FAA Additive Manufacturing Research & Development

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FAA William J. Hughes Technical Center

A11C.SIC.15: Non-Metallic Additive Manufacturing
A11C.SIM.1: Advancement of Metal Additive Manufacturing Materials

AVS Sponsors: Cindy Ashforth, Michael Gorelik; ANG Program Managers: Danielle Stephens, Kevin Stonaker

Research Project Description

Congressionally directed funding to advance the use of additive materials into the commercial aviation industry

- Development of a framework for the qualification of AM materials including guidelines and recommendations for their characterization, testing, design, and utilization
- Transition of generated test data and guidelines into shared databases
- Targeted research on topics such as effect of defects, surface integrity, etc.

Sponsor Anticipated Outcome

- Ensure metal AM technology is safely and efficiently integrated into aircraft, engine, and propeller applications. Proactively identify potential hazardous conditions in order to prevent fatal accidents due to material defects or manufacturing flaws. Promote certification efficiency through industry standardization efforts.

Critical Milestones

- Qualification Programs (material, technology):
    - PEKK, LB-PBF: Q2, 2023
    - Onyx, FDM: Q3, 2023
    - Ti-6Al-4V, LB-PBF: Q4, 2024
- Finalize Building Block test plan (non-metal and metal), Q4 2022
- Complete Ti-6Al-4V key process variable drift and effect of defects testing, Q1 2023

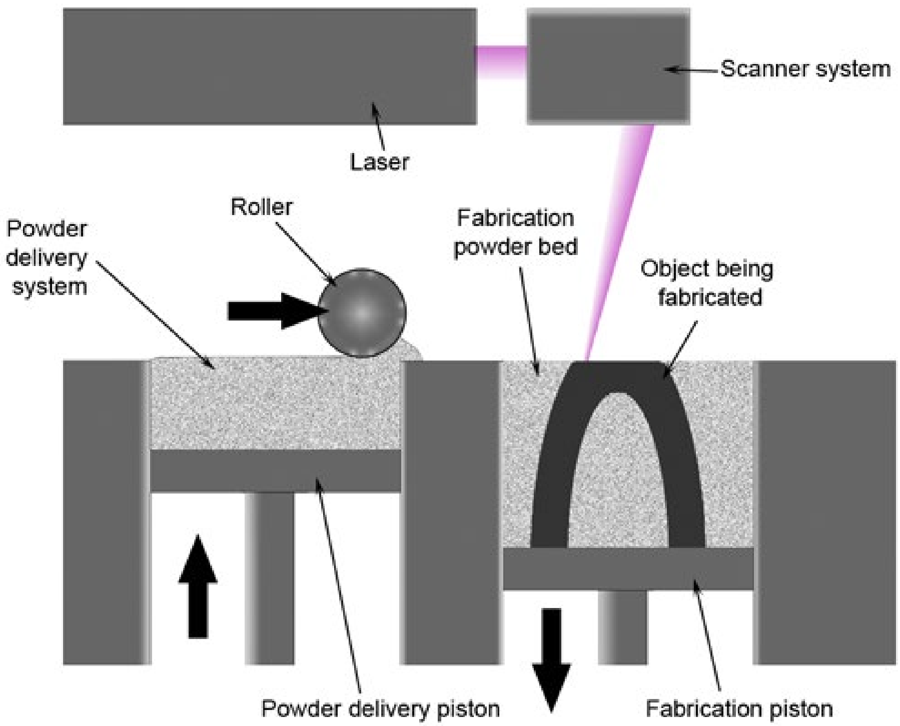
Research Accomplishments in FY22

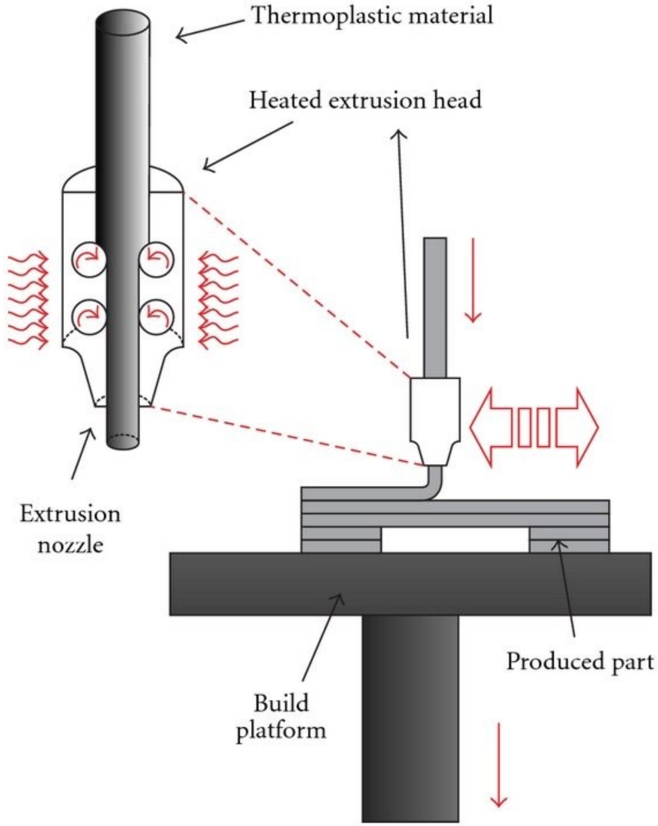
- Hex-PEKK laser-powder bed fusion: Completed all prequalification activities and began formal qualification program
- ASTM Committee F42 on Additive Manufacturing Technologies: “Guide for Additive Manufacturing of Polymer – Guide to Material Extrusion – Recommendation for Material Handling and Evaluation of Static Mechanical Properties” is Out to Ballot
- Ti-6Al-4V qualification: Completed Process Control Document (PCD) rev F and began site comparison study

