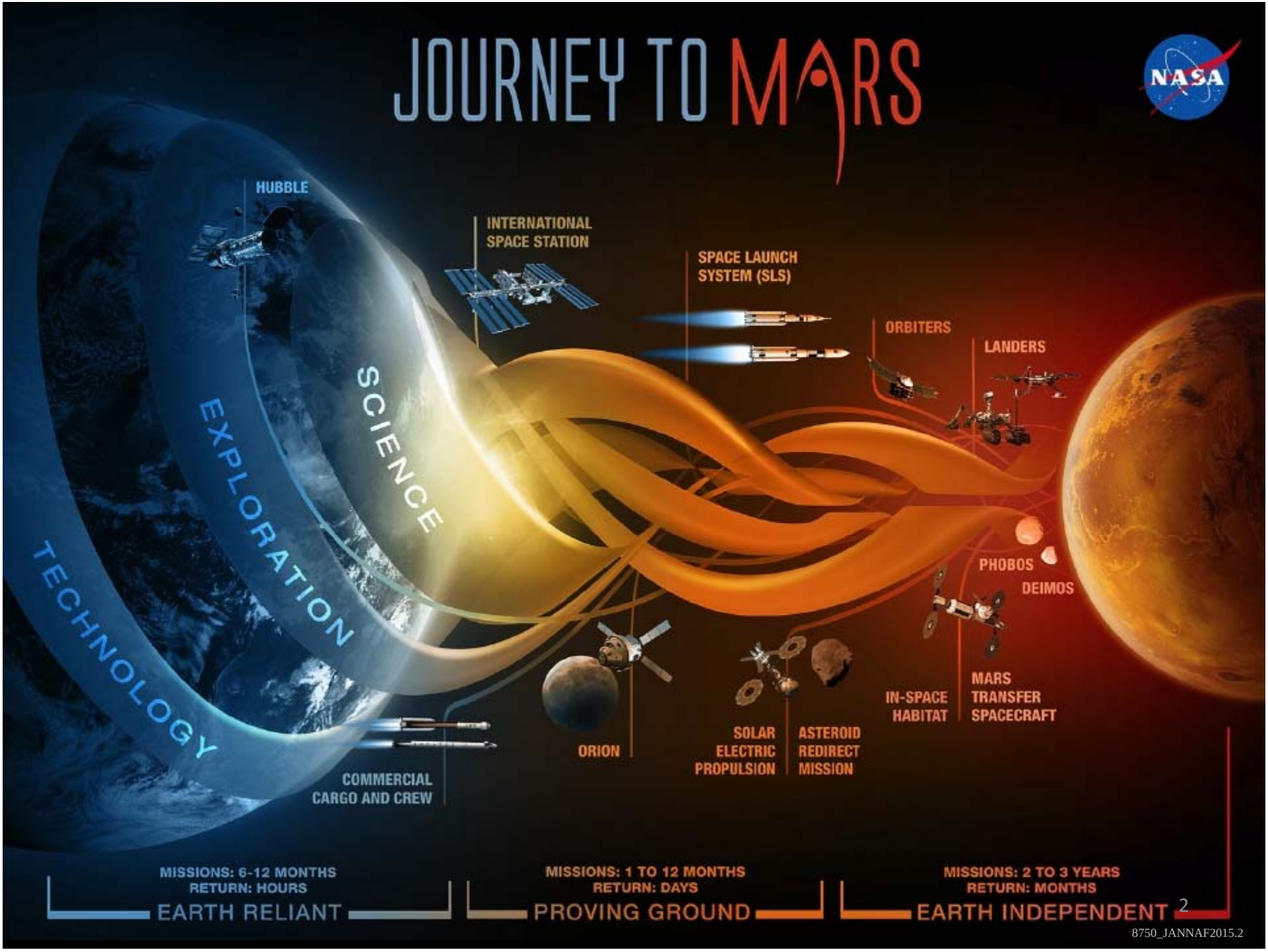
National Aeronautics and Space Administration

