National Aeronautics and Space Administration
Marshall Space Flight Center

Transforming Manufacturing

Transitioning from Rapid Prototyping to Hybrid Manufacturing

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From Rapid Prototyping to Hybrid Manufacturing

On-Earth Manufacturing for Space Flight

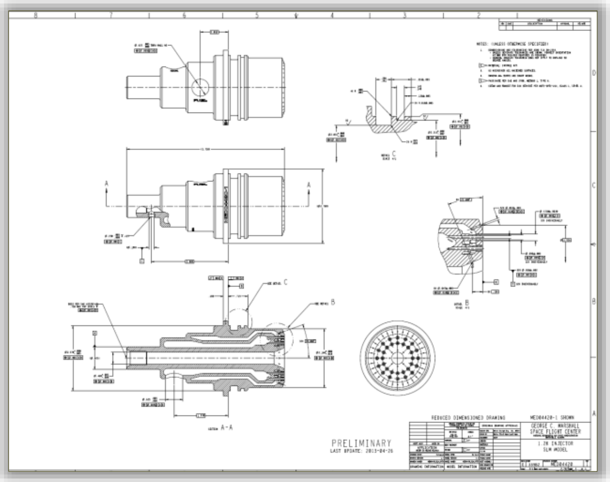
- Rapid Production
- Low Cost
- Reduced Weight
- Small Production Volume
- Singular Tooling
- Materially Efficient

The NASA Investment in Additive Manufacturing

Where the NASA On-Earth Effort Stands:

- 10M USD Investment made over 3 years
- Lab space and capacity has tripled.
- Four Metal Machines
  - ARCAM EBM
  - ConceptLaser M1, M2, and Xline 1000R
- Polymer capabilities includes FDM and Stereolithography.
- Further expansion and investment planned in the near future.

Case Study: 64 Element Injector Selection



- Small LOX-GH_2 Injector based on extensively used heritage design.
  - Simple Coaxial Injector and Chamber
  - Pre-Existing GR-Copper-84 Throat
- Intricate internal fuel passages design would demonstrate AM usability in flow components.

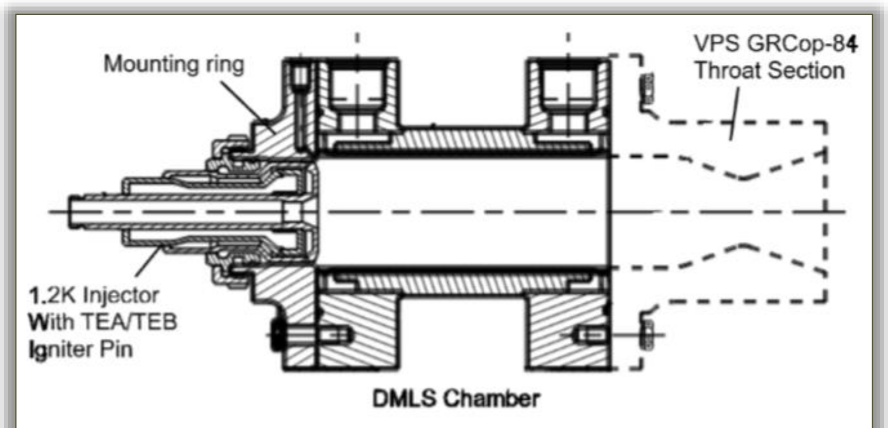
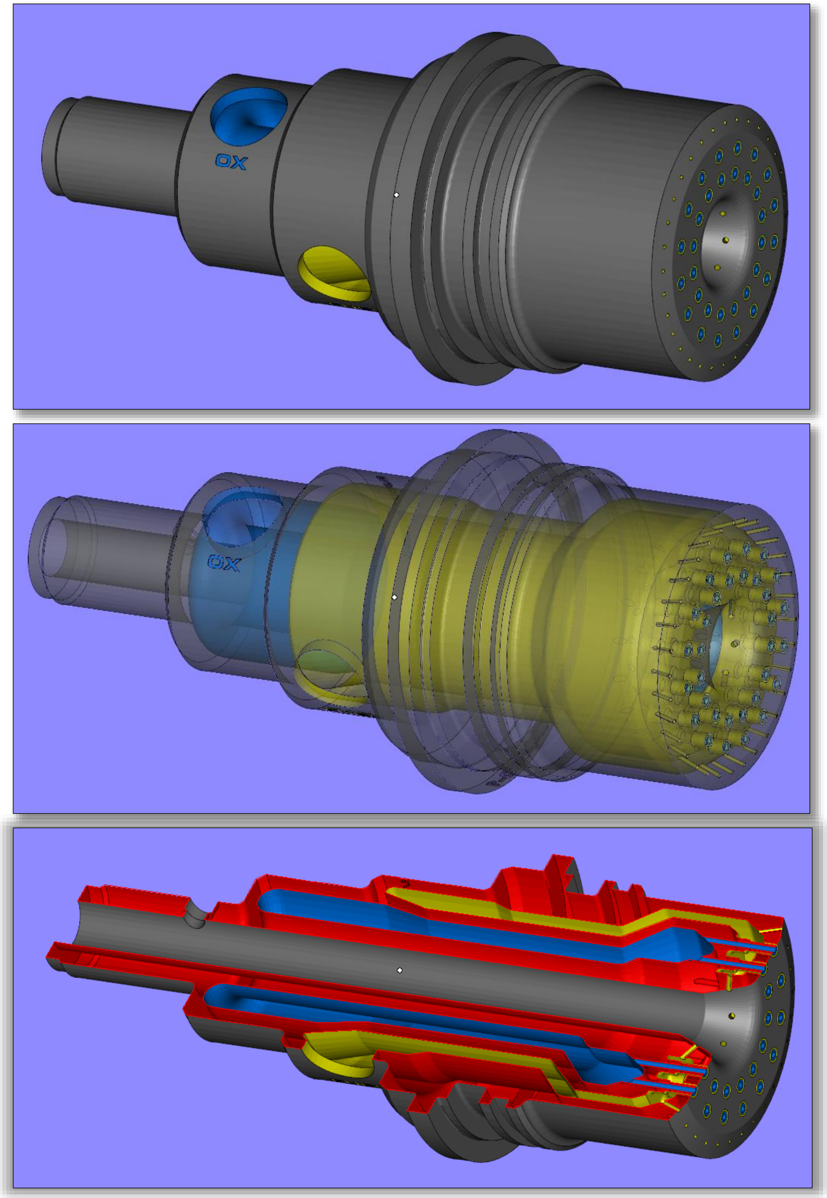


