NASA Marshall Space Flight Center Progress in Manufacturing Technology

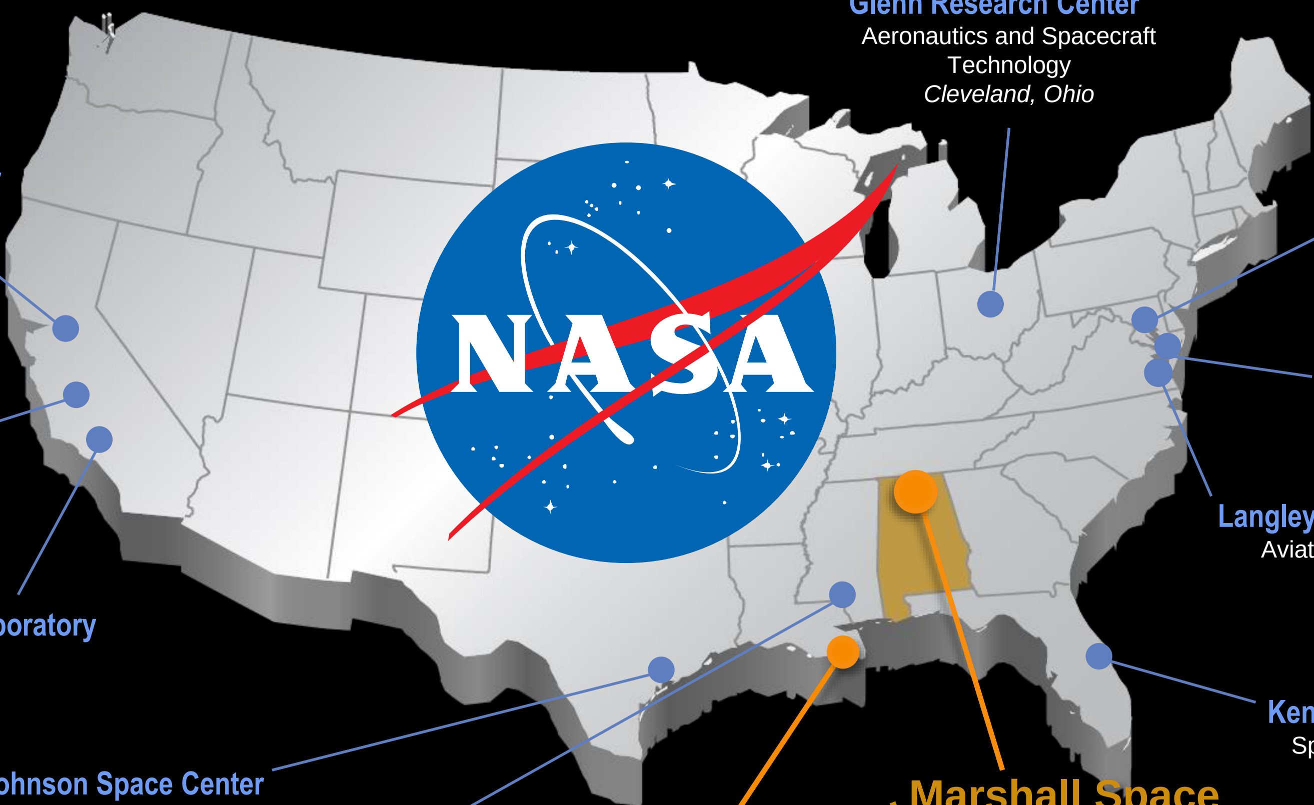
SAE International Systems, Standards and Technology Council

01 June 2015

marshall

Andrew S. Keys
MSFC Center Chief Technologist

NASA Around the Country



Supporting NASA's mission with unique engineering expertise.

Marshall and the Community

Marshall Space Flight Center

6,000 employees

nationwide impact of over

40,000 jobs

3rd largest employer

Huntsville / Madison County

$2B expenditures

$6.7B economic impact

Aerospace/Defense Community

Huntsville's U.S. Rankings:

2nd largest research park

Highest per capita concentration of high-growth companies

2nd largest concentration of high-tech workers

Highest concentration of degreed engineers

Top 10 Tech Hubs

3rd best place for STEM graduates

Redstone Arsenal

37,000 employees

$100B in annual Federal budgets

National Aeronautics and Space Administration

Human Exploration and Operations

Space Technology

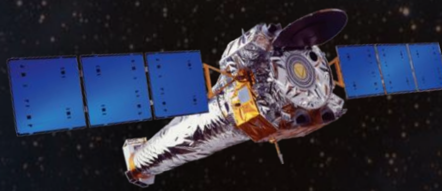
Science

Aeronautics Research

Marshall supports three of the NASA Mission Areas.

