Wichita State University

NIAR

Metallic Additive Manufacturing Guidelines for Aircraft Design and Certification

John Tomblin, WSU-NIAR
Royal Lovingfoss, WSU-NIAR
Rachael Andrulonis, WSU-NIAR
Joel White, WSU-NIAR

FAA Technical Monitor: Kevin Stonaker
FAA Sponsor: Cindy Ashforth, Michael Gorelik

April 18, 2023

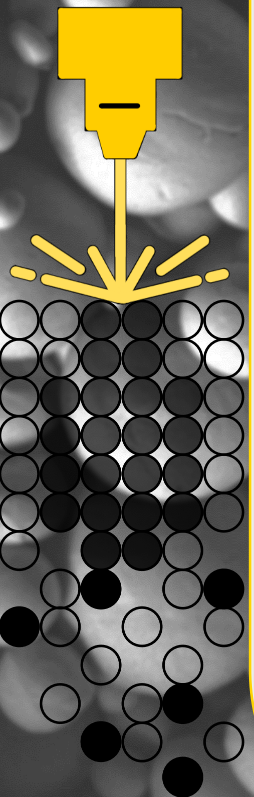
Seattle, WA

Federal Aviation Administration

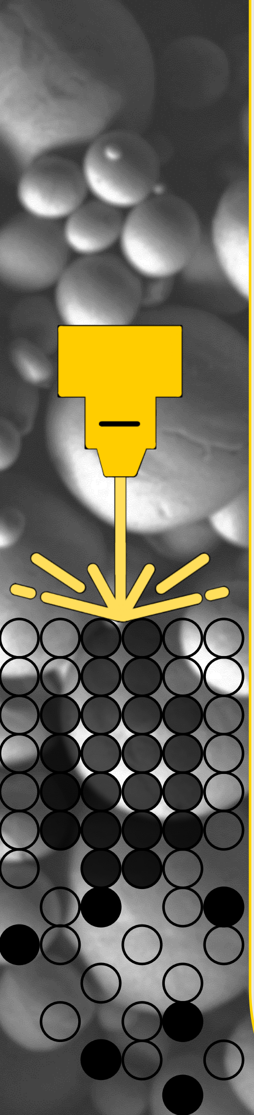
JAMS
Joint Centers of Excellence for Advanced Materials

A Center of Excellence
AMTAS
Advanced Materials in Transport Aircraft Structures

CECAM
center of excellence for composites and advanced materials



Technical Approach



Material Qualification

- Baseline Testing Applied to Increasingly Complicated Materials
- Expand Framework to Additional AM Technologies
- Perform Equivalencies to Demonstrate Framework

Factors Effecting Qualification

- Validate and Expand Processing Window
- FST Studies – Impact of Design
- Scaling – Specimen to Part Correlations
- Building Block – Application Specific Characterization

Pre-Qualification Considerations

- Static & Dynamic Property Behaviors
- Effect of Defects
- Machine to Machine Variability
- Within Chamber Variability

Overview

- Metallic qualification: JMADD Ti-6Al-4V LPBF Qual
- Expansion from metal qualification effort:
  - Feature-Level Building Block Study
  - Metal Additive Manufacturing Surface Feature Inspection
  - Equivalency: GE M2 Ti-6Al-4V LPBF
  - Investigation of Post-Processing Effects by Fatigue Curve Generation

Current JAMS Material and Process Investigations

Ti 6-4 – M290

Ti 6-4 Fatigue Curves

🚫 Inconel 718 – M290

e Ti 6-4 – GE M2

CCF Onyx + X7

e CCF Onyx + X7

HEXAM – P800

e HEXAM Equiv.

Dynamic Testing

Machining

Dynamic Testing

Notching Methods

ULTEM9085 + Fortus 900mc

e ULTEM9085 Equiv. x2

Micro-structure + Parameter Mapping

ULTEM9085 + F900

- FY16
- FY18
- FY19
- FY20
- FY21

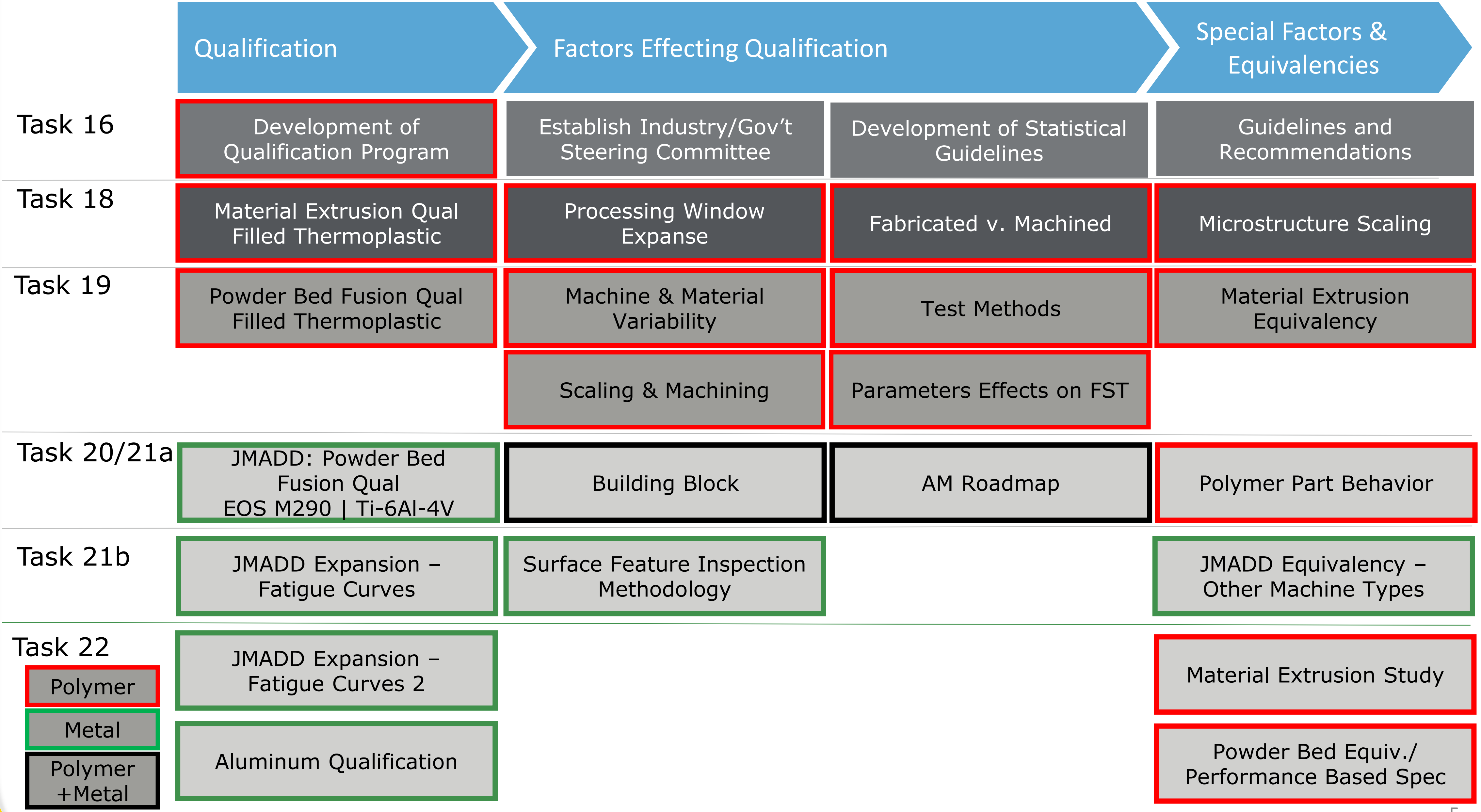
🚫 Not in use for FAA programs

Test Methods

Handbook Development

SDO Support

Overview of all NIAR JAMS AM Tasks



	Qualification	Factors Effecting Qualification		Special Factors & Equivalencies
Task 16	Development of Qualification Program	Establish Industry/Gov't Steering Committee	Development of Statistical Guidelines	Guidelines and Recommendations
Task 18	Material Extrusion Qual Filled Thermoplastic	Processing Window Expanse	Fabricated v. Machined	Microstructure Scaling
Task 19	Powder Bed Fusion Qual Filled Thermoplastic	Machine & Material Variability	Test Methods	Material Extrusion Equivalency
		Scaling & Machining	Parameters Effects on FST	
Task 20/21a	JMADD: Powder Bed Fusion Qual EOS M290 | Ti-6Al-4V	Building Block	AM Roadmap	Polymer Part Behavior
Task 21b	JMADD Expansion – Fatigue Curves	Surface Feature Inspection Methodology		JMADD Equivalency – Other Machine Types
Task 22	JMADD Expansion – Fatigue Curves 2			Material Extrusion Study
	Aluminum Qualification			Powder Bed Equiv./ Performance Based Spec

Polymer

Metal

Polymer +Metal

JAMS Metal AM Programs

- **Current Programs:**
  - **JMADD Ti-6Al-4V laser powder bed fusion qualification**
    - EOS m290 Ti-6Al-4V grade 5 –stress relief, HIP, machined state
    - Metal AM framework creation and A-basis allowable generation
  - **Building Block – Feature level testing program**
- **Initiated 2023**
  - **Expanding Metal Framework to Additional Machine Types**
  - **Ti-6-4 JMADD Fatigue Curves**
  - **Metal Additive Manufacturing Surface Feature Inspection**

