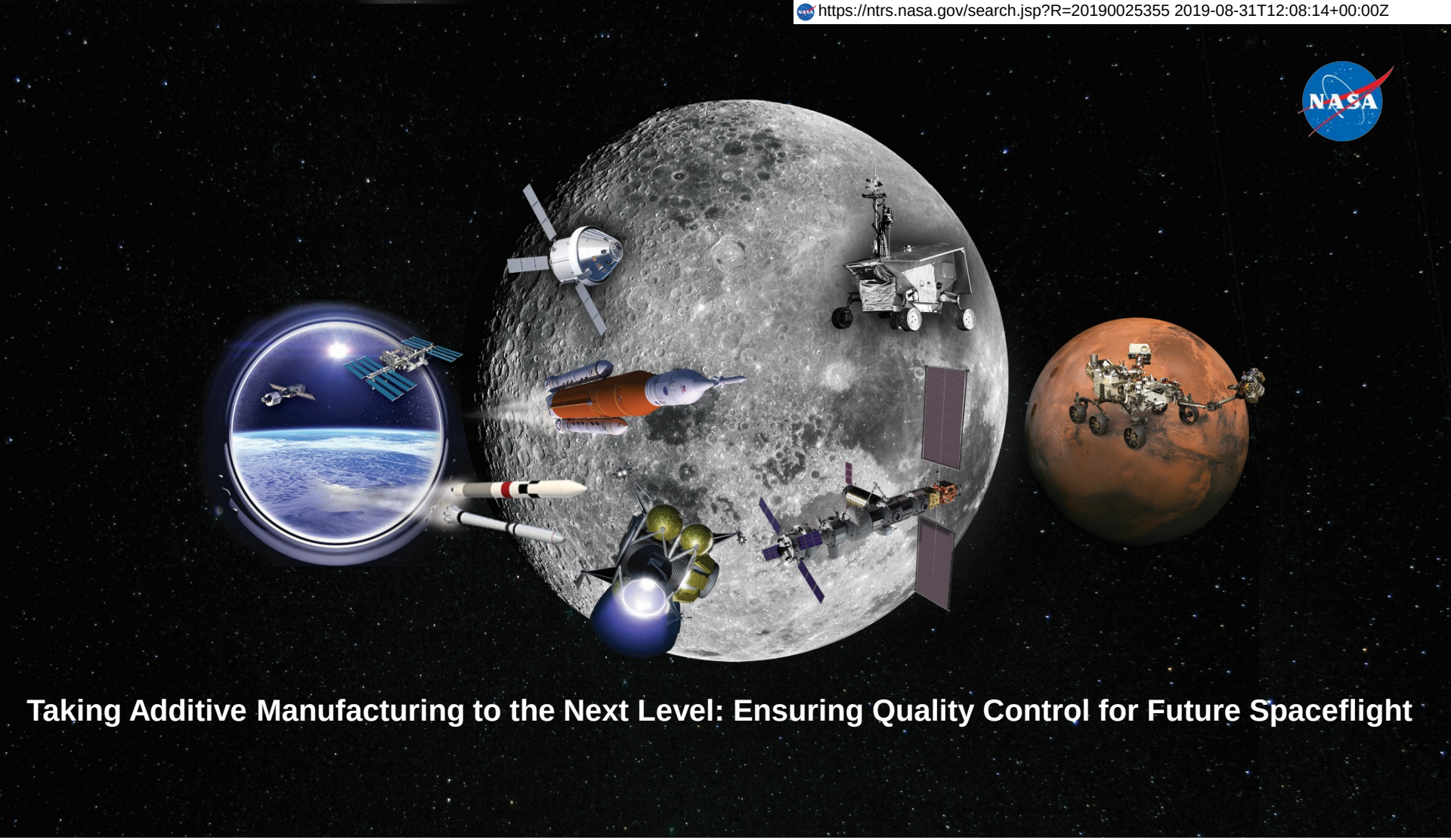

Taking Additive Manufacturing to the Next Level: Ensuring Quality Control for Future Spaceflight

