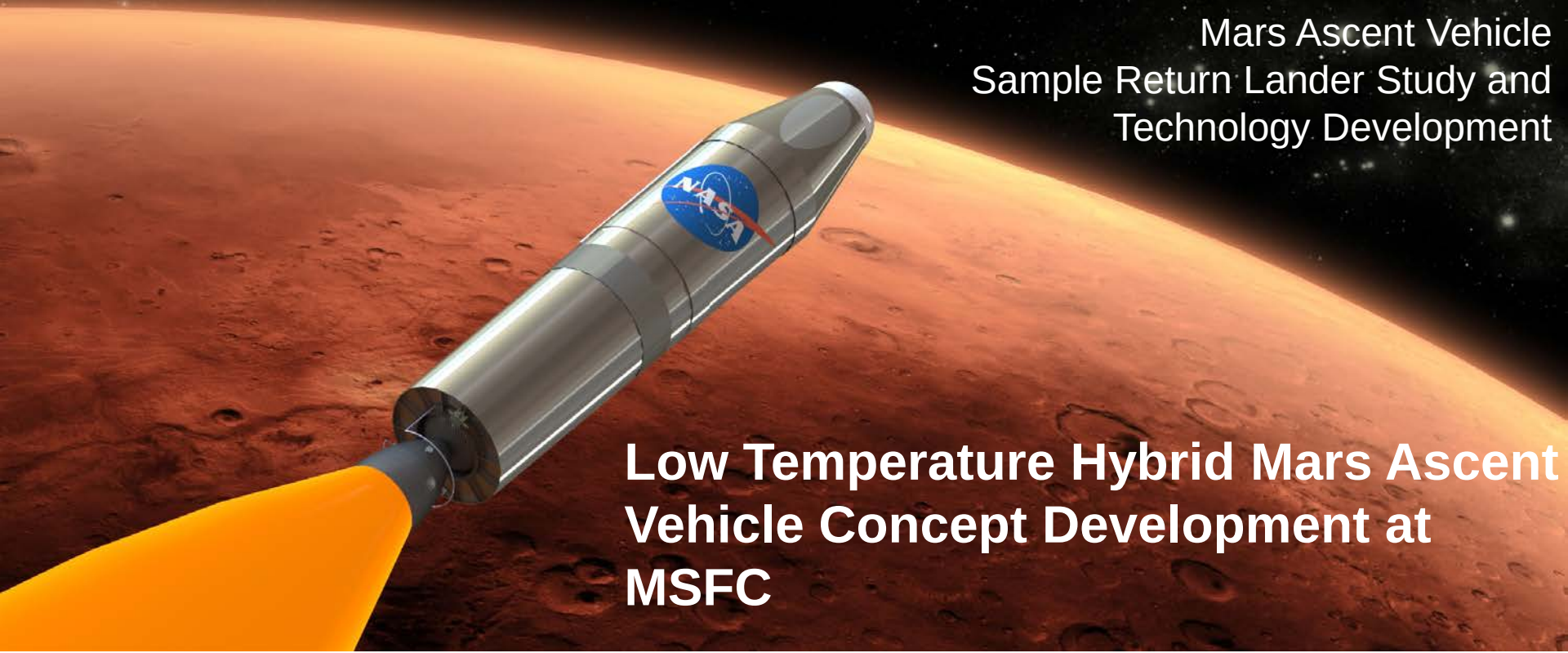

Mars Ascent Vehicle
Sample Return Lander Study and
Technology Development

Low Temperature Hybrid Mars Ascent Vehicle Concept Development at MSFC

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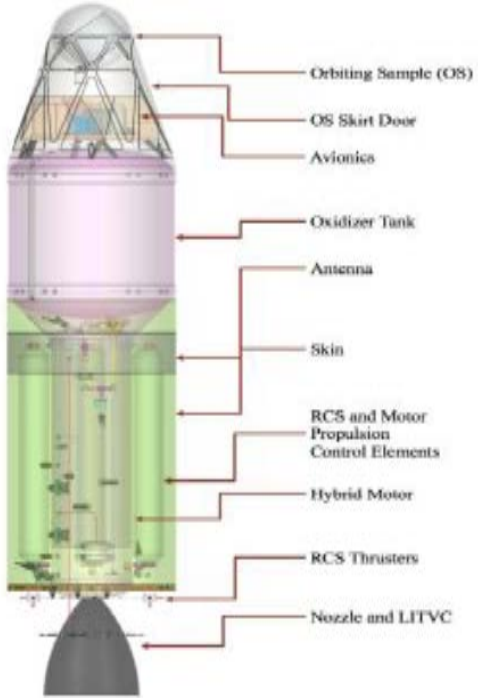
Mars Ascent Vehicle Background

- Return samples from Mars
  - Dr. Karp's Presentation from earlier
    - AIAA-2018-4834 Update on Technology Development Plan for a Low Temperature Hybrid Mars Ascent Vehicle Concept
- Space Propulsion Group (SPG) developed the SP7 formulation, a Wax based fuel
- SPG developed a technique for processing the fuel and delivered the grains for 2016 testing at both SPG and Parabilis
- Two companies started testing in 2017
  - SPG
  - Whittinghill Aerospace

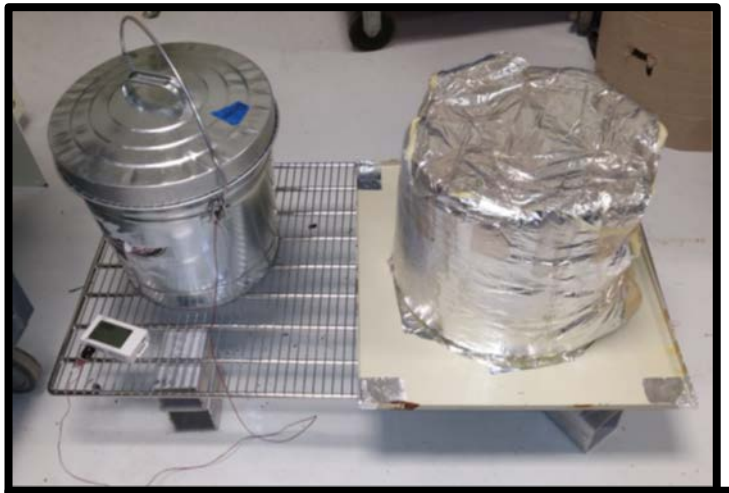


Fuel Processing – Early work

- MSFC's Solid and Hybrid Propulsion Systems (SHyPS) Lab selected to manufacture grains for most recent round of testing.
  - There would be no conflict of interest if an outside party made the grains for both test groups.
  - JPL requested fabrication of a monolithic grain.
- Initial testing included a deep fryer to melt the ingredients and see how small pours reacted in ambient conditions.
  - Shrinkage from liquid to solid state.
  - Large CTE issues.

Fuel Processing – Early work

- Large wax melter was procured and that sped up processing and increased the potential sample size.
- Some early testing concepts included the thermal mass and end cooler techniques.
  - End cooler abandoned (thermal mass way too much)
  - Thermal mass eventually replaced with ovens.



Fuel Processing – First grains

- Good success with grains cast in thin, shallow pans and ambient cooled, which allowed for essentially one dimensional cooling.
- Machining processes were developed.

Mix area

Have had success with grains ambient cooled to certain L/Ds, however identical grains sometimes crack or don't crack in cooling. Higher L/Ds have more cracks. More development work to understand/improve process.

Faces milled flat.

Water jet cut the OD and ID, smooth finish. Baseline process.

Have made enough grain wafers for two test grains (additional segments not shown)

Development test with a forstner drill bit, worked well but chipped the backside. Could be fixed with additional material supporting the grain. (chipping happens with wood also).

Fuel Processing – Grain Bonding

- One of the vendors wanted a cartridge loaded grain.
- It was a process with it's own learning curve.
  - Stacked the grains, 'buttered' the grain OD and case ID, and slid the case over the grains.
- Low viscosity adhesive lead to voids and reworks.