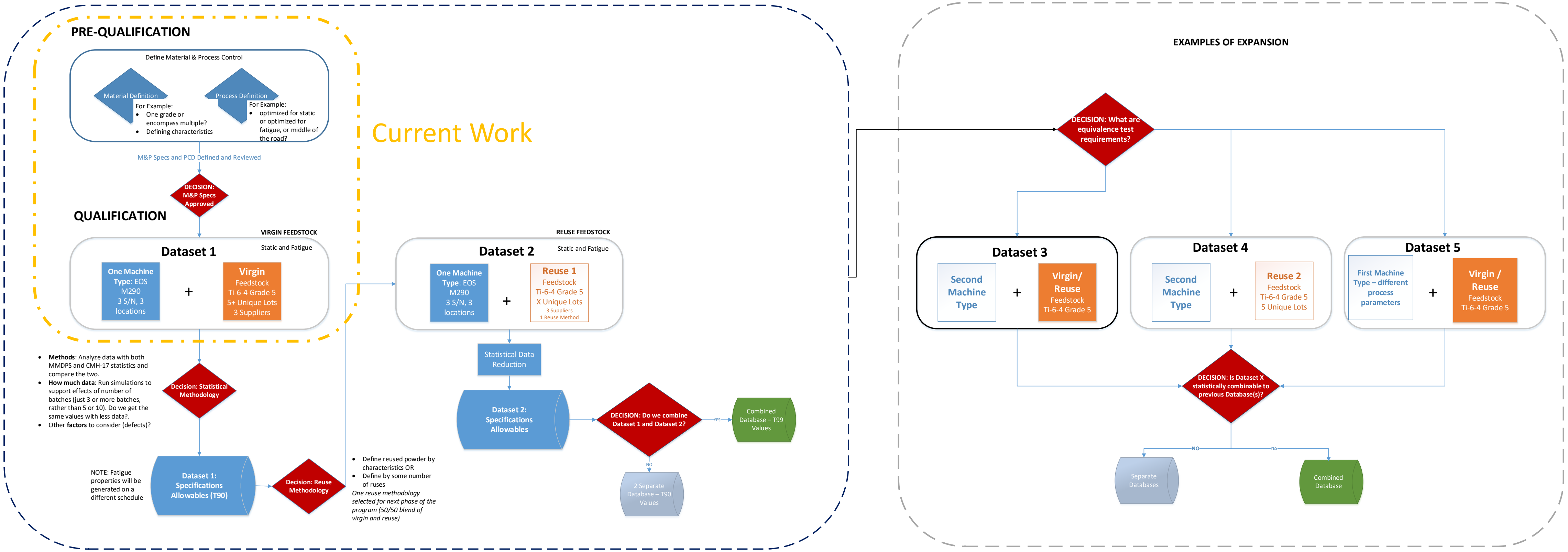
JMADD Qual Project Objective

- To produce a set of publicly available statistically substantiated material property data of bulk material properties for metallic AM material with a corresponding material and process specification as well as a framework for future database development projects.

- The selection of a single material and process is necessary to manage the scope of such project, and to begin the work of identifying a standard process to develop material allowables and design data for Metal AM. The initial process and material combination for the scope of this project is Laser Powder Bed Fusion (L-PBF) of Ti-6Al-4V grade 5 alloy.

- The overall objective is to achieve NCAMP B and A-basis (T90 and T99) material allowable data and establish a best practice for developing AM allowables and specifications that is publicly available for L-PBF of Ti-6Al-4V.

JMADD Expanded Qualification Framework



SCOPE OF CURRENT JMADD PROGRAM

Current Work

PRE-QUALIFICATION

Define Material & Process Control

Material Definition

For Example:
- One grade or encompass multiple?
- Defining characteristics

Process Definition

For Example:
- optimized for static or optimized for fatigue, or middle of the road?

M&P Specs and PCD Defined and Reviewed

DECISION: M&P Specs Approved

QUALIFICATION

VIRGIN FEEDSTOCK

Dataset 1

Static and Fatigue

One Machine Type: EOS M290 3 S/N, 3 locations

\+

Virgin Feedstock Ti-6-4 Grade 5 5+ Unique Lots 3 Suppliers

- **Methods**: Analyze data with both MMDPS and CMH-17 statistics and compare the two.
- **How much data**: Run simulations to support effects of number of batches (just 3 or more batches, rather than 5 or 10). Do we get the same values with less data?.
- Other **factors** to consider (defects)?

Decision: Statistical Methodology

NOTE: Fatigue properties will be generated on a different schedule

Dataset 1: Specifications Allowables (T90)

Decision: Reuse Methodology

- Define reused powder by characteristics OR
- Define by some number of ruses

One reuse methodology selected for next phase of the program (50/50 blend of virgin and reuse)

REUSE FEEDSTOCK

Dataset 2

Static and Fatigue

One Machine Type: EOS M290 3 S/N, 3 locations

\+

Reuse 1 Feedstock Ti-6-4 Grade 5 X Unique Lots 3 Suppliers 1 Reuse Method

Statistical Data Reduction

Dataset 2: Specifications Allowables

DECISION: Do we combine Dataset 1 and Dataset 2?

YES

Combined Database – T99 Values

NO

2 Separate Database – T90 Values

EXPANDING THE DATABASE – FUTURE WORK

EXAMPLES OF EXPANSION

DECISION: What are equivalence test requirements?

Dataset 3

Second Machine Type

\+

Virgin/ Reuse Feedstock Ti-6-4 Grade 5

Dataset 4

Second Machine Type

\+

Reuse 2 Feedstock Ti-6-4 Grade 5 5 Unique Lots

Dataset 5

First Machine Type – different process parameters

\+

Virgin / Reuse Feedstock Ti-6-4 Grade 5

DECISION: Is Dataset X statistically combinable to previous Database(s)?

NO

Separate Databases

YES

Combined Database

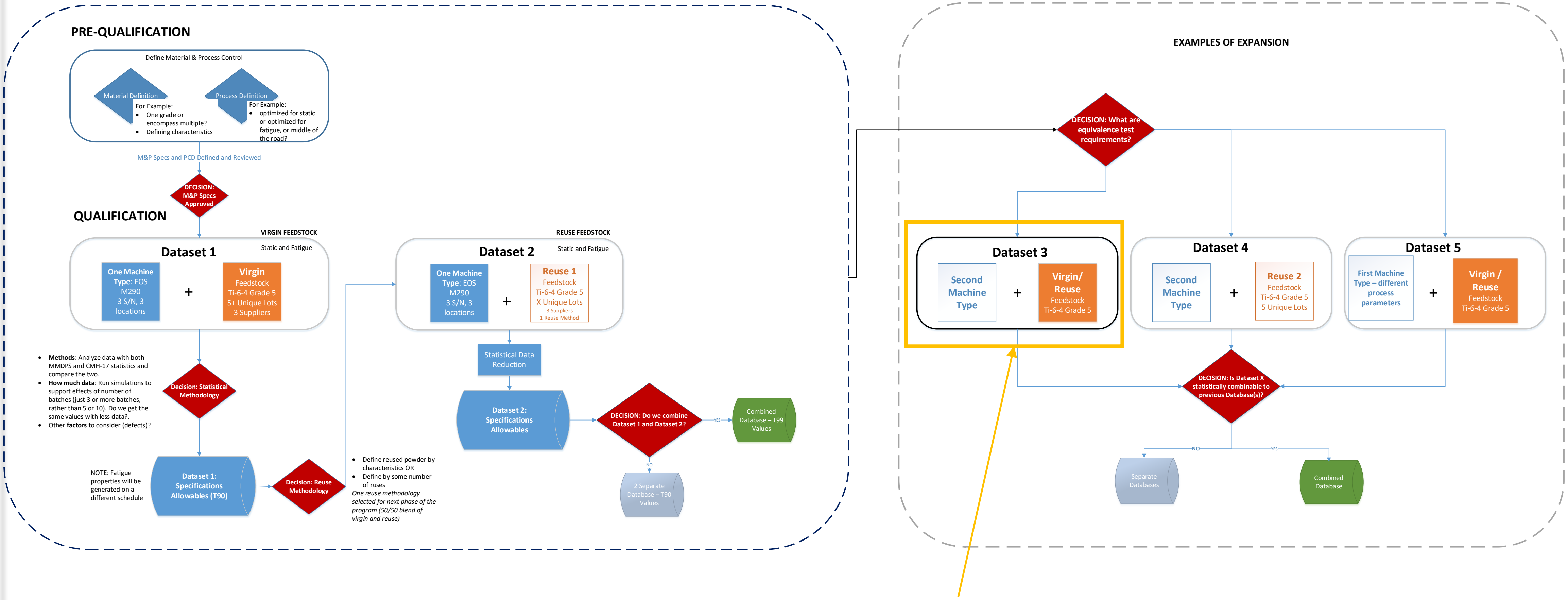
Project Includes:

- 3 Fabricators
- 3 Feedstock manufacturers
- Virgin and Reuse feedstock
- 10+ heats
- Gov't steering committee (33 members)
- Public Advisory Committee (80 members)
- NCAMP spec and allowable generation
- Data submission for consideration by MMPDS
- All specimens in SR, HIP, machined state
- Fully pedigreed data
- ~3600 specimens total

JMADD Expanded Qualification Framework

SCOPE OF CURRENT JMADD PROGRAM

EXPANDING THE DATABASE – FUTURE WORK



PRE-QUALIFICATION

Define Material & Process Control

Material Definition

For Example:
- One grade or encompass multiple?
- Defining characteristics

Process Definition

For Example:
- optimized for static or optimized for fatigue, or middle of the road?

M&P Specs and PCD Defined and Reviewed

DECISION: M&P Specs Approved

QUALIFICATION

VIRGIN FEEDSTOCK

Dataset 1

Static and Fatigue

One Machine Type: EOS M290 3 S/N, 3 locations + **Virgin** Feedstock Ti-6-4 Grade 5 5+ Unique Lots 3 Suppliers

- **Methods**: Analyze data with both MMDPS and CMH-17 statistics and compare the two.
- **How much data**: Run simulations to support effects of number of batches (just 3 or more batches, rather than 5 or 10). Do we get the same values with less data?.
- Other **factors** to consider (defects)?

Decision: Statistical Methodology

NOTE: Fatigue properties will be generated on a different schedule

Dataset 1: Specifications Allowables (T90)

Decision: Reuse Methodology

- Define reused powder by characteristics OR
- Define by some number of ruses

One reuse methodology selected for next phase of the program (50/50 blend of virgin and reuse)

REUSE FEEDSTOCK

Dataset 2

Static and Fatigue

One Machine Type: EOS M290 3 S/N, 3 locations + **Reuse 1** Feedstock Ti-6-4 Grade 5 X Unique Lots 3 Suppliers 1 Reuse Method

Statistical Data Reduction

Dataset 2: Specifications Allowables

DECISION: Do we combine Dataset 1 and Dataset 2?