Figure 2-1. Test Assembly for DMLS Chamber

- Successful additive manufacturing would eliminate multiple welds and significant assembly time.
- Small size of parts would allow for rapid additive manufacturing of multiple components.

Case Study: 64 Element Injector Production



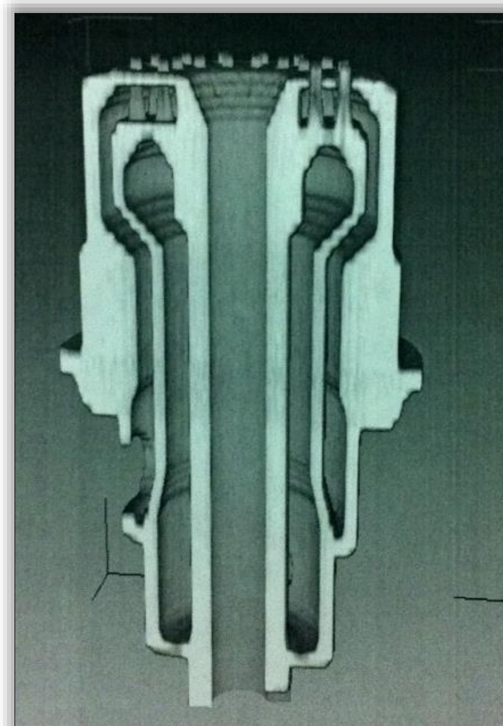
Injector and internal passages running the full 150mm length.

- 64 Element Injector measuring 70mm x 150mm.
- Nickel-Chromium Alloy 718
- Manufactured on MSFC ConceptLaser M2 System
- Initial build was one test unit
- Second build was three units built side-by-side.
- Build plate removed with Wire Electrical Discharge
- Heat Treated according to AMS 5664
- Surface finish and seal groove machined in accordance to drawings.
- Non-destructively evaluated using internal CT scanning capabilities.

