National Aeronautics and
Space Administration

Marshall Space Flight Center

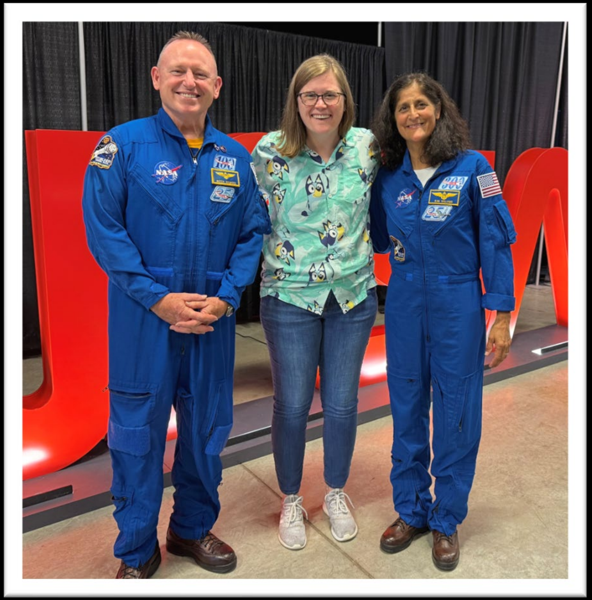
Additive Manufacturing Capabilities Overview

Mallory James, MSFC

August 4, 2025

About Me

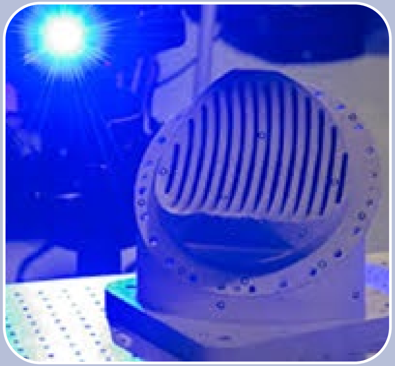
National Aeronautics and Space Administration



- B.S. in Industrial and Systems Engineering from Auburn University, 2013
- M.S. in Human Factors in Aeronautics from Florida Institute of Technology, 2017
- 10 years in various DoD systems engineering and manufacturing roles supporting acquisition of aviation and weapons systems for both the Army and Navy
  - Highlights of systems supported: mid-body guidance sections for 2.75” rockets, oxygen systems, night vision goggles, ejection seats, torpedoes, rotor and fixed wing platform integration, turbine engines
  - Critical design reviews, manufacturing readiness, structural and environmental testing, integration testing, airworthiness
- Additive manufacturing certification & strategy lead at Marshall before transitioning into Partnerships and Opportunities Development Office in June
  - New role will focus on Surface Systems, Advanced Manufacturing, and In Space Manufacturing Partnerships and Formulation
- Wife and mom to two kiddos and a rescue pup named Blueman
  - We enjoy baseball, swimming, baking, snacking

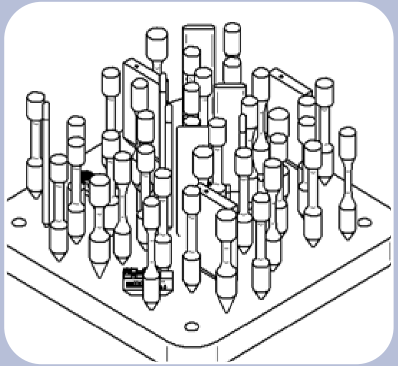
Additive Manufacturing
NASA's success enabled through Partnerships

- Drive AM technological innovations & maturity
- Provide framework for AM hardware certification for human-rated spaceflight
- Technical and risk cultures vary by component criticality & mission portfolios
  - Standards establish a common language & risk communication tools
  - Requirements are tailorable
- Share knowledge and data in pursuit of a well-informed AM user community
  - ***A rising tide lifts all boats***
- Experience in numerous AM technologies
  - Metallic: Laser Powder Bed Fusion, Directed Energy Deposition, Wire Arc AM, Liquid Droplet
  - Polymers: Fused Deposition Modeling, Stereolithography
  - Ceramics: Stereolithography



Innovate

Collaborative effort between NASA and Aerojet Rocketdyne to 3D print RS-25 pogo accumulator resulted in 78% reduction in welds, 35% cost reduction, and 80% production time savings. The team went on to leverage AM for more than 30 other components on the new engine.



Qualify

NASA-STD-6030 and NASA-STD-6033 provide the requirements framework for material process qualification and component certification of AM spaceflight hardware.

NASA has also supported AM research & development of custom alloys including GRCop-42 and HR-1.

Certify

Beyond AM material & process qualification, NASA has immense expertise in system qualification and certification testing.

Requirements are tailorable in accordance with mission and part classification to meet each project's unique risk posture.

Institutionalize

Programs like SLS's RS-25 provided *fleet leader* success for a systematic and institutional approach to leveraging AM to its fullest potential. NASA's Artemis portfolio includes many other AM applications, tailored appropriately to unique AM applications and risk postures.

Laser Powder Bed Fusion

Metal Powders

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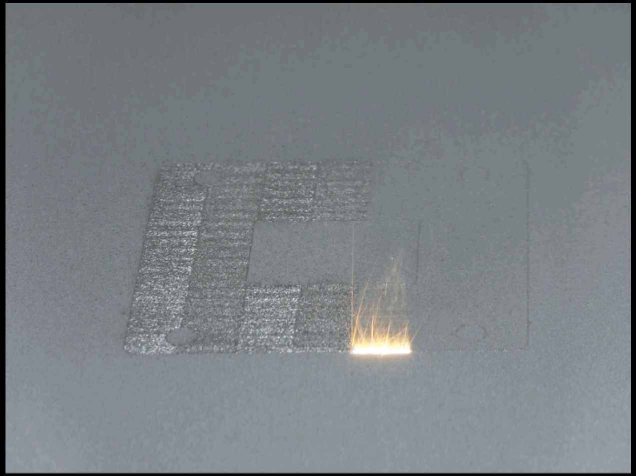

Velo Sapphire
In718
Build Volume: 315 Ø x 400 mm z

Laser Fusion Solutions upgraded M1
Various Materials including Lunar Regolith Simulant
Build Volume: 250 mm^3