Marshall Mission Areas

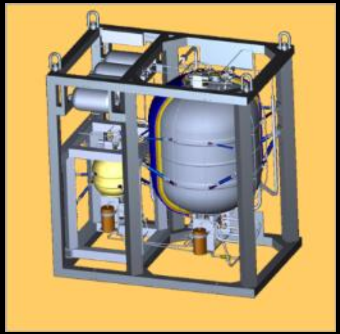
Understanding Our World and Beyond



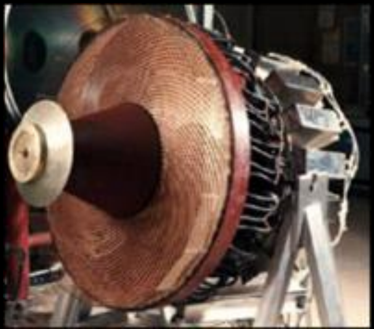
Living and Working in Space

Traveling To and Through Space

MSFC Technology Emphasis Areas



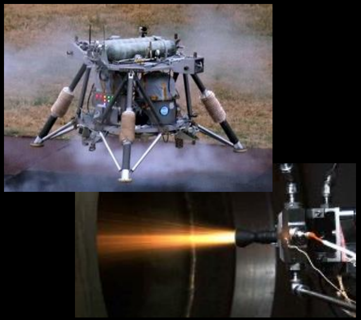
In-Space Propulsion with Emphasis on Cryogenics



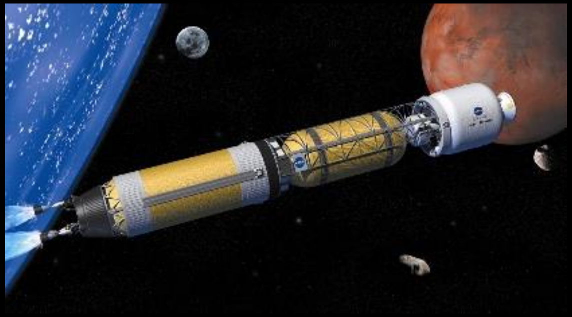
In-Space Propulsion (Green Propellants, Electric)

In-Space Propulsion (Nuclear)

In-Space Propulsion (Solar Sails, Tethers)

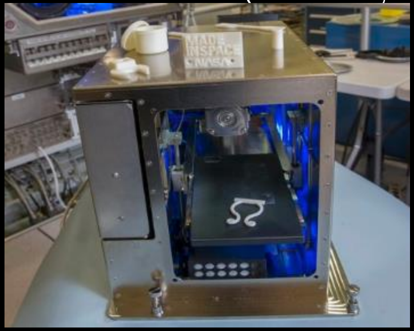


Propulsion Testbeds and Demonstration Missions



Habitats and Technologies for "Beyond Low Earth Orbit" Exploration

Technologies Supporting Utilization of ISS

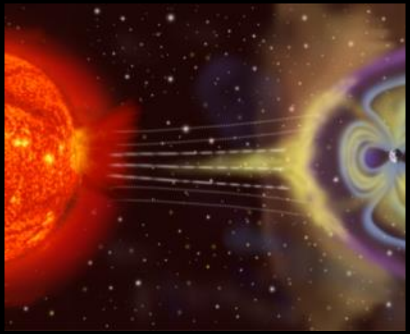


Advanced Manufacturing with Emphasis on In-Situ Fabrication and Repair

Human Habitation Elements and Life Support Systems

Technologies for Small payload Launch

X-ray Astrophysics; Scientific Instrument Dev.



Space Environments and Space Weather, Research to Operations

Small Spacecraft and Enabling Technologies

Rapid/Affordable Manufacturing with Emphasis on Propulsion Components

NASA Advanced Manufacturing Technology Development and Capability

Develop advanced manufacturing technologies that enable the realization of spacecraft and launch vehicles with decreased cost and increased capability.

Collaborate with the National Network for Manufacturing Innovation (NNMI) and partner with other government agencies (DoD, DoE, DoC/NIST, NSF), Industry, and Academia.

Utilize advanced manufacturing technologies in aerospace applications.

MANUFACTURING "FOR SPACE"

MANUFACTURING "IN SPACE"