marshall

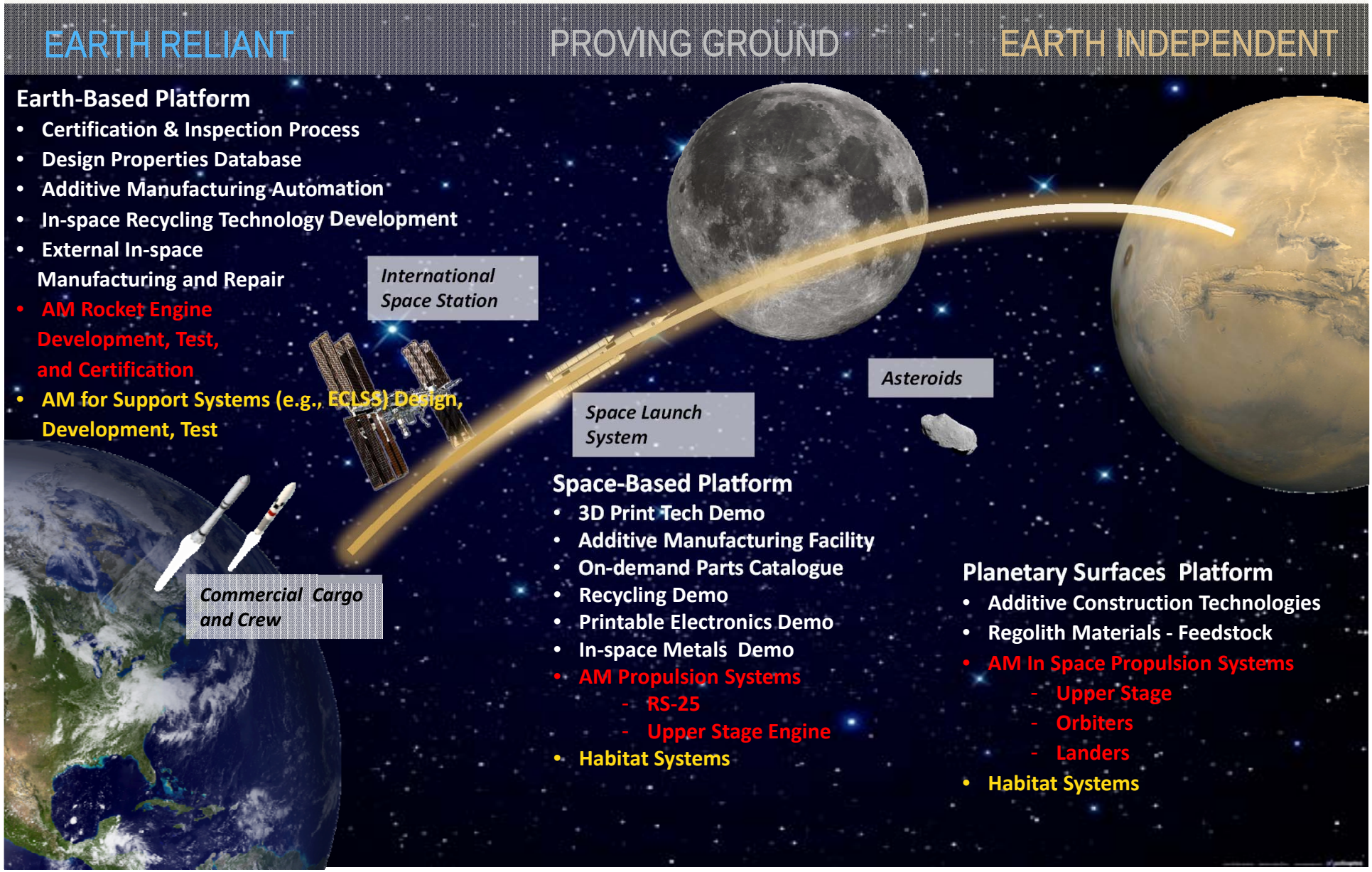
Additive Manufacturing at NASA Marshall Space Flight Center: In-space and For-space Initiatives

