MAV
Mars Ascent Vehicle

Thermal Cycling for Development of Hybrid Fuel for a Notional Mars Ascent Vehicle

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AIAA Propulsion and Energy, 2016

MSFC
Marshall Space Flight Center

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Pre-decisional, for information and discussion purposes only.

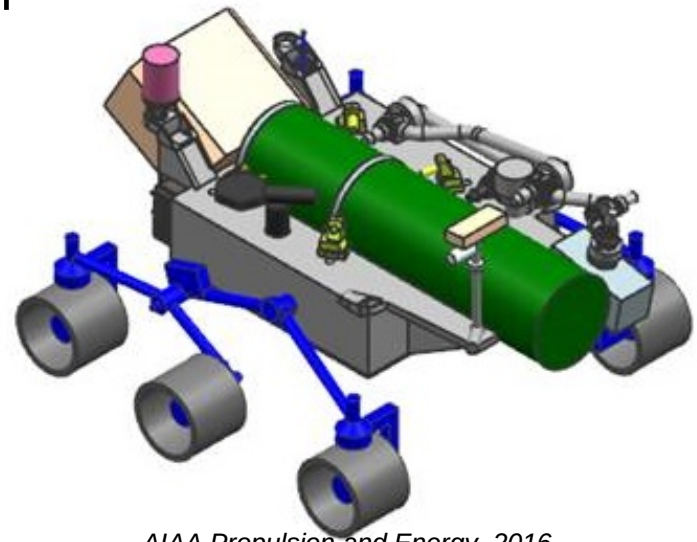
Outline

Mars Ascent Vehicle

- MAV Concept Introduction
- Thermal Design Concept
- Thermal Analysis
- Thermal Testing
  - Preliminary Testing
  - Long-Term Cycling
- Fuel Cracking Observations
- Future Work
- Conclusions

Introduction

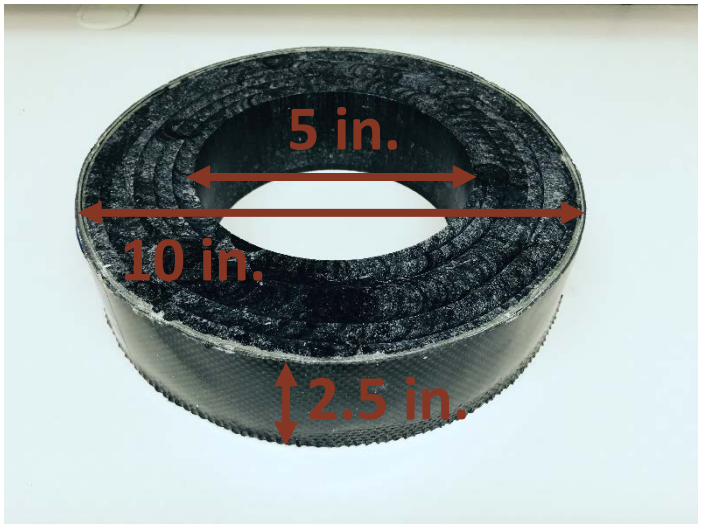
- Potential Mars Sample Return: a series of missions that would return Martian samples to Earth
  - Collect Martian samples
  - Launch samples into Mars orbit
  - Return samples to Earth
- A Mars Ascent Vehicle (MAV) would accomplish the second phase
  - Notional concept for a mobile MAV:



Hybrid Fuel: SP7

- Hybrid rockets utilize solid fuel and liquid oxidizer
  - Good candidate for a MAV mission concept due to predicted excellent low temperature behavior
- Space Propulsion Group, Inc. formulated a wax-based fuel, SP7, for consideration for a MAV mission concept
  - Designed for operability within -100°C to 50°C
  - Two versions:

Non-aluminized



Aluminized (20% by mass)