EOS M100
Various Materials
Build Volume: 100 Ø x 95 mm z

Concept Laser M2
GRCop-42
Build Volume: 245 x 245 x 350 mm

Concept Laser Xline 2000R
In718
Build Volume: 400 x 800 x 500 mm

EOS M290
Nickel-based Alloys, presently HR2
Build Volume: 250 x 250 x 325 mm

Directed Energy Deposition
Blown Metal Powder

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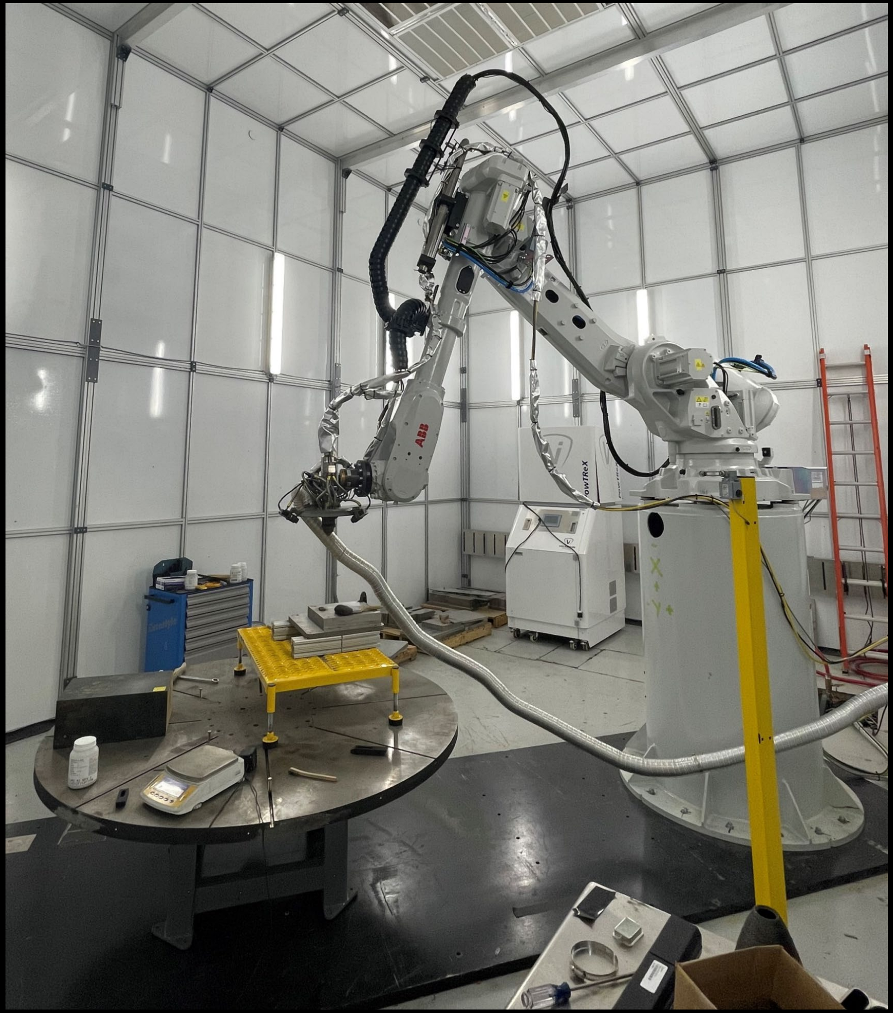
DM3D LP-DED



Working primarily in nickel alloys like In718 and HR-1

Cell was sized with RS-25 nozzle in mind.

RPMI 222XR LP-DED

Example Hardware on larger machine at RPMI in NASA HR-1

Coming Soon
Fall 2025

JBK-75 to start

Cold Metal Transfer

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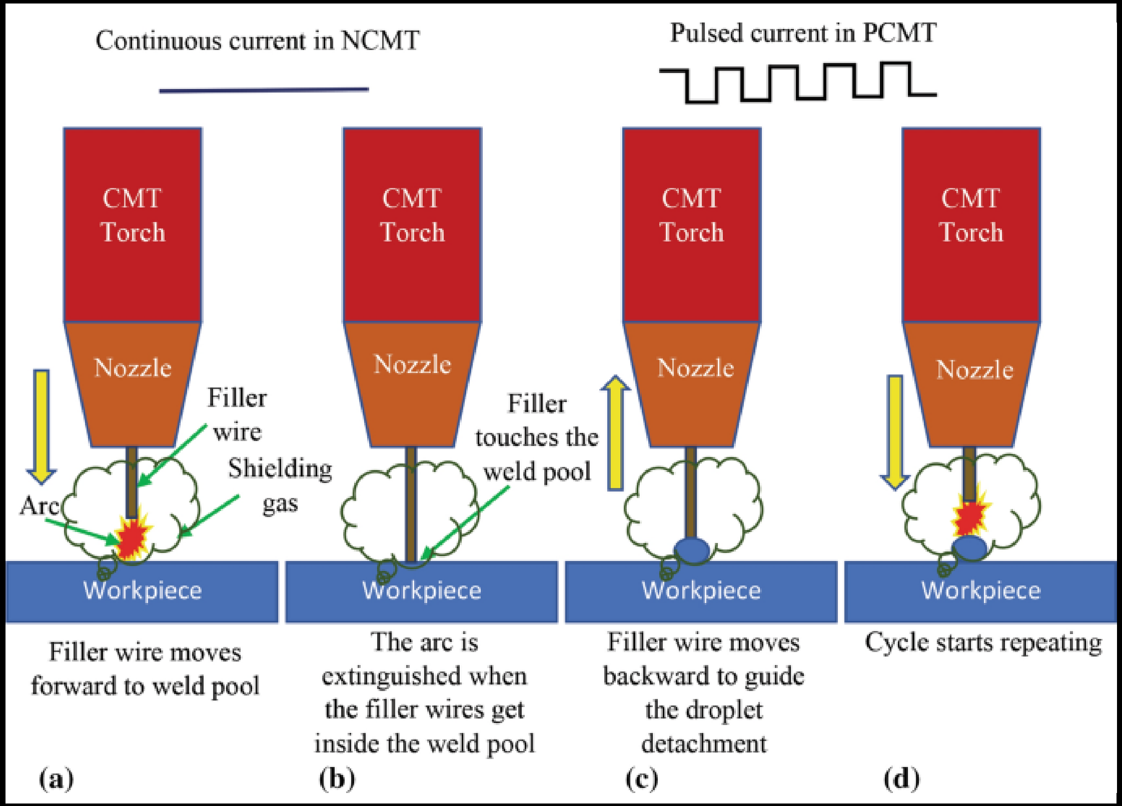
Commercial Fronius power supply on a Fanuc 6-axis robot

Materials

Various Aluminum alloys:
2319, 5183, 2050



Polymers

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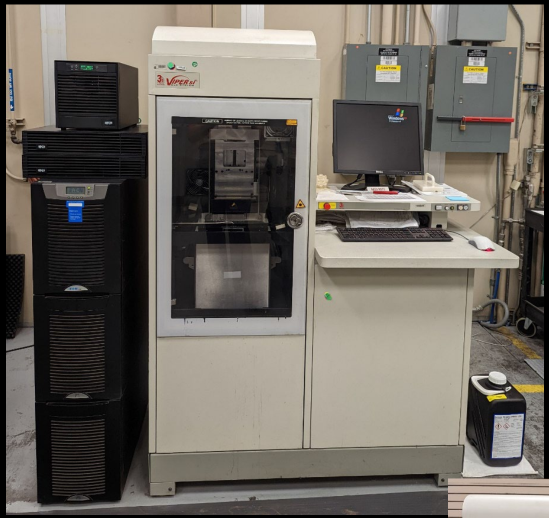
Stereolithography

