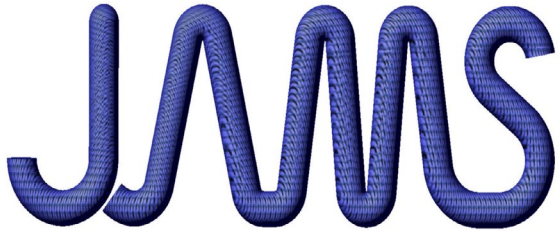
WICHITA STATE UNIVERSITY

Mid-level Building Block Testing for Additively Manufactured Ti-6Al-4V

Rachael Andrulonis, Director of Advanced Materials Research

INDUSTRIAL MODERNIZATION
OF MATERIALS & MANUFACTURING



Joint Centers of Excellence for Advanced Materials

Federal Aviation Administration

Research Team & Objectives

John Tomblin, PhD
Senior Vice President for Industry and Defense Programs, WSU-NIAR Executive Director

Rachael Andrulonis
Director of Advanced Materials Research

Mark Shaw
Chief Engineer, Defense Industrial Base Strategy

Lauren Tubesing
Business Development Leader, Advanced Manufacturing Strategy

Brandon Saathoff
Senior Engineering Manager, Advanced Materials Research

Eathan Devine
Research Engineer, Advanced Materials Research

Neville Tay
Research Engineer, Advanced Materials Research

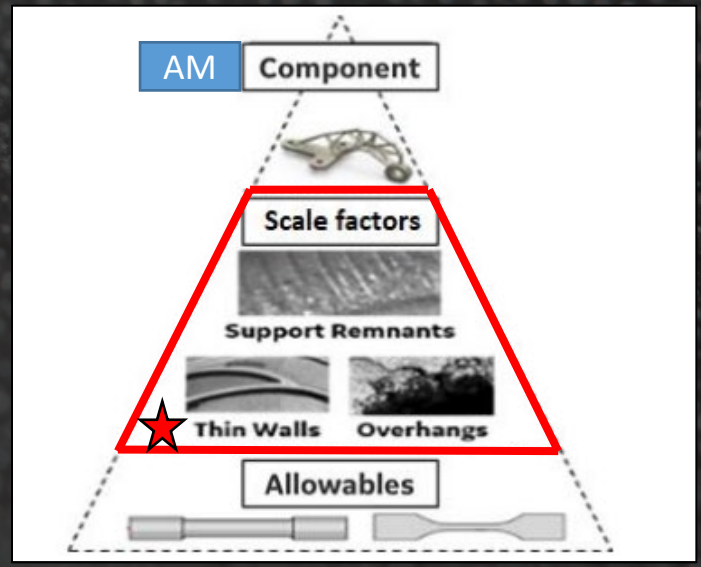
Cindy Ashforth
Senior Technical Specialist for Advanced Composite Materials

Ahmet Oztekin, PhD
Advanced Materials Research Program Manager, JAMS Program Manager

Kevin Stonaker
Technical Monitor

PROJECT OVERVIEW

- **RESEARCH OBJECTIVES**
  - Investigate feature-level performance debits for AM test articles via static test characterization.
    - Metal AM
    - Polymer AM