YES – Combined Database – T99 Values

NO – 2 Separate Database – T90 Values

EXAMPLES OF EXPANSION

DECISION: What are equivalence test requirements?

Dataset 3

Second Machine Type + **Virgin/ Reuse** Feedstock Ti-6-4 Grade 5

Dataset 4

Second Machine Type + **Reuse 2** Feedstock Ti-6-4 Grade 5 5 Unique Lots

Dataset 5

First Machine Type – different process parameters + **Virgin / Reuse** Feedstock Ti-6-4 Grade 5

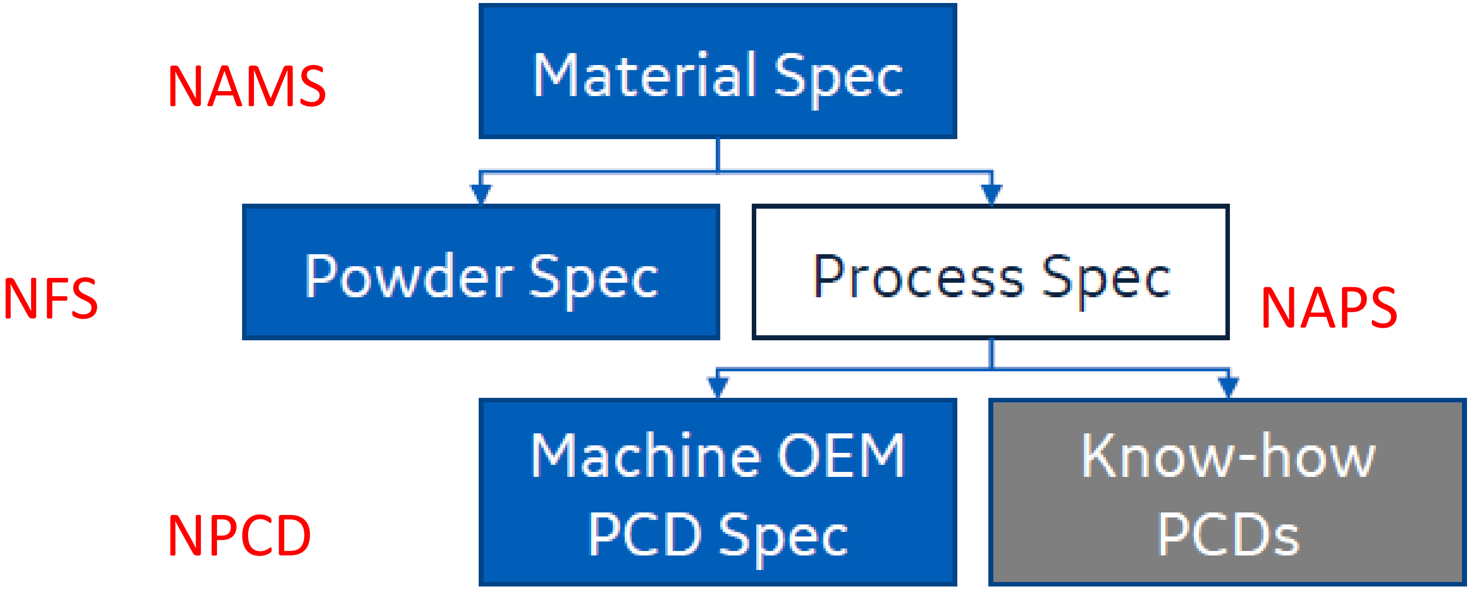
DECISION: Is Dataset X statistically combinable to previous Database(s)?

NO – Separate Databases

YES – Combined Database

21B-2: Expansion to second machine type

NCAMP Additive Documentation Framework



NAMS

Material Spec

NFS

Powder Spec

Process Spec

NAPS

NPCD

Machine OEM PCD Spec

Know-how PCDs

- ***NAMS (additive material spec) includes fully defined key characteristics including chemistry, density, min tensile strength, grain size, porosity limit and surface finish.***
- ***NPS is a material and machine agnostic L-PBF process spec.***
- ***Powder Spec defines limits for feedstock material***
- ***PCD includes line by line operational instructions and full post-processing conditions.***
- ***All specs will be posted publicly along with allowables generates from the program.***

All specifications have been reviewed by GSC and NCAMP DER

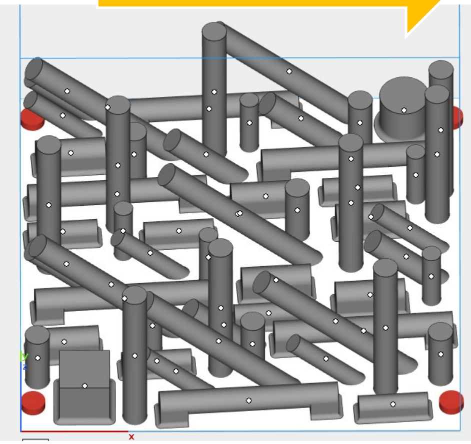
Qualification Process Chain

NIAR

Fabricators

Build Design

Feedstock



Fabrication

Build Inspection

CLEAN

SR 700° C

SHIP

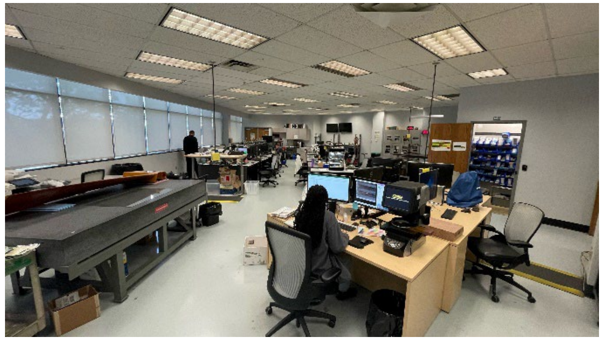
Wire-EDM

CLEAN

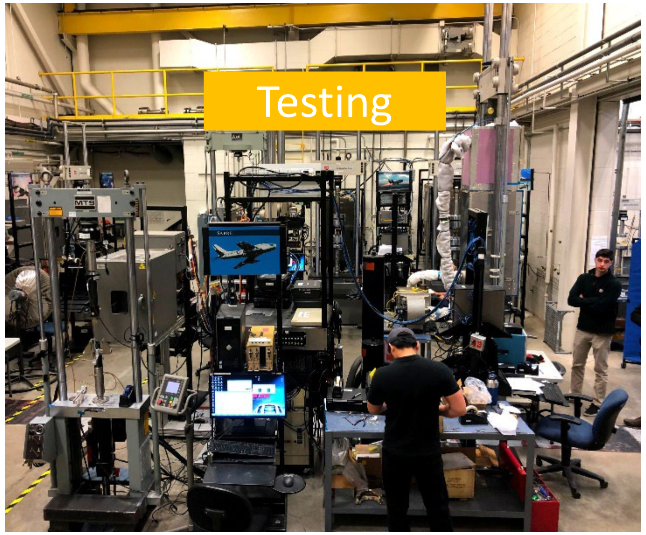
HIP

(200 MPa, 815°C)

Machining



Quality Control



Testing

Qualification 1 fabrication

- Qualification 1 fabrication began in Nov 2022.
- NIAR and Boeing fabricated 25 and 9 builds respectively for generation of the 1st of 2 datasets along with a third fabricator.
- NIAR's builds N1-N25 have been fabricated. Complete 3/10.
- Build failures:

  N3 – improper specimen .stl z-location. Files have been corrected.

  N13 – argon pressure drop due to argon dewar valve malfunction.
- Additional powder was purchased to re-fabricate builds N3 and N13. Fabrication complete 3/24.
- Boeing completed all 9 qual build fabrications without failure.
- NIAR received Boeing builds B1-B9 3/7/23.
- 350 of the submitted 500 specimens have completed final machining and are in queue for QC and testing. Approx 1600 total defined for Qual 1 testing.

NIAR Q1 Fabrication				Beehive Q1 Fabrication				Boeing Q1 Fabrication			
Powder	**Lot**	**Build Design**	**Build #**	**Powder**	**Lot**	**Build Design**	**Build #**	**Powder**	**Lot**	**Build Design**	**Build #**
ATI	1	D11	N1	ATI	2	D11	A1	Tekna	1	D11	B1
			N2				A2				B2
		D12	N3			D12	A3				B3
			N4				A4			D12	B4
	3	D11	N5		4	D11	A5				B5
		D12	N6			D12	A6				B6
		D13	N7			D13	A7			D13	B7
	5	D11	N8		6	D11	A8				B8
		D12	N9				A9				B9
		D13	N10			D12	A10				
	7	D11	N11	AP&C	2	D11	A11				
		D12	N12				A12				
	8	D13	N13				A13				
Tekna	1	D11	N14			D12	A14				
			N15				A15				
		D12	N16				A16				
			N17			D13	A17				
		D13	N18				A18				
			N19				A19				
AP&C	1	D11	N20								
			N21								
		D12	N22								
			N23								
		D13	N24								
			N25								
Tekna	2	D12	N3-2								
		D13	N13-2								

Additional builds completed

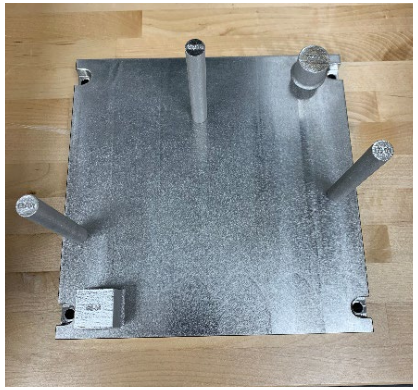
🟩 Fabricated

🟨 In process

Build Failure

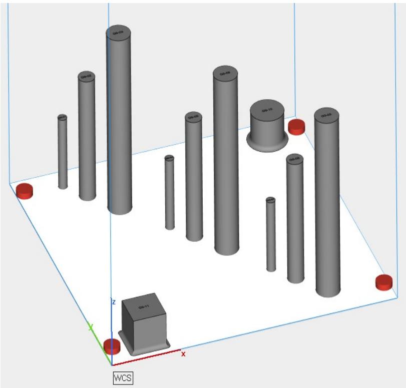
Prequalification Studies:
Orientation Down Selection Study Builds

