Space-Based, On-Demand Fabrication of Metallic Parts Using Additive Manufacturing

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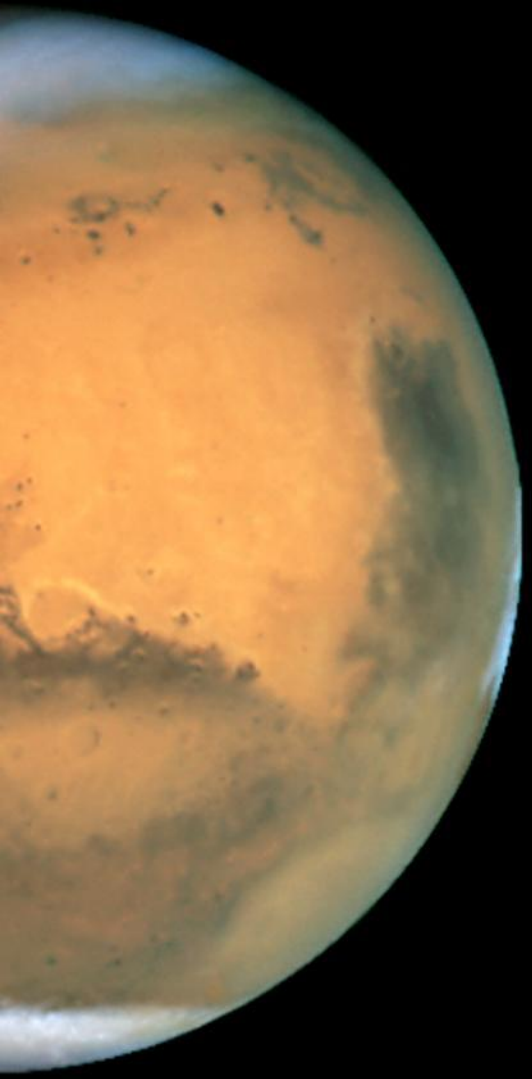
Supportability of Long-Term Human Exploration Missions



- On-demand fabrication of metallic parts using additive manufacturing
  - Fabricate replacement parts, new tools or repair damaged components
  - Long term: recycle broken parts to provide feedstock to fabricate replacement parts
- ISS is an ideal testbed for technology demonstration for future exploration missions
- Supportability concept is enabling for longer missions to distant destinations
  - Lengthy travel times with existing launch and propulsion systems makes re-supply from Earth an impossibility

Technology Development for Supportability Concepts

- ISS as a technology testbed:
  - Relevant environment (0-g)
  - Human (astronaut) involvement possible for testing technologies
  - Control from Earth without appreciable time lags
- Current (ground-based) efforts are developing framework and demonstrating key components
  - Design, build, finish, inspect, certification of parts, communications protocols
  - Current activities all on Earth to reduce risk and develop technologies for use in space
- Effort includes researchers at four NASA centers: GRC, JSC, LaRC, MSFC

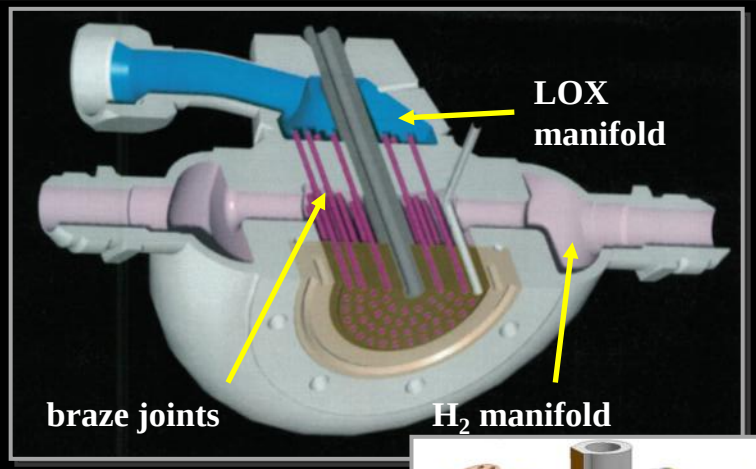
Design of Additive Manufactured Metallic Part

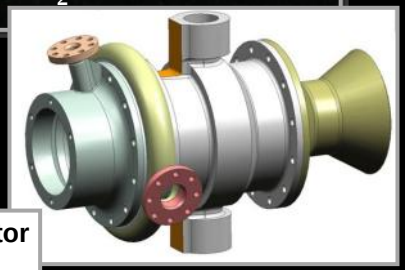
Basics:

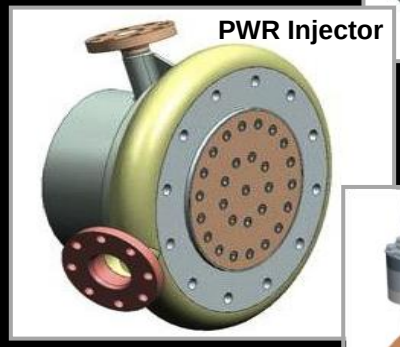
- U.S. liquid rocket engine manufacturers are experimenting with additive manufacturing techniques for next generation rocket engine components
- Focus on GH_2/LOX injectors representative of in-space engine
- Intricate metal parts are being produced by sintering layers of powder using an electron beam or laser
- Demo sub-scale additively manufacture rocket engine injectors under hot-fire conditions

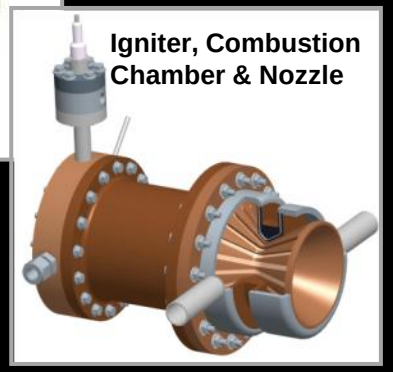
Benefits:

- Reduce injector manufacture time from months to weeks
- Potential to reduce full scale injector cost by nearly an order of magnitude (~90% reduction)
- Successful hot-fire experiments will infuse additive manufacturing tech into US rocket engine industrial base
- Demo capability to build in-space rocket engine injector









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Candidate Metal Additive Process: Electron Beam Freeform Fabrication (EBF^3)

Basics:

- Layer-additive process to build parts using CNC techniques
- Electron beam melts pool on substrate, metal wire added to build up part
- Successfully demonstrated in 0-g during parabolic flight tests
- Demonstrating design and build of candidate replacement part for finishing and testing in ground-system testbed
- Developing S-basis allowables and modeling to predict properties for certification

Benefits:

- High energy efficiency and feedstock usage efficiency compatible with space-based operations
- Electron beam can be modulated to perform multiple operations (welding, deposition, heating, surface modification, machining, etc.)
- Wire feedstock safely handled in reduced gravity
- Can process wide variety of metallic materials

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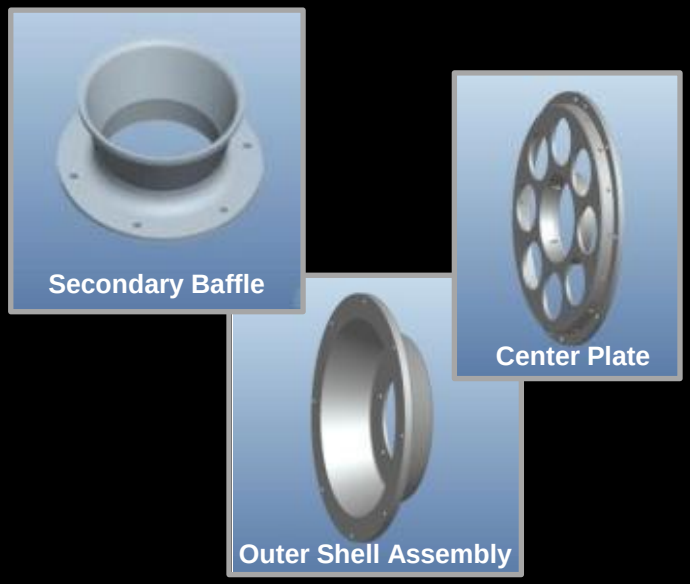
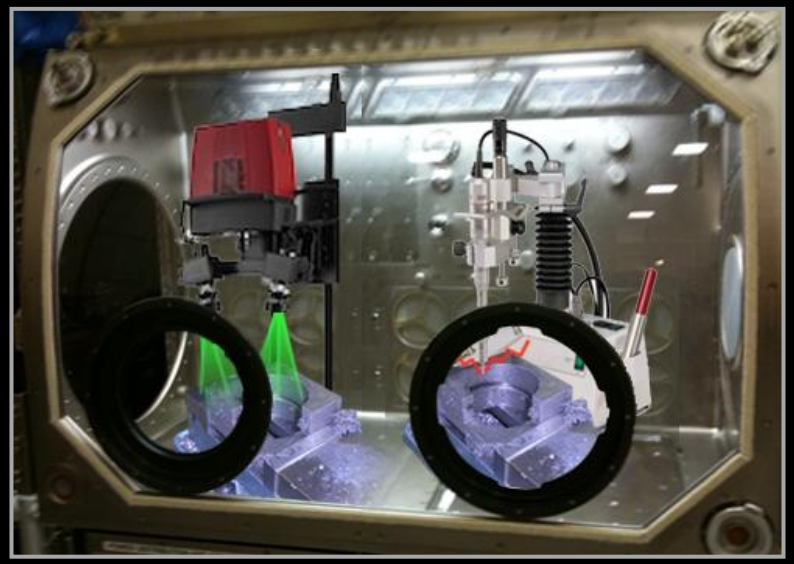
Inspection and Finishing of Near-Net Shape Metallic Components