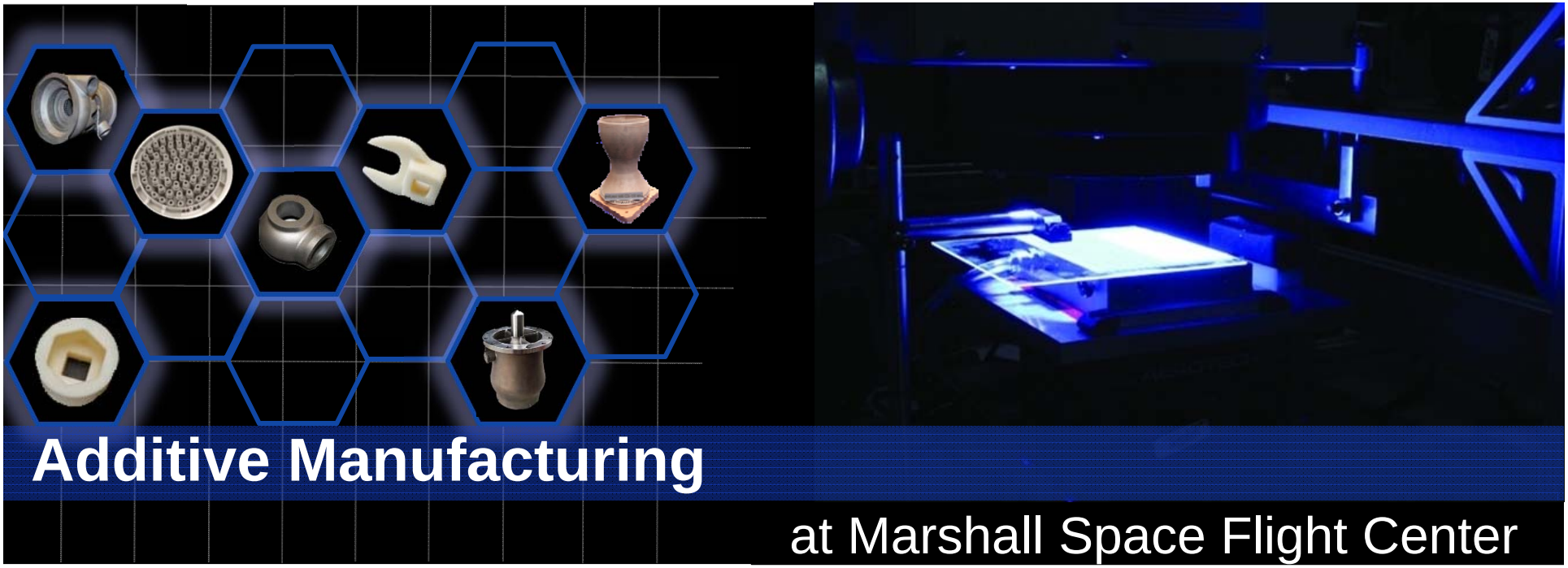
Elizabeth Robertson, Engine Systems Branch

Marshall Space Flight Center


JOURNEY TO MARS
NASA
HUBBLE
INTERNATIONAL SPACE STATION
SPACE LAUNCH SYSTEM (SLS)
ORBITERS
LANDERS
SCIENCE
EXPLORATION
TECHNOLOGY
PHOBOS
DEIMOS
IN-SPACE HABITAT
MARS TRANSFER SPACECRAFT
ORION
SOLAR ELECTRIC PROPULSION
ASTEROID REDIRECT MISSION
COMMERCIAL CARGO AND CREW
MISSIONS: 6-12 MONTHS
RETURN: HOURS
EARTH RELIANT
MISSIONS: 1 TO 12 MONTHS
RETURN: DAYS
PROVING GROUND
MISSIONS: 2 TO 3 YEARS
RETURN: MONTHS
EARTH INDEPENDENT