Case Study: AM 64 Element Injector Production

Injector support lattice still in place

Support Lattice Removed



In-House CT Scans

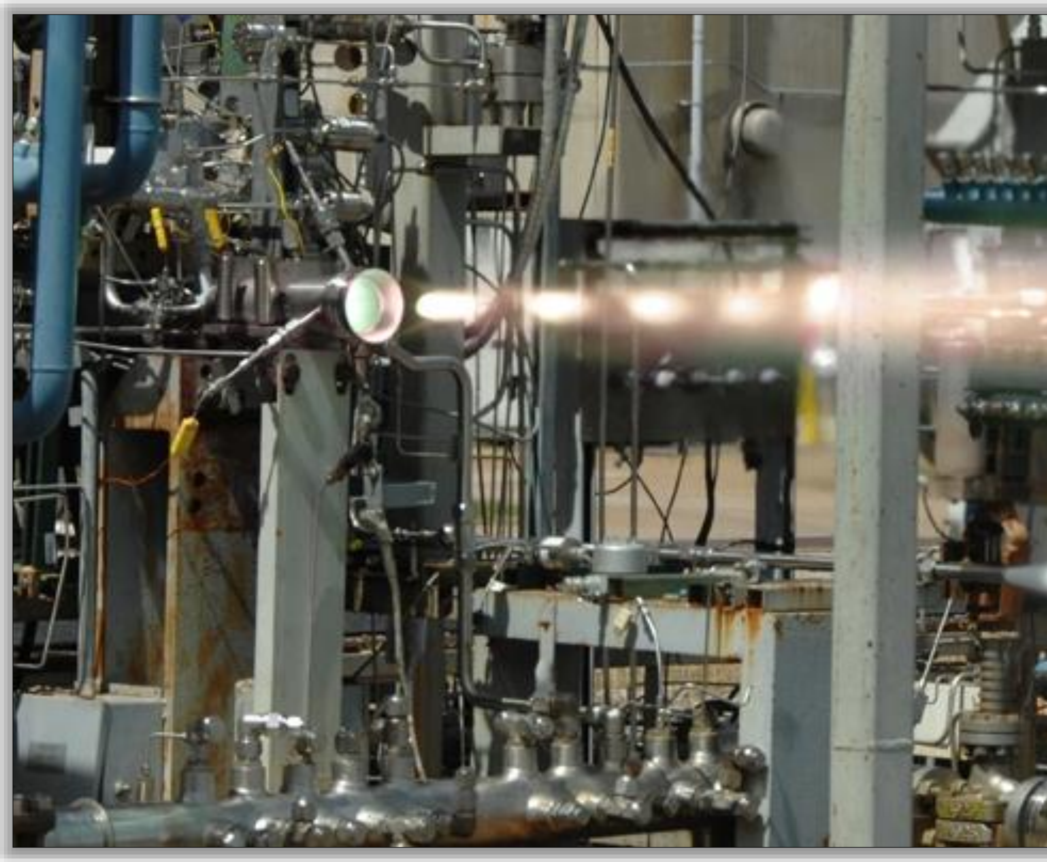
Post Heat Treatment and Surface Machined

Face plate coated with zirconia
Attachment ring and fuel fittings welded on

Face plate as seen in test stand

Case Study: AM 64 Element Injector Lessons

- All manufactured injectors were successfully and satisfactorily tested in the MSFC test area.
- Additive Manufacturing of injector ultimately resulted in:
  - Elimination of 5 welds
  - Elimination of 32 braze joints
  - Reduction of 38 parts to 1
- **12** week production reduced to **5** weeks.
- **$11,500.00** cost reduced to **$4,500.00**