G1 G2
Specimen orientation study

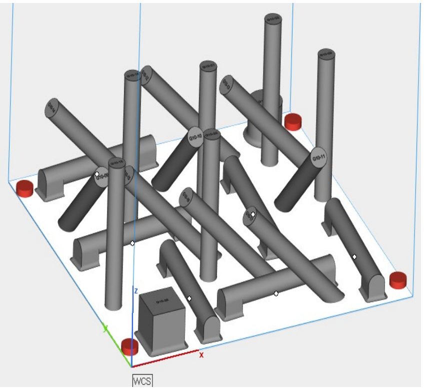


G3 G4 G5
Time between layer exposure study

G6 G7 G8
Specimen spacing study



G9
Specimen Scaling study

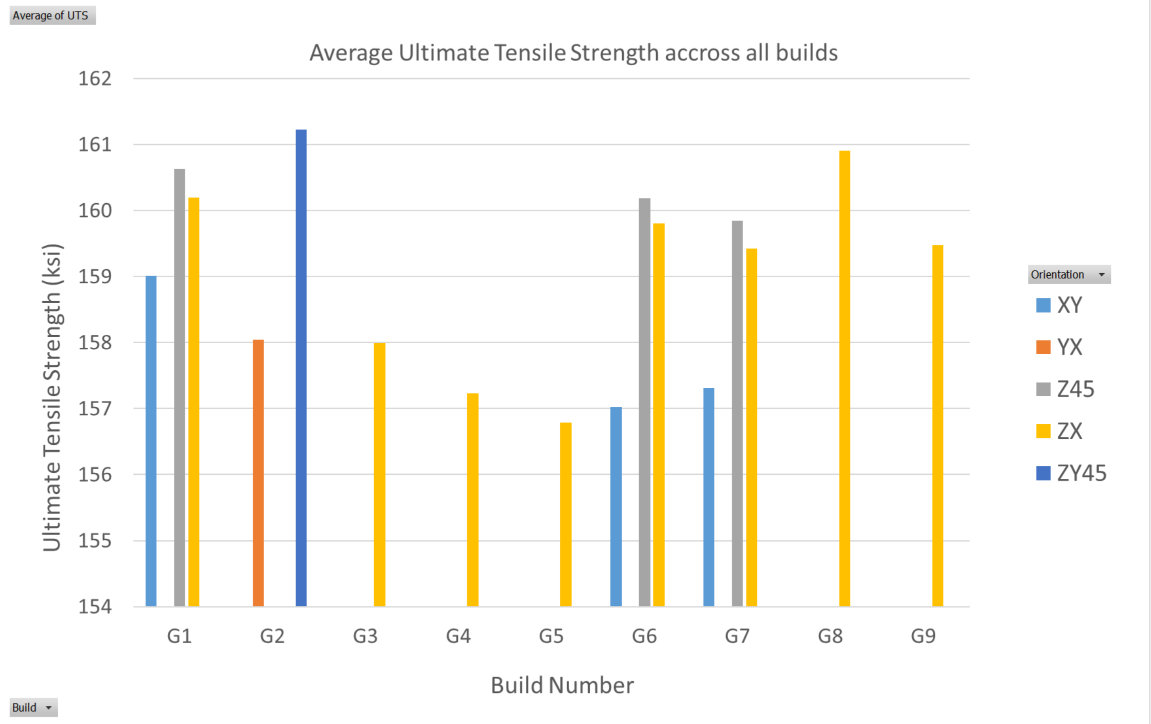


G10
Low Cycle Fatigue

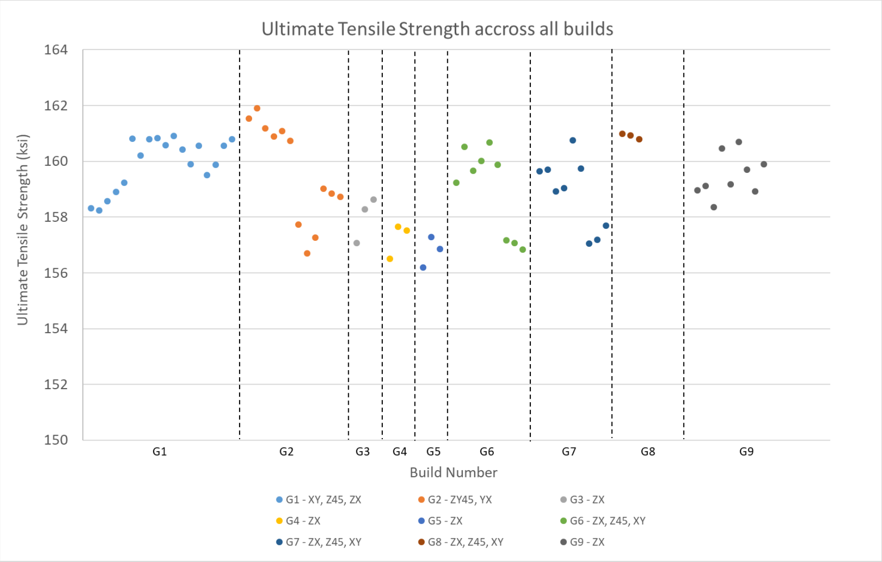
Builds 9 and 10 were completed but photos were not taken prior to wire EDM of build plate

Orientation Down Selection Study
ASTM E8 – Ultimate tensile Strength (UTS) across all builds

- Includes all 69 tested ASTM E8 specimens across nine builds (G1 through G9)
- All data groups fair closely, although there is visual separation between orientation data groups. ZY45 specimens showed highest results, followed by Z45, then ZX. Similar trends for HIP specimens were seen in the paper by Meier, et al. (2022)



“Influences of Surface, Heat Treatment, and Print Orientation on the Anisotropy of the Mechanical Properties and the Impact Strength of Ti 6Al 4V Processed by Laser Powder Bed Fusion”

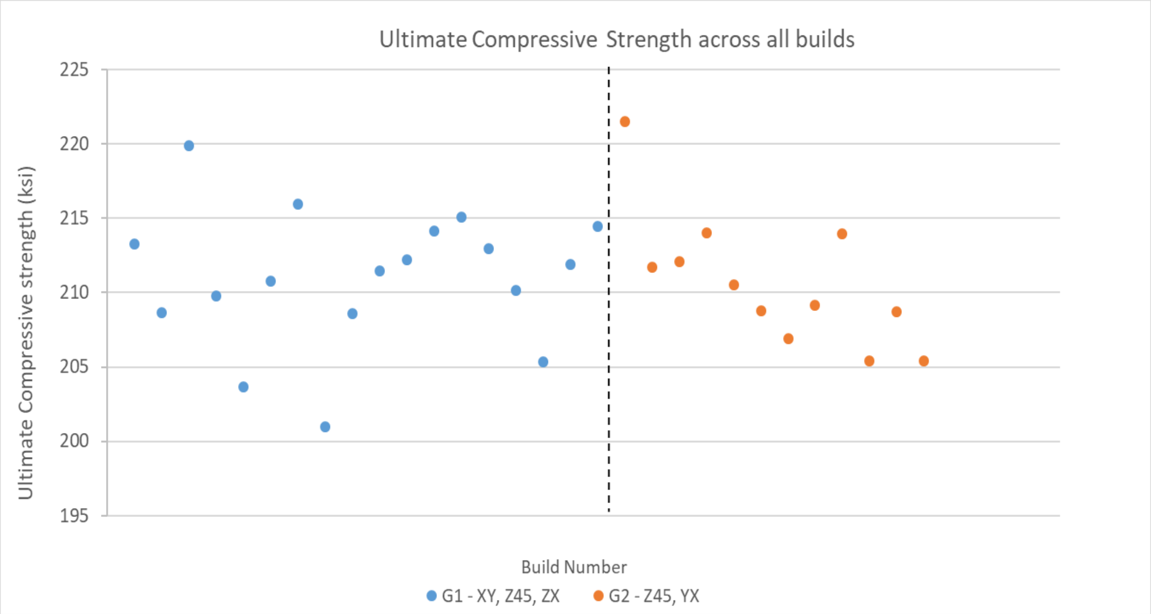


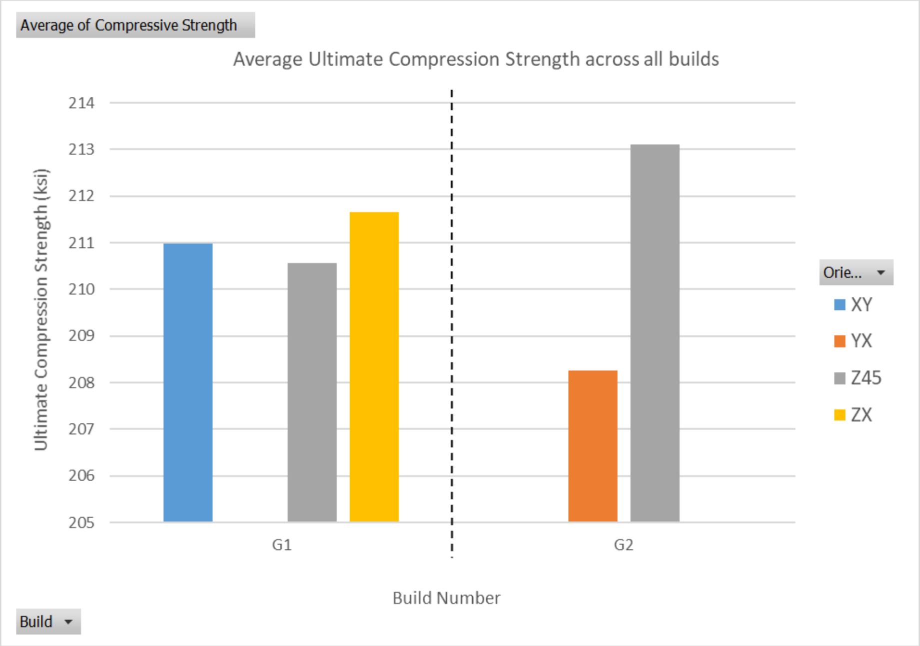
	Average	Standard Deviation	Coefficient of Variation (%)
Ultimate Tensile Strength (ksi)	159.27	1.47	0.92
Modulus (Msi)	17.19	0.24	1.42
0.2% Offset Yield Strength (ksi)	147	2.02	1.38
Percent Elongation at yield (%)	1.05	0.01	1.05
Percent Elongation at fracture (%)	12.77	0.77	6.07

(https://www.mdpi.com/2504-4494/6/4/87/htm)

ASTM E9 – Ultimate Compression Strength across all builds

- A total of 30 specimens (0.5” diameter x 1.0” length) in different orientations across builds G1 and G2 were tested.
- Upon reviewing the gathered compression data, the results varied minimally across builds. However, there was a separation between the orientation data groups, with Z45 specimens showing the highest UCS, followed by ZX, and then XY specimens.
- On build G2, a single Z45 specimen outperformed all specimens, which resulted in a higher average for Z45 orientation specimens.