AM Building Block Approach

IQ/OQ/PQ – Consolidated Qualification Strategy

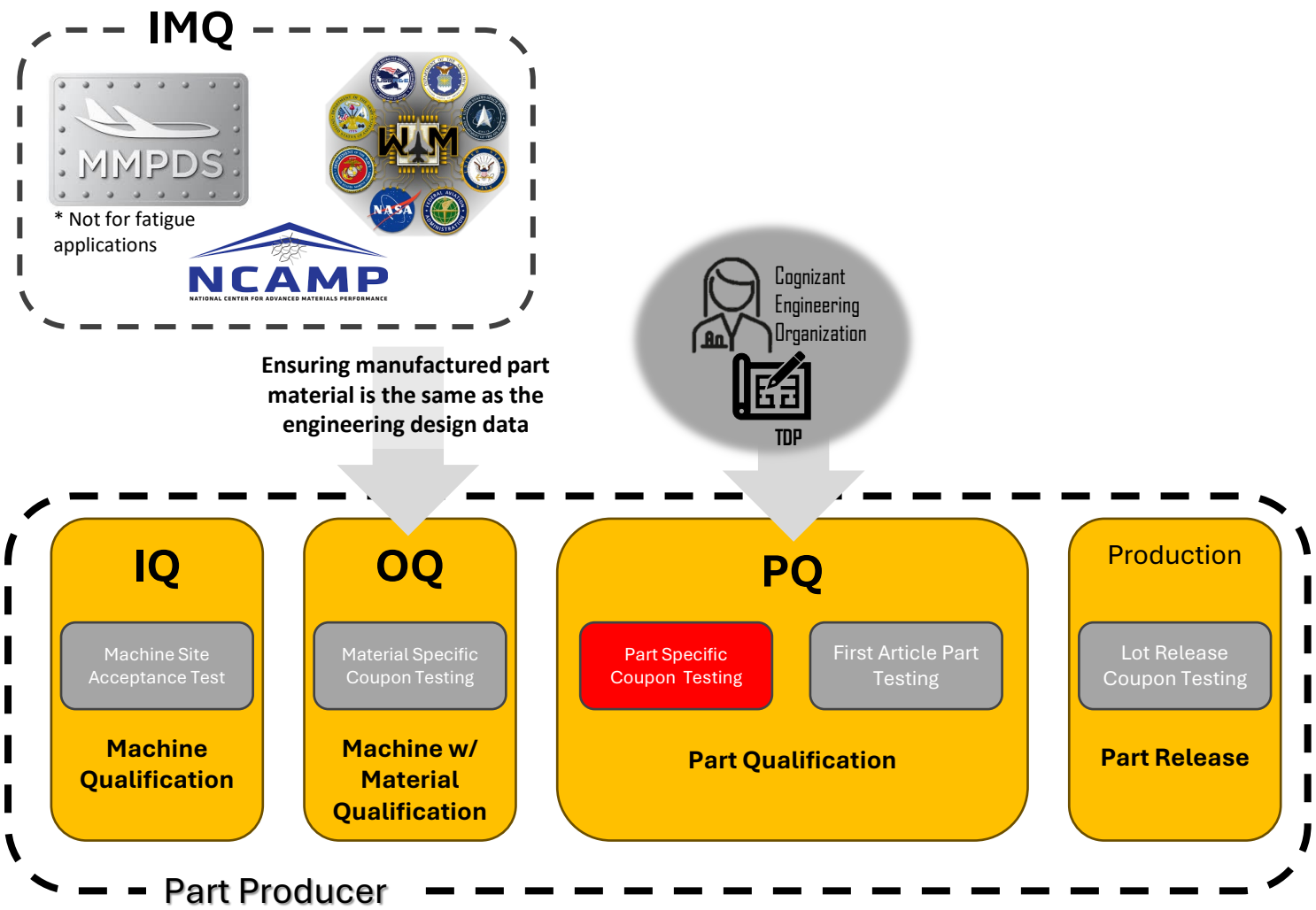
Consolidated Strategy

IMQ = Initial Material Qualification

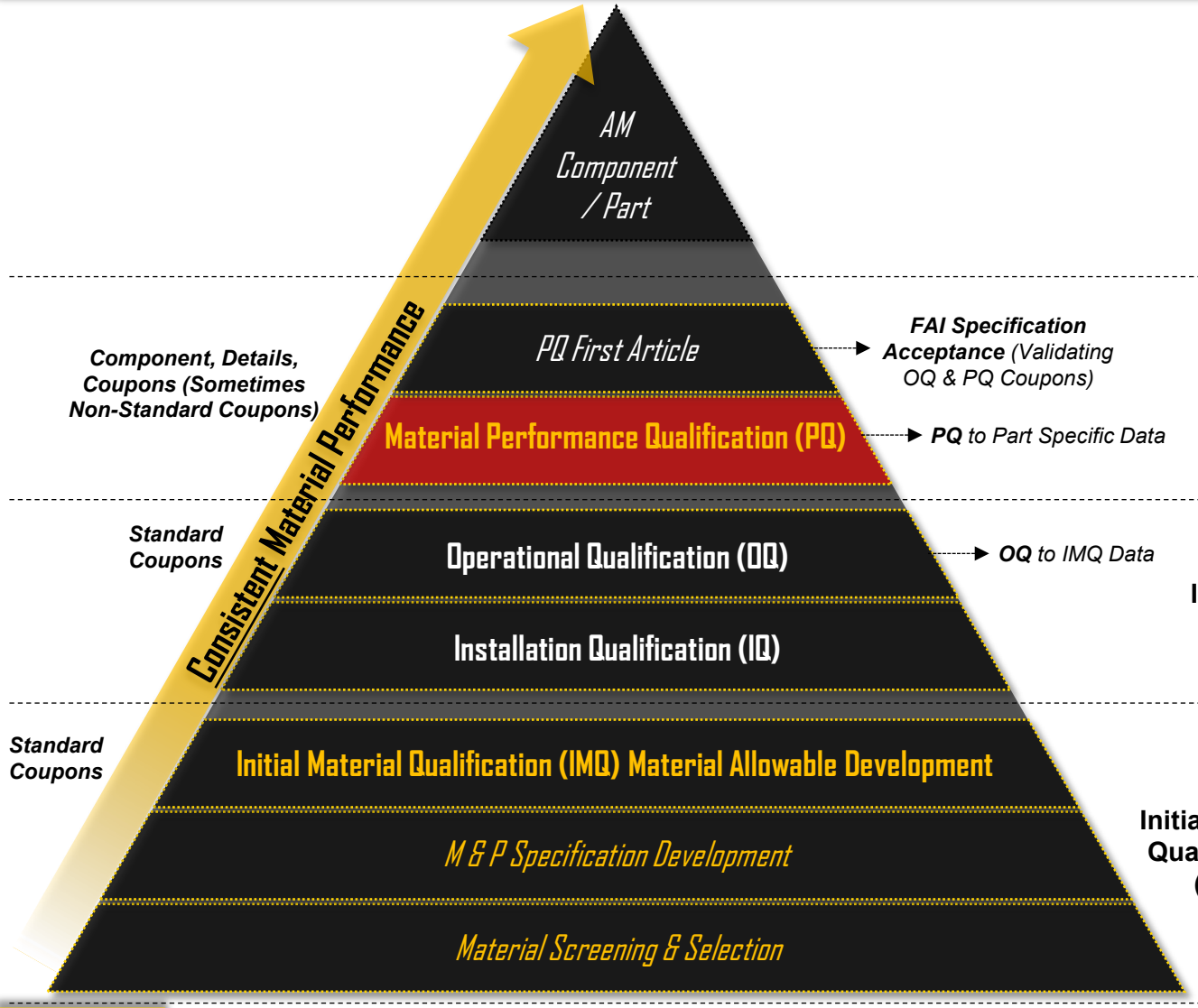
IQ = Installation Qualification

OQ = Operational Qualification

PQ = Performance Qualification



Metal AM Building Block Relating to NIAR's FAA Project Portfolio



	L-PBF Ti-6Al-4V GR5	L-PBF CoCrMo	Future Work
PQ	JMADX Fatigue Curves; Building Block Feature Studies	Surface Inspection	Round Robin Part Production; OQ/PQ Future Work
IQ/OQ	Machines from IMQ used in PQ		
Initial Material Qualification (IMQ)	JMADX (4th Machine); JMADX (5th Machine); JMADD (3 Machines)		New Alloy/Process Qualification – Wire DED of Ti64

FAA JAMS – Metal AM | Program Overview

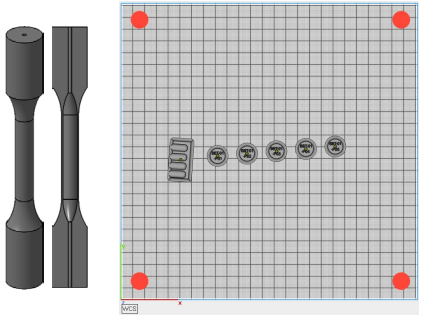
M-JMADD	**JMADD** **Joint Metal Additive Database Definition**	Baseline qualification program for Ti-6-4/EOS M290 *Jointly funded with America Makes*
M-JMADX	**JMADD Expansion**	• Generate data on 4th JMADD machine for dataset inclusion. • Development of fatigue curves for various post processing conditions.
M-MASFI	**Surface Inspection**	Investigate as-printed surface design values and bulk material inspection methods on fatigue sensitive LPBF components.
M-NANPQ	**New Alloy/Process Qualification**	Qualification of new alloy/process of interest to the FAA and related industry.
M-BBFLP	**Building Block**	Investigate feature-level performance debits for AM test articles via static test characterization.