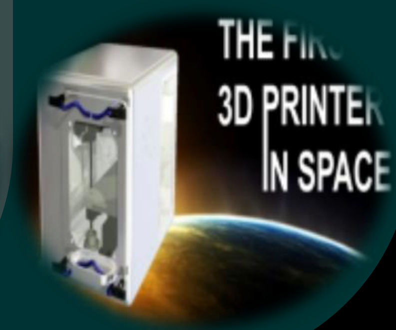
ADDITIVE

COMPOSITES

METALS

DIGITAL

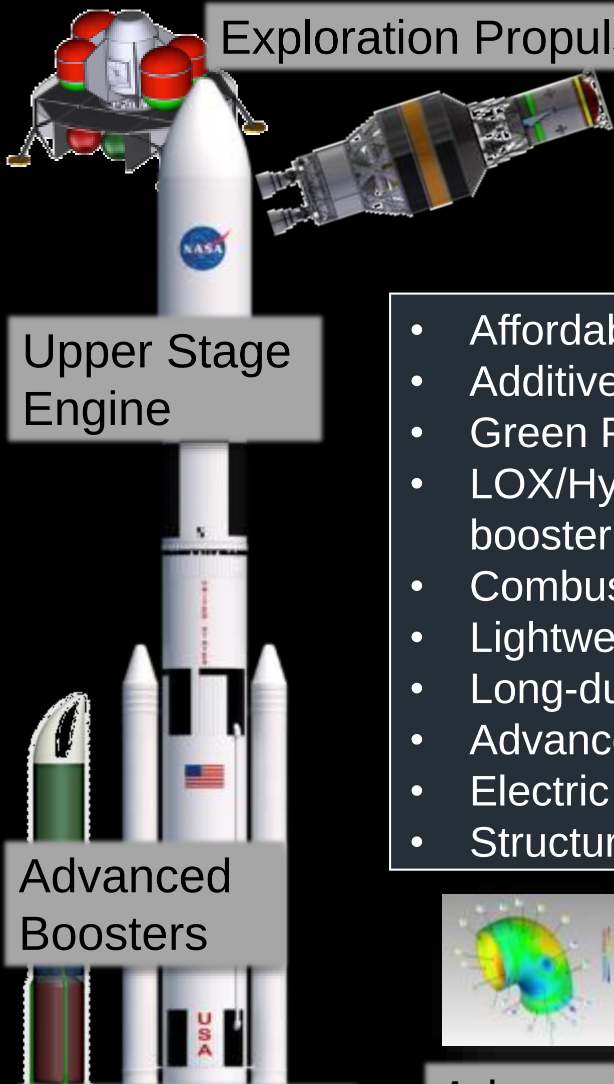
IN-SPACE



Advanced Manufacturing is Critical to all NASA Mission Areas.

NASA Technology Maturation
Spinoff to NSS and Commercial Space Systems

Exploration Propulsion Systems



Upper Stage Engine

Advanced Boosters

Boost Engines RS-25

- Affordable RS-25 components
- Additive Manufacturing
- Green Propellants
- LOX/Hydrocarbon engine design for booster and space exploration applications
- Combustion stability analysis
- Lightweight cryogenic tanks
- Long-duration cryogenic storage
- Advanced solid booster technologies
- Electric propulsion
- Structured Light Scanning

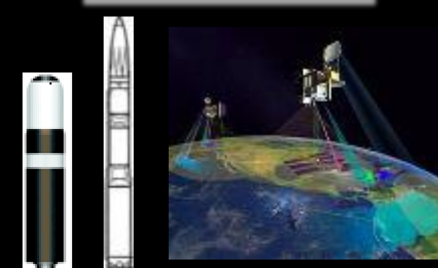
Advanced Manufacturing Demonstration (AMD)

Next Generation Space Launch

COTS

COMMERCIAL CREW PROGRAM

NSS Space

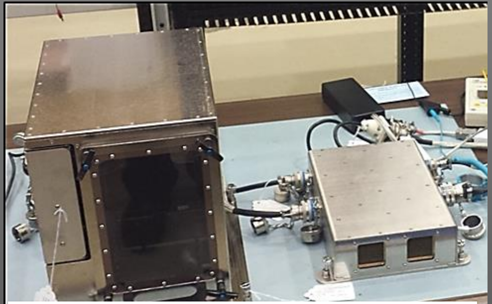


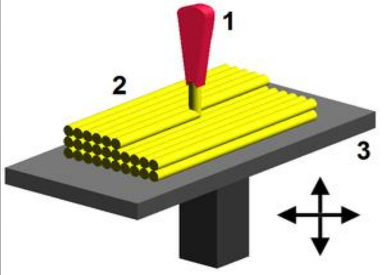
3D Printing in Zero-G (3DP)

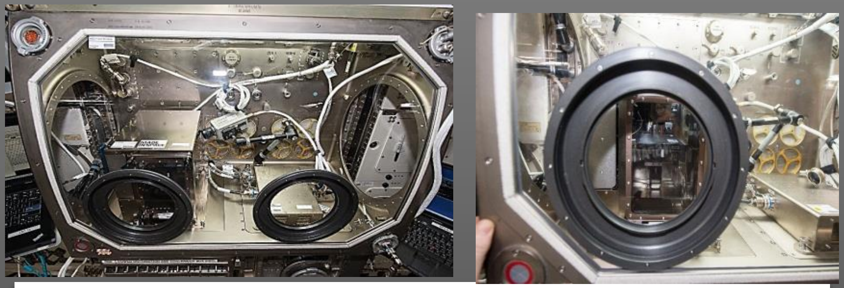
Project Description:
Partnered with Made In Space, Inc. to deliver the first 3D printer to the ISS to investigate the effects of microgravity on melt deposition additive manufacturing and print parts in space. Payload is utilizing Microgravity Science Glovebox and will print multiple parts from polymer material, demonstrate nominal extrusion and traversing, and perform on-demand printing via CAD file uplink. Printed parts will be tested on the ground for quality and strength.