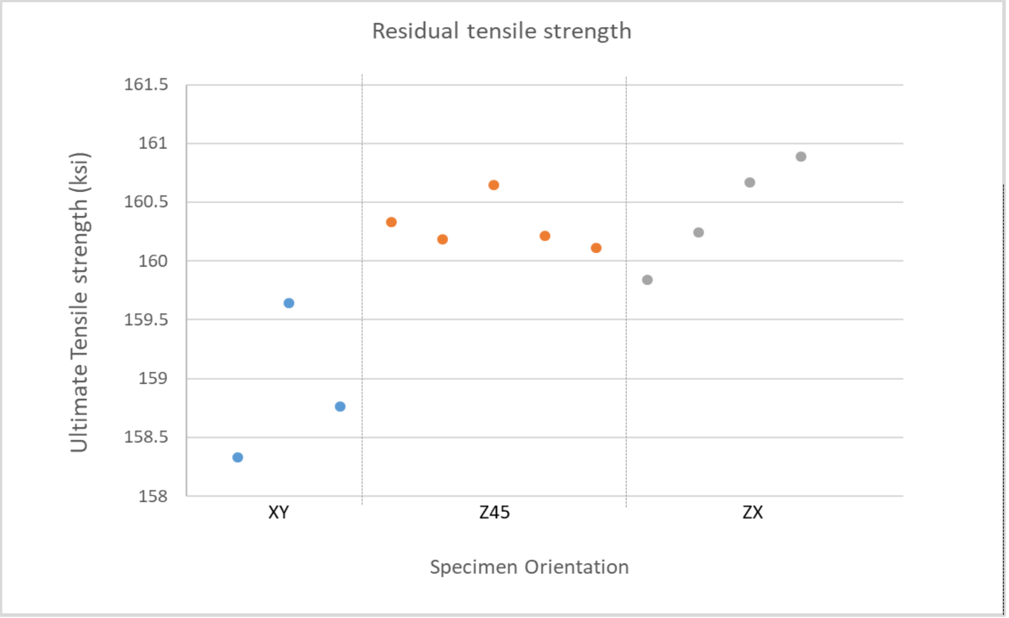


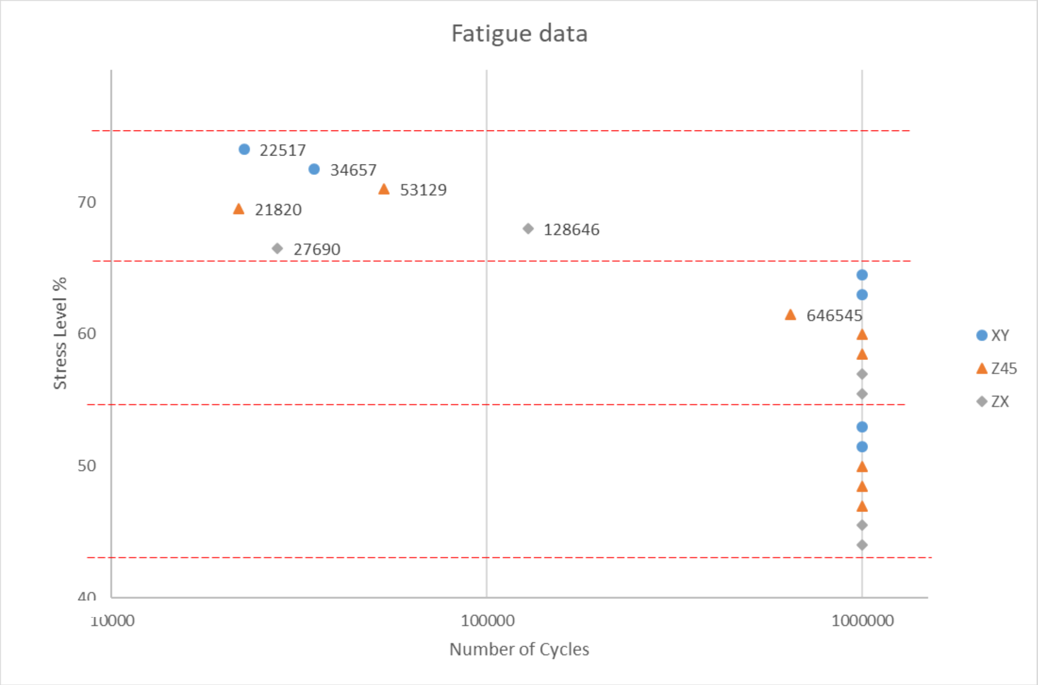


ASTM E9 – Compression Data	Average	Standard Deviation	Coefficient of Variation (%)
0.2% Offset Yield Strength (ksi)	160.57	3.95	2.46
Ultimate Compression Strength (ksi)	210.91	4.46	2.11
Modulus (Msi)	17.82	0.34	1.88

ASTM E466 – Low Cycle Fatigue data

- 50,000 cycles strain control; remaining load control. (R: -1 at RTA)
- Specimens at 70% stress level failed before a million cycles; most specimens tested at 50% and 60% stress levels survived. One Z45 failed at 646,545 cycles.
- Residual strengths matched static tensile data. Residual elongation at fracture is higher than static tensile tests.

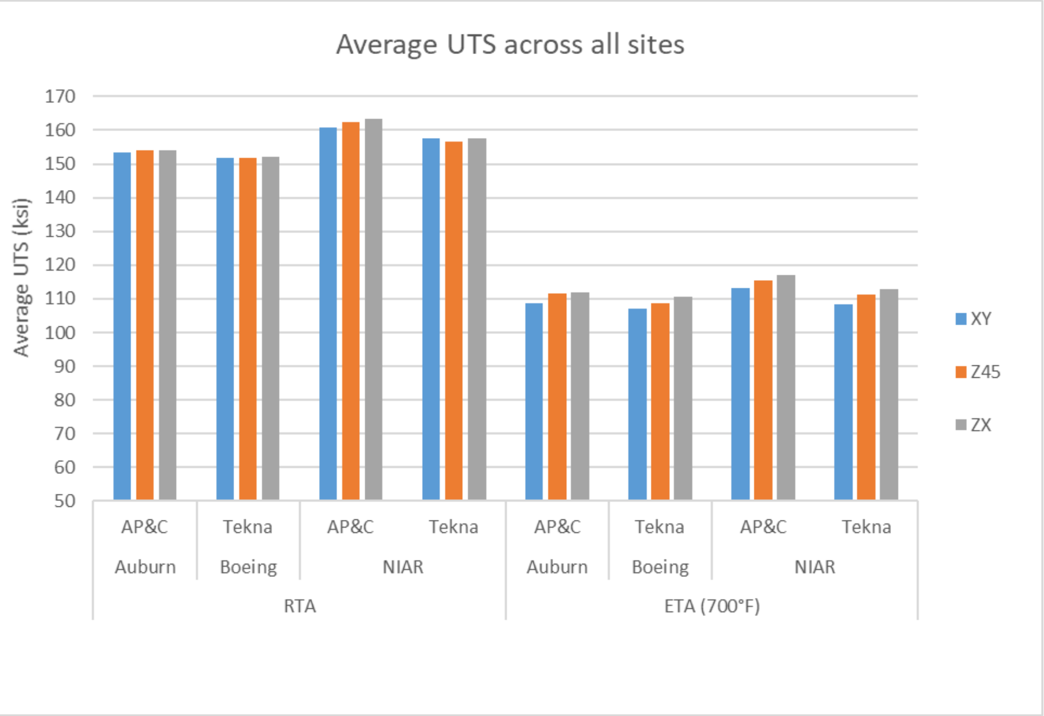


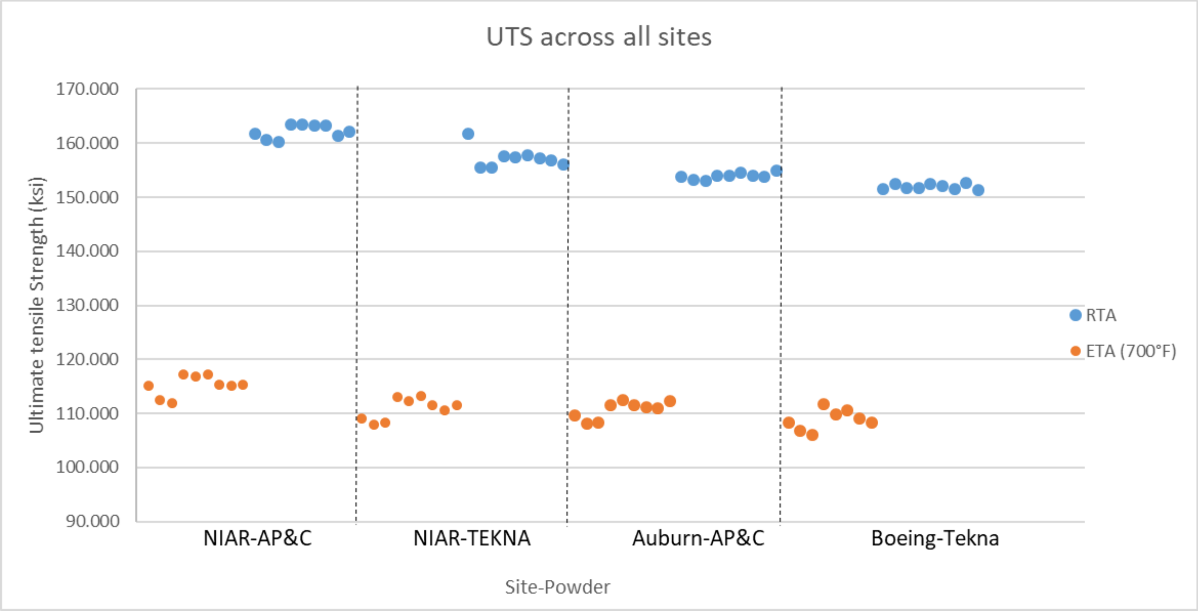


<u>ASTM E466 – Residual Strength</u>	**Average**	**Standard Deviation**	**Coefficient of Variation (%)**
0.2% Offset Yield Strength (ksi)	146.77	1.63	1.11
Ultimate Tensile Strength (ksi)	159.99	0.76	0.48
Modulus (Msi)	17.25	0.18	1.02
Percent Elongation at yield (%)	1.05	0.01	0.61
Percent Elongation at fracture (%)	17.23	0.76	4.39