Metal AM Thin Wall Feature Study Project Roadmap

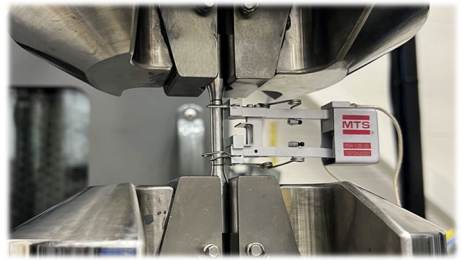
Task 1: Literature Survey & Feature Selection

Task 2: Test Plan Development

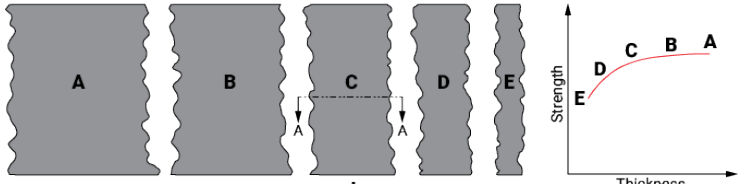
WE ARE HERE



Task 3: Specimen Inspection & Mechanical Testing

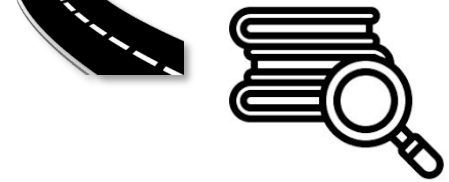


Task 4: Data Summary & Reporting (Guidance Documentation)



Metal AM Thin Wall Feature Study Project Roadmap

Task 1: Literature Survey & Feature Selection



Task 2: Test Plan Development

Task 3: Specimen Inspection & Mechanical Testing

Task 4: Data Summary & Reporting (Guidance Documentation)

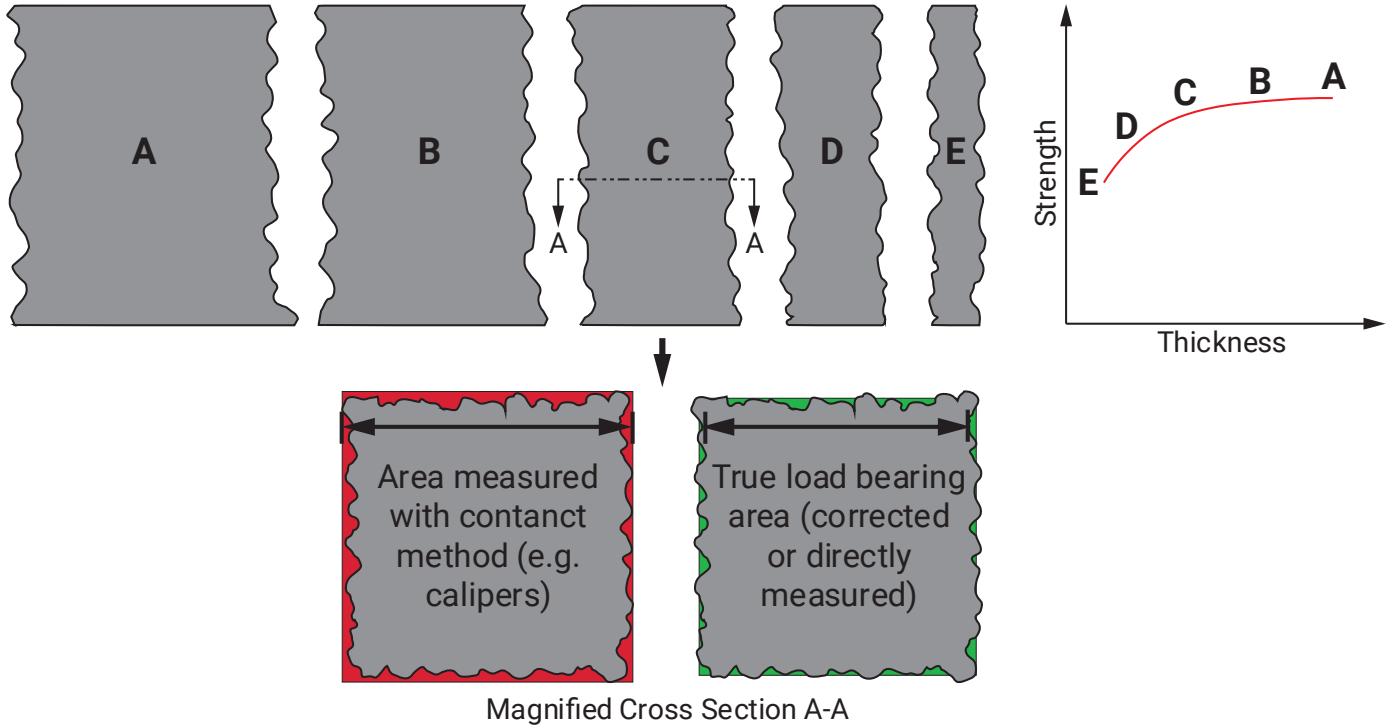
Thin Wall Literature Survey Summary

Three main contributing factors to reduced tensile properties in thin walls:

1. Contact measurement methods (e.g. calipers) generally *overestimate* cross-sectional area due to surface roughness
2. After correcting the area, stress concentration effects could still remain
3. Suboptimal process parameters for thin walls can create suboptimal microstructure