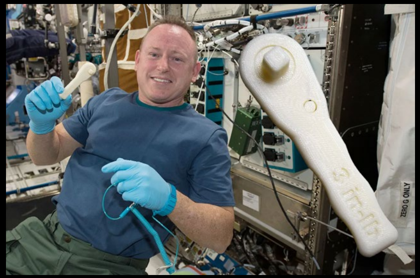


Viper SLA
DMX Somos
Build Volume: 10x10x10 in


5000 SLA
Somos Watershed 11122 XC
Build Volume: 20x20x20 in

Fused Deposition Modeling

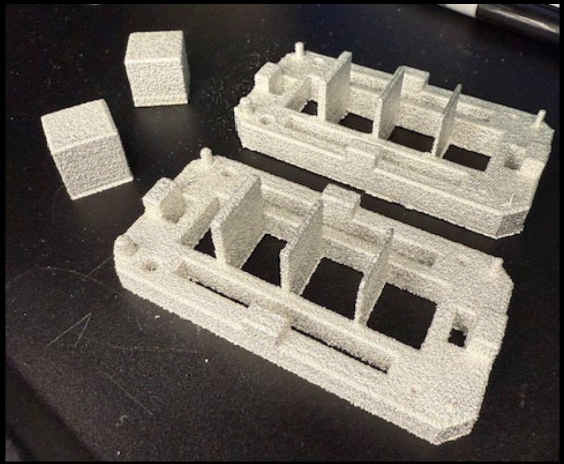
Stratasys Fortus 900
ABS, Polycarbonate, Ultem 9085,
Antero 840CN03
Build Volume: 914 x 609 x 914 mm



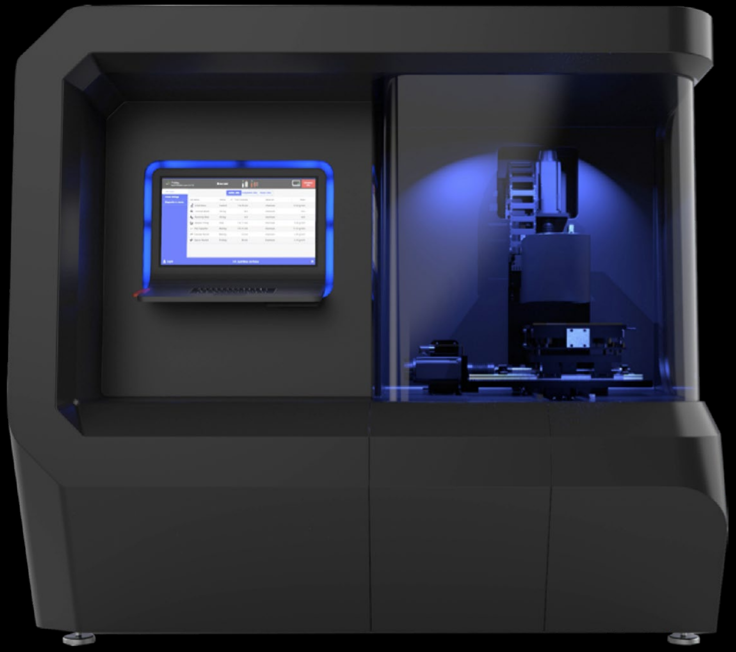
AON M2+
PEEK, PEKK, ESD Polycarbonate
Build Volume: 450 × 450 × 565 mm

Markforged Mark Two
Carbon Fiber, Glass Fiber, Kevlar
Build Volume:
320 x 132 x 154 mm

Liquid Metal Jetting Printing



Additec ElemX

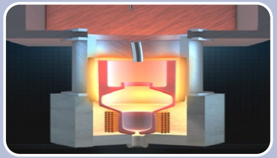


Build Volume
12in x 12in x 4.7 in
300mm x 300mm x 120mm

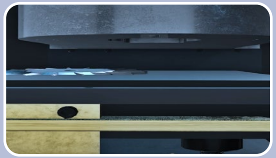
Maximum Build Rate
0.5 pounds/hour

Minimum Layer Thickness
0.24 mm

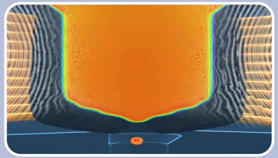
Feedstocks
1.6mm wire diameter



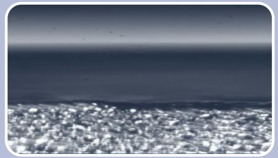
Wire feedstock fed into ceramic crucible and melted



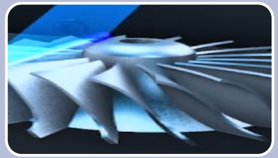
Build plate rapidly moved along toolpath for the layer