MSFC Role:
Project management (Niki Werkheiser); provided insight to ensure that hardware met minimum flight requirements; completed all flight qualification and acceptance testing

Customers: Space Technology Mission Directorate (STMD) Game Changing Development, Advanced Exploration Systems (AES)/HEOMD, and ISS Program







Accomplishments:
- Met all milestones on or ahead of schedule, within budget, and with minimal risk
- Delivered flight hardware to MSFC on 3/10/14
- Completed flight qualification testing on 4/10/14, Acceptance Review 5/12/14, and Phase III Safety Review 5/21/14
- Delivered flight hardware to JSC for integration into launch vehicle 6/6/14
- Launched on SpaceX-4 on 9/21/14
- Installed 3D Printer, electronics box, and camera setup in MSG on ISS 11/17/14

NASA In-space Manufacturing Technology Development Vision

3D Print Tech Demo

Metal Printing

Optical Scanner

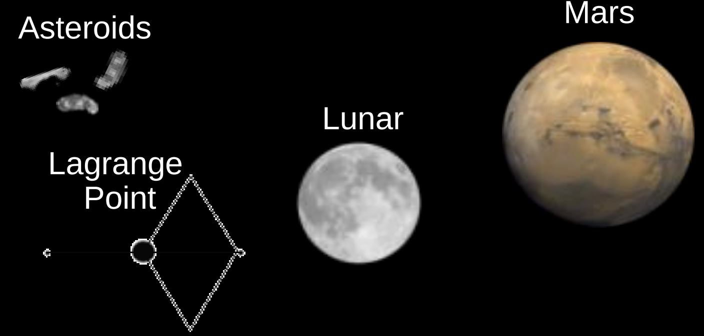
Printable Electronics

SmallSats

Recycler

Add Mfctr. Facility

Self-repair/ replicate



Pre-2012

Ground & Parabolic centric:

- Multiple FDM Zero-G parabolic flights
- Trade/System Studies for Metals
- Ground-based Printable Electronics/Spacecraft
- Verification & Certification Processes under development
- Materials Database
- Cubesat Design & Development

2015

- **POC 3D Print: First Plastic Printer on ISS Tech Demo**
- **NIAC Contour Crafting**
- **NIAC Printable Spacecraft**
- **Small Sat in a Day**
- **NRC Study**
- **Center In-house work in additive, synbio, ISRU, robotics**

2016

- Next Generation 3DPrint
- SmallSat in a Day ISS Demo
- Recycler Demo: recycle plastic

2017

2018

ISS: *Utilization/Facility Focus*

- Integrated Facility Systems for stronger types of extrusion materials for multiple uses including metals & various plastics
- Printable Electronics Tech Demo
- SmallSat Build & Deploy

2020-25

Lunar, Lagrange FabLabs

- Initial Robotic/Remote Missions
- Provision some feedstock
- Evolve to utilizing in situ materials (natural resources, synthetic biology)
- Product: Ability to produce multiple spares, parts, tools, etc. "living off the land"
- Autonomous final milling to

2025

Planetary Surfaces Points Fab

- Transport vehicle and sites would need Fab capability
- Additive Construction

2030 - 40

Mars Multi-Material Fab Lab

- Utilize in situ resources for feedstock
- Build various items from multiple types of materials (metal, plastic, composite, ceramic, etc.)
- Product: Fab Lab providing self-sustainment at remote destination

ISS Technology Demonstrations are Key in 'Bridging' Technology Development to Full Implementation of this Critical Exploration Technology. We believe this design is the right one for taking the very first step toward manufacturing in

All dates and plans beyond 2015 are notional and do not imply planned investments

Additive Manufacturing for Heritage Parts

- Flexibility inherent in the AM technologies increases design freedom; enables complex geometries. Designers can explore lightweight structures; integrate functionality; customize parts to specific applications and environments.
- Goal: reduce part count, welds, machining operations → reduce $ and time

J-2X Gas Generator Duct

Pogo Z-Baffle

Turbopump Inducer

RS-25 Flex Joint

Part	Cost Savings	Time Savings
J-2X Gas Generator Duct	70%	50%
Pogo Z-Baffle	64%	75%
Turbopump Inducer	50%	80%