Thin-wall thickness ranges in the literature:

- 0.1mm – 6.25mm (commonly 0.4mm – 5mm)
- Difficult/uncommon to print wall thickness <0.25mm
- EOS M290 Ti64 datasheet: 0.3mm – 0.4mm (min)
- Recommend **0.5mm – 2.5 mm**



Magnified Cross Section A-A

Most studies found that UTS and ductility generally decrease with decreasing wall thickness

Methods for finding effective load bearing area

Direct measurement of area:

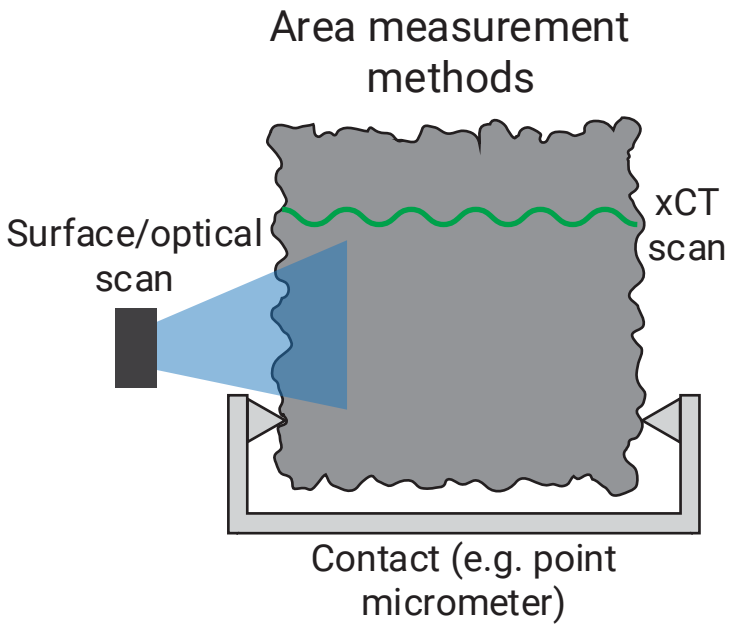
1. Requires accurate measurement of surface topography or of "valley-to-valley" distances
2. Measure surface roughness to learn if it can provide information about load bearing area

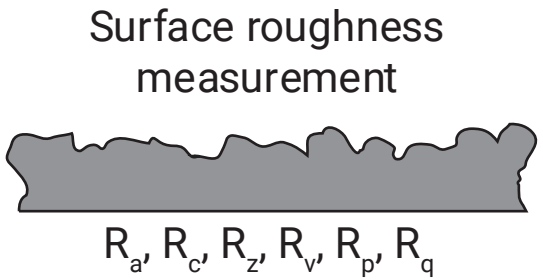
Potential measurement methods (increasing time/cost):

1. Standard micrometer (line-of-sight)
2. Point micrometer (line-of-sight)
3. Optical scanner (line-of-sight, surface topography)
4. xCT (3D volumetric profile)

Paradise et al. (2022) compares different area measurement methods listed above

What method best measures the effective load bearing area?



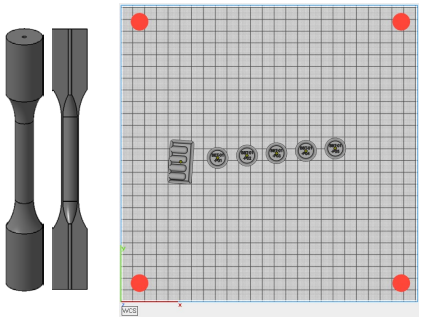


For example, De Formanoir et al. (2016), Salzbrenner et al. (2017), Yu et al. (2020) utilize surface roughness parameters to adjust the area calculation

Metal AM Thin Wall Feature Study Project Roadmap

Task 1: Literature Survey & Feature Selection

Task 2: Test Plan Development



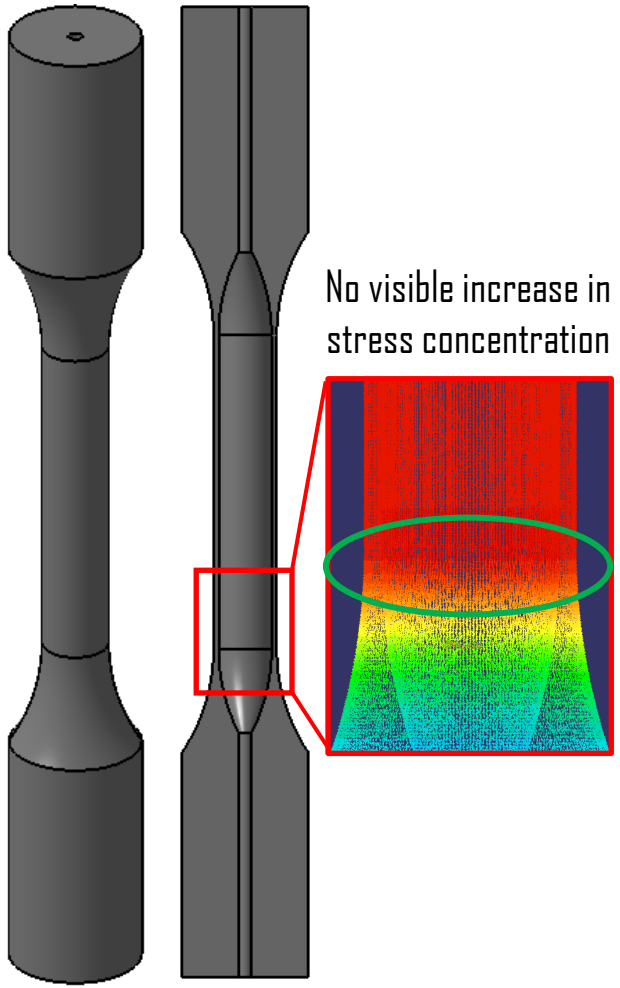
Task 3: Specimen Inspection & Mechanical Testing