Basics:

- Ground-based concept of operations demonstrating components can be designed, fabricated, finished and inspected
- Selected Ti-6-4 assembly from Environmental Control and Life Support System (ECLSS) on ISS

- Finishing and inspection system concept includes:
  - Miniature milling machine, studying chip containment, vibration and noise issues for compatibility with ISS environment
  - 3D white light scanner for surface inspection
  - Proposed operation in Microgravity Sciences Glovebox on ISS



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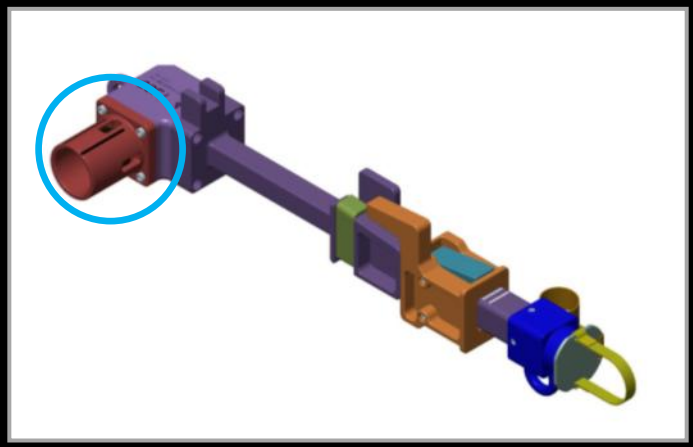
Certification of Additively Manufactured Parts

- Demonstrate flight certification process for additive manufactured metal part
- EVA tool used during STS-135
- Design load of 45 lbs.
- Qualification unit tested to failure at 440 lbs.
- Certification not pursued due to flight schedule
- Additional EBF^3 components now being evaluated for potential flight certification
- Developing S-basis allowables on various alloys to aide in certification assessments



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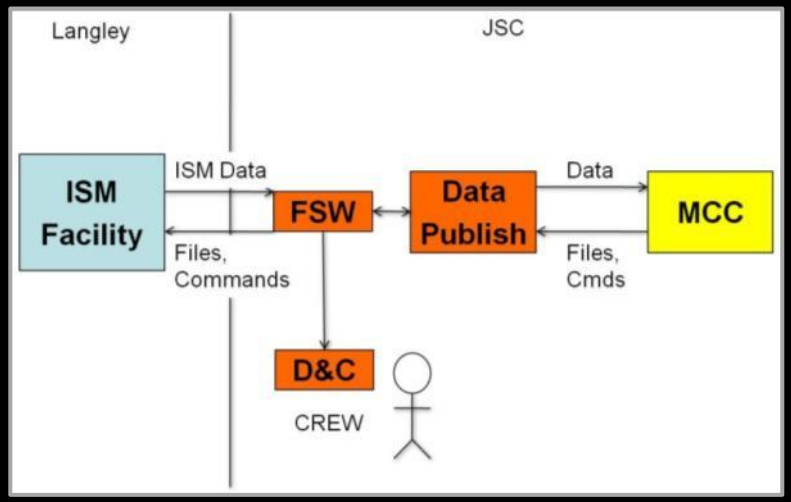
Remote Access and Operability of Deployed Additive Manufacturing System

- Integrated Power, Avionics, and Software (iPAS) facility is intended to be an integrated hardware/software test and evaluation environment
- Provide a common testbed framework that supports integrated hardware/software testing for a variety of applications
- Planned demonstration of EBF^3 system connected through iPAS for data transfer and remote system control
- Establish a simple “reference mission”
  - Part to be built
  - Role of ground personnel and crew
- Create Interface Control Document (ICD)
  - Identify the data to be passed to Crew/MCC
  - Possible file uploads or commands to system
  - Define format for exchanging data
- Establish Data Connectivity through DSNet



- Demonstrate ability to produce part in one location, while all command and control, including data evaluation for qualification and certification, is conducted at a separate location

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Summary:

- Supportability is critical for longer duration, more remote exploration missions
- Currently working series of development activities to demonstrate concept of operations for space-based on-demand additive manufacturing
- ISS is an ideal platform for testing efficacy of on-demand additive manufacturing in a relevant space environment
- If demonstration on ISS is conducted, equipment provides residual capability for use on ISS beyond proof-of-concept experiments