Fuel Processing – Oven Cooling

- To control the cooling and make grains more efficiently, an oven was acquired to control the grain cool down.
- Significant improvement in number of grains that survived.
- Small changes can lead to cracks.

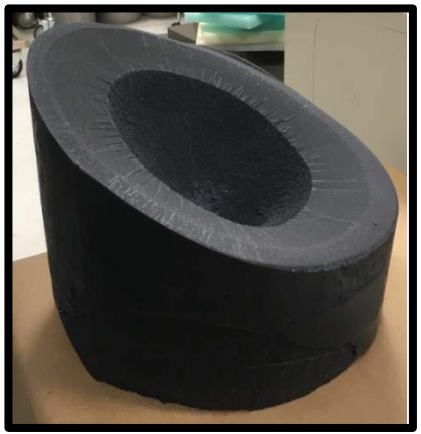
Casting Process - Oven Cooling

Oven cooling allowed manufacturing of larger segments, with a good survival rate.

Pieces were turned on a lathe.

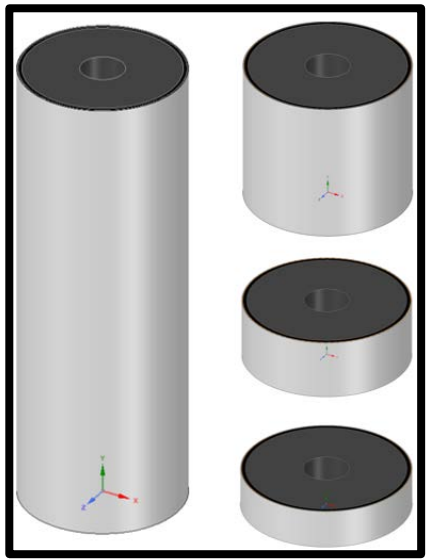
Fuel Processing – Monolithic Grain

- There was a program objective to make a monolithic grain.
- Grain was cast, cooled and moved to another facility for machining, on the way it cracked.
- Machined into the shorter of the grain shapes.



Structural Analysis

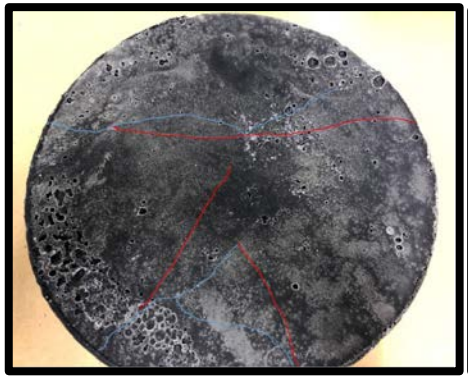
- Analysis indicated that going to a multisegment grain configuration would lower the stresses in the grain.
  - Reducing the segment length of the SP7 propellant has theoretically shown to have a correlative impact on the peak stresses seen within the propellant and along the propellant boundary.
  - The most significant improvement is realized in the axial stress direction. Tensile stresses, specifically, see the most improvement.

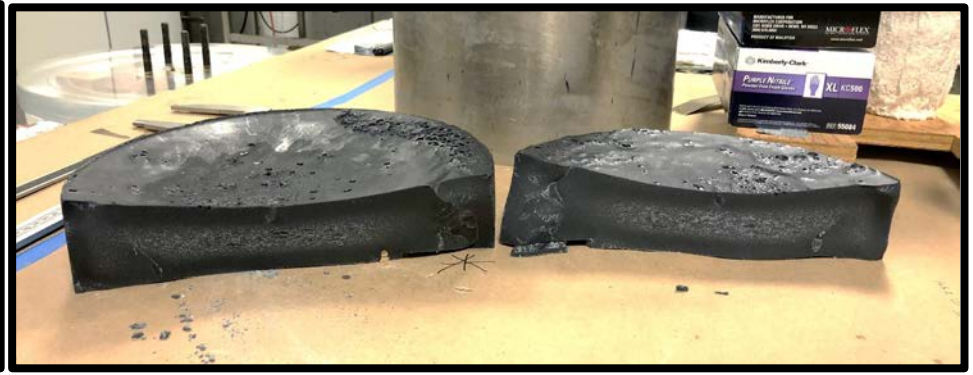


Cold shock

- Decided to use the monolithic grain.
- Stored over the weekend at ~-30C(-22F) and then brought into a ~20C(68F) workspace.
- Broke apart in ~2 hours.
- Analysis and other testing done to confirm failure mode.