SP7 Thermo-physical Properties

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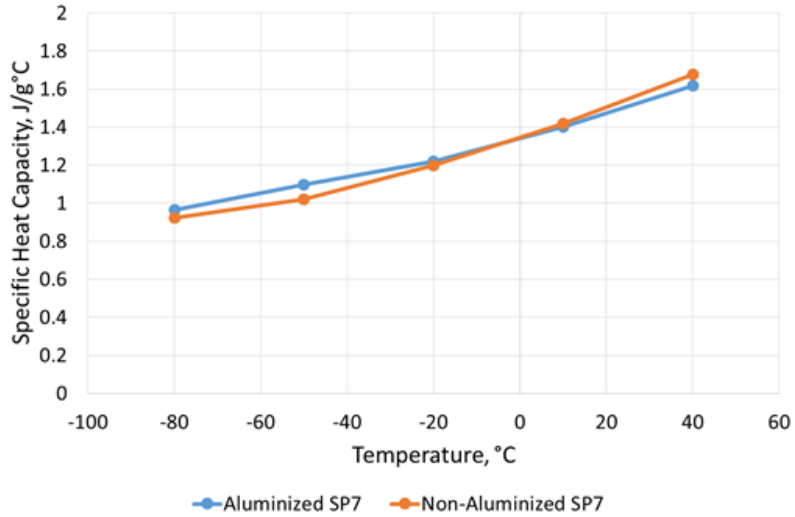

