine | IEEE Xplore

Data Pedigree, M&S, VVUQ, and Digital Twins

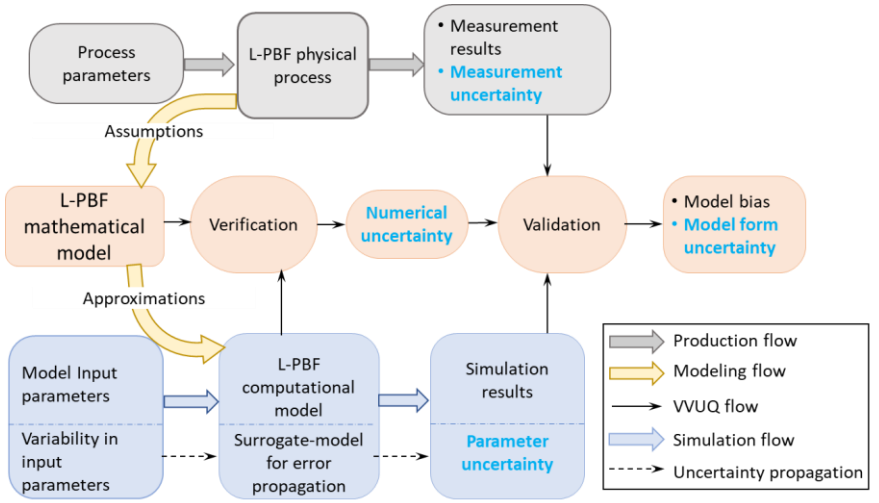
Existing standards can be leveraged to support the development of a DT in AM

- ASTM F3490-21 Standard Practice for Additive Manufacturing — General Principles — Overview of Data Pedigree
- ISO TC 184 WG 15 ISO 23247 Digital Twin Framework for Manufacturing

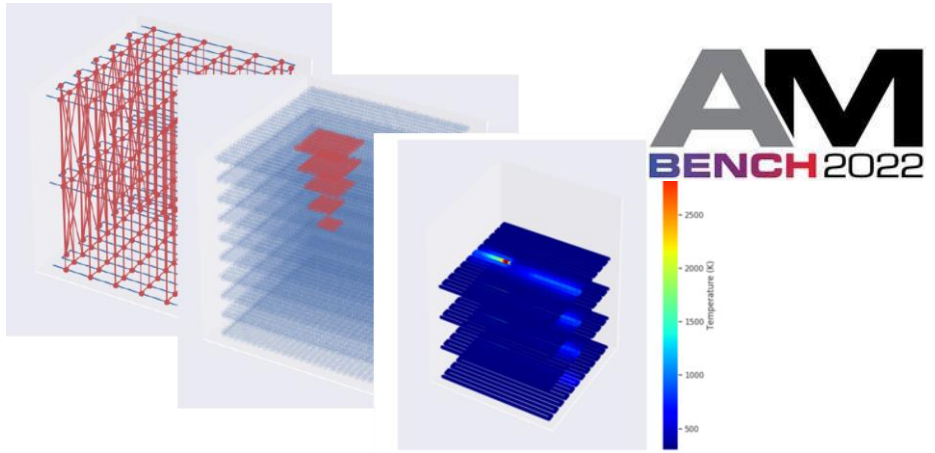
Expected standards will support the USE of a DT in AM

- ASME V&V 50 Subcommittee on Advanced Manufacturing- Additive Manufacturing
- ISO TC 261 JG73 General Principles-Modeling and Simulation for AM

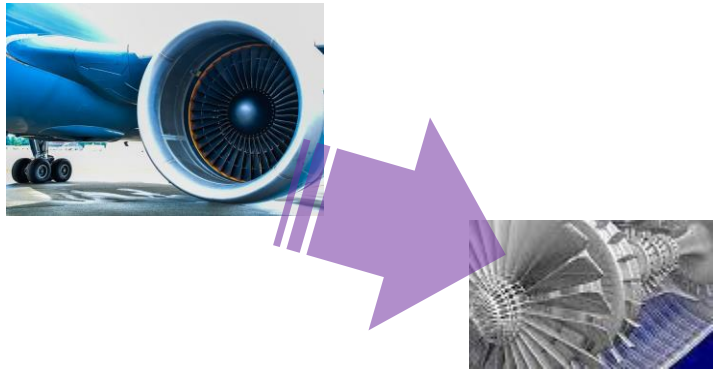
New initiative to quantify uncertainty in AM models for prediction and qualification.