Prequalification: Site Comparison Study

- All sites provided RTA and ETA UTS results with low variance – Coefficient of variation (CoV) below 2%
- 6% difference seen between highest and lowest performing RTA site and feedstock vendor





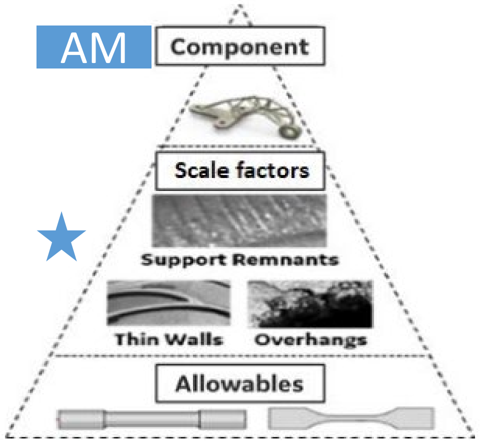
Site Comparison Study

ASTM E8 – Ultimate Tensile Strength across all sites (Continued)

	RTA								ETA							
	NIAR				Auburn		Boeing		NIAR				Auburn		Boeing	
	AP&C		TEKNA		AP&C		TEKNA		AP&C		TEKNA		AP&C		TEKNA	
	Avg .	Cov (%)	Avg .	Cov (%)	Avg .	Cov (%)	Avg .	Cov (%)	Avg .	Cov (%)	Avg .	Cov (%)	Avg .	Cov (%)	Avg .	Cov (%)
0.2% Offset Yield Strength (ksi)	149.84	1.50	144.11	1.77	141.57	1.15	139.26	1.31	95.94	2.58	91.60	2.30	91.77	1.77	90.15	2.23
Ultimate Tensile Strength (ksi)	162.19	0.78	157.31	1.18	153.88	0.37	151.92	0.33	115.18	1.68	110.87	1.80	110.68	1.45	108.85	1.70
Young's Modulus (Msi)	16.80	2.39	16.29	2.20	16.85	1.34	16.93	1.44	14.45	2.93	14.45	1.60	14.44	1.63	14.65	1.69
Percent Elongation at yield (%)	1.07	2.36	1.04	2.91	1.04	0.20	1.02	0.45	0.86	2.16	0.83	0.63	0.83	1.92	0.79	4.69
Percent Elongation at fracture (%)	14.19	5.98	12.90	4.29	12.50	3.35	12.20	4.87	12.19	2.42	11.73	3.07	11.91	1.94	11.38	3.35

Ongoing Project: Building Block

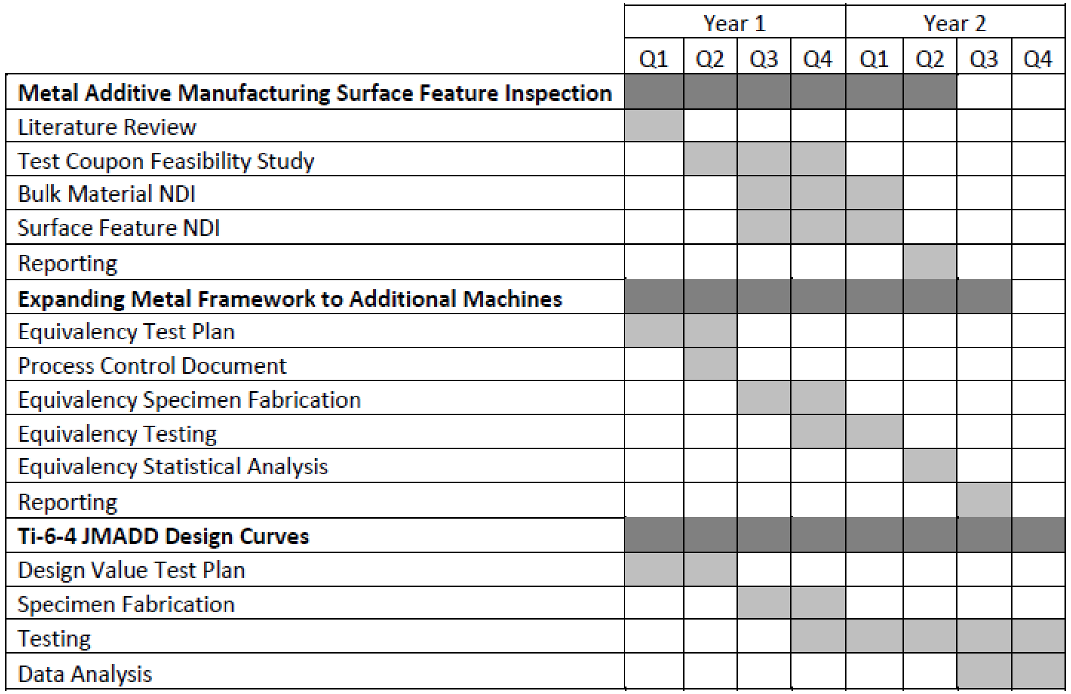
- Project work ongoing throughout 2022, but consensus from sponsors and industry steering committee has not been reached.
- Scope options previously discussed:
  1) Define test methods for detail/element configurations for the purpose of defining structural feature design values/ performance debits.
    - Feature options for investigation include: thin walls, overhangs, roofs, holes/lugs, radii, which may be adjusted based on AM process type being investigated.
  2) Define test methods for detail/element configurations for the purpose of demonstrating manufacturing capability of certain features.
    - This would allow for certification of manufacturers to fabricate parts which include the feature types demonstrated.
- This project will be defined to work in conjunction with the Fatigue Curves project.



AM Building Block Approach

2023 New Projects

- Expanding Metal AM Qualification Framework to Additional Machine Types
- JMADD Fatigue Curves
- Surface Feature Inspection



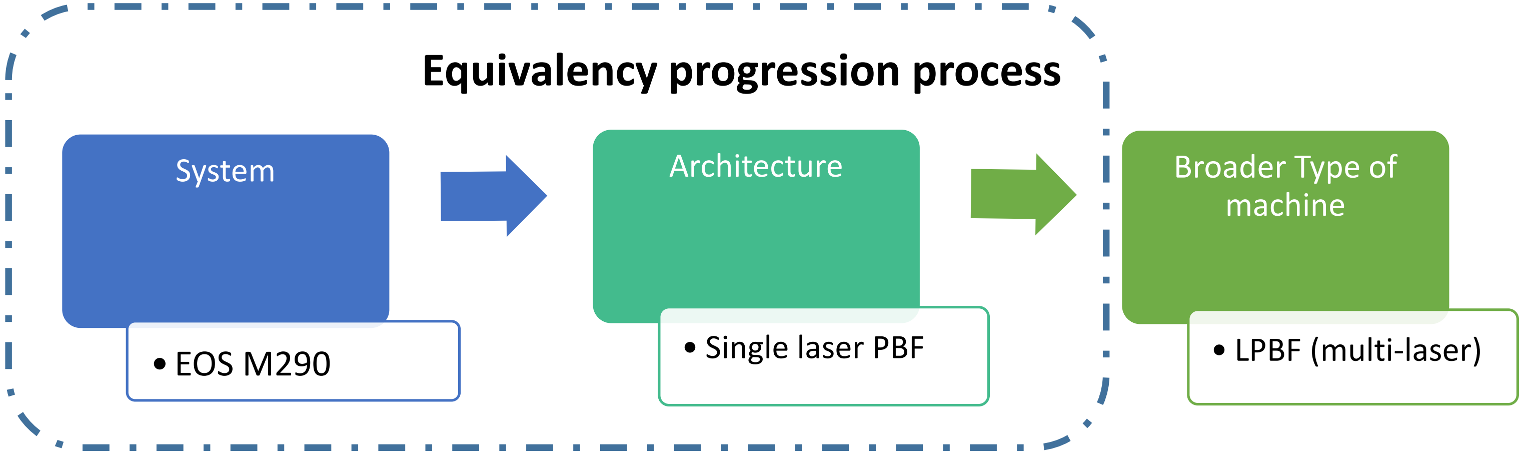
	Year 1				Year 2			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Metal Additive Manufacturing Surface Feature Inspection	■	■	■	■	■	■		
Literature Review	▨							
Test Coupon Feasibility Study		▨	▨	▨				
Bulk Material NDI			▨	▨	▨			
Surface Feature NDI			▨	▨	▨			
Reporting						▨		
Expanding Metal Framework to Additional Machines	■	■	■	■	■	■	■	
Equivalency Test Plan	▨	▨						
Process Control Document		▨						
Equivalency Specimen Fabrication			▨	▨				
Equivalency Testing				▨	▨			
Equivalency Statistical Analysis						▨		
Reporting							▨	
Ti-6-4 JMADD Design Curves	■	■	■	■	■	■	■	■
Design Value Test Plan	▨	▨						
Specimen Fabrication			▨	▨				
Testing				▨	▨	▨	▨	▨
Data Analysis							▨	▨

Expanding Metal AM Framework to Additional Machine Types

- **PoP**: 18-24 months
- **Background**: Feedback from Industry, the Public Advisory Committee, and the Government Steering Group all have commented that while the decision to limit the initial database to a single machine architecture is well understood and supported, further expansion to include machine agnostic standards and specifications so that additional machines are qualified is critical to move the industry forward.
- **Objectives**: Develop a robust equivalency approach for metals including static and dynamic properties. Perform an equivalency on a different (secondary) laser powder bed fusion machine architecture that is capable of processing Ti-6Al-4V alloy.