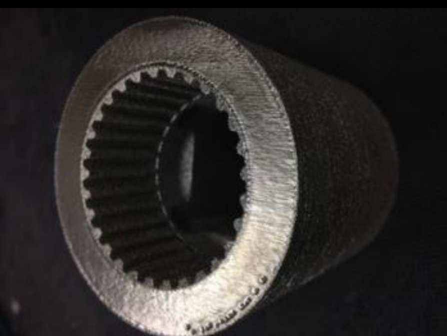
RS-25 Flex Joint	Heritage Design	SLM Design
Part Count	45	17
# Welds	70+	26
Machining Operations	~147	~57

Additive Manufacturing for New Parts

- Fabricate new parts and tooling
- "Art to Part" in hours
- Design freedom and flexibility
- Design for function

Part	Cost Savings	Time Savings
F-1 Torque Adapter	N/A	70%
Custom Wrenches	N/A	70%
Turbopump Inducer	50%	80%

Custom Tooling



Custom Instrumentation

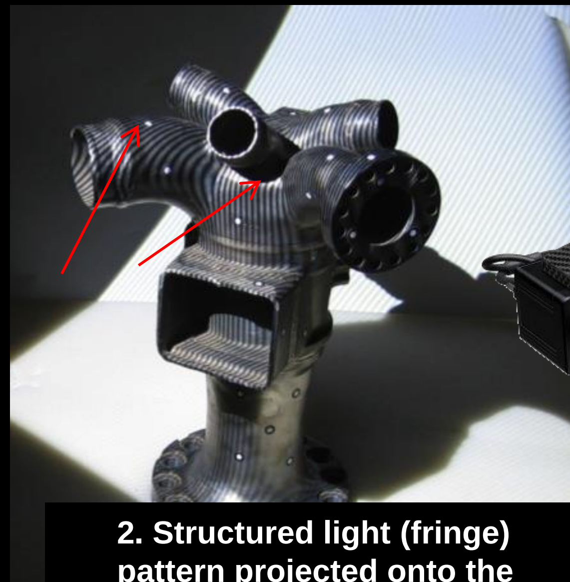
Valve Housing

Turbopump Inducer

Imagine the possibilities!

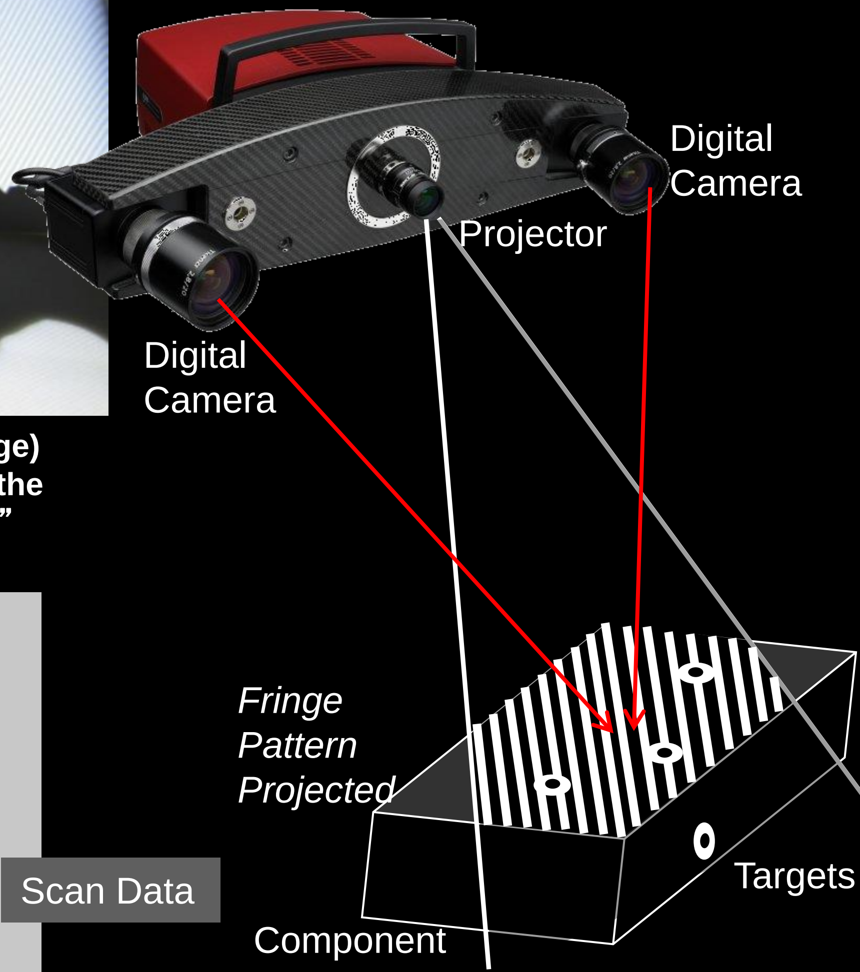
Structured Light Scanning

1. Targets are placed on the hardware



2. Structured light (fringe) pattern projected onto the component that “shifts” rapidly

3. Two digital cameras take a series of simultaneous images



4. Series of simultaneous images and scans are processed in the software, and based on triangulation methods, the software will calculate 3D coordinates of the part and create a continuous contour