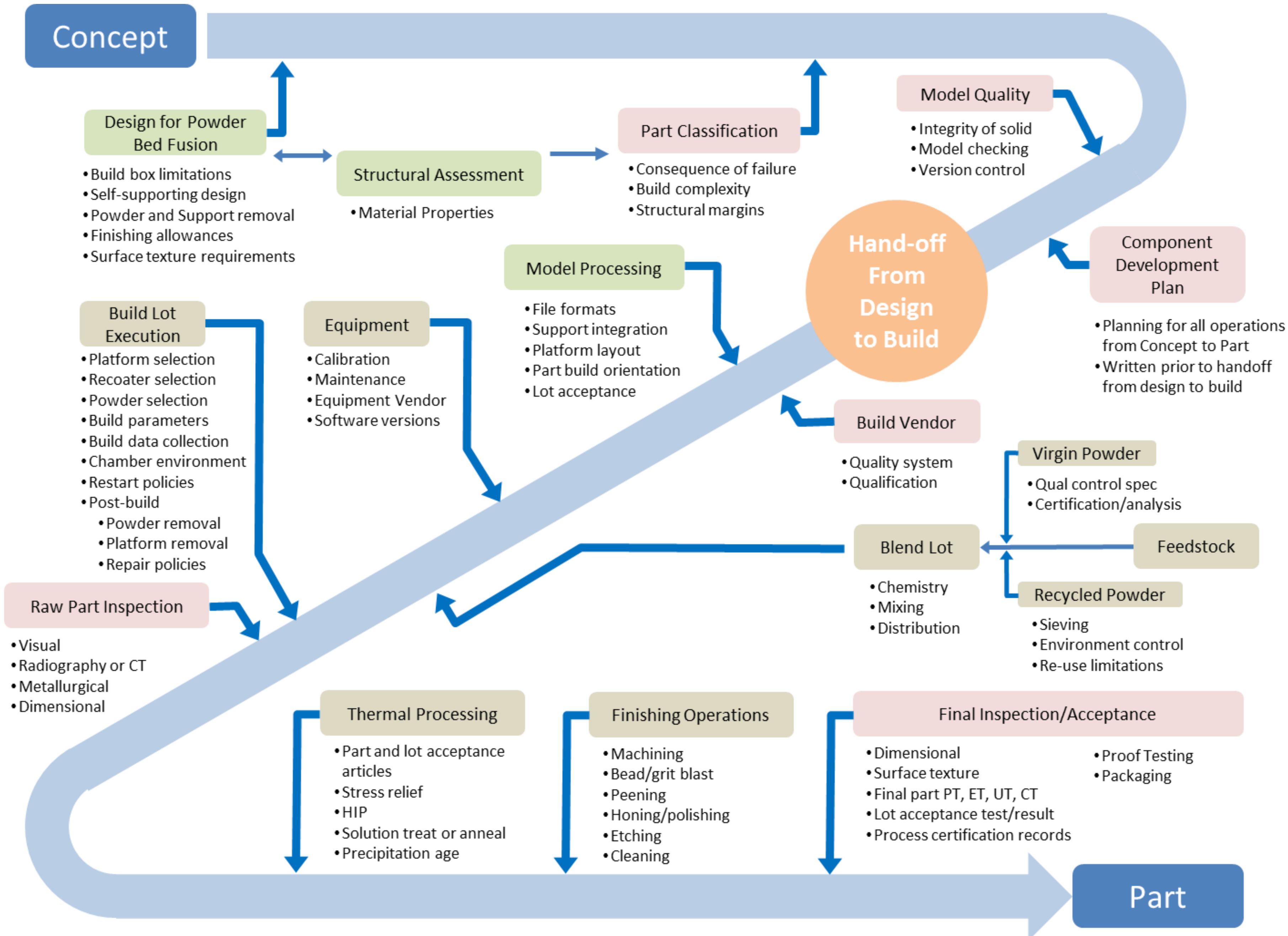


First successful hot-fire of AM 64-Element Injector at Marshall Space Flight Center Test Area