Expanding Metal AM Framework to Additional Machine Types

- **Scope**
  - The project will establish and utilize a NCAMP metal AM equivalency process to act as a pathfinder machine to machine equivalency within the same process type (LPBF)
  - Expand the baseline specification framework to include machine-agnostic process specifications and standards
  - Specification documents from JMADD program will be leveraged but investigation into definition of a performance-based printed material specification (leveraging JMADD NAMS) will be performed.
    - Characterize "intermediate requirements with associated responses" in an effort to achieve the performance based spec requirements (such as thermal post processing to achieve desired microstructure)
    - This will further enable additive machines with same AM process type to leverage baseline database.



Equivalency progression process

System
- EOS M290

Architecture
- Single laser PBF

Broader Type of machine
- LPBF (multi-laser)

Machine Equivalency: Approach

- Utilize established NIAR GE M2 machine, specifications, process definition, and framework to define and conduct a metal AM equivalency to JMADD dataset.
  - NIAR - owned GE M2 Series 5 LPBF machine (single or dual laser capability)
  - Established JMADD LPBF-specific Process Specification
  - JMADD post-processing chain definition as starting point
  - Leverage NCAMP composites equivalency framework and JMADD NCAMP metal AM qualification framework to generate a metal AM equivalency method
  - Utilize JMADD Additive Material Spec (final material characterization) as starting point for performance-based spec definition
- Generate and execute a fully defined equivalency methodology for comparison to JMADD dataset

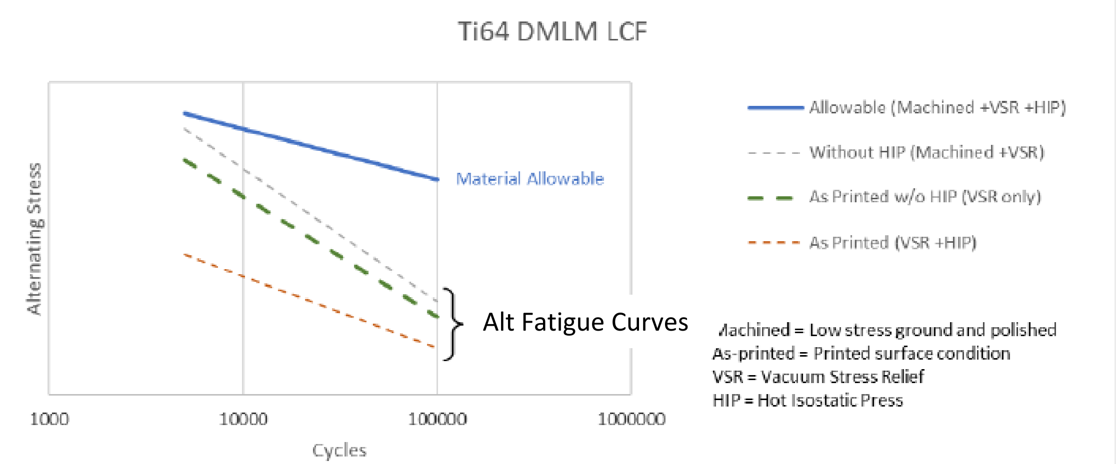
EOS m290/JMADD

GE M2 Series 5
Single laser use

Deliverables: A deliverables report documenting the equivalency framework and results, including statistical equivalency comparison between the Concept Laser M2 data and the baseline EOS M290 qualification.

Ti-6-4 JMADD Fatigue Curves

- **PoP**: 24 months
- **Background**: A significant difference exists between bulk material allowables and alternative post processing. Fatigue curves are commonly used to show performance debits for alternatives in material or part definition. Clarifying data and guidelines are needed to enable industry use. No public database showing the different fatigue curve debits for alternate post processing operations exists for any AM alloy.



Notional Graphic of Material Allowable and Fatigue Curves

Objectives: Leveraging the JMADD program, which is developing bulk material allowables, this task will generate fatigue curves for the as-fabricated and additional alternate post-processing conditions for comparison back to JMADD fatigue values.

Deliverables: Fatigue Curves, Report documenting lessons learned and guidelines

*It is noted that a change in heat treatment/post-processing is generally considered a material change for the output material. Instead of creating a B or S-basis property dataset for these new materials, a fatigue curve approach was recommended to specifically capture fatigue performance effects from alternate post-processing methods.

Ti-6-4 JMADD Fatigue Curves

	JMADD	Alternate Post-Process Combinations			Alternate HIP
		#1	#2	#3	
SR	X	X	X	X	X
200 MPa HIP	X			X	
100 MPa HIP					X
Machined	X	X			X

JMADD process condition shown for generation of baseline allowables (red)

Notes:

1) Industry partners have discussed that fatigue performance may be negatively impacted in the HIPed state if parts are not machined, due to surface α-case formation.

Design Values definitions #2 vs #3 are included to generate data to characterize this performance difference.

2) GAMAT P-DED allowables project is in post-processing definition discussion. 100 MPa HIP is a processing front-runner and comparison to JMADD could be valuable.

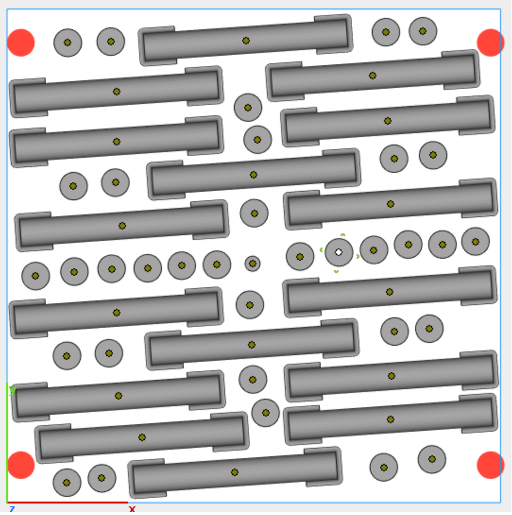
- After bulk material allowables have been generated (JMADD), fatigue curves must be created to enable design of parts based off of differing surface finish and post-processing, such as stress relief and HIP. Additional curves may be generated in industry to provide characterization of knock-downs for other part features.
- Three conditions for fatigue curves were defined for generation:
  1. Machined and Vacuum/Inert Stress Relief (No HIP)
  2. As Printed, Vacuum/Inert Stress Relief (No HIP)
  3. As Printed, Vacuum/Inert Stress Relief and HIP

  Additional or alternate option:

  4. *Machined, VSR and 100 MPa HIP (Potential GAMAT)*
  5. *Machined and HIP (no Stress Relief)*
- Knockdowns and behavior associated with each iterations above will be generated
- JMADD test plan and specifications will be leveraged to ensure resulting data aligns with methodology used in the original JMADD qualification Program.

Approach

- Create common mixed build design for fabrication and performance comparison across builds (8 builds)
- Fabricate specimens from single material lot and vendor
- Post-process and machine per test matrix definition
- Generate RTA fatigue curves for comparison to JMADD baseline
- Include E8 static tensile lot release specimen on each build



Notional mixed build design

Test Matrix/HT

Vendor	Lot	R-Ratio	Stress Levels	Orientation	DV	Finish	Condition	Specimens per SL	ZX Specimens	XY Specimens
AP&C	A	-1	5	XY	#1	Machined	VSR	12		60
				ZX	#1	Machined	VSR	12	60	
				ZX	#2	AF	VSR	12	60	
				ZX	#3	AF	VSR + HIP	12	60	
				XY	GAMAT*	Machined	HIP or SR+100 HIP	12		60
				ZX	GAMAT*	Machined	HIP or SR+100 HIP	12	60	
									240	**120**
								Total Specimens	**360**	

*As-fabricated Z45 specimen limitation due to specimen radius down-skin angle

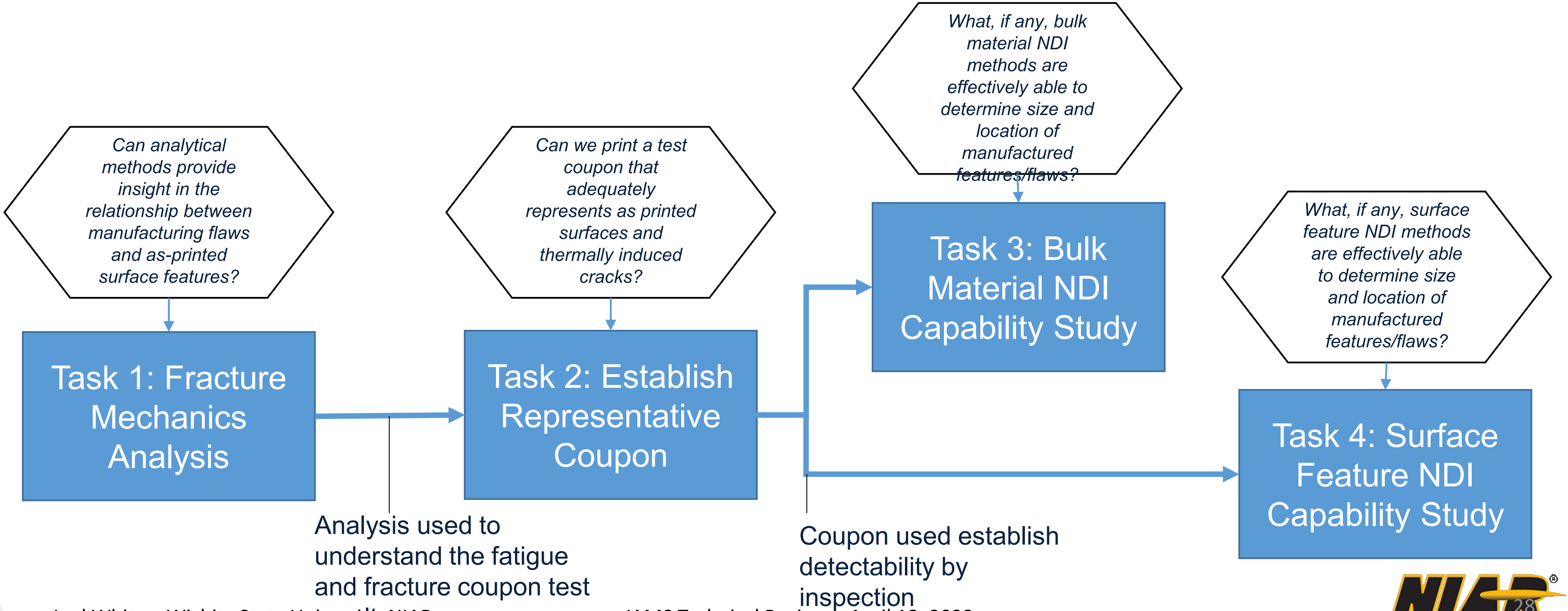
Metal Additive Manufacturing Surface Feature Inspection