Additive Manufacturing Certification for Flight Applications

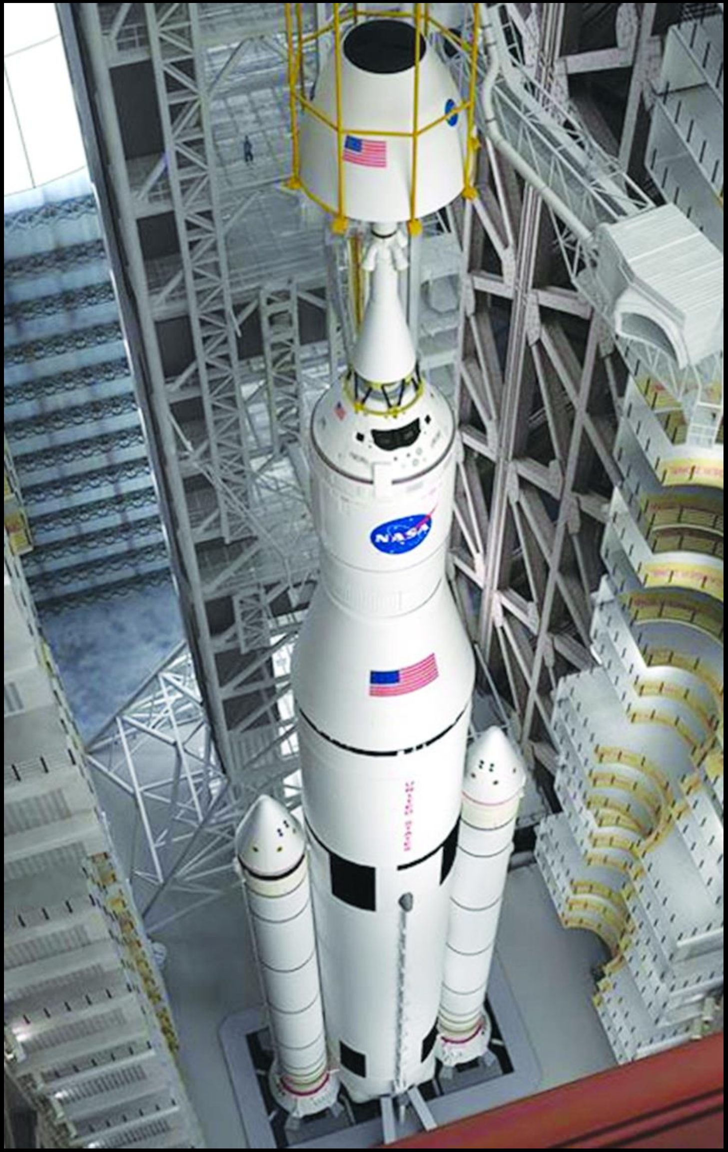
Certification is…

…the affirmation by the program, project, or other reviewing authority…

…that the verification and validation process is complete…

…and has adequately assured that the design and as-built hardware meet the established requirements…

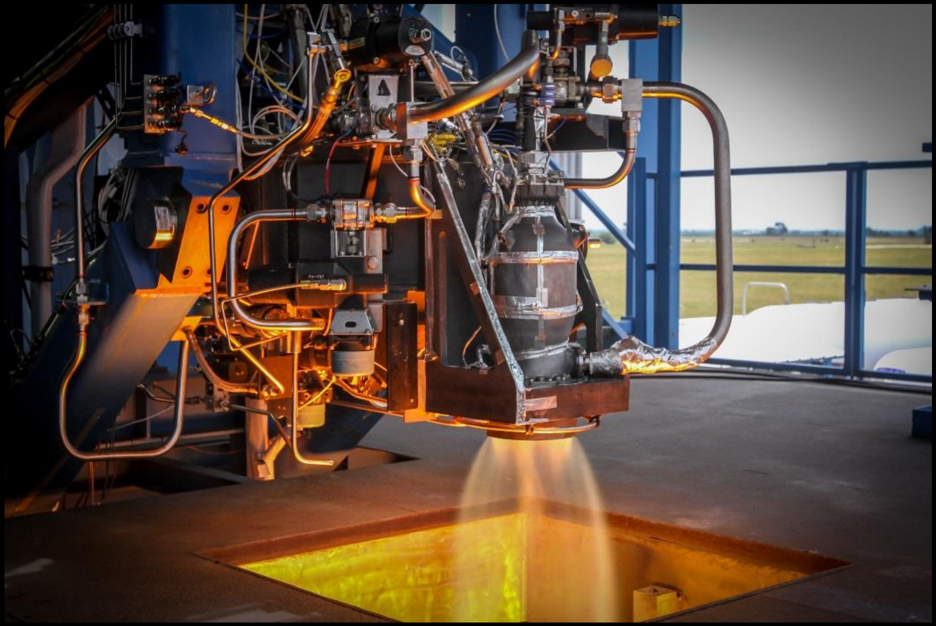
…to safely and reliably complete the intended mission.