Outline

- **AM Background**
- **NDT Considerations**
- **FAA AM R&D Programs**
  - Polymer Based AM Programs
  - Metal AM Programs
- **Summary**

Additive Manufacturing Background

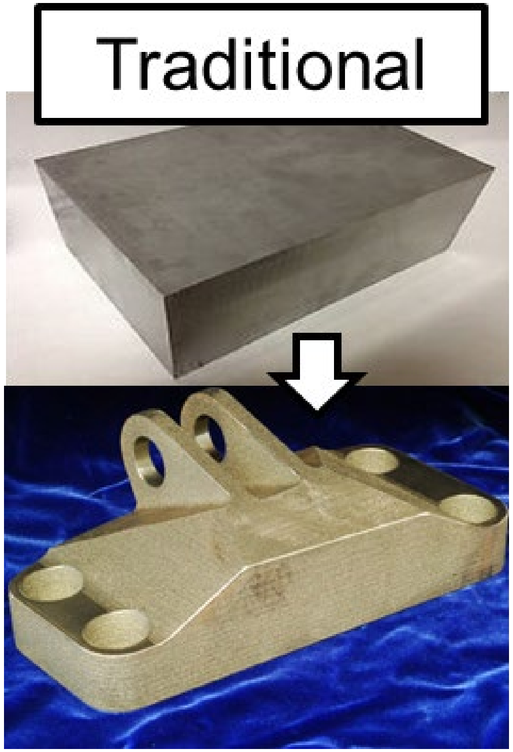


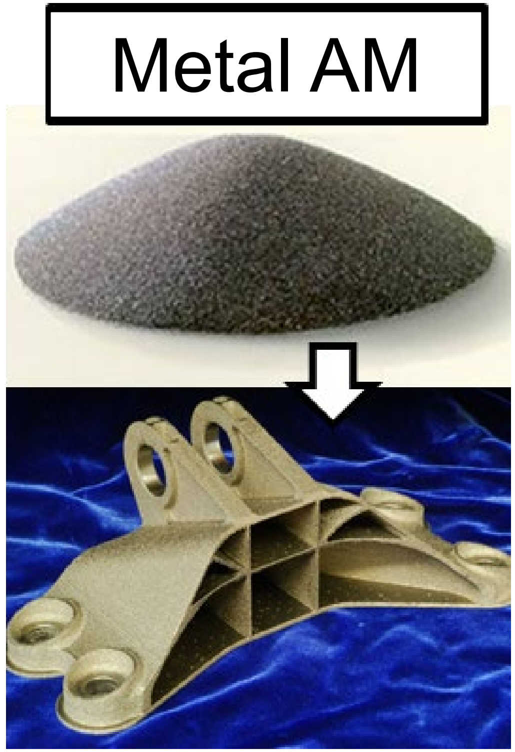


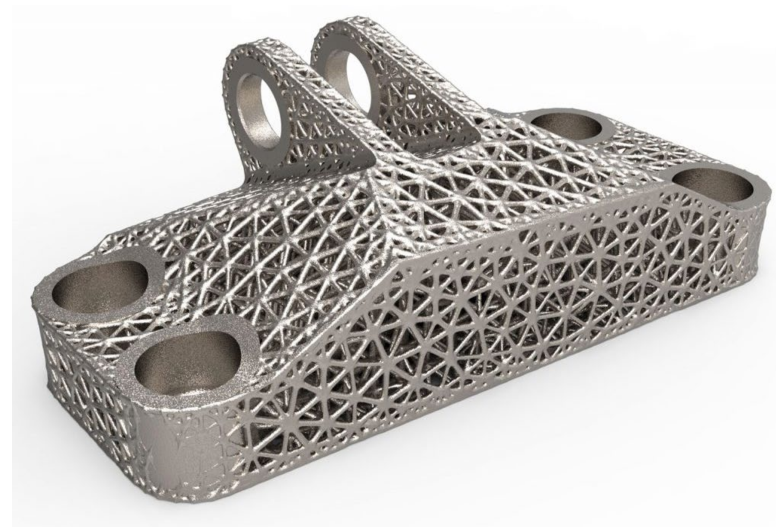
Powder Bed Fusion

Fused Deposition Modeling

Additive Manufacturing Background





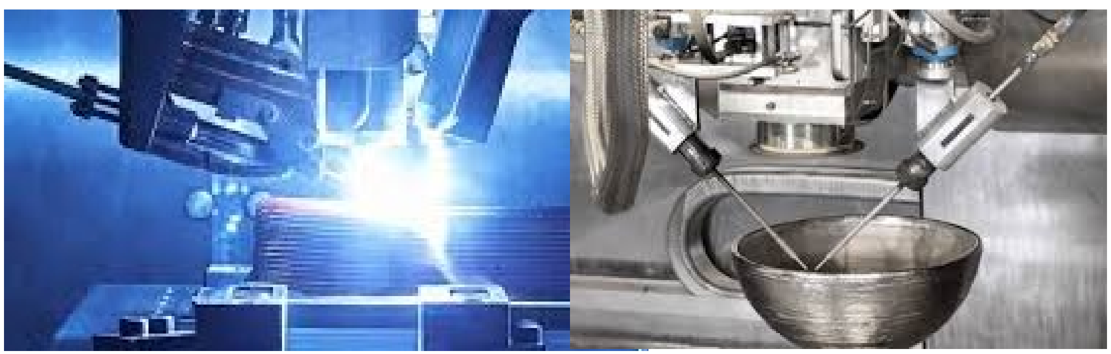


Additive Manufacturing Background

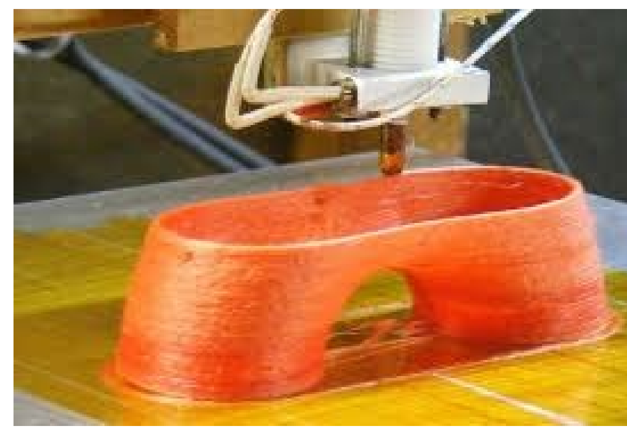
Powder Bed Fusion

Blown Powder
Direct Energy Deposition

Vat Polymerization



Wire-fed Direct Energy Deposition



Fused Deposition Modeling

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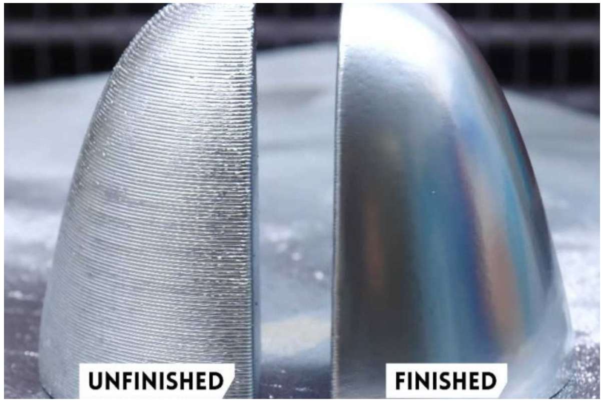
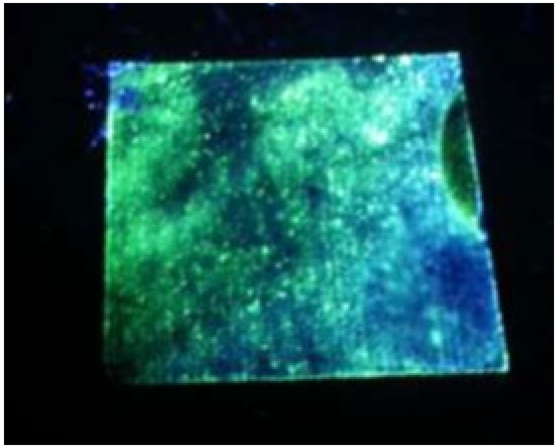
NDT Considerations for AM

- AM parts pose unique challenges to some traditional NDT techniques:
  - Rough as-built surfaces
  - Internal passages or structures
  - Textured material microstructure
  - Unique morphology of defects
- AM parts currently have very limited service history to learn from
- Inspectability of AM parts will become more important as the number of parts flying and their criticality increases
- Some practitioners view in-situ monitoring as a sub-set of NDT methods for AM
- FAA research is currently focused on other fundamental aspects of AM but does incorporate NDT wherever practical





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FAA AM Research Outtakes

Research Planning

- Funding has been coming from two sources:
  - FAA AVS RE&D process funding: typically around $100K annually
  - Congressionally directed funding: $6M annually since 2019 directed to the Joint Advanced Materials and Structure (JAMS) COE
- JAMS has 1:1 cost match programs; additional partnerships provide further leverage for funding
- Benchmarking and industry involvement for all programs ensure timeliness and usefulness of research

Research Outcomes and Use

- All results made public through various means; FAA reports, presentations, training, etc.
- Data and conclusions are used to support FAA participation in creating industry consensus documents through Standards Development Organizations and other groups

