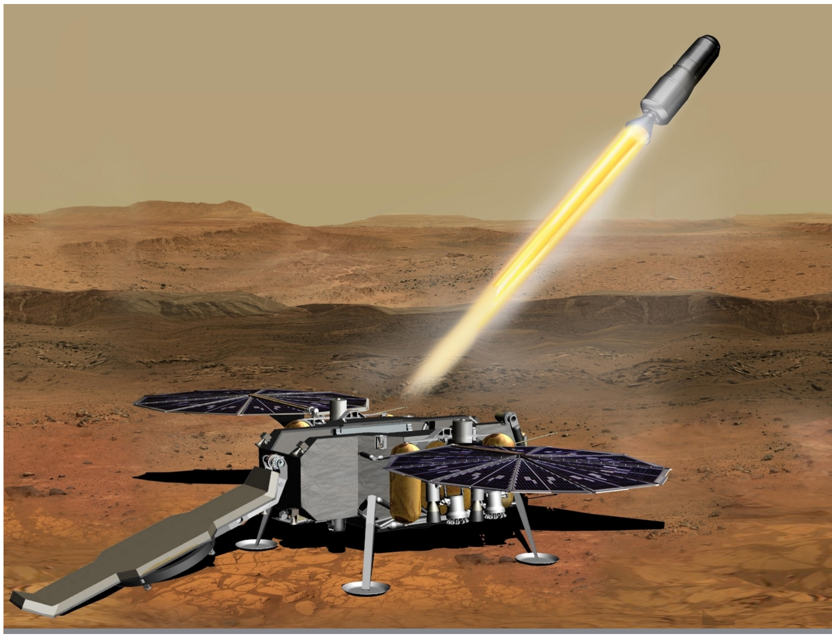


National Aeronautics and
Space Administration

TECHNOLOGY SOLUTION

Propulsion

Defect-Free Paraffin Fuel Manufacturing

Improvements in Paraffin Fuel Grain Manufacturing

Innovators at the Marshall Space Flight Center (MSFC) developed a novel paraffin-based fuel and manufacturing process for use in hybrid rocket engines for the Mars Ascent Vehicle (MAV). The fuel has a suitable regression rate and additives for additional strength and survivability. The process addresses the manufacturing issues with larger-diameter paraffin fuel grains. The manufacturing process employs a novel cooling protocol to result in intact monolithic fuel grains at scale for use in propulsion systems with hybrid rocket engines. Engineers are investigating the use of this paraffin-based fuel specifically for MAV because the fuel has a wider storage temperature range than other propellants. The paraffin based fuel survives in low temperatures (-100 C), freeing up energy for other vehicle or mission purposes. Challenges arose with manufacturing these fuel grains due to the ~15% volume liquid to solid phase change, different density ingredients and inherent brittle nature of paraffin wax. Prior manufacturing efforts lead to problems with cracked, unusable fuel grains, and the inability to produce at the scale needed for use in propulsion systems.

BENEFITS

- Effective: prior paraffin fuel grain manufacturing efforts with this paraffin-based fuel resulted in damaged grains that had cracks and posed safety hazards during testing, along with not reaching the required scale for the MAV. The novel manufacturing process results in intact, usable grains.
- Safe and storable: creates paraffin-based fuel grains devoid of cracks and flaws, thereby greatly decreasing the risk of failure of the grain.
- Consistent: provides a process to manufacture intact full-scale paraffin fuel grains with greater consistency than previous manufacturing efforts.
- Efficient: intact paraffin fuel grains have a higher mass loading per diameter in comparison to other lower regression rate hybrid fuel types.

APPLICATIONS

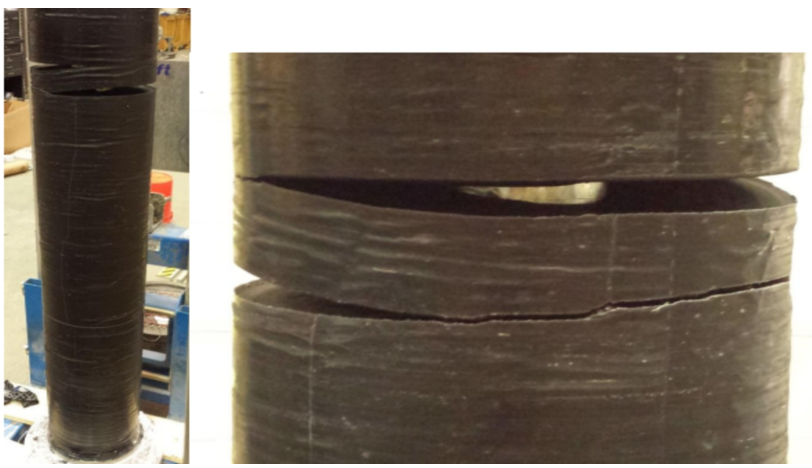
The technology has several potential applications:

- Aerospace: ascent vehicles, lunar breaking motors, and any spacecraft utilizing a hybrid rocket engine
- General wax casting: this process can be used for any application involving casting a monolithic wax structure.

THE TECHNOLOGY

A paraffin-based hybrid fuel formulation for low-temperature cycling has been developed. Cracked or flawed paraffin fuel grains can pose a safety risk during testing and are unuseable. Cracking of the fuel grain typically occurs during the cool-down process. The paraffin-based fuel grain contracts by as much as 15% while cooling from a liquid at 230°F to a solid state and eventually room temperature, not only causing visible cracking, but residual stresses that can damage the grain throughout processing. The new process is an improvement to others that were tried and found unworkable including spin casting and some additive manufacturing techniques.

To remedy the issues with previous manufacturing efforts, the innovators at MSFC developed an oven program mimicking the intrinsic cooldown process of paraffin wax for use in monolithic casting. Innovators monitored paraffin wax cooling in a stainless steel vessel with four thermocouples to develop the program. Rather than cooling quickly, the oven program cools the grain incrementally, allowing the temperature to equilibrate along the entire grain before cooling further, resulting in greater temperature uniformity. This process produces intact full-scale paraffin fuel grains (11" diameter by 35" length) capable of surviving cold temperatures for use in propulsion systems with hybrid engines.



Full-scale paraffin fuel grain cast using incremental additions of paraffin wax wafers. Residual stresses arising from this method led to visible cracking of the grain.

A monolithic paraffin fuel grain cast with the novel oven cooling process and devoid of cracks. The paraffin fuel grain is full-scale for use in Mars Ascent Vehicles.

PUBLICATIONS

Patent No: 11,186,794

George T. Story, Andrew Prince, Jessica Chaffin, Timothy P. Kibbey, Britt Oglesby and Ashley C. Karp (2018). Low Temperature Hybrid Mars Ascent Vehicle Concept Development and Planning at MSFC. 2018 Joint Propulsion Conference. AIAA. Ashley C. Karp, Barry Nakazono, Robert Shotwell, Joel Benito, David Vaughan and George T. Story (2017). Technology Development Plan and Preliminary Results for a Low Temperature Hybrid Mars Ascent Vehicle Concept. 53rd AIAA/SAE/ASEE Joint Propulsion Conference. AIAA.

More Information

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MFS-33633-1, MFS-TOPS-103