Metal droplets ejected by pulsed Lorentz force using external coil



Liquid metal coalesces one drop at a time on heated build plate

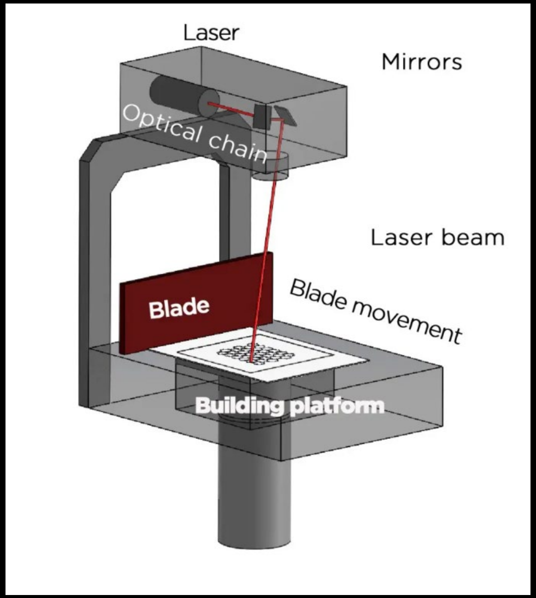


Layer is scanned once completed and process progresses to next layer

Simple water quench to remove from build plate

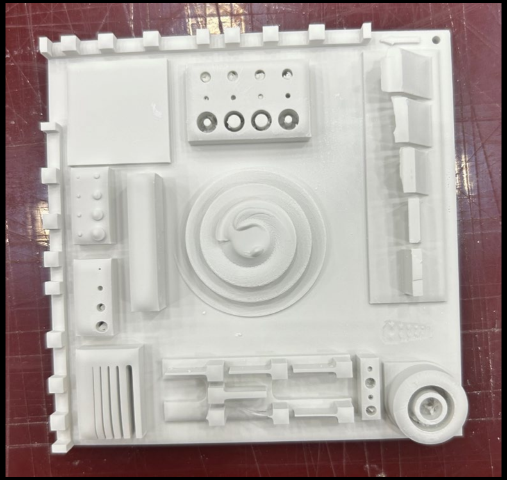
Ceramic Printing

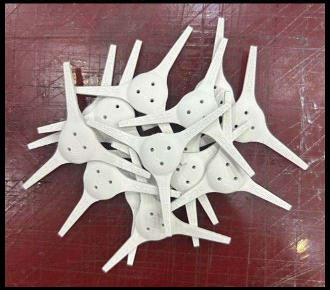
3DCeram C1000 Flexmatic

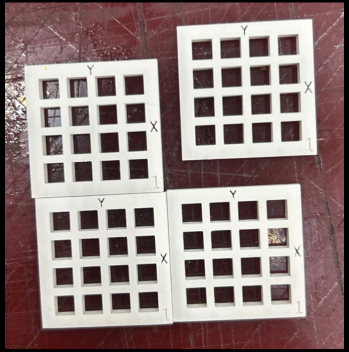


Build Volume
320mm x 320mm x 200mm

Layer Thickness
0.025 – 0.125 mm

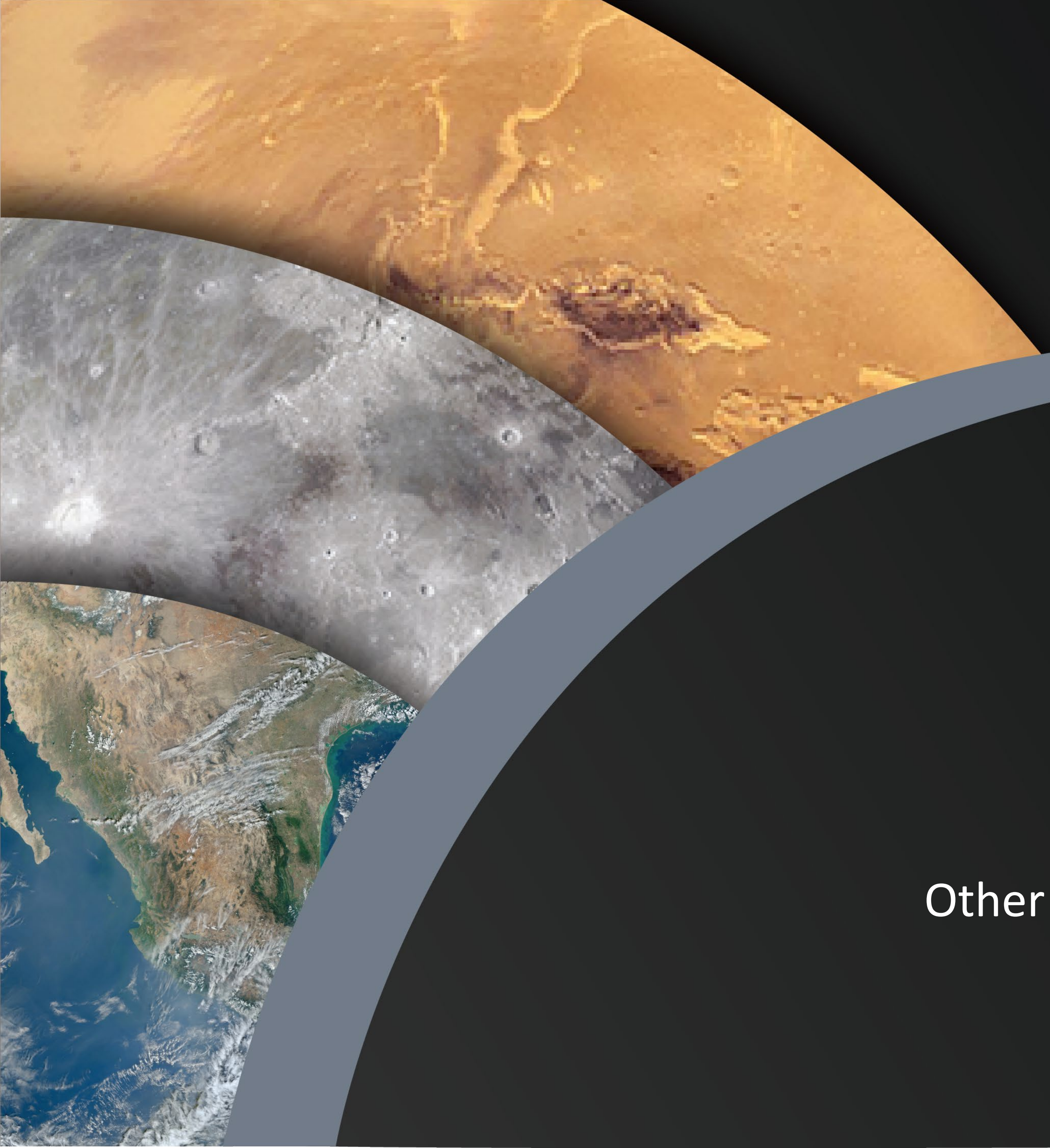






Material Catalog

- Alumina
- Silicore DS/DX
- Aluminum Nitride
- Silicon Nitride
- Silicore
- Alumina Toughened Zirconia
- Cordierite
- Zirconia 8Y
- Tricalcium Phosphate
- Fused Silica
- Zirconia 3Y
- Hydroxyapatite



It takes a village!

Other Capabilities Supporting Additive at Marshall

Powder Feedstock Characterization

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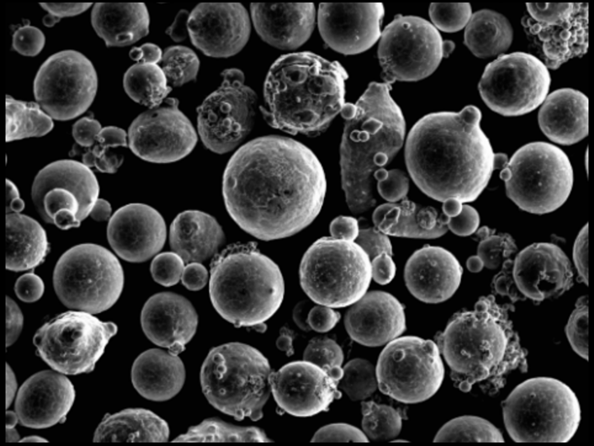
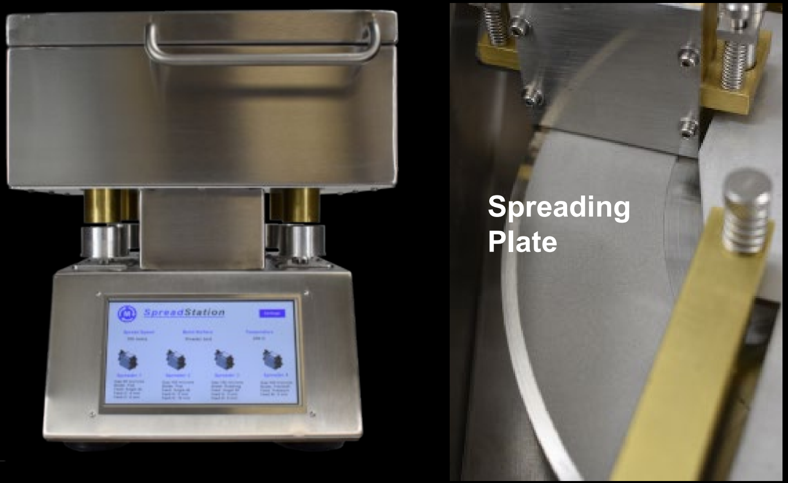
Capabilities:

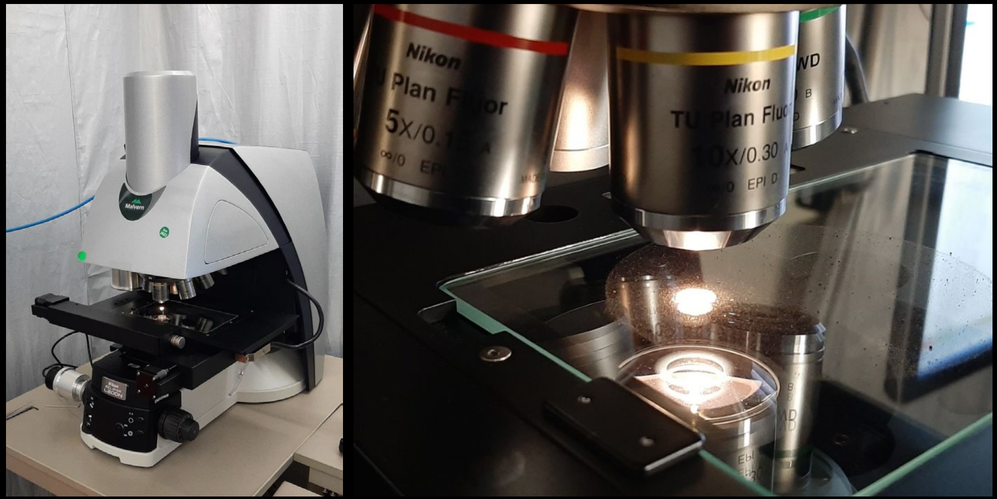
- Density
  - Density Cup
  - Carney & Hall Flow
  - Tap Density
  - Ro-Tap Sieve Shaker
- Flowability
  - GranuTools GranuFlow
  - GranuTools GranuHeap
- Spreadability
  - Mercury Scientific SpreadStation Powder Analyzer
- Particle Size Distribution (PSD) & Morphology
  - Light Scattering Analyzer
  - Malven Morphologi Optical Analyzer
- Thermal Conductivity
  - Linseis Laser Flash Analyzer



C103 Niobium characterized at MSFC



SpreadStation Powder Analyzer



Morphology Equipment

POC: Justin McElderry

Materials Diagnostics & Characterization

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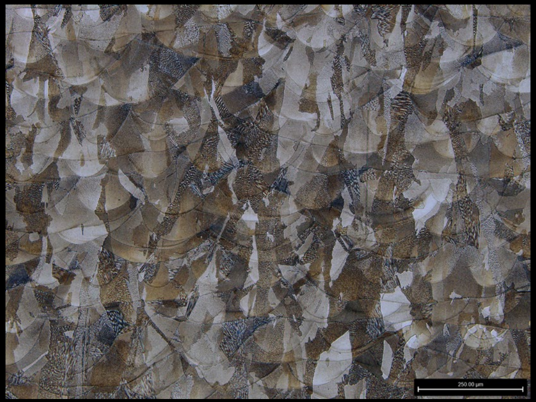
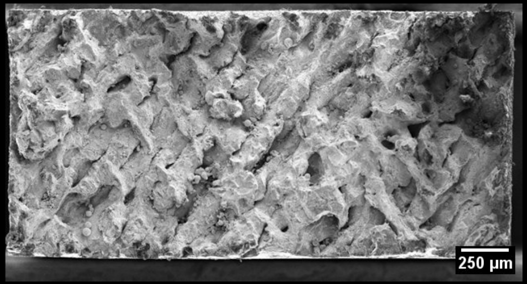
- Sample preparation
  - Sectioning, Mounting, Polishing, and Etching
- Microscopy Services
  - Optical microscopy, 3D stereomicroscopy, scanning electron microscopy, laser confocal microscopy
  - Analysis of all material types (metallic, ceramic, composite, geological, and biological)
  - High-resolution images of surfaces and internal microstructures can be captured at magnification up to 1,000,000X
  - Bulk Chemical and Crystallographic Analysis
  - Energy and Wavelength Dispersive x-ray Spectroscopy (EDS and WDS in SEM)
  - X-ray Diffraction (XRD)
  - Electron Backscatter Diffraction (EBSD in SEM)
- Surface Analysis Services
  - Electron Spectroscopy for Chemical Analysis (ESCA)
- Metallic Materials Analysis
- RoboMet Automated Serial Sectioning
  - Automated serial polishing and microscopy for 3D evaluation of materials

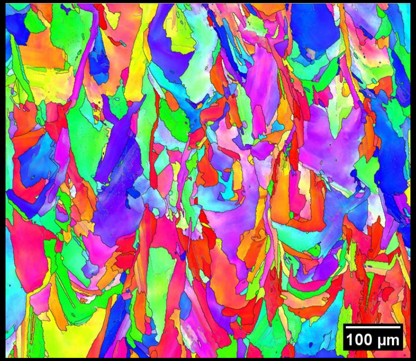
Optical Microscopy for Microstructural Analysis



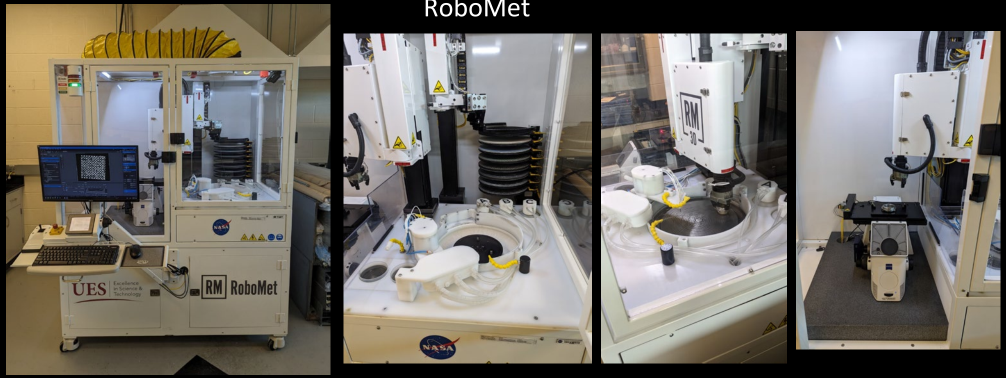
Fractographic Analysis with Optical or Electron Microscopy



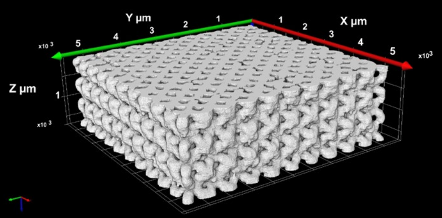
EBSD of AM Materials for Crystallographic Analysis