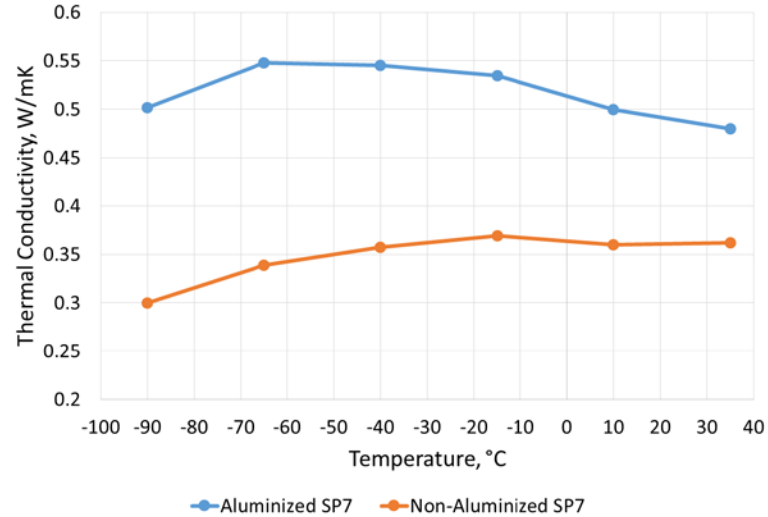

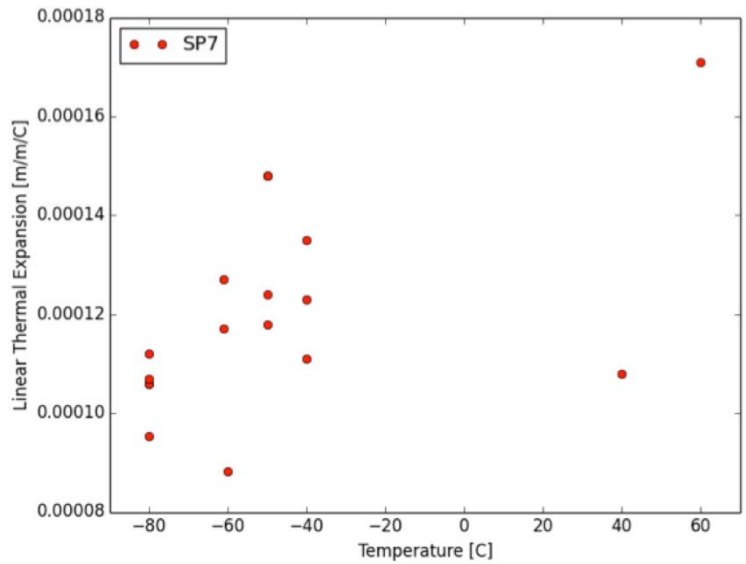

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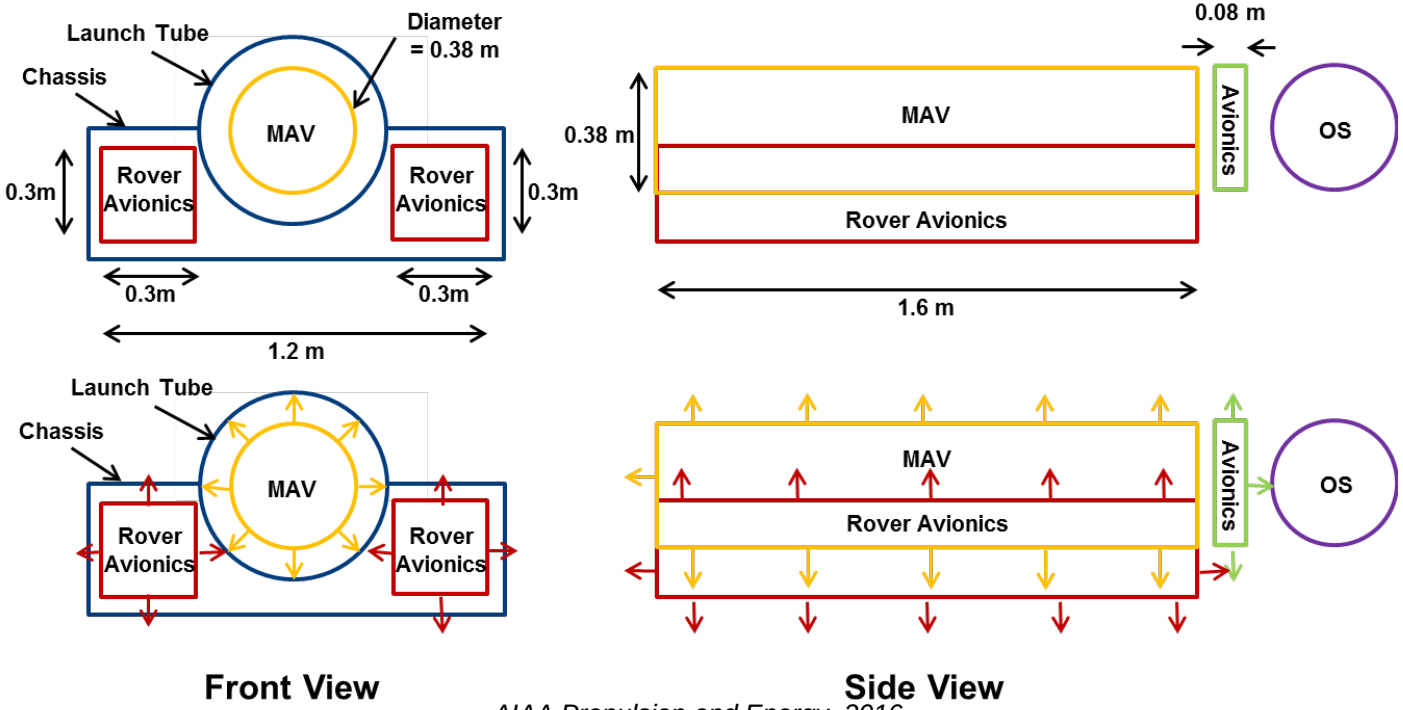
Thermal Design Concept

- Survival heating would be important as ambient temperatures reach -130°C during winter
- Similar thermal design as MSL rover assumed for survival heating sensitivity study
  - 2 inches of CO_2 gas gap for insulating internal components
    - 4 inches of gas gap assumed for insulating the MAV



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Survival Heating Sensitivity