Non-metallic AM Overview

Topic	Partner	Technology	Material	Start	End
PBAM Database	WSU	FDM	Ultem 9085	2016	2018
PBAM Equivalence	WSU	FDM, FFF	Ultem 9085	2016	2022
PBAM Database	WSU	FDM	CCF Onyx	2018	2022
PBAM Parameter Sensitivity	WSU	FDM	Ultem 9085	2018	2021
PBAM Test Method Guidance	WSU	FDM	Ultem 9085	2019	2022
PBAM Database	WSU	PBF	HexAM	2019	2022
PBAM Equivalence	WSU	FDM	CCF Onyx	2019	2023
PBAM Equivalence	WSU	PBF	HexAM	2020	2023
Mid-Level Building Block Standards	WSU	Multiple	Multiple	2021	2023
Roadmap Activities	DoD, WSU, America Makes	Multiple	Multiple	2021	2024
Lessons Learned Database	TBD	Multiple	Multiple	2020	2025
Material Handbook Development (CMH-17)	WSU	Multiple	Multiple	2018	---

*WSU: Wichita State University

Polymer Based AM Qualification

Research Purpose:

- PBAM is finding wider use for intricate interior parts. Emerging stronger, fiber reinforced material may make PBAM practical for structural parts.
- PBAM typically uses different technology than metal AM and brings a different set of certification issues.
- This research is being used to formulate certification guidance for PBAM parts.

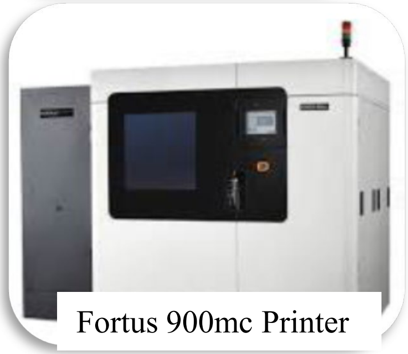
Major Milestones Achieved:

- Complete, qualified database of material properties & Statistical Analysis Report for Fused Deposition Modeling AM of Ultem 9085 Resin
- Results of work being added to CMH-17 AM volume
- Work with standards development organizations (SAE, ASTM, CMH-17) in creating documentation derived from qualification framework (e.g., specifications, test methods, best practices)

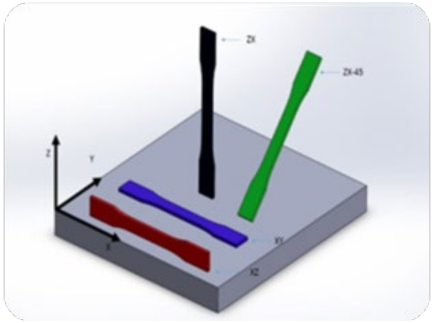
Framework Expansion:

- Material systems
- Machines
- Processes
- Optimization

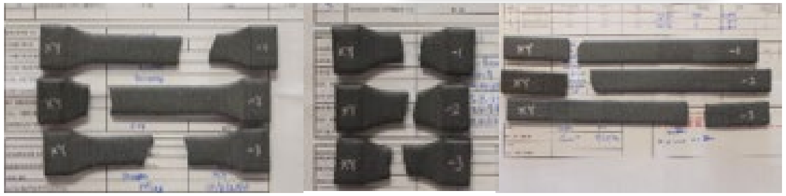
C-17 Cooling ducts



Fortus 900mc Printer



Build orientation reference

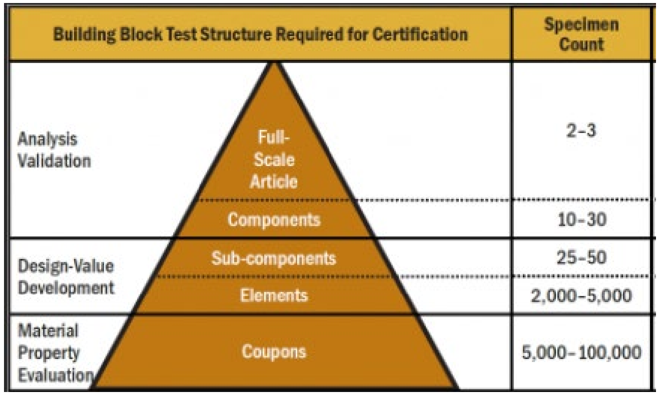


Hex-PEKK laser-powder bed fusion qualification.
Post-test photographs of failed specimens

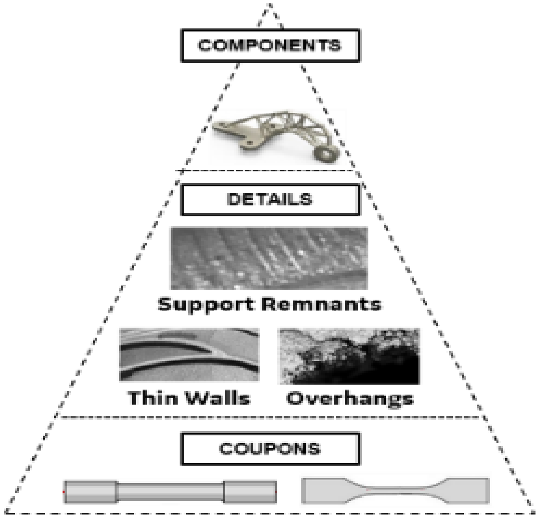
Federal Aviation Administration

Development of Higher Level Building Block Standards for AM

- Test methods exist for polymer and metallic AM coupons that characterize bulk material properties
- Additive manufacturing certification can utilize a building block certification approach, but standards do not exist for these test methods
- Research to help develop guidelines and/or standards to interrogate behavior of common additively manufactured part features
  - Parallel program developing mid-level building block standards and guidelines for composites