Task 4: Data Summary & Reporting (Guidance Documentation)

Specimen types under consideration with basic FEM

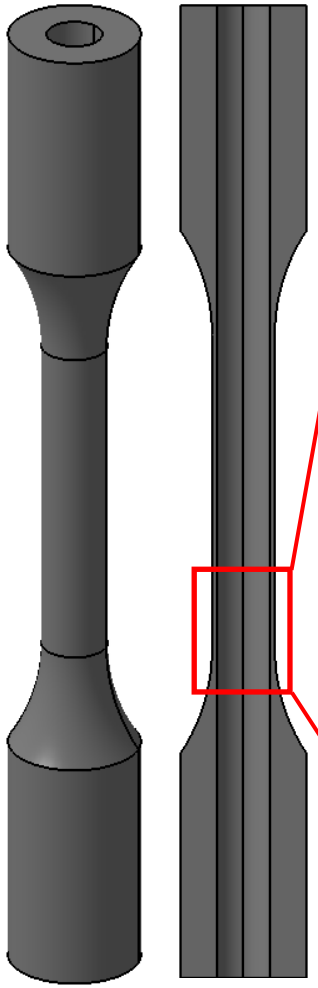
- All specimen types except Option 1 predict slight increases in stress intensity at the transition between the grip section and gauge section

1. Hollow ASTM E8 Fillet Specimen

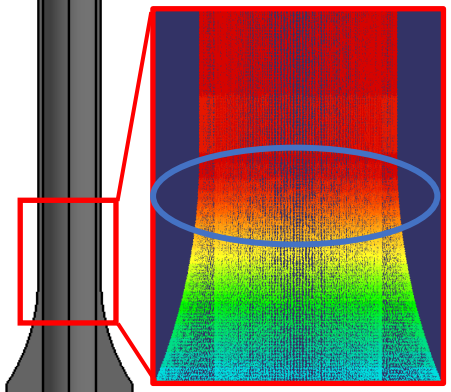


No visible increase in stress concentration

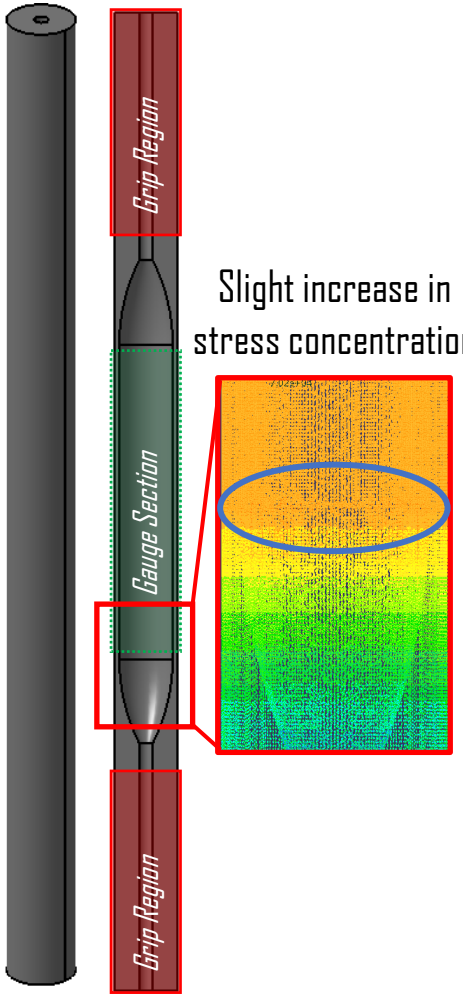
2. Hollow ASTM E8 Straight Bore Specimen