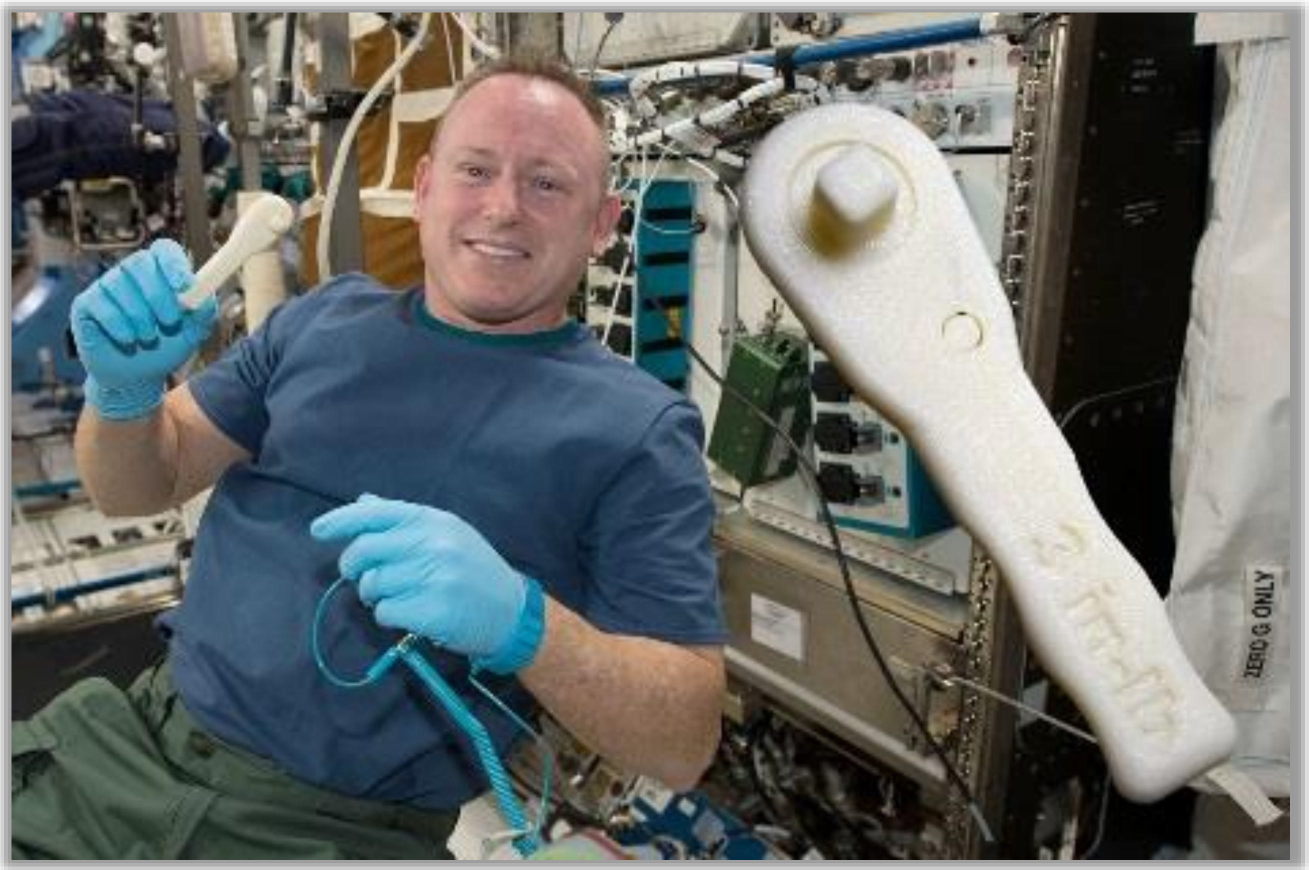
The Path Forward: Rising to Greater Demand

- Certification of additive manufacturing processes for human-rated space flight vehicles
- Further reduction of required post processing by process optimization
- Further leveraging the advantages offered by AM by changing our design principles and cycles
- Establish additive manufacturing process of additional propulsion critical alloys
- Production of larger components and full assemblies

The Path Forward: Rising to Greater Demand



In-Space Manufacturing



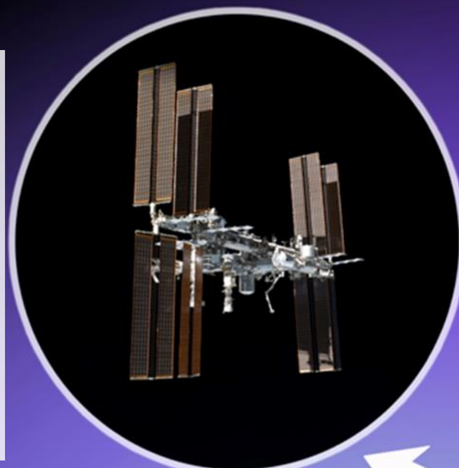
- On demand access to replacement parts and tools
- Streamlined orbital supply chain
- Critical technology for exploration missions

In-Space Manufacturing Overview

***International Space Station(ISS) Technology Demonstrations are Key to 'Bridging' necessary Technology Development to Full Implementation of the Required In-space Manufacturing Capabilities* for Exploration Missions.**

ISS Platform

- 3D Print Tech Demo
- Qualification/Inspection of On-orbit Parts using Optical Scanner
- Additive Mfctr. Facility (AMF)
- In-space Plastic Feedstock Recycling
- Utilization Catalogue



Planetary Surfaces Platform

In-situ Feedstock Test Beds and Reduced Gravity Flights Which Directly Support Technology Advancements for Asteroid Manufacturing as well as Future Deep Space Missions.