Exceeded 10.8 C/hr max rate from Farias AIAA-2016-4563



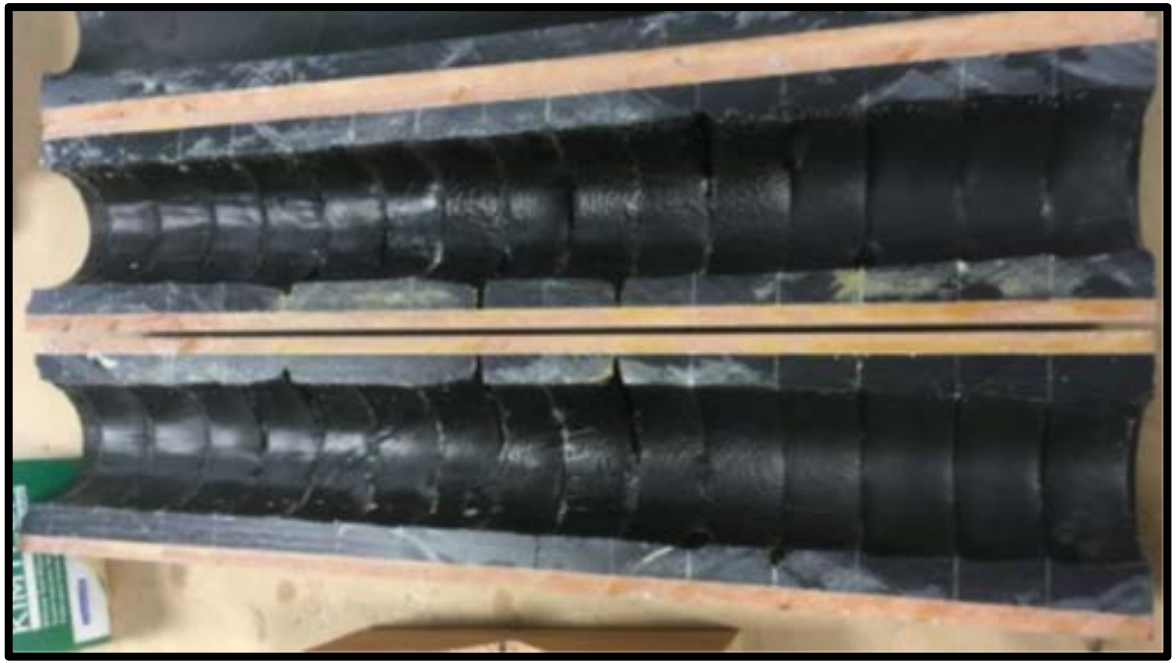


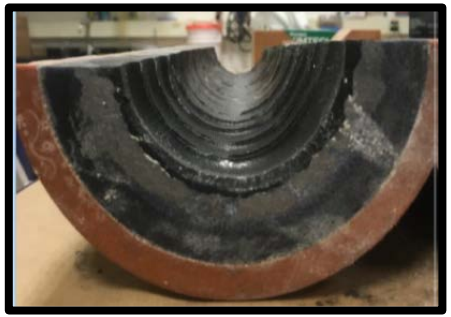
SFT – Solid fuel tests

- Solid Fuel Torch is a testbed to simulate solid rocket motor combustion on insulator materials.
- Wanted to test the multisegment configuration to see what it would do to the burn rate surface.
- 3 configurations tested
  - Bonded segments
  - Unbonded segments
  - Monolithic

Bonding was done with the same material used in the bonding of the cartridge to the grains. Not an exhaustive search of materials.