Slight increase in stress concentration

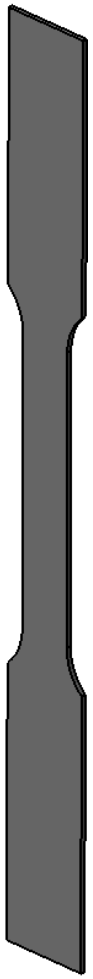


3. Custom Cylindrical Specimen



Slight increase in stress concentration

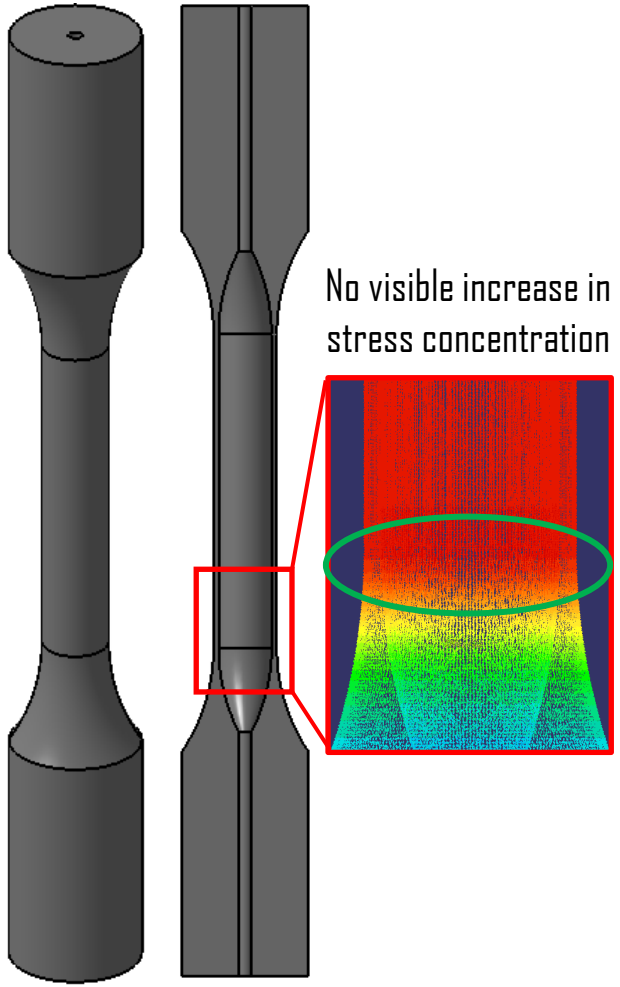
4. ASTM E8 Flat Specimen



Specimen types under consideration with basic FEM

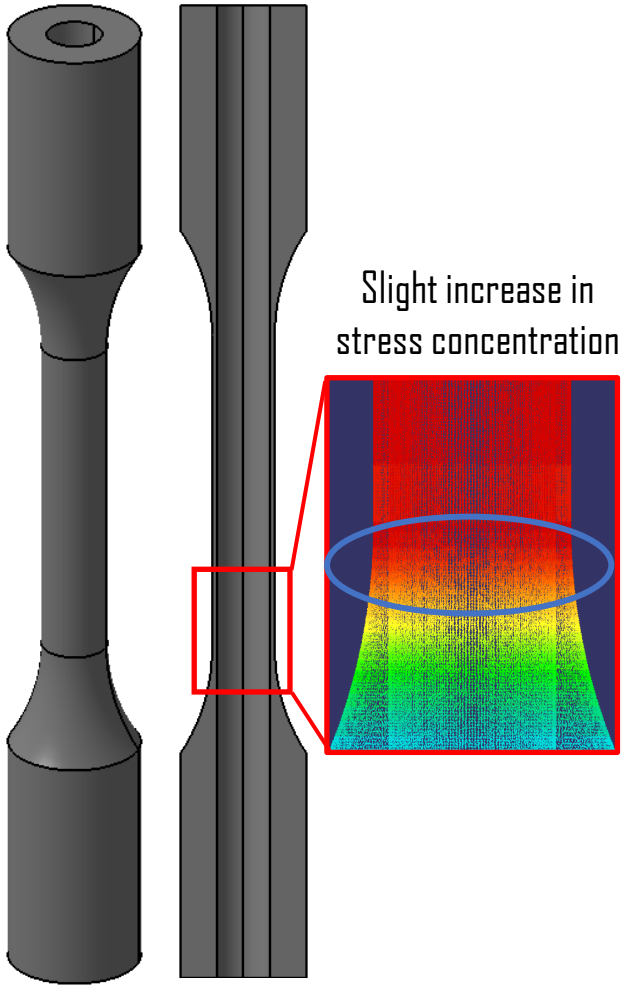
- All specimen types except Option 1 predict slight increases in stress intensity at the transition between the grip section and gauge section
- Trial builds will proceed with Options 1,2, and 4 (Option 3 removed from consideration due to higher stress concentration/geometric redundancy)