Additive Manufacturing Path to Exploration





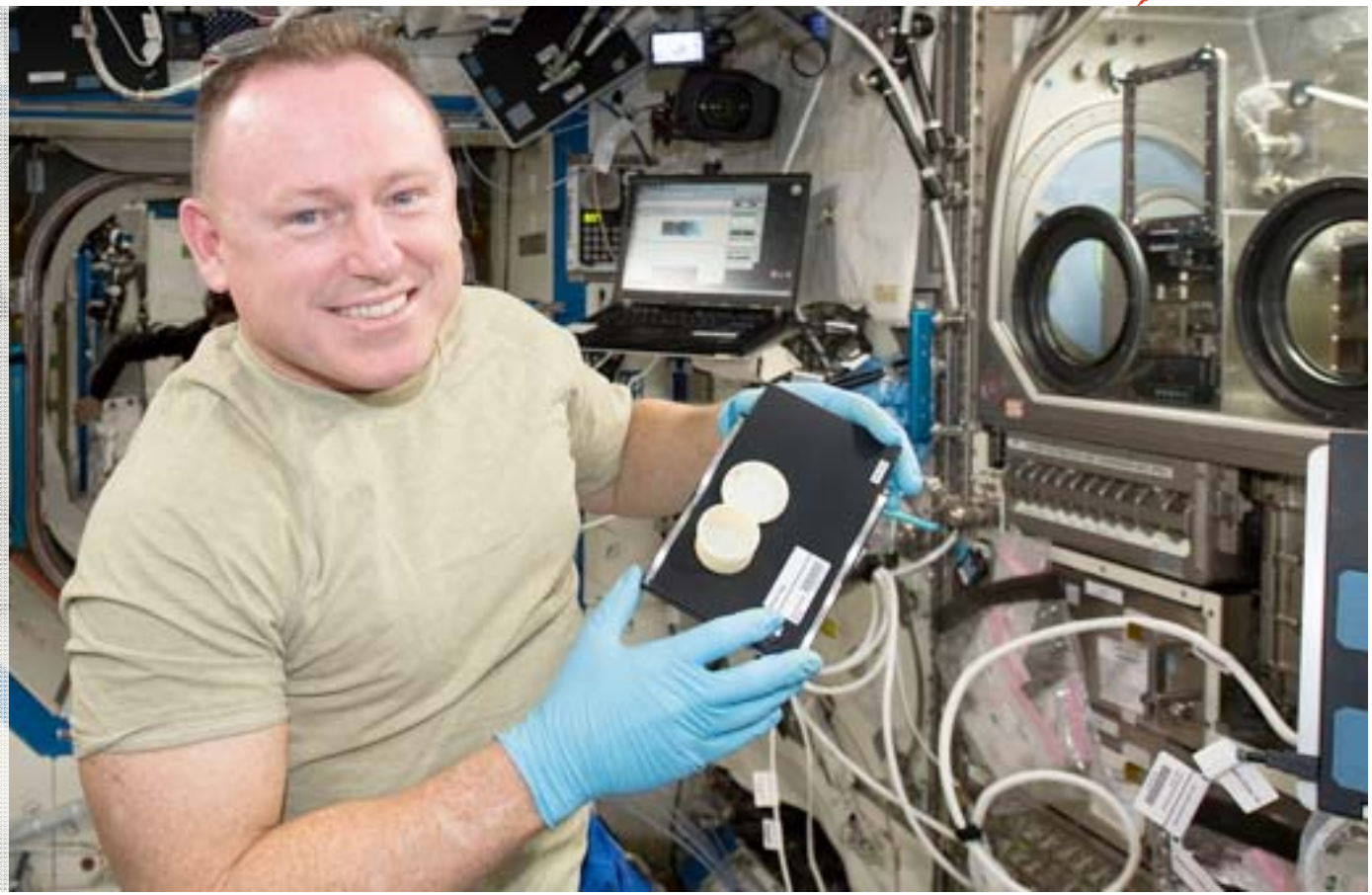
Additive Manufacturing

at Marshall Space Flight Center

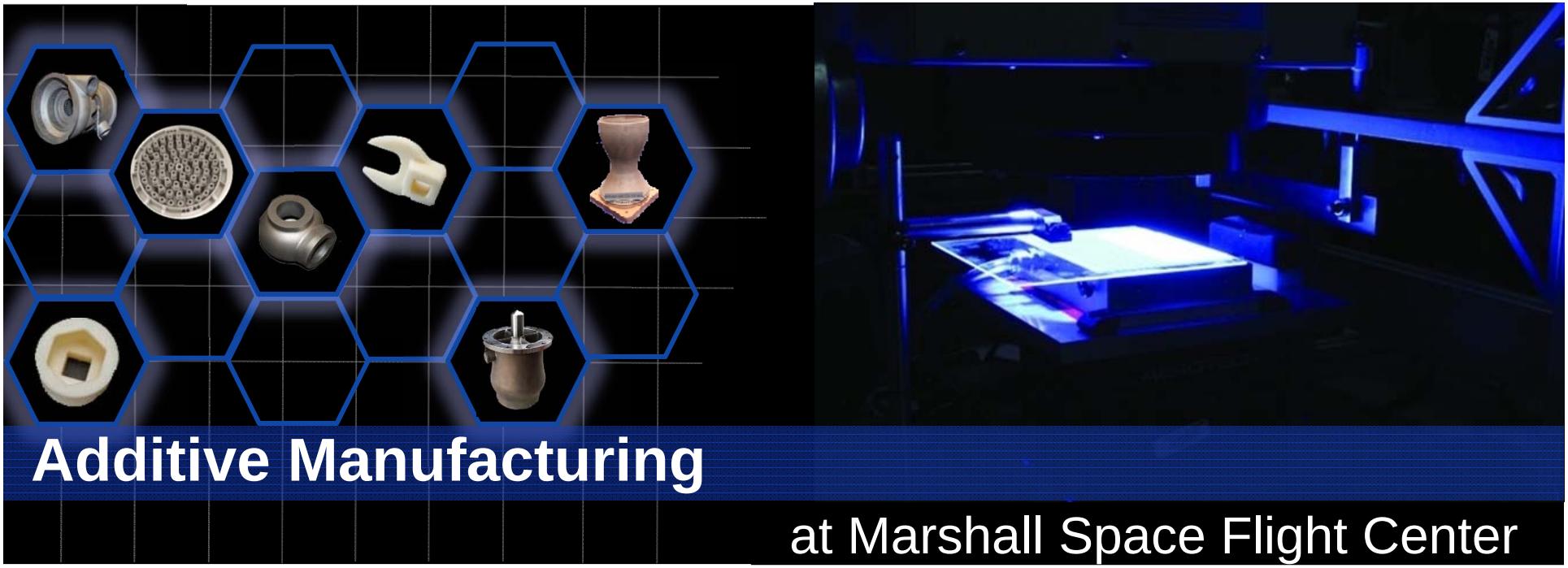
In Space Manufacturing Initiative

International Space Station Is Helping NASA Get to Mars

Understanding how to manufacture items in space (3-D Printing)



As crews head to Mars, there may be items that are unanticipated or that break during the mission. Having the ability to manufacture new objects on demand while in space will greatly benefit missions. The 3-D Printing in Zero-G Technology Demonstration validates that a 3-D printer works normally in space. This is the first step towards establishing an on-demand machine shop in space, which is a critical enabling component for crewed missions to deep space.