- Additive Construction
- Regolith Materials Development & Test
- Synthetic Biology: Engineer and Characterize Bio-Feedstock Materials & Processes

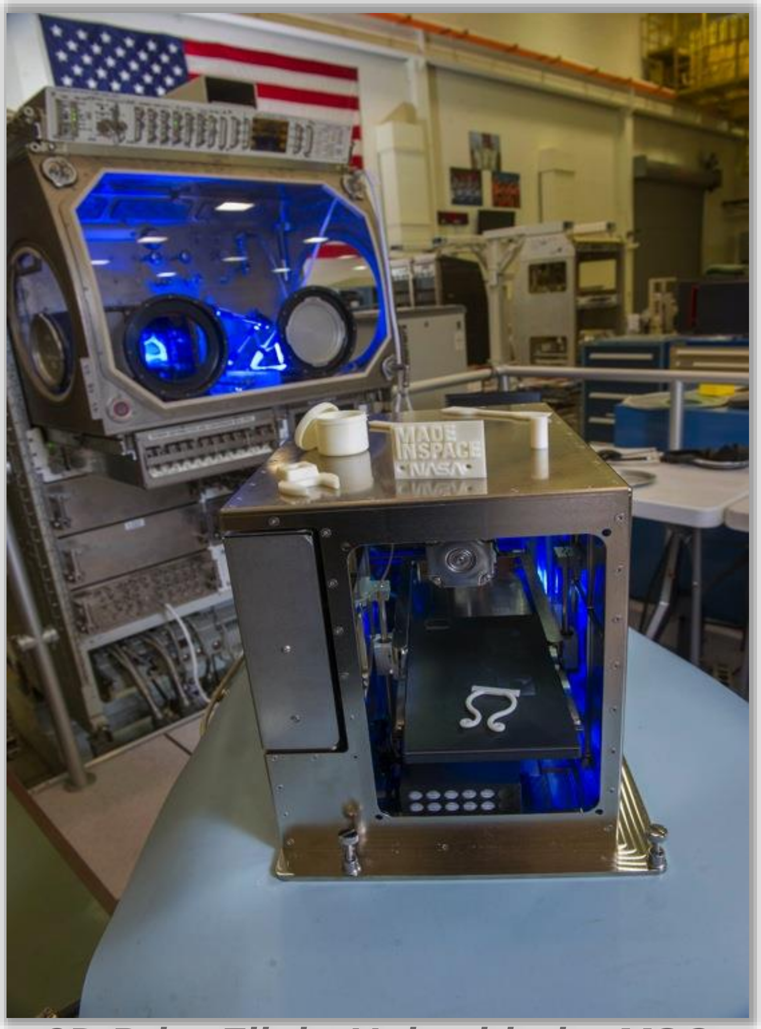
Earth-based Platform

- Certification & Inspection of Parts Produced In-space
- In-space Characterization Database
- Printable Electronics & Spacecraft
- External In-space Manufacturing (not currently funded)

Earth-based Platform (cont.)

- In-space Metals Manufacturing Process Study (not currently funded)
- Additive Repair Ground Testing
- Self-Replicating/Repairing Machines
- In-situ Feedstock Development & Test: See Asteroid Platform

3D Print Technology Demonstration



3D Print Flight Unit with the MSG Engineering Unit in the background

- First manufacturing capability on ISS
- Phase 1: Proof of concept experiment
- 21 parts made on the ground with the flight unit and flight feedstock
- Same 21 parts made on orbit
- Comparisons will be made between flight and ground samples
  - Identify any discrepancies
  - Porosity
  - Layer adhesion
  - Mechanical properties
- Phase 2 will incorporate practical application