Building Block Test Structure Required for Certification		Specimen Count
Analysis Validation	Full-Scale Article	2-3
	Components	10-30
Design-Value Development	Sub-components	25-50
	Elements	2,000-5,000
Material Property Evaluation	Coupons	5,000-100,000



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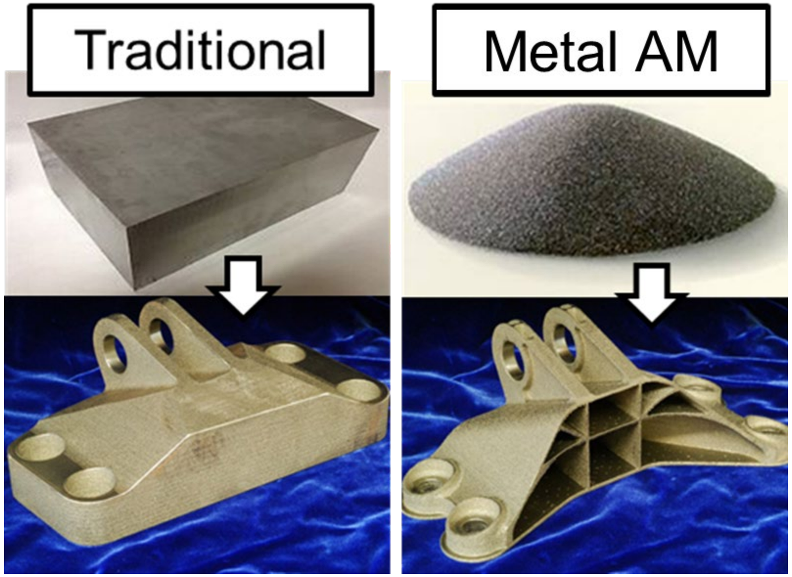
Metallic AM Overview

Topic	Partner	Technology	Material	Start	End
Metals Database (JMADD)	DoD, WSU, America Makes	LB-PBF	Ti-6Al-4V	2020	2023
Metals Equivalence (JMADD)	DoD, WSU, America Makes	LB-PBF	Ti-6Al-4V	2021	2024
Key Process Variable Drift	Auburn	LB-PBF	Ti-6Al-4V	2019	2023
LB-PBF Effect of Defects	Auburn	LB-PBF	Ti-6Al-4V	2019	2023
Surface Integrity	Auburn	LB-PBF	Ti-6Al-4V	2020	2023
Process Variability	UW	LB-PBF	Ti-6Al-4V	2020	2024
Structural Integrity Assessment Tools	SwRI	Multiple	Multiple	2019	2024
Material Handbook Development (MMPDS)	Battelle	Multiple	Multiple	2018	---
Lessons Learned Database	TBD	Multiple	Multiple	TBD	---
DED Effect of Defects	TBD	Wire DED	TBD	TBD	---
Assessment of NDI	TBD	Multiple	TBD	TBD	---
Process Monitoring Assessment	TBD	Multiple	TBD	TBD	---

*WSU: Wichita State University

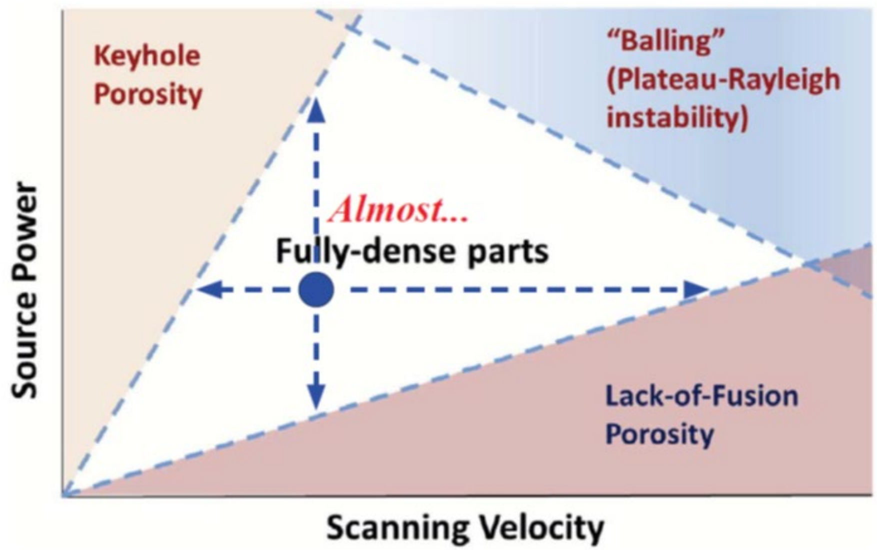
Joint Metals Additive Database Definition (JMADD)

- **Research Purpose:**
  - Develop a set of publicly available statistically substantiated data for the bulk material properties of Ti-6Al-4V using LB-PBF with a corresponding material and process specification
- **Expected Outcomes:**
  - Identification of a standard process that could be used to develop Material Allowables and Design Data for metal AM
- **Partner Organizations:**
  - DoD, NASA, AmericaMakes, Auburn University, Boeing
- **Work Planned (*partial list*):**
  - Develop test plan and associated specifications
  - Static property specimen build and test
  - Fatigue property specimen build and test