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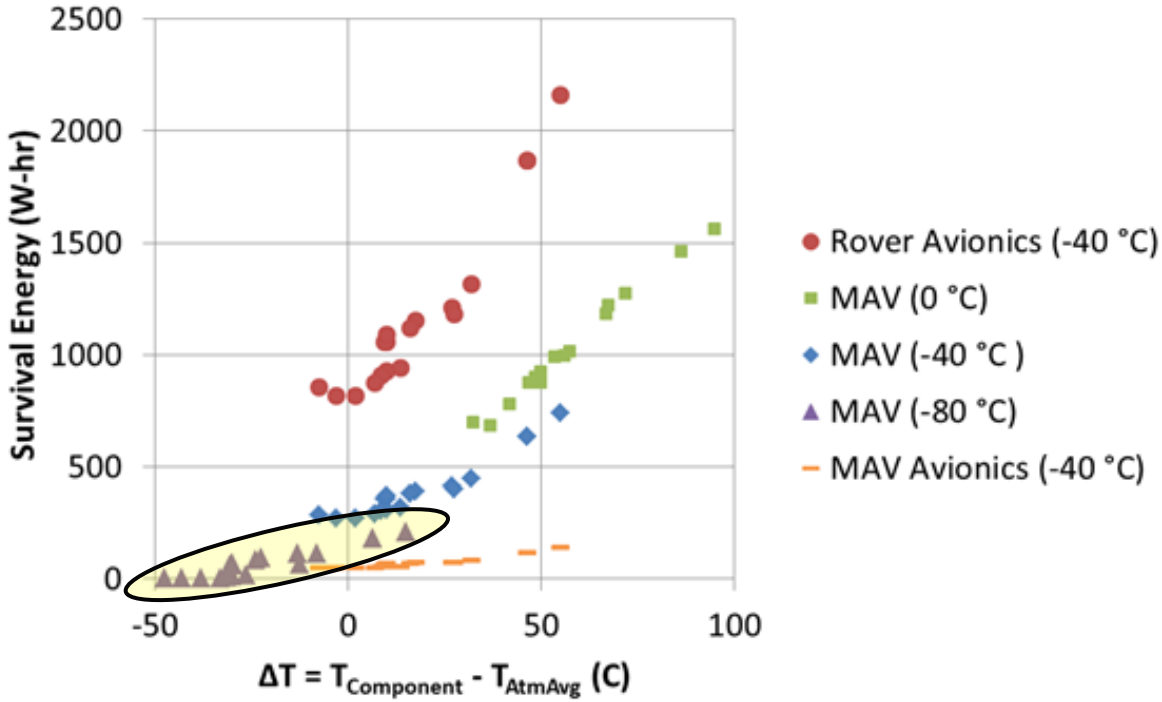
- Survival heating estimated for 3 seasons (summer, spring, winter) at 6 latitudes between +/-30°
- A MAV concept capable of surviving cold temperatures reduces the needed survival energy and could allow for reduced insulation



Thermal Analysis

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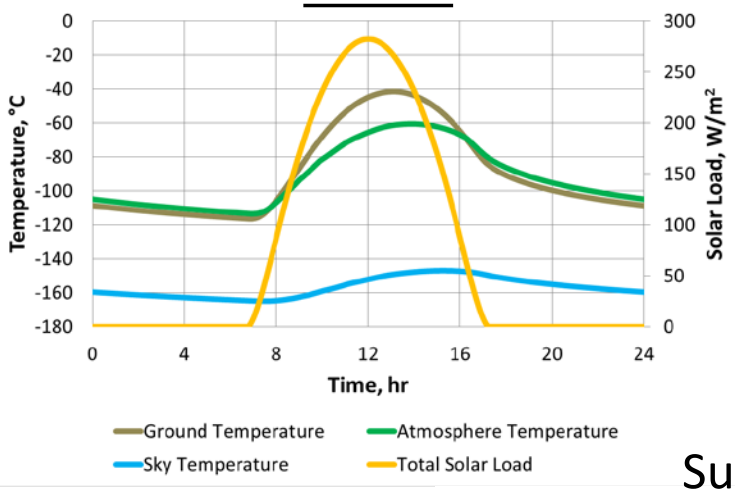
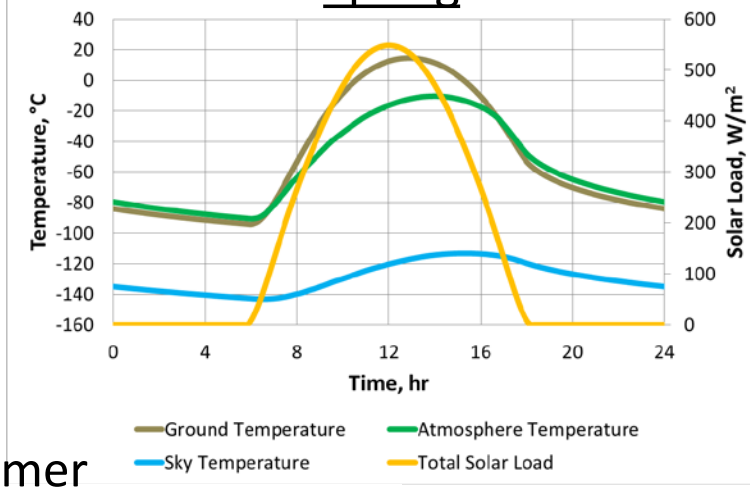
- Bounding environments used to estimate the temperature response of a MAV with 2 inches of CO_2 gas insulation