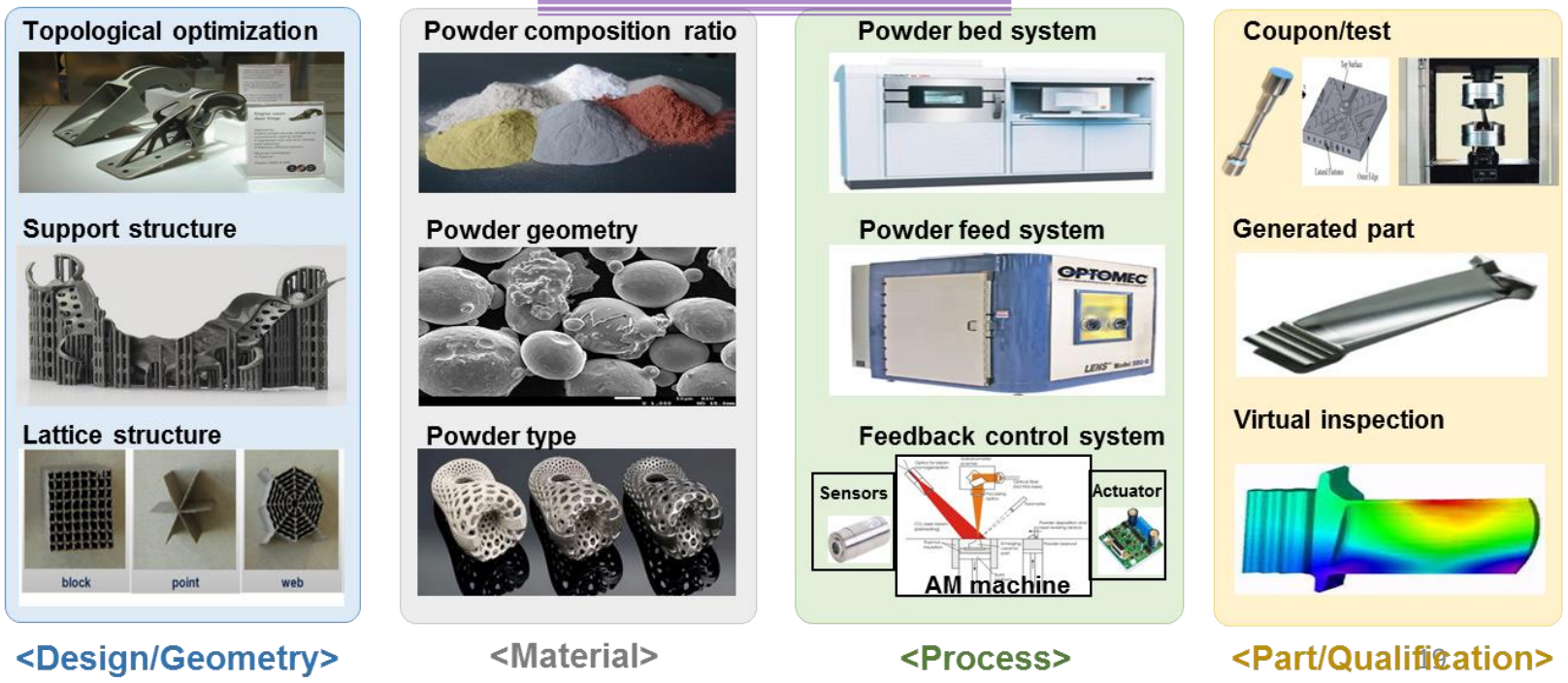


ASTM F3490-21 Standard Practice for Additive Manufacturing — General Principles — Overview of Data Pedigree Published in 2021