1. Hollow ASTM E8 Fillet Specimen



No visible increase in stress concentration

2. Hollow ASTM E8 Straight Bore Specimen

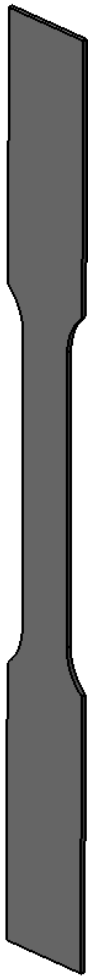


Slight increase in stress concentration

3. Custom Cylindrical Specimen

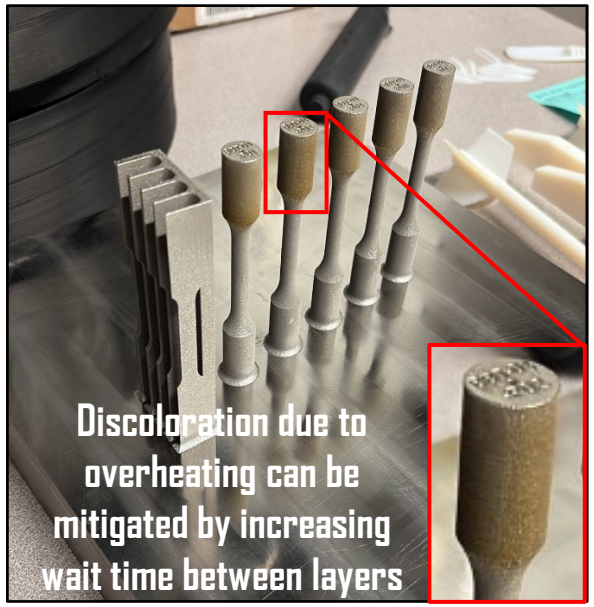
Slight increase in stress concentration

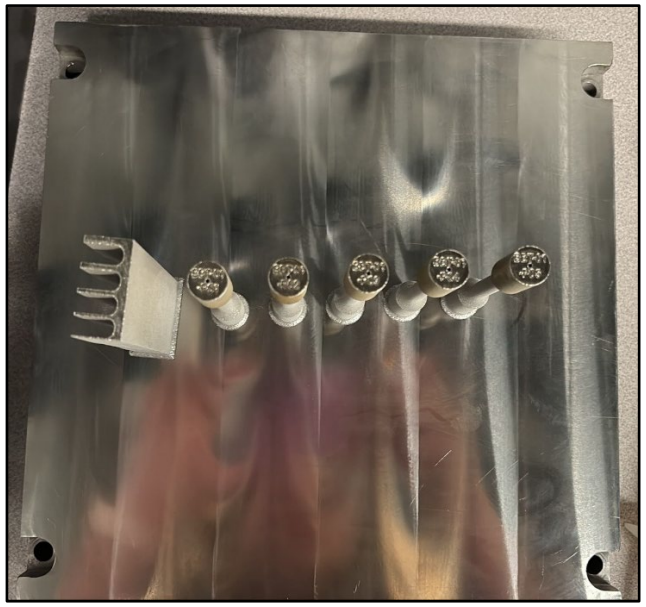
4. ASTM E8 Flat Specimen

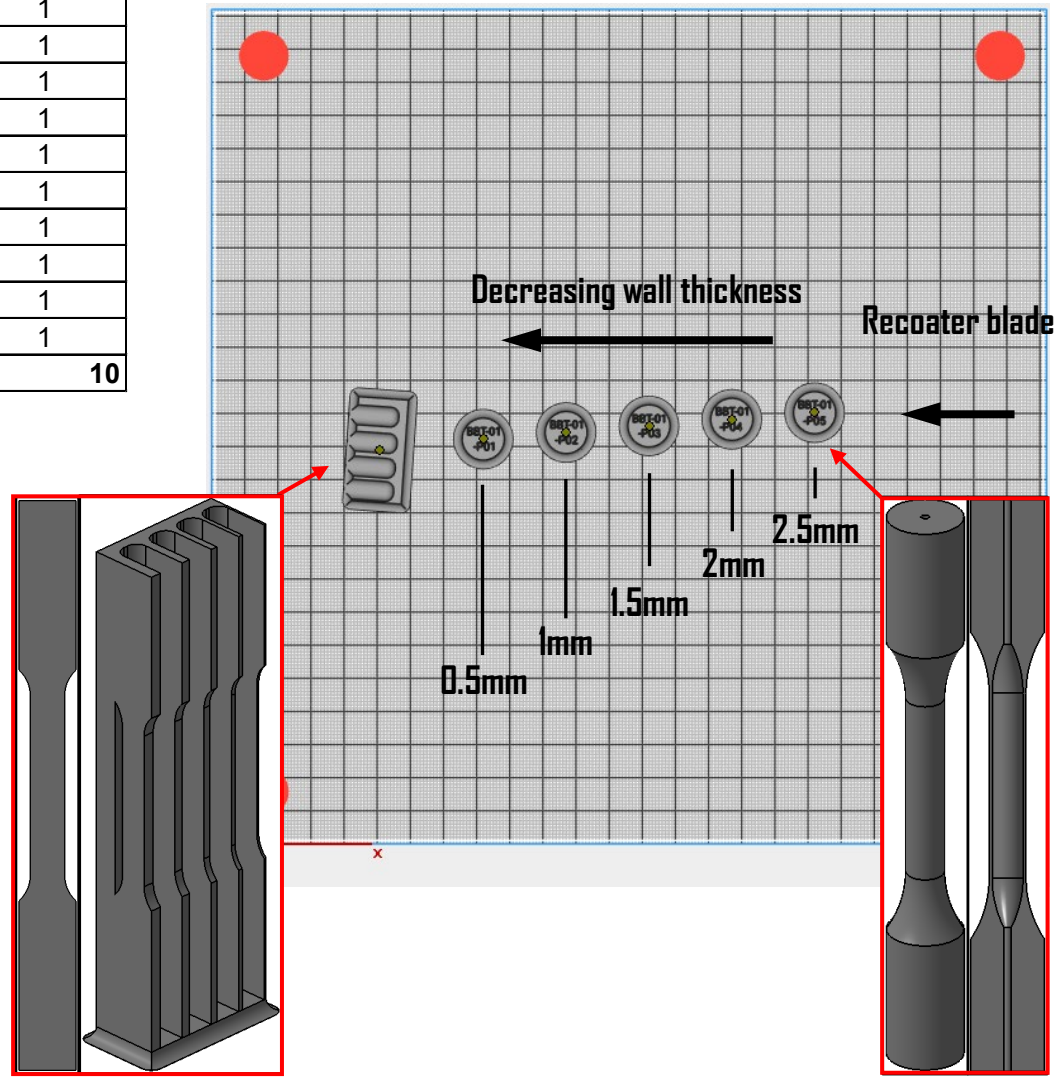


Trial Build 1 – Determine how thin we can print

Material	Process	Machine	Specimen Type	Test Type	Orientation	Thickness (mm)	Specimens
Ti-6Al-4V GR5 (VSR+HIP)	L-PBF	EOS M290	**Flat**	Tensile (UTS, 0.2%YS, %Elong, ROA)	ZX	0.5	1
					ZX	1	1
					ZX	1.5	1
					ZX	2	1
					ZX	2.5	1
			Cylindrical internal fillet	Tensile (UTS, 0.2%YS, %Elong, ROA)	ZX	0.5	1
					ZX	1	1
					ZX	1.5	1
					ZX	2	1
					ZX	2.5	1
						Total	**10**