A Growing Need for Certification of Design, Processes and Hardware

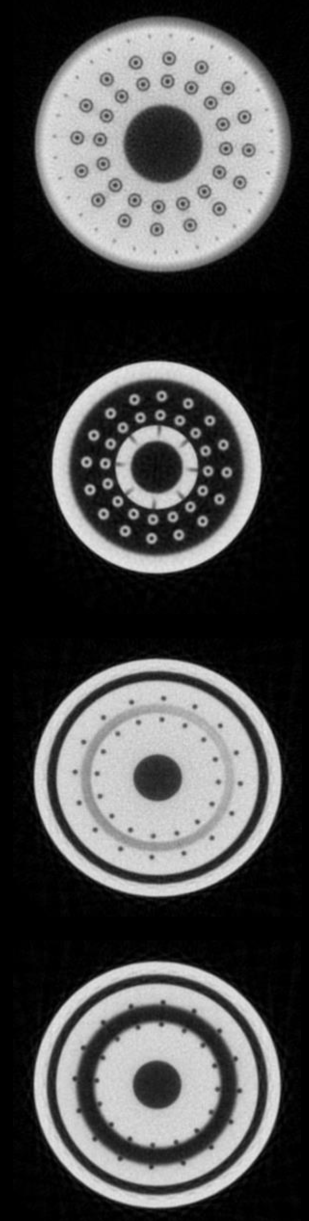
- The ability to create parts is quickly outpacing the ability to certify parts.
- Government and commercial aerospace applications require certifications specific to aerospace design, fabrication process, and utilization as applied to additively manufactured parts.
- Existing standards do not appropriately address aerospace applications.

Example: Commercial crew contractor SpaceX using Direct Metal Laser Sintering processes to fabricate combustion chamber in SuperDraco engines on Dragon capsule.



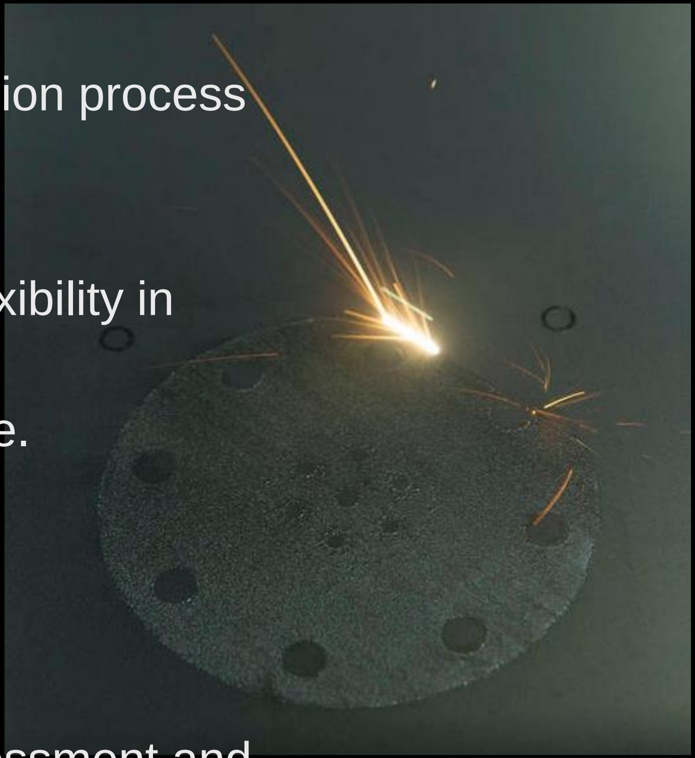
Challenges with Powder Bed Fusion Verification Methods

- Lack of standardization
  - Physical part definition
  - Materials
  - Part Finishing Procedures
  - Non-destructive Inspections
- Lack of systematic understanding of process failure modes
  - Mechanisms of process failure
  - Characteristic defects attributable to process



MSFC Addressing Need for Certification Standard

- Requirements document being developed by MSFC and routed for review to ensure part quality based on part application.
  - Initial effort specific to metallic Powder Bed Fusion process for manned spaceflight applications.
  - Must understand failure modes.
  - As technology matures, must accommodate flexibility in industrial and government supply base
  - Develop an enabling material property database.
  - Specify methods of part verification:
    - Part lot acceptance
    - Non-Destructive Evaluation
    - Proof test methodologies
  - Closed-loop in-process methods of quality assessment and production control to reduce part-by-part acceptance testing.