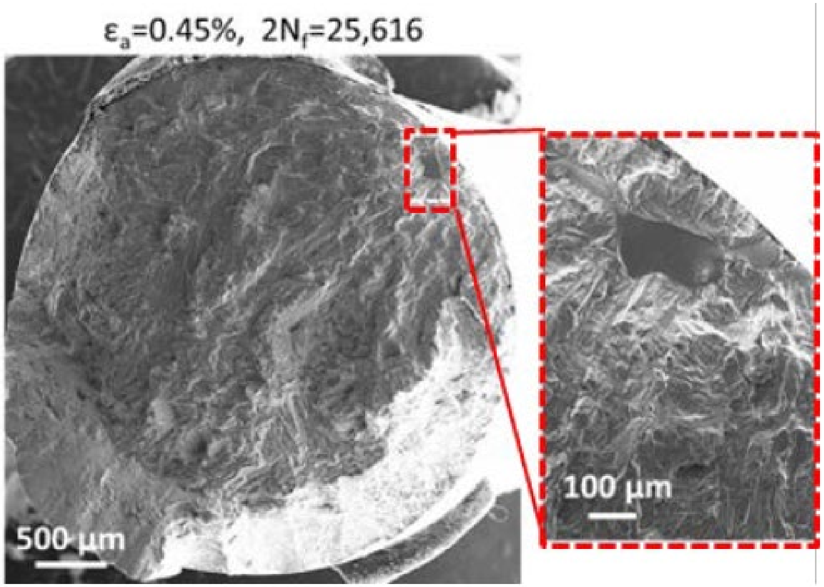
Key Process Variable Drift

- **Research Purpose:**
  - Identify the effect of key process variable drift (e.g., laser power) within machine tolerance on mechanical properties
- **Expected Outcomes:**
  - Data on the interaction of key process variables and the identification of any potentially unsafe combination as those variables drift during a typical maintenance period
- **Work Planned:**
  - Powder re-use and location dependency study
  - Specimen builds following design of experiments for 2-5 key process variables
  - Inspection, testing, and post-test fractography



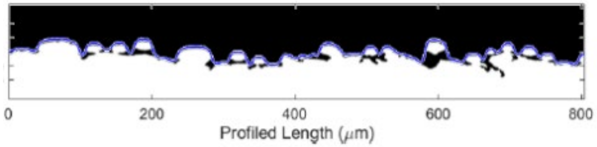
Effect of Defects

- **Research Purpose:**
  - Identify the critical defect size, shape, and location (relative to free surface) for LB-PBF of Ti-6Al-4V and quantify the effect on fatigue behavior
- **Expected Outcomes:**
  - Data on the distribution of porosity type defects, which typically initiate fatigue cracks, and the associated impact to fatigue life
- **Work Planned:**
  - Process mapping to consistently produce specimens with different levels of defects
  - Batch production of specimens with defects
  - Fatigue testing
  - Inspection including X-ray CT, mechanical testing, and post-test fractography

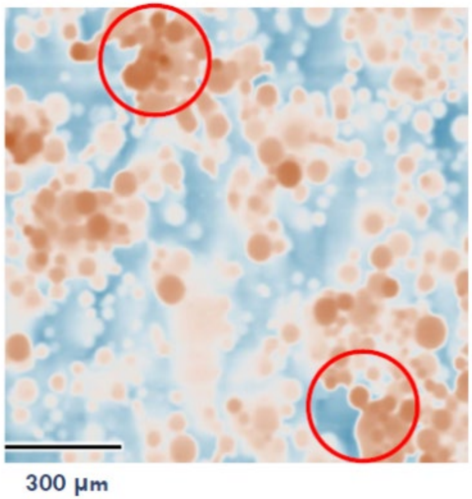


Surface Integrity

- **Research Purpose:**
  - Characterize the surface condition of metal AM parts and quantify the effect on mechanical properties (primarily fatigue)
- **Expected Outcomes:**
  - Data on the condition of the surface and near-surface region of metal AM parts, characterization of the features that lead to specimen failure, and the associated reduction to mechanical properties

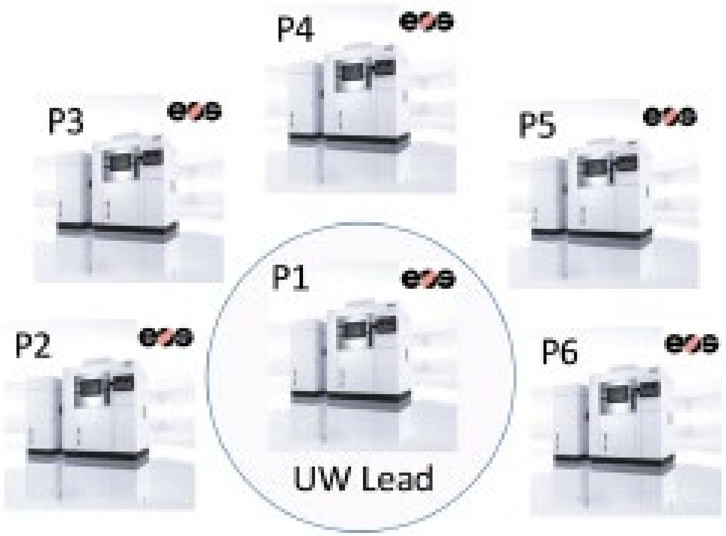


- **Work Planned:**
  - Process mapping of contour parameters to consistently produce specimens with different surface conditions
  - Batch production of specimens with different surface conditions including surface finishing
  - Fatigue testing
  - Inspection including X-ray CT, mechanical testing, and post-test fractography