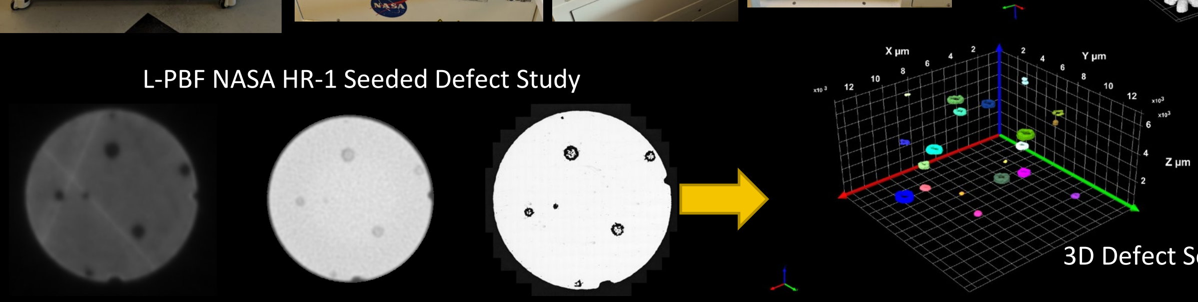
RoboMet



W Lattice Reconstruction



L-PBF NASA HR-1 Seeded Defect Study



In-Situ Monitoring

CT Slice

RoboMet Slice

3D Defect Segmentation

POC: Colton Katsarelis

New AM Alloy Development

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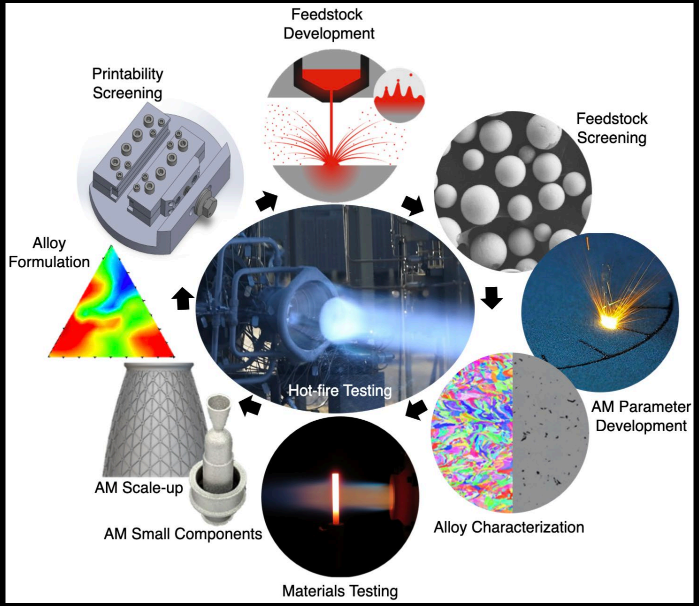
- Small scale alloy development lab has been targeted at AM, particularly for refractory alloy development due to feedstock costs
- Lab designed for rapid alloy development and evaluation to reduce development cycle and cost to go from initial formulation to upscaling
  - Alloys developed can be shifted to upscale in EM42 lab or commercial partner
- Capabilities:
  - ThermoCalc software for model-based approach
  - Arc melter furnace for initial ingot forming
  - High temperature furnaces both air and vacuum with capability to 2200°C
  - AMAZEMET Ultrasonic Atomizer for powder atomization with high temperature module for refractory alloys
  - EOS M100 L-PBF system for small volume AM parameter development
    - Reduced volume build plate and hopper to lower powder needs for parameter dev to <500g
  - XACT Metal XM200G L-PBF system being installed for newer and slightly larger build volume than EOS M100
    - Open parameters

Arc Melter

Ultrasonic Atomizer



Rapid Alloy Development Cycle

Small Format LPBF Machines

POC: Colton Katsarelis

Mechanical Testing

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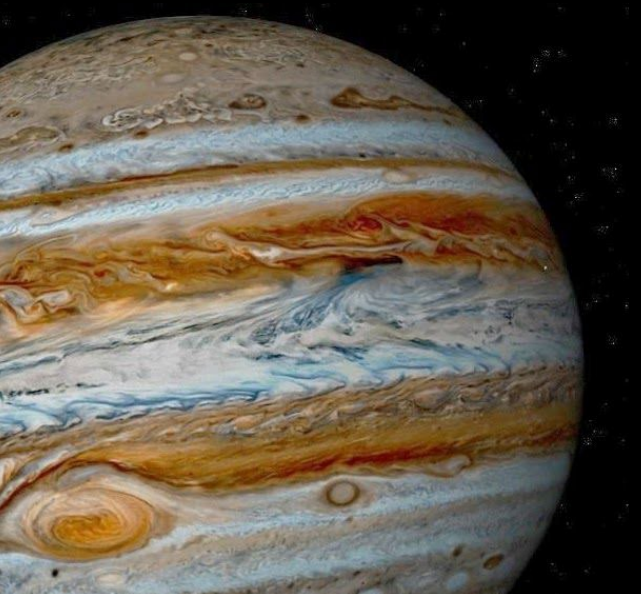
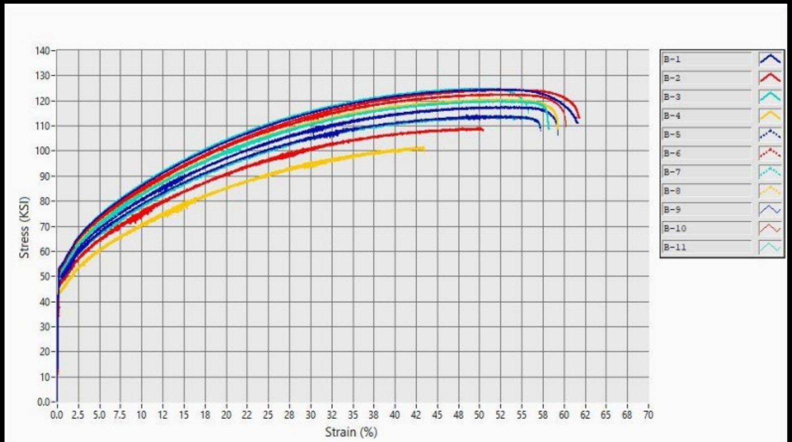
- Tension Testing
- Elevated Temperatures
- Cryogenic Testing
- Non-standard specimens
- Various data acquisition methods
- Fatigue Mechanics Testing
- Fracture Toughness
- Compression
- Modulus
- Simulated service