Cube Sat Clip

Tensile Coupon

Range Coupon

Path Forward: Near Term ISS Technology Demonstrations

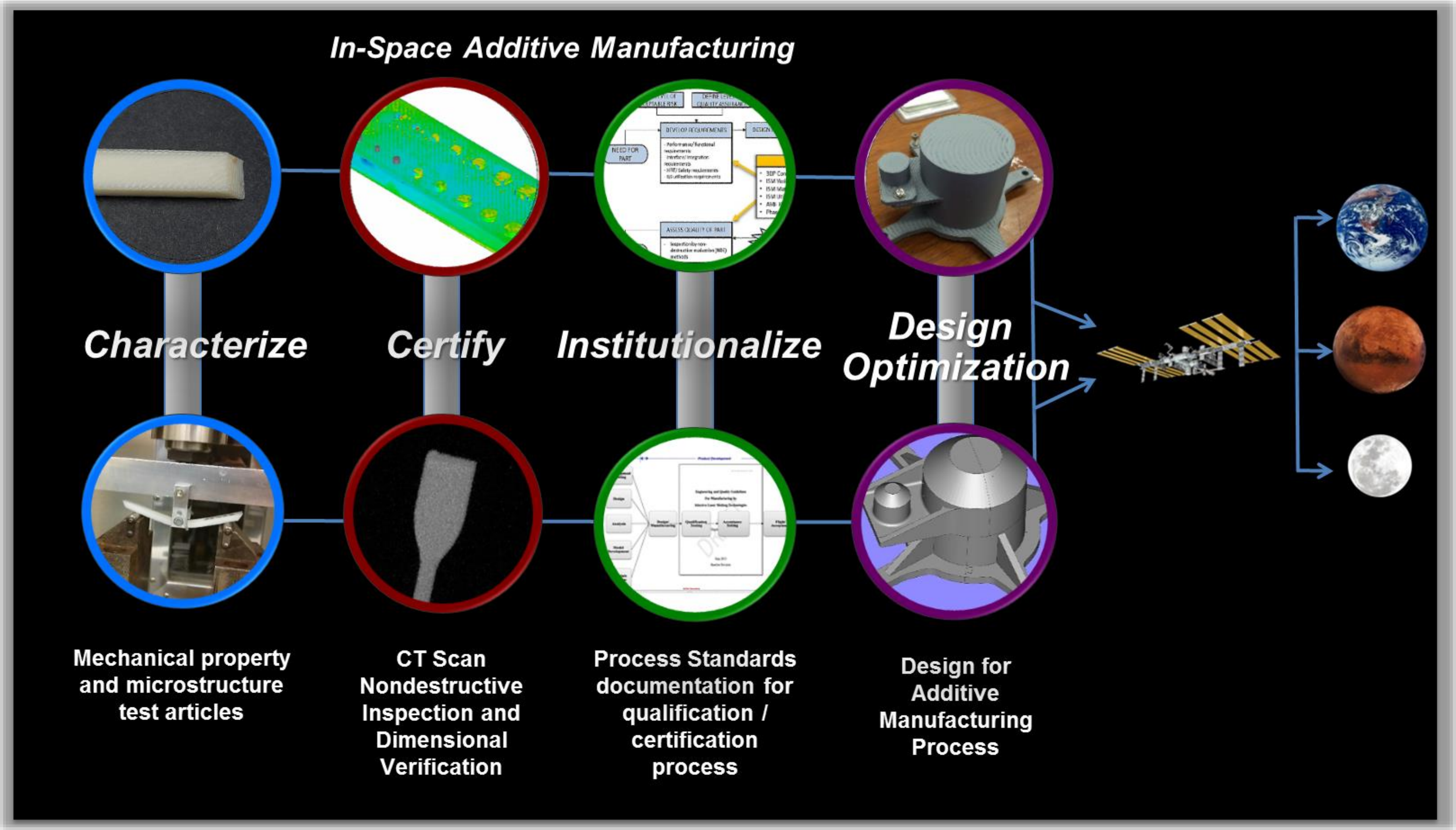
Recycler
- Recycling / Reclaiming 3D Printed Parts and / or packing materials into feedstock filament
- Crucial capability to sustainability in-space
- Reduce up-mass of feedstock resupply and down-mass of packaging waste

Additive Manufacturing Facility
- Next generation 3D Printer developed by Made In Space
- Commercial 3D Printer on ISS for both external and NASA customers
- New material capabilities (for more usable, robust parts)

Image: NASA

External Structures & Repairs
- Perform repairs on tools, components, and structures in space
- Structured light scanning to create digital model of damage
- Repair with AM technologies such as 3D Print and metallic manufacturing technologies (e.g. E-beam welding, ultrasonic welding, EBF3) to perform the repair.

Utilization Catalogue



- Provides astronauts with a library of pre-approved part files to build as needed
- Begin by re-designing crew tools and non-critical replacement parts
- Influence ISS and Exploration systems designs to incorporate AM design philosophy
- Ongoing effort will include replacement parts for critical systems

NASA