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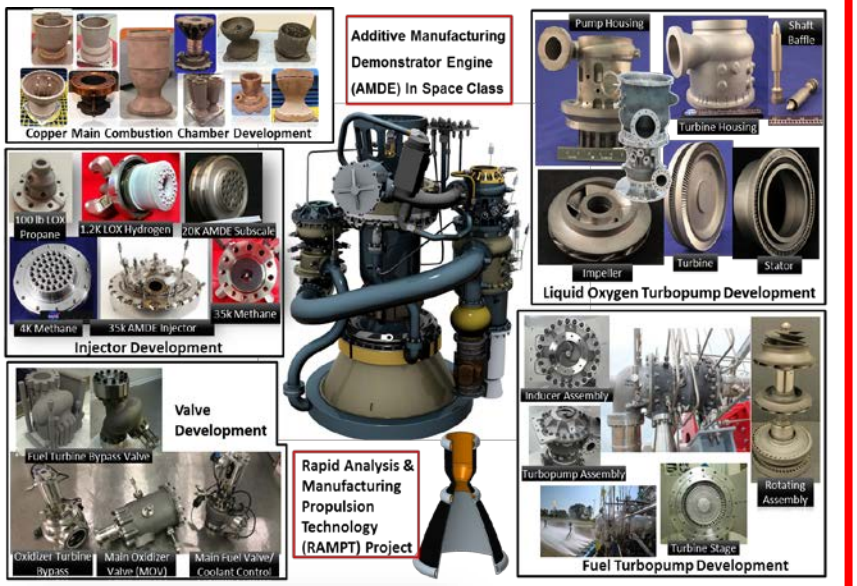
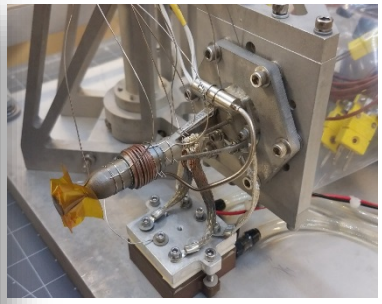
Pasadena CA