Additive Manufacturing

at Marshall Space Flight Center

For Space Manufacturing

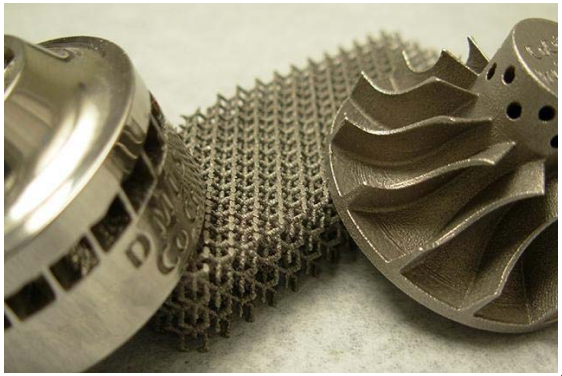
Advanced Manufacturing Demonstrator:
Liquid Propulsion System

AM Process Development and Characterization

Performance

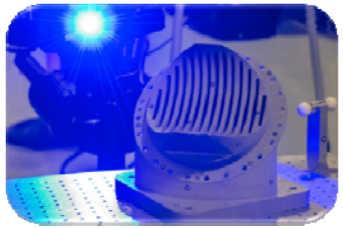
Powder

MAPTIS



Characterization

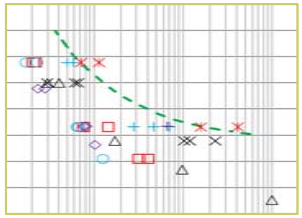
Process Parameters



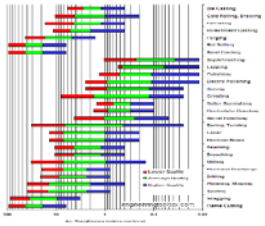
Dimensional &
NDE Inspections

Digital Thread

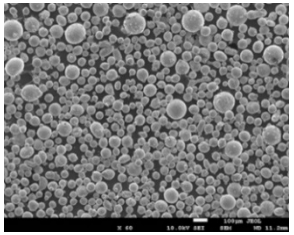
Heat Treatment



Test & Properties



Surface Finish



Microstructure

Hardware and Testing Accomplishments

LCUSP MCC Liner

Main Fuel Valve Cryo Test

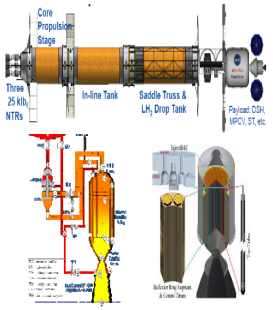
Fuel Turbopump Performance Test in Hydrogen and Methane

Injector and System Hot Fire Testing

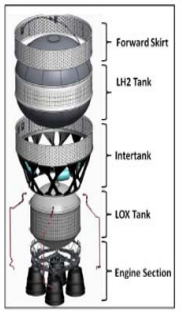
Advanced Manufacturing Demonstrator (AMD)

Investment directly benefits prototype engine development and indirectly enables and facilitates technology across multiple current and future activities for NASA and industry.