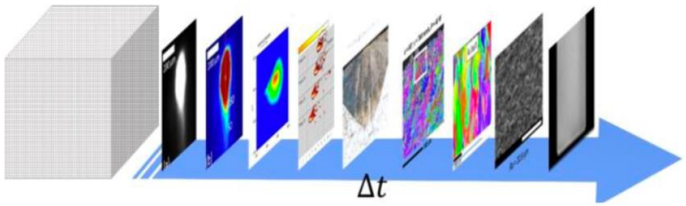


Digital Twin for Part Acceptance



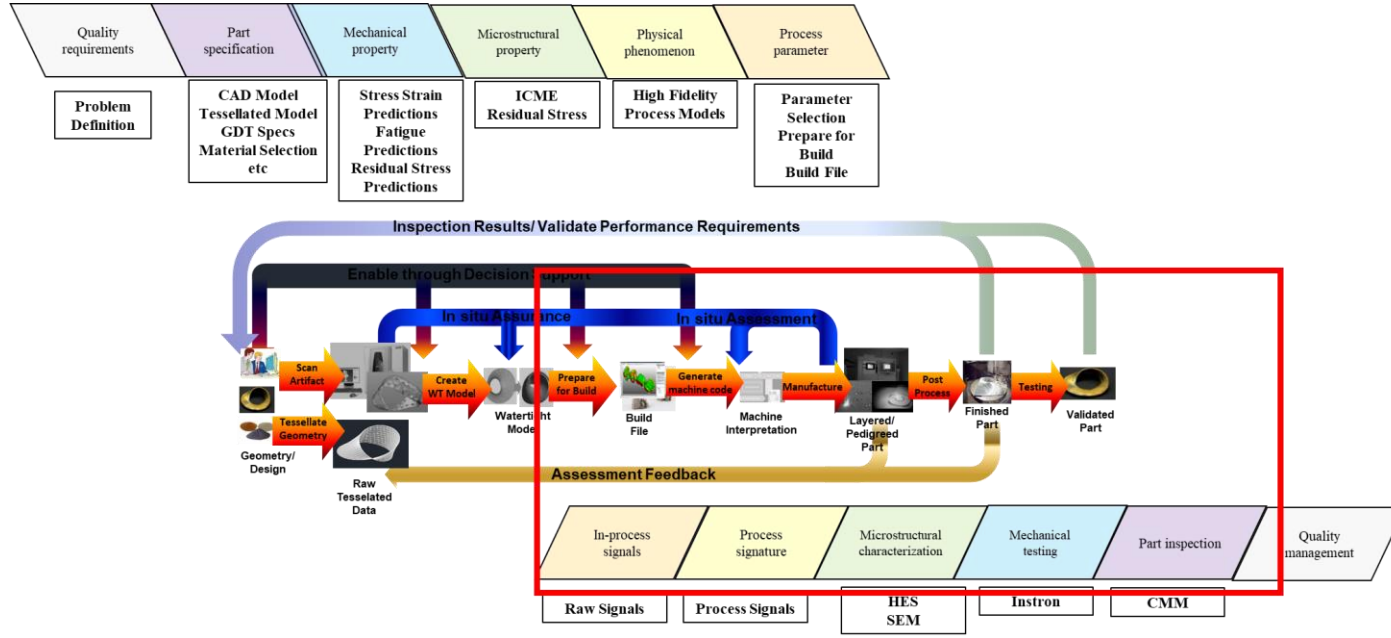


- Leverage the digital twin to build confidence in process and part
  - Digital twins can be used for establishing provenance of parts, processes, and part-process interactions
  - Digital twins can be used to provide a basis on which detailed analyses can be performed



Summary

- Additive manufacturing is being integrated into supply chains
- Different approaches to integrating AM are being developed and adopted
- Many approaches focus on maturing materials, processes, and facilities
- Approaches are accompanied by data management requirements; data management is evolving and often case by case
- Emerging standards are setting the stage for establishing part provenance and developing digital twins to support more standardized approaches to part acceptance

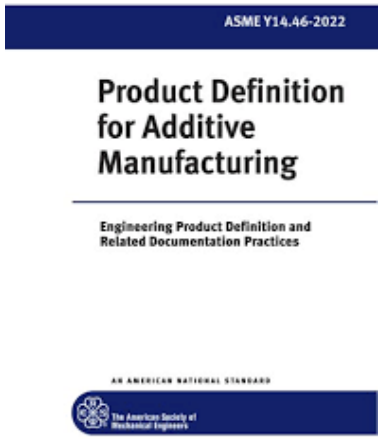


ASME AM Overview: Standards

Specification

Inspection

Y 14.46



New revision in development to reflect maturing AM needs.

VVUQ 50

Verification, Validation, and Uncertainty Quantification for Advanced Manufacturing

New Subcommittee established to address VVUQ in AM models and simulation

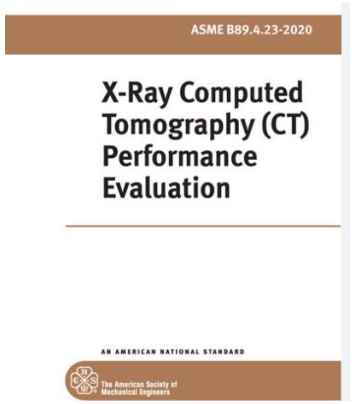
B89

All contained in Appendix B-5:

- References to standard AM terminology, characterization best practices, and other relevant standards are provided
- Handling issues from cracks and porosity (similar to casting)
- Cautionary statements on limited knowledge base and wide range of AM systems and materials

Appendix B-5 published specifically address AM.

B46



New AM specifics in development but not yet published.