Stress-Strain Curve, In625 Thin Wall Study


Tension Test in Liquid Hydrogen

POC: Eric King

3D Scanning

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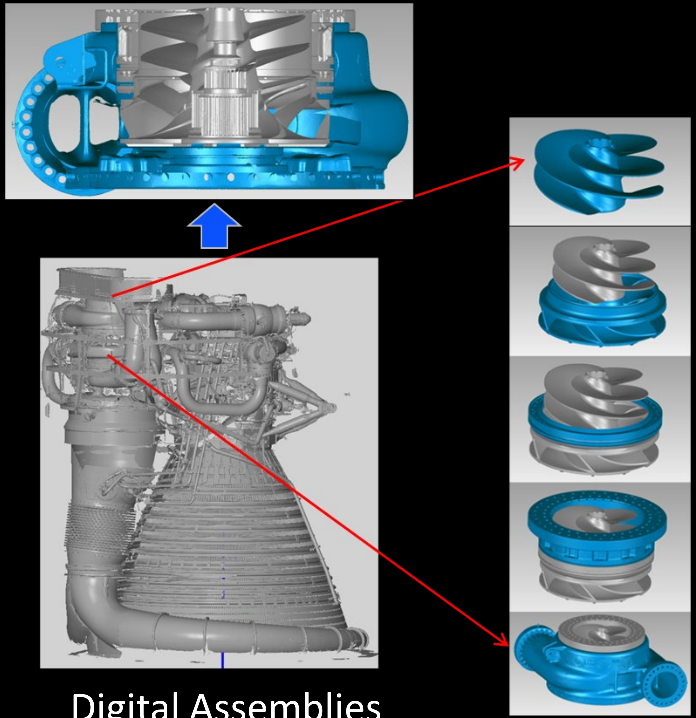
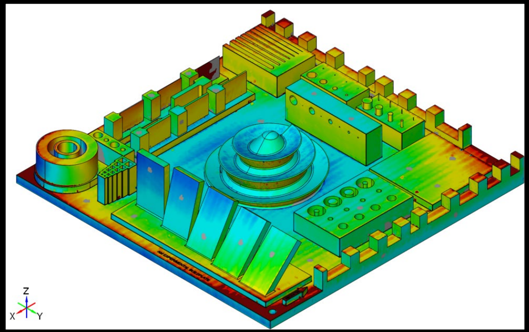
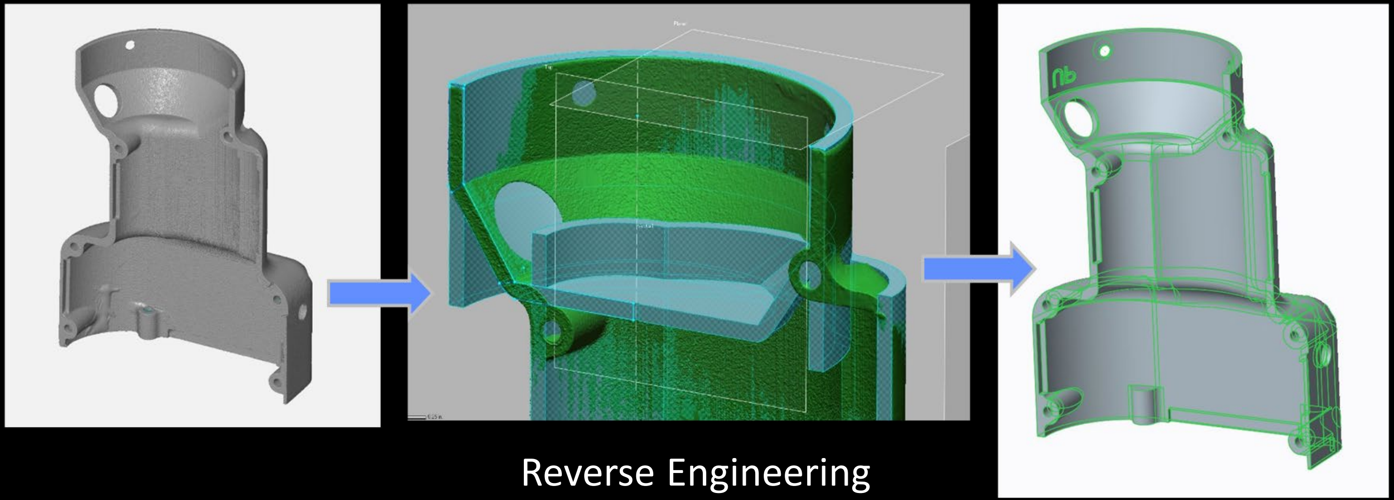


Digital Assemblies

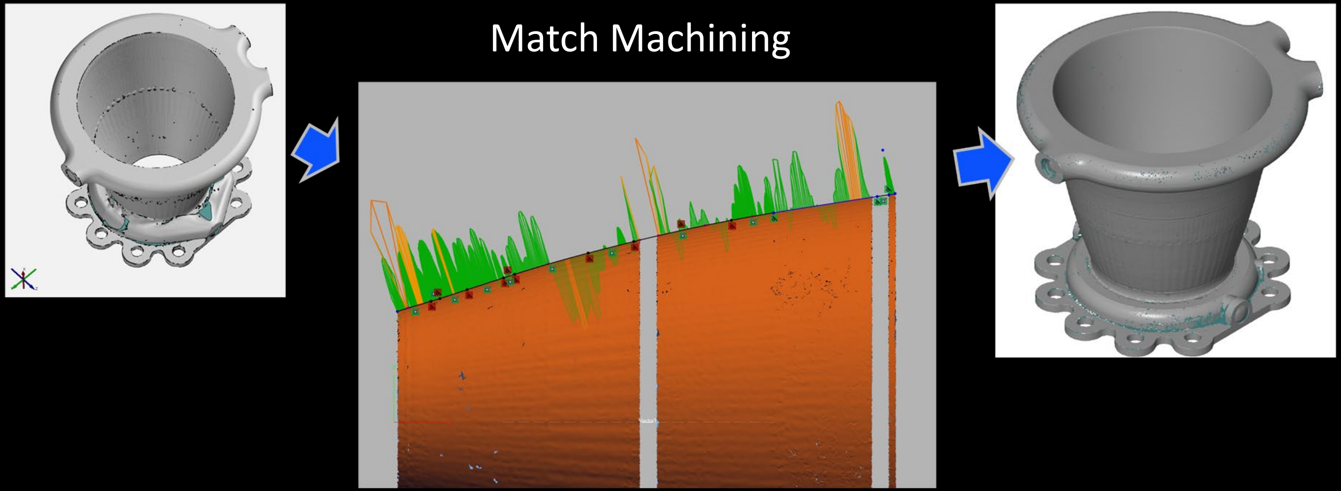


Part Inspection



Reverse Engineering

Match Machining

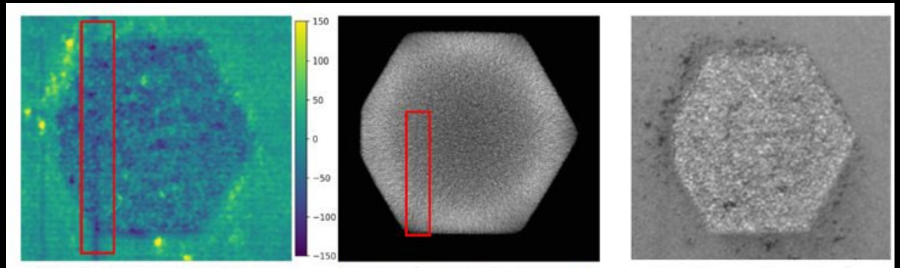


POC: John Ivester

Non-Destructive Evaluation

- Ultrasonic Testing
- Dye Penetrant Inspection
- Magnetic Particle Testing
- Eddy Current Inspection
- Radiography
- Infrared Flash Thermography
- Shearography
- Acoustic Emission

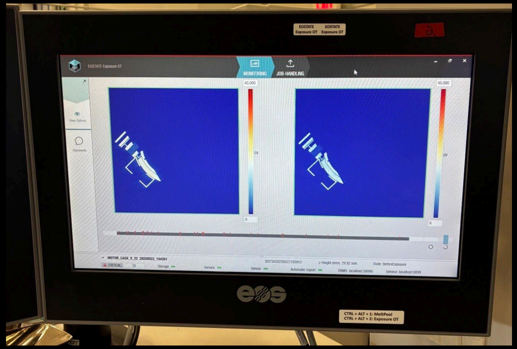
- **Computed Tomography**
- **In-situ Process Monitoring**
  - **Phase3D**
  - **EOS OT & Melt Pool Monitoring**
  - **Concept Laser QM Meltpool**



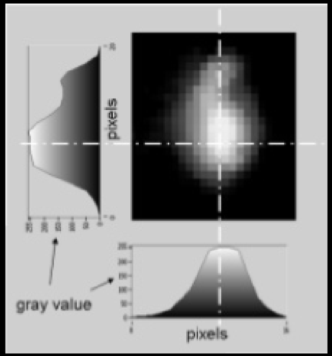
Powder height anomaly detected in Phase3D height map