Methane Lander

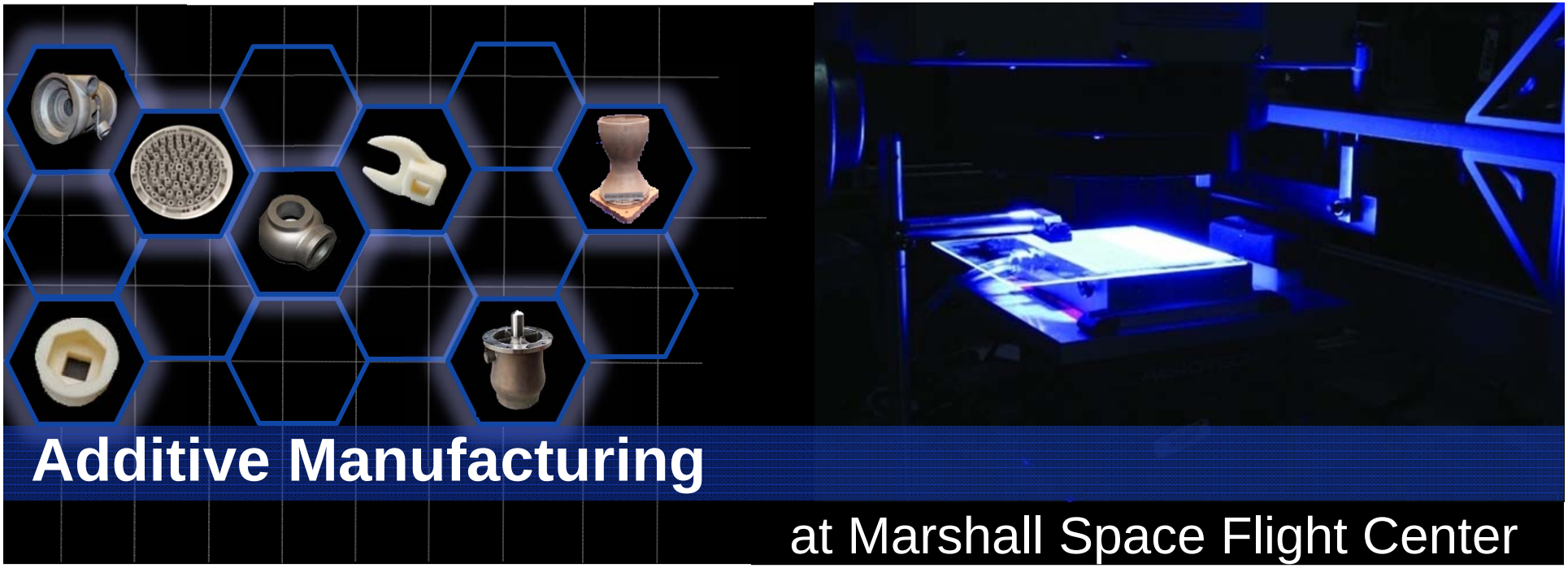


Nuclear Thermal Propulsion (NTP)



Exploration Upper Stage (EUS)

National Aeronautics and Space Administration



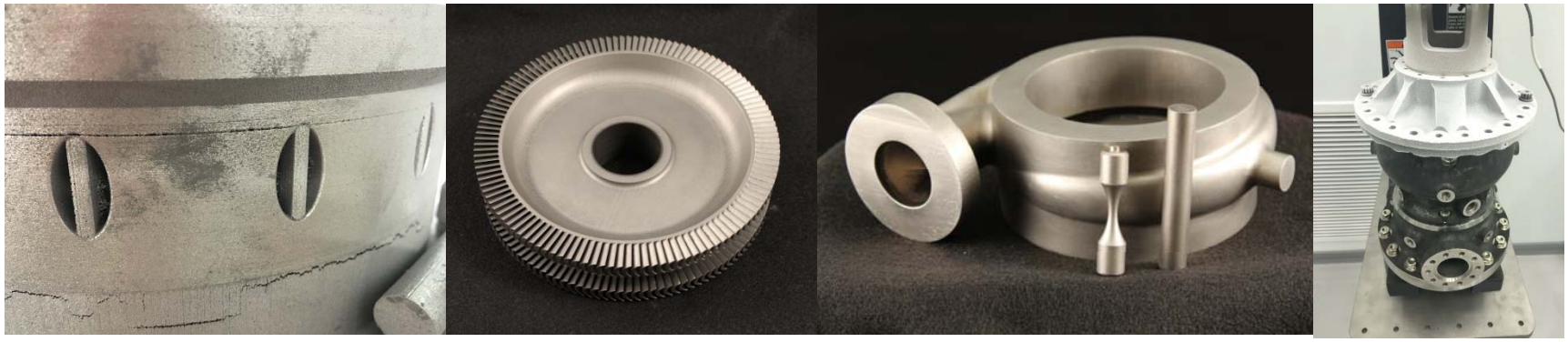
Additive Manufacturing

at Marshall Space Flight Center

Lessons Learned and The Next Steps

Lessons Learned

- Challenges remain with additive manufacturing for propulsion
  - Industry is growing and changing rapidly
  - Quality seems to shift with personnel
  - Repeatability is necessary for flight hardware
- A consistent approach to requirements that does not inhibit the cost and schedule savings is needed
- Manufacturing technique is still an “art”
- .Engage manufacturing vendors as early as possible in the design phase
- Designing for additive manufacturing