Flexible Certification Approach

Early part builds and acceptance tests occur in parallel with design and contribute to a growing materials database and understanding of the AM process.

- Individualized part development plans for the process required to fabricate a particular part.
- Part classification for customizable requirements
- Comprehensive first-article testing
- Thorough build-by-build lot acceptance testing and rigorous proof testing
- Fatigue testing as common lot acceptance procedure
- Frequent and direct interaction with vendors and full insight into vendor process controls

Path to Flight Certification

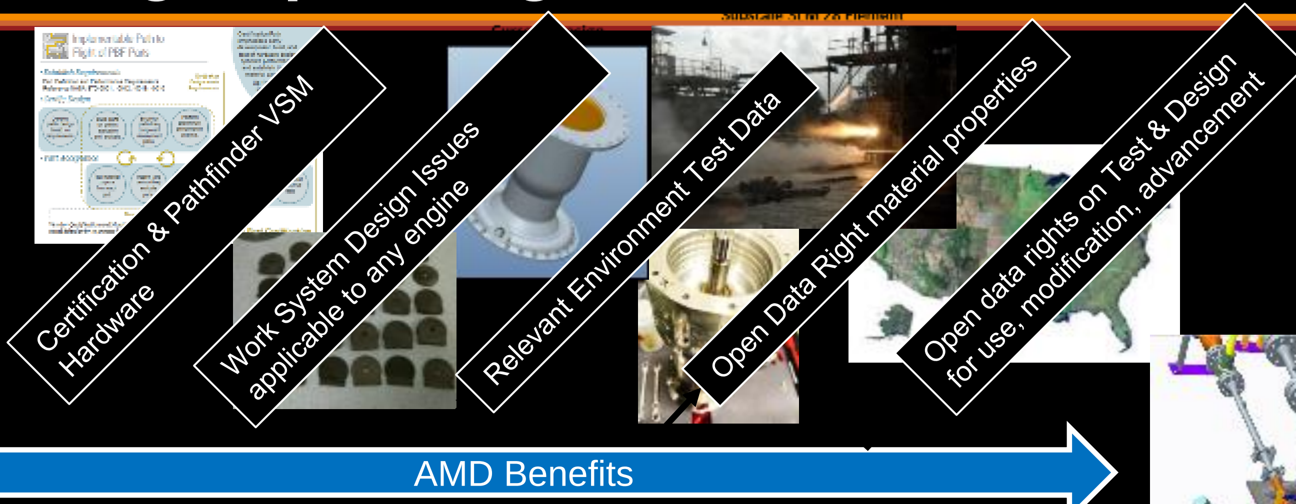
- Understand process failure modes
- Provide for adequate process controls
- Characterize process variability
  - Material properties
- Enforce comprehensive part development plans
  - Design & Assessment
  - Materials & Processes
  - Inspections
  - Testing
- Verify individual build lot quality
  - Lot acceptance for strength, chemistry, microstructure
  - Proof testing
  - NDE
- Develop/adopt design and process specifications

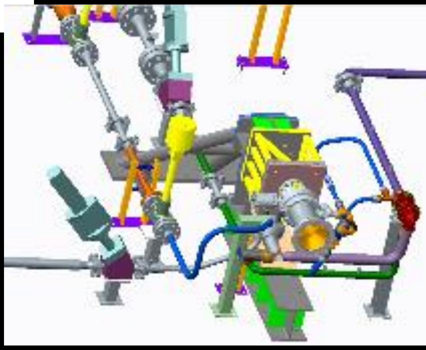
Many Issues to Address

- How do we certify vendors for additively manufactured part supply?
- How do we keep up with process compliance?
- Once process is locked down, what flexibilities are allowed?
  - Does a software update to the machine require re-certification?
  - How critical is maintaining a consistent operator? Training?
  - If a part fails, how much re-certification is required?
  - How much machine preventive maintenance and cleaning may be tolerated?

Advanced Manufacturing Demonstration (AMD)
Transforming Liquid Engine DDT&E

Concept Prototype Engine





Advanced Manufacturing Demonstration (AMD) Engine in Test

Precursor to Exploration in Space & Lander Propulsion
Enabling Manufacturing Affordability & Sustainability Agile Vendor Base
Providing fundamental 'Smart Buyer' Knowledge for Commercial Space


Somewhere, something
Incredible is waiting to be known.
— Carl Sagan

www.nasa.gov/marshall