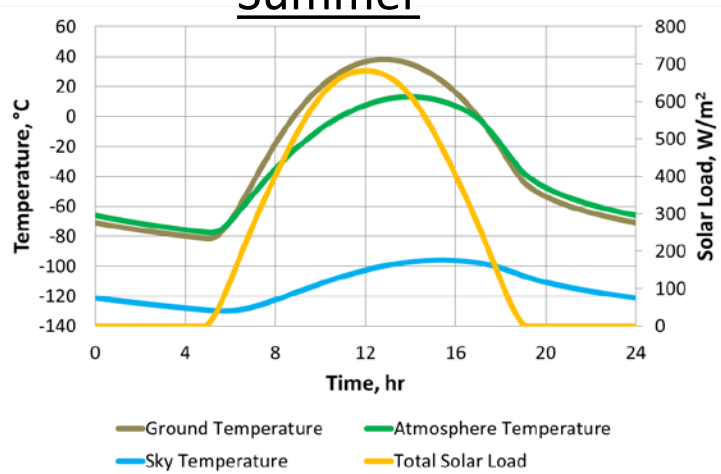
Winter



Spring

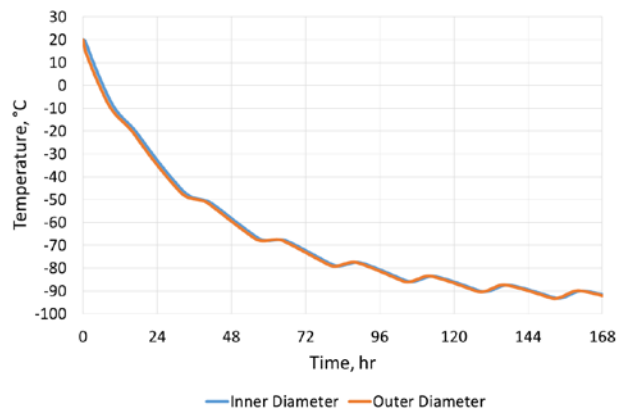


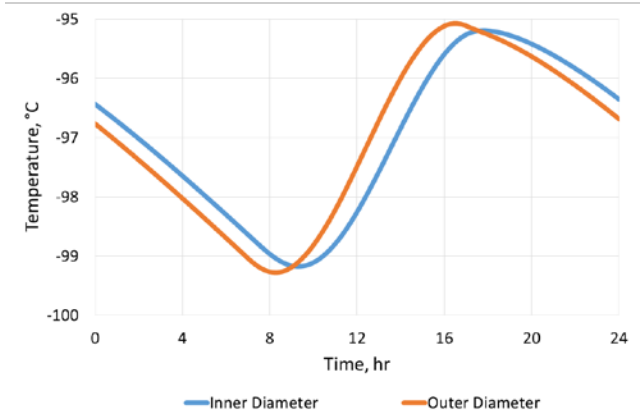
Summer

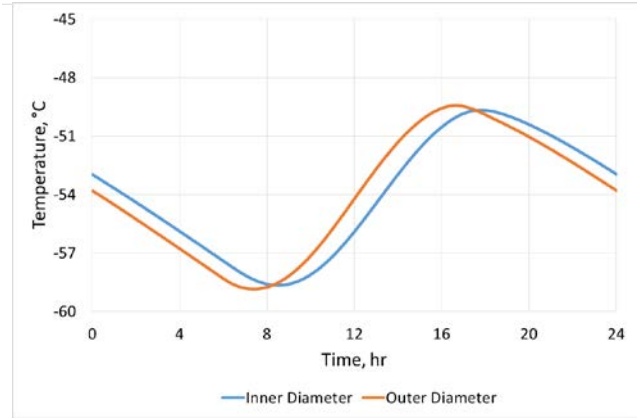


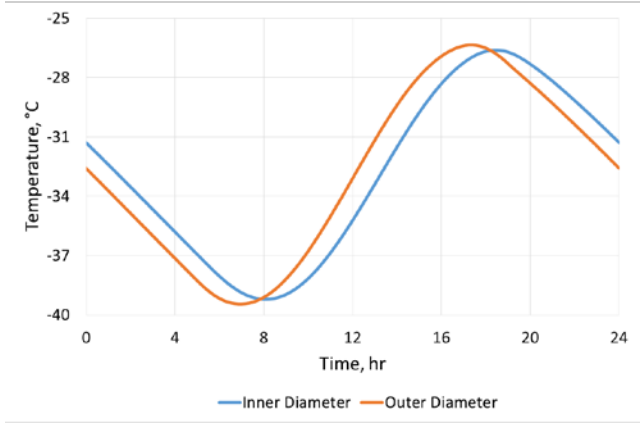
Thermal Analysis

	EDL	Winter	Spring	Summer
Max Temperature, °C	N/A	-95	-49	-27
Min Temperature, °C	N/A	-100	-59	-40
Max Radial Gradient, °C	7.0	0.9	1.8	2.3