NASA Marshall Space Flight Center Additive Manufacturing Initiatives

In Space Manufacturing Path to Exploration – Key Thrust Areas

MSFC Spec and Standard Additively Manufactured Spaceflight Hardware

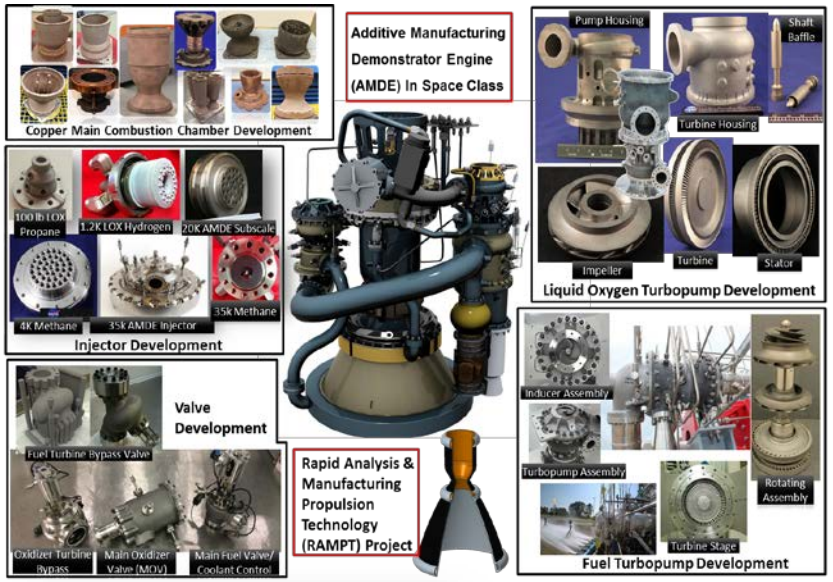


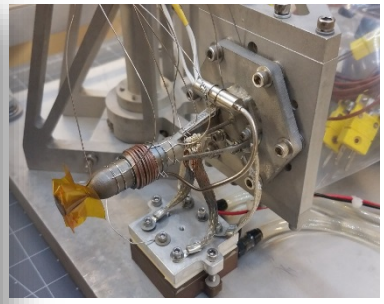


Additive Manufacturing for Space Propulsion Systems

NASA Marshall Space Flight Center Additive Manufacturing Initiatives

In Space Manufacturing Path to Exploration – Key Thrust Areas





Additive Manufacturing for Space Propulsion Systems

Taking Additive Manufacturing to the Next Level: Ensuring Quality Control for Future Spaceflight

Material Selection

- The operational requirements shall include, but are not limited to, the following:
  - (1) Operational temperature limits.
  - (2) Loads.
  - (3) Contamination.
  - (4) Life expectancy.
  - (5) Moisture or other fluid media exposure.
  - (6) Vehicle-related induced and natural space environments e.g.:
    - Gravity Conditions
    - Accelerations
    - Acoustics
    - Vibration
    - Space Radiation
    - Thermal
    - Stress
    - Combined Environments
- Properties that shall be considered in material selection include, but are not limited to, the following:
  - (1) Mechanical properties.
  - (2) Fracture toughness.
  - (3) Flammability and offgassing characteristics.
  - (4) Corrosion.
  - (5) Stress corrosion.
  - (6) Thermal and mechanical fatigue properties.
  - (7) Creep
  - (8) Glass-transition temperature.
  - (9) Coefficient of thermal expansion mismatch.
  - (10) Vacuum outgassing.
  - (11) Fluids compatibility.
  - (12) Microbial resistance.
  - (13) Moisture resistance.
  - (14) Conductivity
- Material Availability/Supply Chain
- Mass requirements
- Process Technologies, both manufacturing and post processing
- Cost

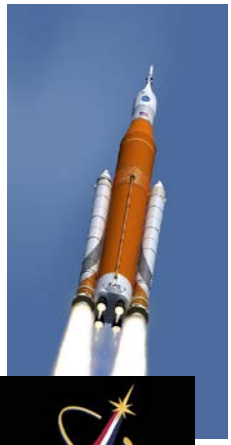
Taking Additive Manufacturing to the Next Level: Ensuring Quality Control for Future Spaceflight

Example Material Properties for Thrust Chamber Assembly Application:

- Mechanical Properties as F(T):
  - Tensile
  - Compressive
  - Shear
  - Fatigue – low and high cycle
  - Fatigue – thermal cycling
  - Crack growth
  - Fracture toughness
  - Creep
- Thermal Properties:
  - Conductivity
  - Diffusivity
  - Specific Heat
  - Expansion
- Physical Properties
  - Density
  - Melting Point

NASA's Plans for Development of Standards for Additive Manufactured Components

NASA was not able to wait for America Makes or other national standards organizations to develop AM standards



- Program partners in manned space flight programs (Commercial Crew, SLS, and Orion) are actively developing AM parts
  - AM parts are currently used for commercial space flight
  - MSFC standard is currently being used for certification via tailoring
- MSFC-STD-3716 lists 65 unique Additive Manufacturing Requirements
- MSFC-SPEC-3717 lists 45 unique Process Control and Qualification Requirements
- Although the MSFC standard was written specifically for the Laser Powder Bed Fusion process it's principles can be applied to any AM process for the purpose of certification
- The NESC formed a team to create Agency Standards and Specifications for Additively Manufactured (AM) components.
  - Team includes representatives from the FAA, Air Force, Navy, Army and nine NASA Centers.
  - One standard each for Crewed, Non-Crewed, and Aeronautic Projects
- Separate specification to cover Equipment and Facility Process Control
- Standards are planned to be ready for Agency-wide review in late 2020