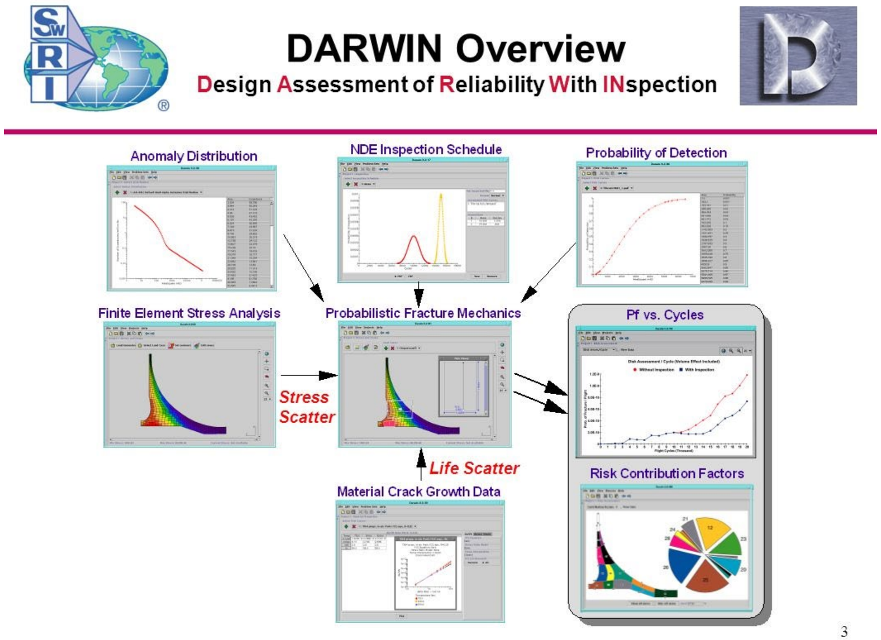
AM Process Variability

- **Research Purpose:**
  - Characterize the variability of LB-PBF within a build, built to build, machine to machine, and facility to facility
- **Expected Outcomes:**
  - Data quantifying the variability of mechanical properties using the same AM machine/model, process parameters, and build file at different partner organizations over time
- **Partner Organizations:**
  - EOS, Boeing, Lockheed Martin, Toray Precision, 3D Logics
- **Work Planned:**
  - Tension and compression specimen production over the course of 1 year
  - Fatigue specimen production over the course of 1 year
  - Inspection including X-ray CT, mechanical testing, and post-test fractography



Structural Integrity Assessment Tools

- **Research Purpose:**
  - Evaluate the potential use of the FAA funded Design Assessment of Reliability with Inspection (DARWIN) structural integrity assessment software for metal AM parts
- **Expected Outcomes:**
  - Enhancements to existing structural integrity assessment tools for certification of AM parts
- **Work Planned:**
  - Develop practical zone-based strategies for certification of AM parts
  - Develop enhancement to existing tools for structural analysis of AM parts
  - Perform case studies to demonstrate improvements



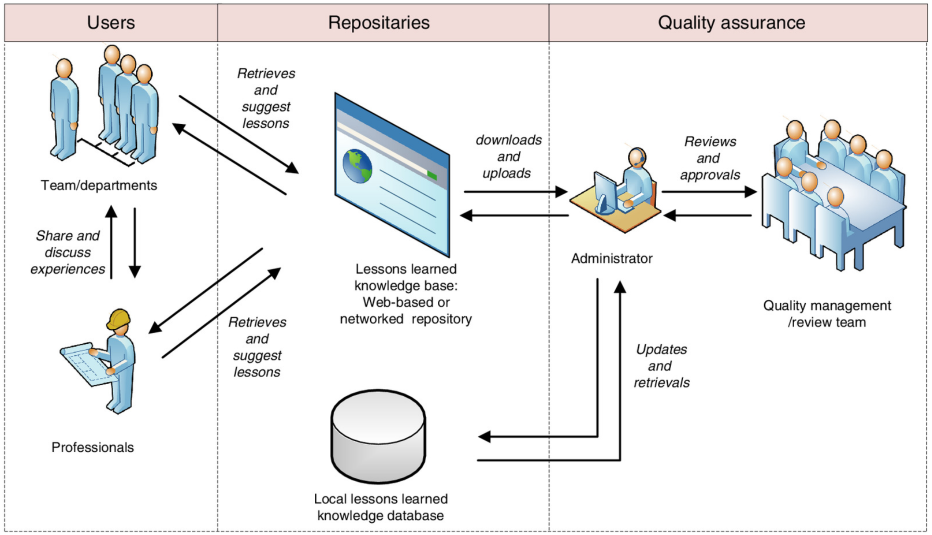
Material Properties for AM

(these efforts cover both metallic and non-metallic AM)