ASME AM Overview: Codes

Significant progress made in last few years:

The Committee on AM has drafted criteria for two Code Cases for Additive Manufacturing:

- Construction of Pressure Equipment using Direct Energy Deposition with Wire Feedstock
- Construction of Pressure Equipment using Powder Bed Fusion

Additional AM Guidance is coming:

- Status B31 (Code for Pressure Piping)
  - Mandatory appendix for AM in the 2026 Edition
- Status B16 (Standards for Pipes and Fittings)
  - Formed a Task Group to incorporate AM
  - Will implement PBF for their first AM Code Case

An AM Standard Committee has been formed under the Board on Pressure Technology Codes and Standards (BPTCS) as of February 2025

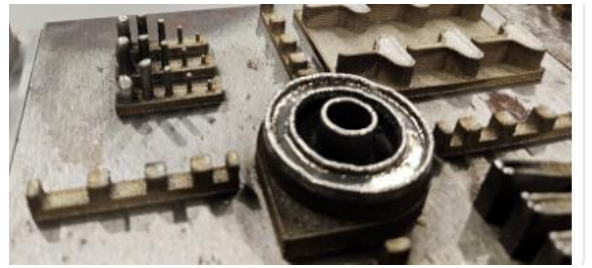
Charter

To establish a standard for publication that provides the requirements for the construction of pressure equipment that utilizes additive manufacturing processes. Construction, as used in this charter, is limited to materials, design, fabrication, examination, inspection, testing, and certification.

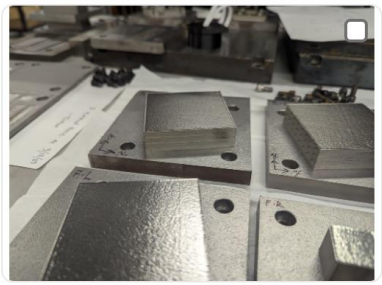
Additive Manufacturing at NIST

NIST's Drivers for Standards and Measurement Science for Additive Manufacturing

Major barriers to broadening adoption of AM include:



- Variations in feedstock types and with **unknown / non-uniform properties**
- Inevitable **process variability** and inconsistent system performance
- Consensus protocols and test data for **qualification and certification** do not exist
- Insufficient **part accuracy and homogeneity** without significant post-processing
- Insufficient **surface finish**



- Insufficient and siloed **data** inhibits transparency in parts and processes and correlations
- Immature **modeling and simulation** capabilities lack robustness and VVUQ considerations
- Need for improved **non-destructive evaluation methods** for characterizing complex defects and part geometry
- **Design and process requirements** to account for secondary post-processing
- Lack of AM-specific **design tools / design guidelines** to take advantage of new AM capabilities

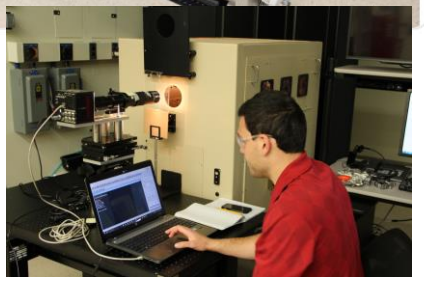
NIST provides trusted data, best practices, test methods, protocols, etc. that provide the scientific foundations for standards, model validation, data interoperability, etc.

NIST MSAM Facilities and Equipment

Additive Manufacturing Research Center

EOS M290,Optomec LENS MR7, ExOne Mlab

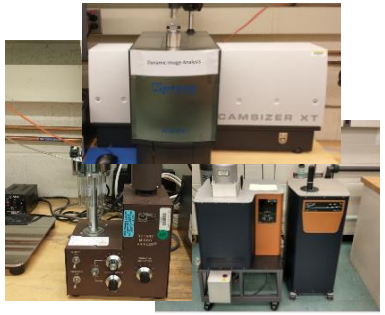
AMMT/ FLaMI Laboratory



Additive Manufacturing Metrology Testbed, Fundamentals of Laser-Matter Interaction (FLaMI), High Temperature Blackbody

Other facilities and equipment including:

- EOS M270 (adjacent to AMRC)
- Powder Characterization Laboratory
- Laser Processing Diffraction Testbed (LPDT)
- Post-processing and testing facilities
  - High temperature heat treatment furnace, EDM
  - XCT, Focus Variation, mechanical testing, SEM, XRD
- Data Testbench Lab



Recently acquired:

- **Renishaw 500Q 4- laser PBF- Metal**
- **Meltio Haas Hybrid CNC / Wire DED**
- **Markforged Binder Jetting (Metal)**

Q&A

Contact:

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paul.witherell@nist.gov

National Institute of Standards and Technology
U.S. Department of Commerce