Resulting structured porosity visible in computed tomography inspection

Visual image of layer showing anomalies are not visible



EOS Optical Tomography & Melt Pool Monitoring



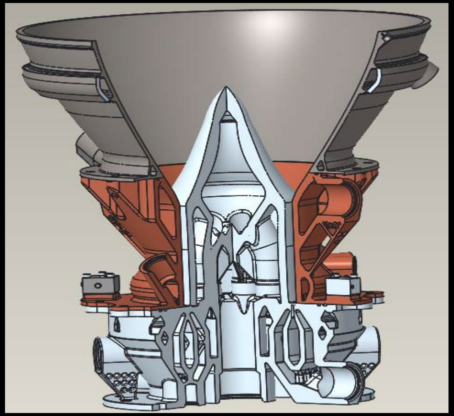
Concept Laser QM Meltpool

POC: Matt McDougal

Integrated Rotating Detonation Engine System (InRoDES)

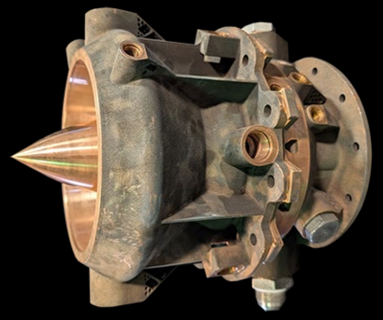
National Aeronautics and Space Administration

- Advancing revolutionary rocket propulsion technology that uses detonative combustion to achieve over 110% of ideal engine performance while being 50-70% shorter than conventional engines
- Design, build, and hot-fire test a complete 10,000 lbf pump-fed system using liquid oxygen and methane to reach TRL 5 leveraging additive manufacturing
- Enables more compact, higher-performance propulsion for NASA's lunar and Mars missions and is already baselined by NASA's Mars Architecture Team for future missions
- InRoDES will provide comprehensive technical documentation to reduce industry risks and accelerate commercial adoption of this game-changing propulsion technology.



Preliminary Design

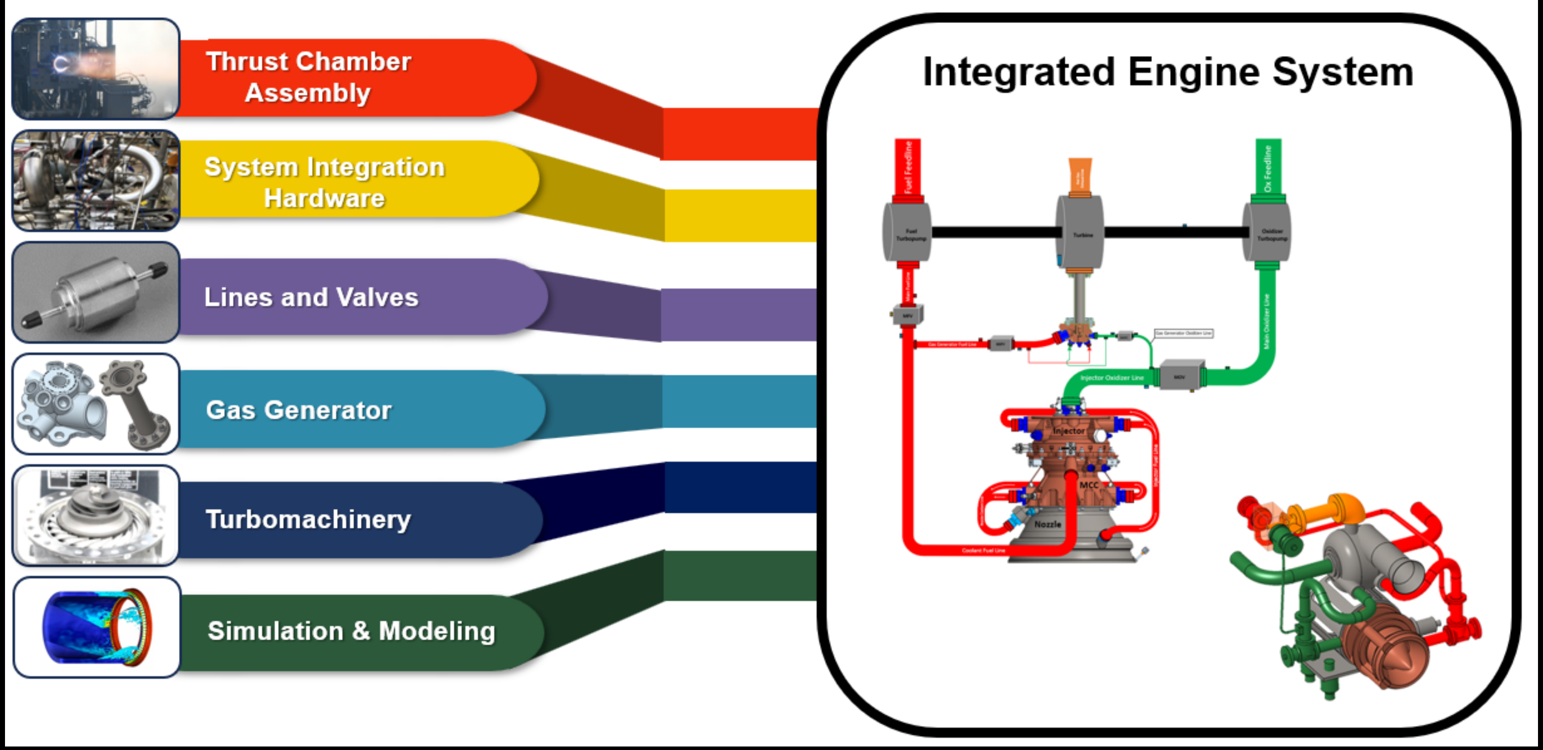
- Nozzle
  - *LPBF, GRX810*
  - *DED, Haynes 230*
- Outer Body
  - *LPBF, GRCop-42*
- Inner Body
  - *LPBF, GRCop-42*



Completed Thrust Chamber Hardware

Turbopump Housing

Gas Generator Testing at Auburn University



POCs: Thomas Teasley, Chris Hill


NASA
We are going.

Questions?

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Team Redstone AM IPT

- In May 2014, leaders from the Army and NASA Marshall established an Additive Manufacturing Integrated Product Team, the *Team Redstone AM IPT*
- The agreement was extended in August 2018, and though some faces have changed, we're still collaborating today—over 11 years later.
- Team Redstone AM IPT - Key Milestones
  - 2014 - Establish & Plan
  - 2015 – AvMC & MSFC – Share about their AM Initiatives
  - 2016 – Expand AM IPT across Team Redstone
  - 2017-2019 – Engage Universities & Non-Profits doing AM Research
  - 2020-2025 – New AM Advances in Government, Industry, & Academia

"One of the team's goals is to identify additive manufacturing research and development needs of greatest importance to the defense and space community."

– Dr. Phil Farrington

Team Redstone AM IPT Panel

National Aeronautics and
Space Administration

Dr. Phillip A. Farrington, Moderator
Advanced Manufacturing SME, TriVector Services

Professor Emeritus of Industrial & Systems Engineering, UAH

Mallory James
Partnerships & Opportunities Development Office, MSFC

Brady Kimbrel
Additive Manufacturing Team Lead, MSFC

Dr. Jeffrey Gaddes
Advanced Manufacturing SME, DEVCOM AvMC

Lance Hall
Additive Manufacturing Technical Lead, DEVCOM AvMC