- **PoP**: 18 months
- **Background**: Fatigue design values are significantly impacted by the as-fabricated surface condition and must be characterized when present on fatigue sensitive components. These surfaces are not able to be inspected using traditional surface inspection methods such as Fluorescent Penetrant Inspection (FPI) and therefore rely on the use of fatigue design value debit factors. This practice has successfully been applied on many certified LPBF parts, and yet questions remain concerning the lack of inspectability of these surfaces. The inspection concern is routed in the uncertainty related to manufacturing flaws, such as cracks, which may exceed the design value debits determined for as-printed surfaces.
- **Objectives**: The specific research goal is to understand whether the combination of as-printed surface design values and bulk material inspection methods such as X-Ray or CT-scan are sufficient to assure the material properties of fatigue sensitive LPBF components.

Metal Additive Manufacturing Surface Feature Inspection

Overall Research Question:

Is the combination of as-printed surface design values and bulk material inspection methods, such as X-Ray or CT-scan, sufficient to assure the material properties of fatigue sensitive LPBF components?



Can analytical methods provide insight in the relationship between manufacturing flaws and as-printed surface features?

Task 1: Fracture Mechanics Analysis

Can we print a test coupon that adequately represents as printed surfaces and thermally induced cracks?

Task 2: Establish Representative Coupon

What, if any, bulk material NDI methods are effectively able to determine size and location of manufactured features/flaws?

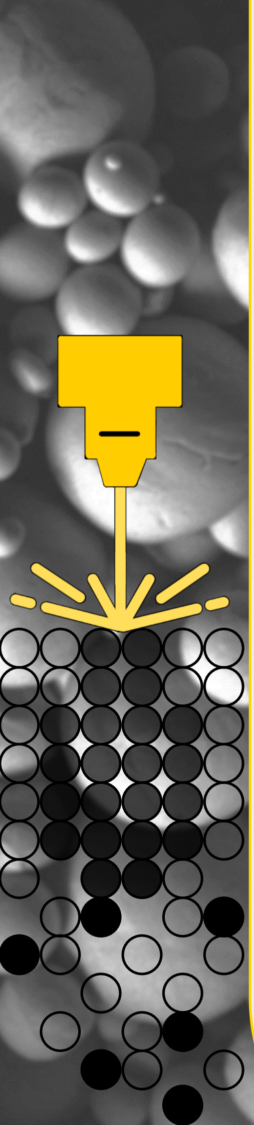
Task 3: Bulk Material NDI Capability Study

What, if any, surface feature NDI methods are effectively able to determine size and location of manufactured features/flaws?

Task 4: Surface Feature NDI Capability Study

Analysis used to understand the fatigue and fracture coupon test results

Coupon used establish detectability by inspection



Near Term Tasks

JMADD:

- Complete B-basis dataset and perform statistical analysis
- Initiate A-basis/reuse fabrication and test

New Projects:

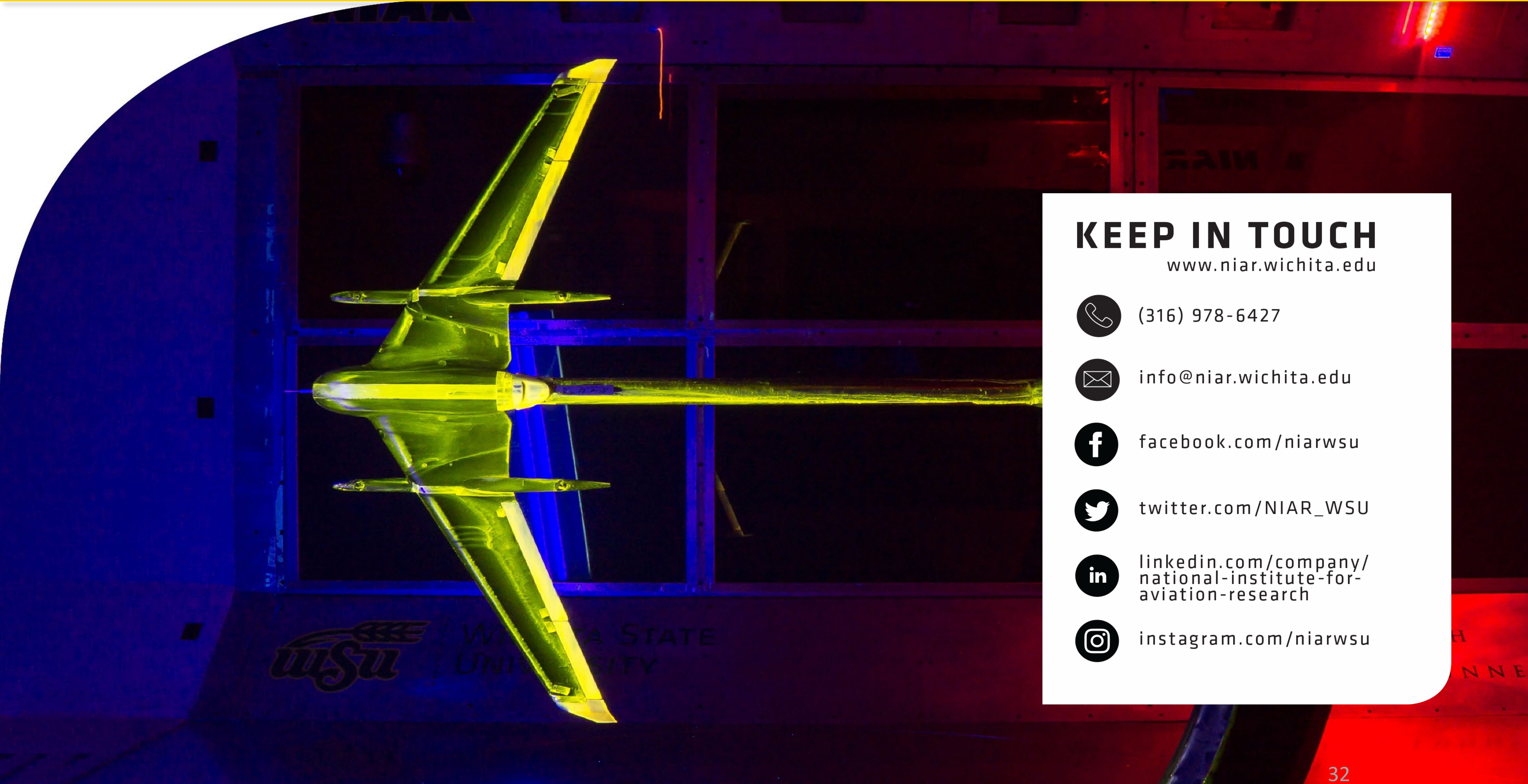
- Confirm FAA objectives and defined scope for each project
- Establish steering committees for each new project
- NIAR to complete development of NCAMP Metal AM Equivalency framework
- NIAR finalizing Fatigue Curves Test and Fabrication plan

Looking Forward

- **Benefits to Aviation**
  - JMADD creates much-needed baseline allowables and specifications for adoption by industry
  - JMADD establishes a qualification & equivalency framework enabling further expansion (machines, materials, AM process types, post-processes)
  - Follow-on programs answer key questions driven by industry need
  - Programs create experience and datsets needed for guidance and standards development and output
- **Future Needs**
  - Demonstrate scalability of AM qualification framework to new materials, machines, and process types
  - Finalize and demonstrate equivalency method to additional machines within material and process type
  - Guidance to define features and tests enabling research continuing up the building block pyramid
- **Contact:**
  - Rachael Andrulonis (Rachael.Andrulonis@idp.Wichita.edu)
  - Joel White (Joel.White@idp.Wichita.edu)

Publications

Publication Type	**Date**	**Publication**
Conference Presentation	Mar-21	R. Lovingfoss, “JMADD Program Update,” presented at America Makes TRX conference, Virtual, March 2021.
FAA Technical Reports	Dec-21	FAA Annual Report, “Additive Manufacturing Guidance for Aircraft Design and Certification,” December 2021 (submitted).
Conference Presentation	Mar-22	JMADD TRX
Conference Presentation	Oct-22	Presentation for FAA-EASA AM Workshop October 18th, 2022, Joint Metal Additive Database Definition (JMADD) Project Overview
Conference Presentation	Nov-22	Presentation for ASTM ICAM Tuesday, November 1st, 2022, Joint Metal Additive Database Definition (JMADD) Project Overview
FAA Technical Report	Dec-22	Joint Metal Additive Database Definition (JMADD) Parameter Set Comparison Study Technical Report
Conference Presentation	Dec-22	Joint Metal Additive Database Definition (JMADD), Defense Manufacturing Conference (DMC)
Conference Presentation	Feb-23	Presentation for MELD Users Group Tuesday, February 7, 2023, Joint Metal Additive Database Definition (JMADD) Project Overview
Conference Presentation	Mar-23	Joint Metal Additive Database Definition (JMADD), America Makes TRX, El Paso, TX, March 6, 2023
Conference Presentation	Apr-23	Joint Metal Additive Database Definition (JMADD) Project Update, Huntsville, AL, April 12, 2023



KEEP IN TOUCH

www.niar.wichita.edu

☎ (316) 978-6427

✉ info@niar.wichita.edu

facebook.com/niarwsu

twitter.com/NIAR_WSU

linkedin.com/company/national-institute-for-aviation-research

instagram.com/niarwsu