- **Research Purpose:**
  - Utilize existing FAA led material handbook activities to identify the data requirements and statistical tools needed to establish material allowables for additively manufactured materials
- **Expected Outcomes:**
  - New volumes/sections of CMH-17 and MMPDS dedicated to additive manufactured materials
- **Work Planned:**
  - In partnership with industry and the respective handbook secretariats, establish data requirements and statistical tools that can be used for material allowable development for AM materials
  - Analyze AM datasets and publish material allowable tables as applicable, subject to availability

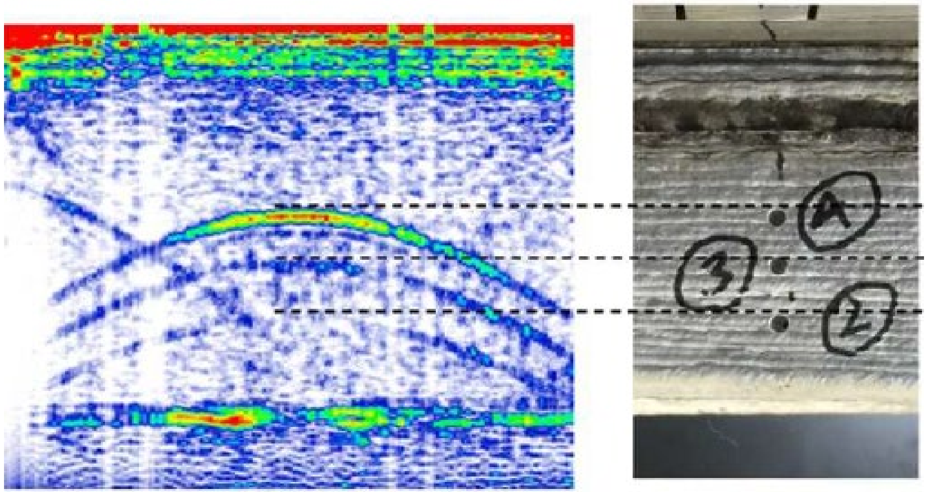
Lessons Learned Database

- **Research Purpose:**
  - Create the framework for a lessons learned database on additive manufacturing
- **Expected Outcomes:**
  - The framework for a public database that is managed by an independent 3rd party and populated by industry/other government agencies with information on best practices, lessons learned, and in-service history of AM parts
- **Work Planned:**
  - Partner with an independent contractor to develop the database framework
  - Socialize the framework and engage with industry and other government agencies



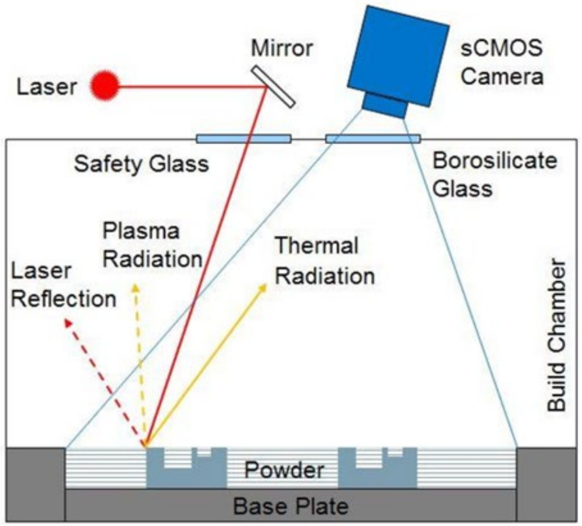
Assessment of NDT

- **Research Purpose:**
  - Identify and evaluate the most promising new and/or existing NDI methods being used for metal AM parts, including feasibility of deployment in production and field environment
- **Expected Outcomes:**
  - Data quantifying the effectiveness of 2-3 NDI methods at detecting key defects of varying sizes, shapes, and locations
- **Work Planned:**
  - Benchmark current industry NDI methodologies
  - Based on availability of funding, design, build, and conduct blind inspections of a set of inspection



Process Monitoring and In-Situ Inspection

- **Research Purpose:**
  - Evaluate the current state of process monitoring and in-situ inspection technology used for metal AM
- **Expected Outcomes:**
  - Benchmarking of current industry trends and plans for in-situ monitoring technology and identification of potential needs for future research
- **Work Planned:**
  - Benchmark current industry use of process monitoring and in-situ inspection technology
  - Development of follow-on research as needed and based on availability of funding



Summary

- AM Background:
  - AM covers a broad range of technologies and materials
  - Creating a part one layer at a time offers unique design freedom but makes it more process sensitive
  - Current lack of full-scale production experience and in-service experience increases initial risk of introduction
- FAA AM Research:
  - Largely funded by congressional direction over the past few years
  - Diverse range of projects covering non-metallic and metallic AM
  - Research outputs support participation in industry consensus documents
- NDT is recognized as an important aspect:
  - NDT is being currently being used by a number of active programs
  - Dedicated NDT program is being planned in coordination with industry and academic partners

Questions?