Areas for Growth & Investment

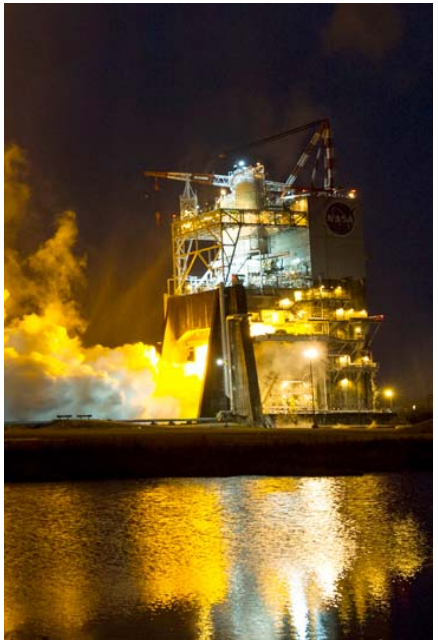
- **Areas for Growth:**
  - Material Characterization and Development
  - Larger Build Volumes
  - Advances in free form techniques and hybrid machines
  - Multi-material builds
  - Non destructive Evaluation

Test Samples

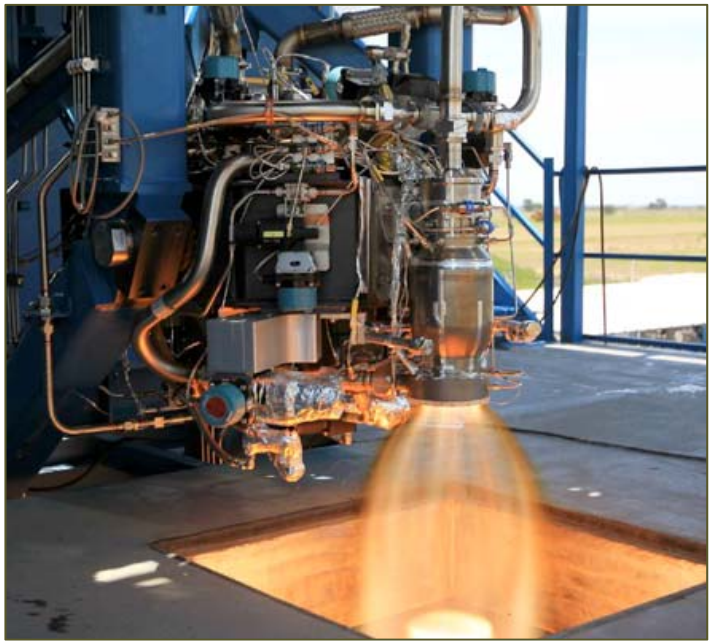
- **Known Unknowns needing investment:**
  - Unknown failure modes :: limited process history
  - Open loop process, needs closure or meaningful feedback
  - Feedstock specifications and controls
  - Thermal processing
  - Process parameter sensitivity
  - Mechanical properties
  - Part Cleaning
  - Welding of AM materials
  - AM Surface improvement strategies
  - Electronic model data controls
  - Equipment faults, modes of failure
  - Machine calibration / maintenance
  - Vendor quality approvals

AM in the Human Exploration and Operations Portfolio

Exploration Systems Development
ORION and SLS



Commercial Crew Program
DRAGON V2



Requirement choices dictate how we embrace, foster, and protect the technology and its opportunities


NASA