Max Ramp Rate, °C/hr	7.3	0.8	1.6	2.0









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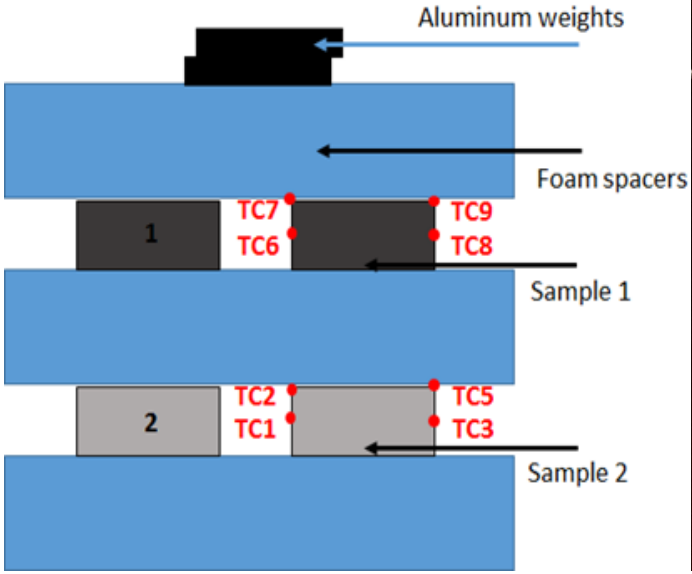
Preliminary Thermal Testing

- Testing conducted using 3 thermal cycles to estimate the max conditions the fuel could experience without cracking



	Preliminary Test Results
Max Temperature, °C	53
Min Temperature, °C	-115
Max Radial Gradient, °C	17.5
Max Ramp Rate, °C/hr	10.8