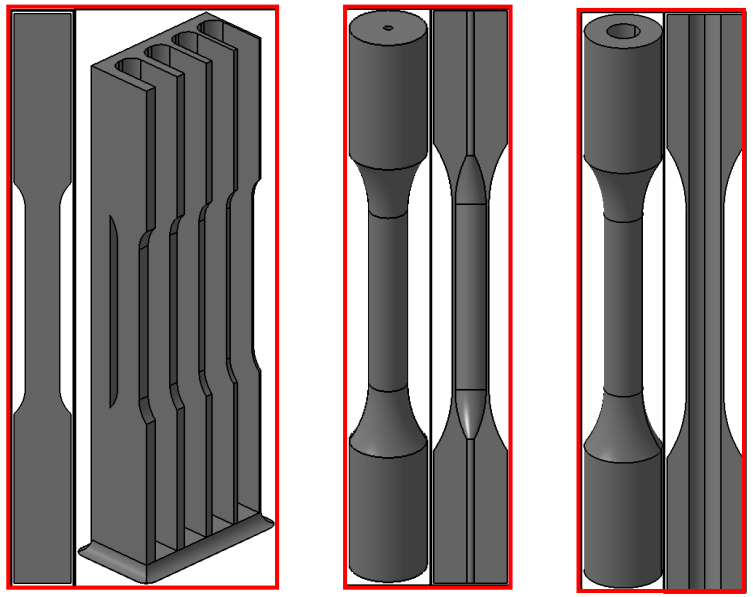


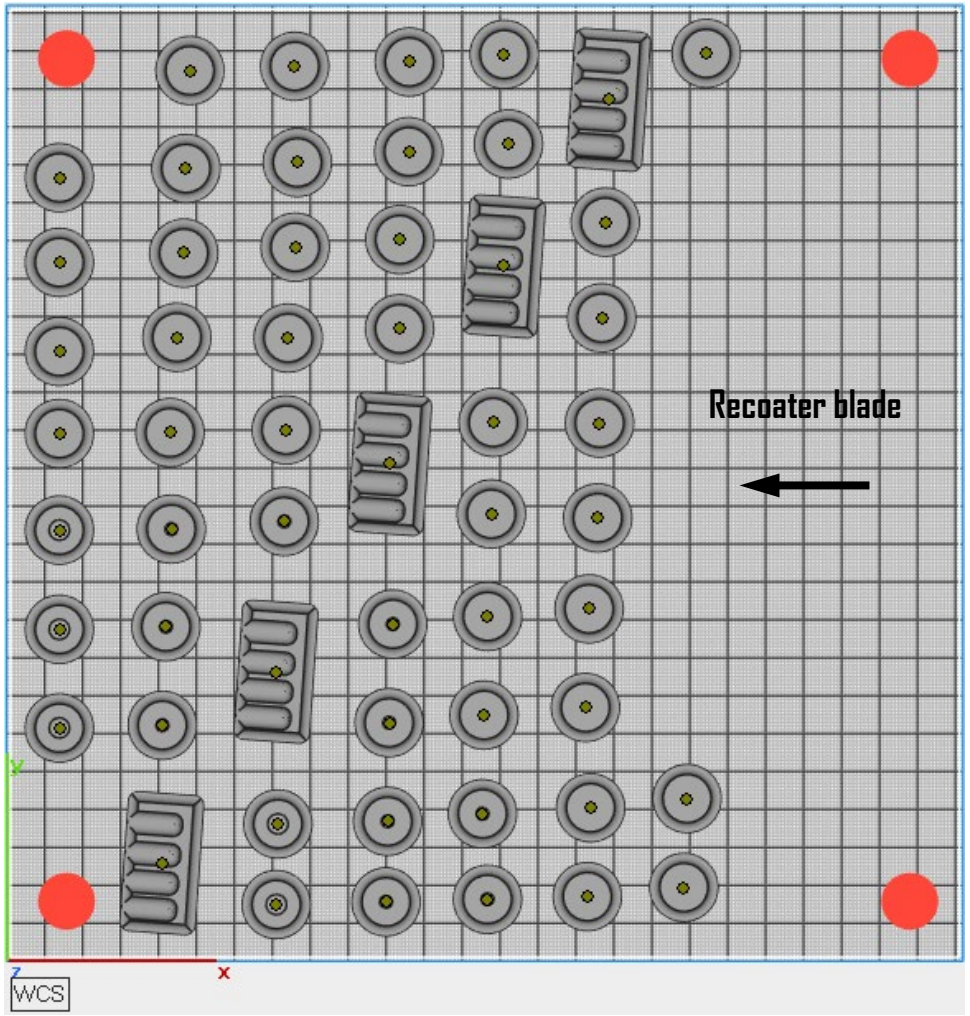


Trial Build 1 successful – future builds will address overheating and build density considerations via simulation

Trial Build 2 – All specimen types

- Trial Build 2 will include all 75 samples planned for the full test matrix to make sure that it can be readily printed, and to work through any encountered problems
- The Full Test Build will proceed pending Trial Build 2 success





Full test matrix

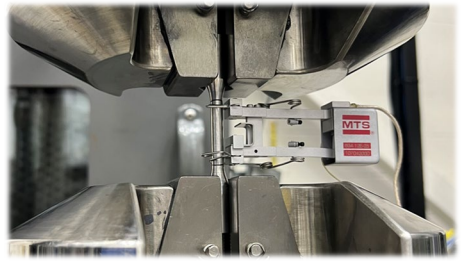
Material	Process	Machine	Area Measurement Method	Specimen Type	Test Type	Orientation	Wall Thickness (mm)	Specimens
Ti-6Al-4V GR5 (VSR+HIP)	L-PBF	EOS M290	xCT, Optical scanner, Point micrometer, Standard Micrometer	**ASTM E8 Rectangular**	Tensile (UTS, 0.2%YS, %Elong, ROA)	ZX	0.5	5
						ZX	1*	5
						ZX	1.5	5
						ZX	2*	5
						ZX	2.5	5
				ASTM E8 Cylindrical internal fillet	Tensile (UTS, 0.2%YS, %Elong, ROA)	ZX	0.5	5
						ZX	1*	5
						ZX	1.5	5
						ZX	2*	5
						ZX	2.5	5
				ASTM E8 Cylindrical straight bore	Tensile (UTS, 0.2%YS, %Elong, ROA)	ZX	0.5	5
						ZX	1*	5
						ZX	1.5	5
						ZX	2*	5
						ZX	2.5	5
							Total	**75**
*no xCT								

- Full area measurement characterization on the 0.5, 1.5, and 2.5mm thick samples (xCT, Optical scanner, micrometers)
- No xCT for 1 and 2mm thick samples

Metal AM Thin Wall Feature Study Project Roadmap

Task 1: Literature Survey & Feature Selection

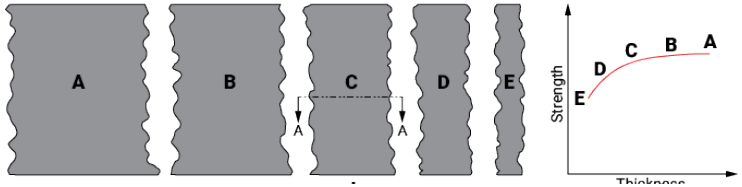
Task 2: Test Plan Development



Task 3: Specimen Inspection & Mechanical Testing

Next Steps

Task 4: Data Summary & Reporting (Guidance Documentation)



Next Steps & Summary

- **Next Steps:**
  - Trial Build 2 – attempting full build plate design following simulations
  - Finalize Thin Wall Test Matrix
  - Mechanical Testing
  - Data Summary and Reporting
- **Potential Future Work:**
  - Characterization of fatigue performance on thin wall structure.
  - Additional feature debits (overhangs, etc.)
- **Benefit to Aviation:**
  - Standardized approach for characterizing thin walls on L-PBF produced parts.

Questions?

- **Contact:**
  - Rachael Andrulonis – rachael.andrulonis@idp.wichita.edu

NATIONAL INSTITUTE FOR AVIATION RESEARCH

WICHITA STATE UNIVERSITY