SFT – Solid fuel tests - Bonded



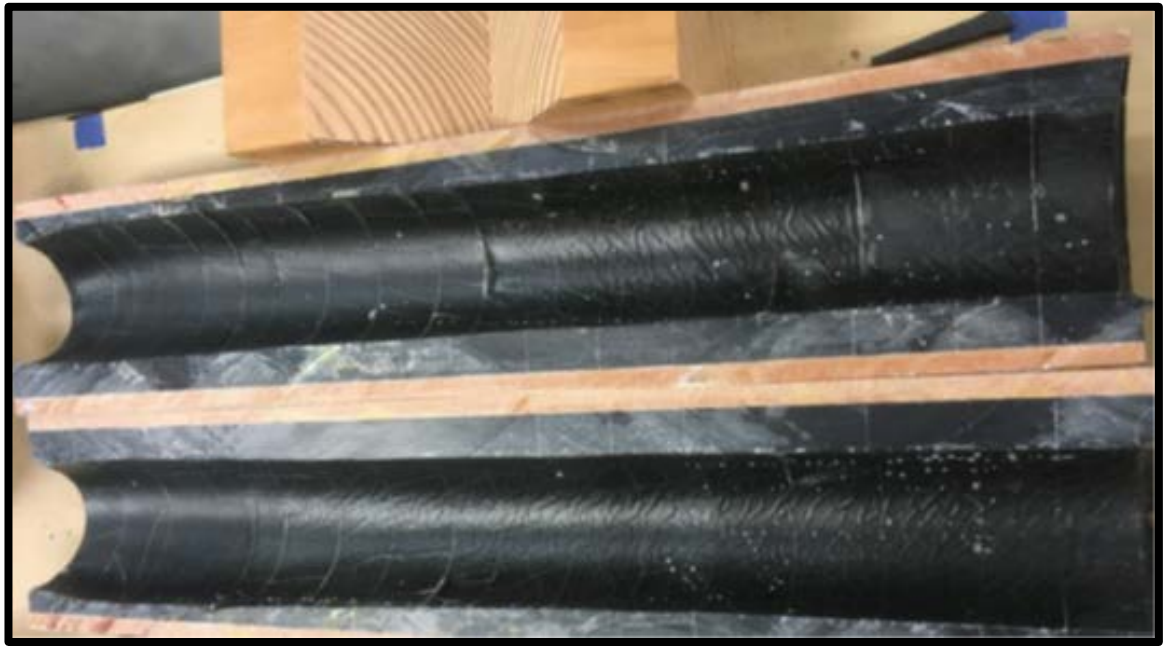


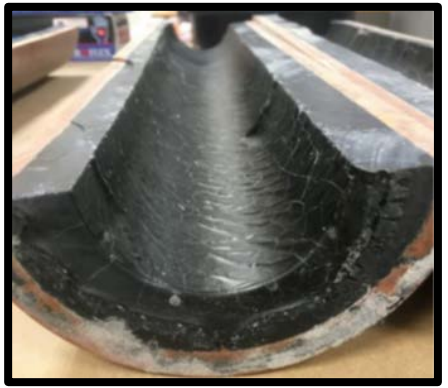
- More regression at the interfaces.

SFT – Solid fuel tests - Monolithic

- Smooth port.

SFT – Solid fuel tests - Unbonded





- Smooth burning at the gaps.

Conclusions

- Processes developed for manufacturing SP7 based grains in the scale needed for the MAV hybrid propulsion system option (~28 cm).
  - Ten full scale fuel grains have been delivered and tested at subcontractors.
  - SP7, being a wax based fuel, is tricky to manufacture because it shrinks by about 20% during the liquid to solid phase transition.
  - SP7 also has a large CTE that makes motor design for the large MAV temperature swings more delicate.
  - Solutions have been found for some of the issues, but others still need to be overcome. 14

- Solid fuel torch testing was used as an indication of how the larger scale grains would behave during hotfire testing.
  - It was an inexpensive, relatively fast way to determine if segmented fuel grains would cause problems such as uneven burning.
  - It was found that the segmented grains without adhesive in between the layers performed as well as the larger (as close to monolithic as possible at the time) in terms of regression rate uniformity.
  - The grains with adhesive regressed more rapidly at the segment boundaries, creating a non-uniform regression rate.

Questions?