Long Term Thermal Cycling

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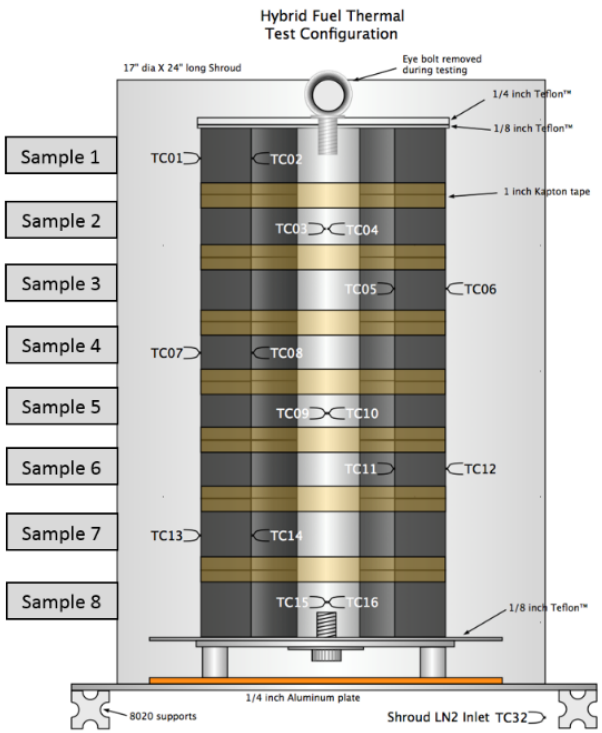
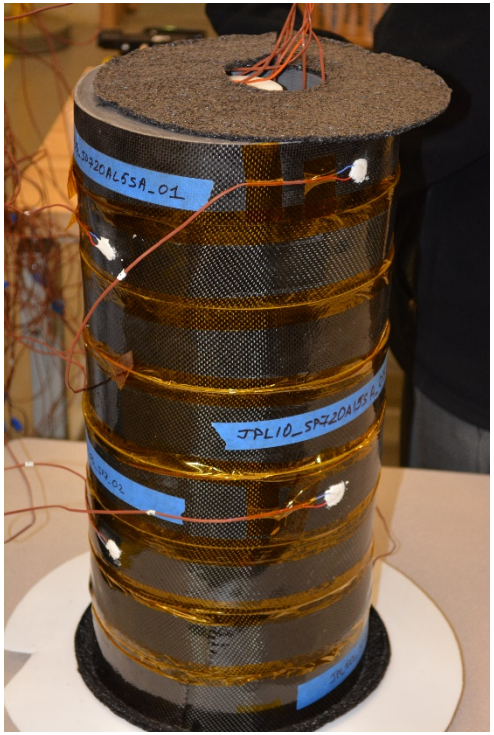
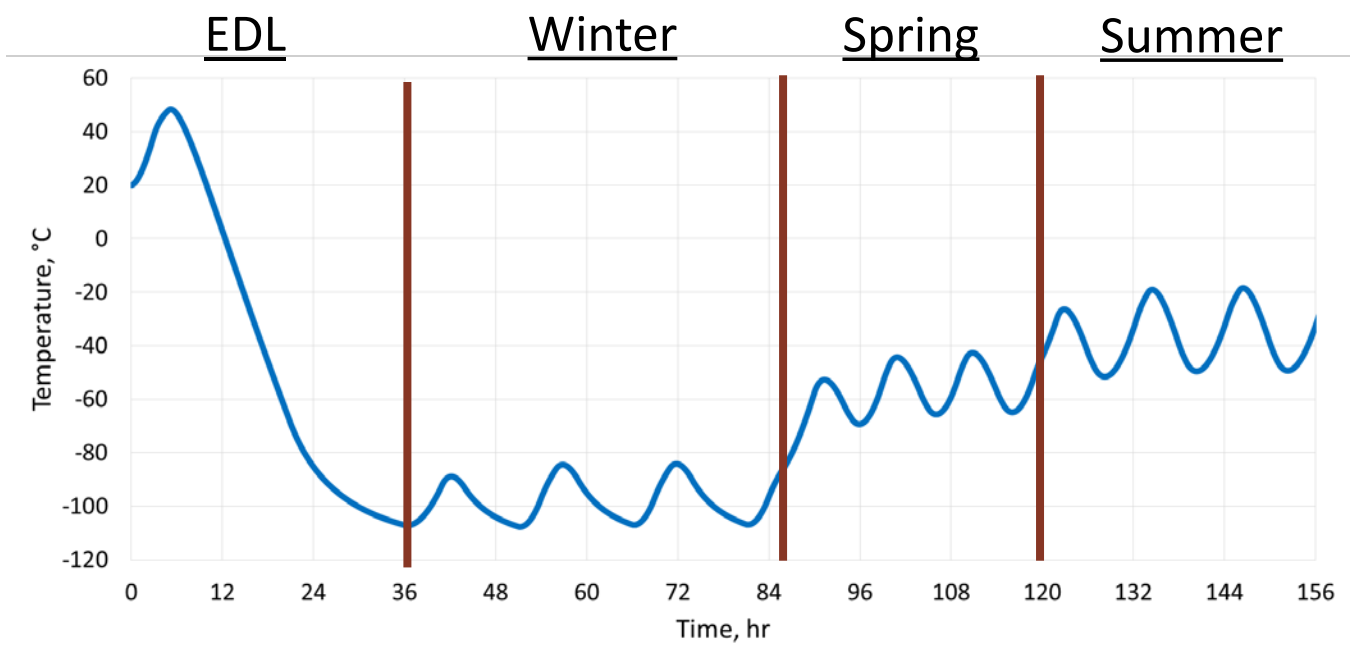
- A MAV mission concept could result in the fuel experiencing over a year of diurnal temperature cycling
- Extended thermal cycling of SP7 necessary to understand capability under numerous cycles
  - Test configuration:





Thermal Cycle Profiles

- A 100-day test plan designed to simulate 1 EDL cycle, 50 winter cycles, 100 spring cycles, and 50 summer cycles
- Predicted results:
  - Only 3 cycles for winter, spring, and summer are shown for clarity



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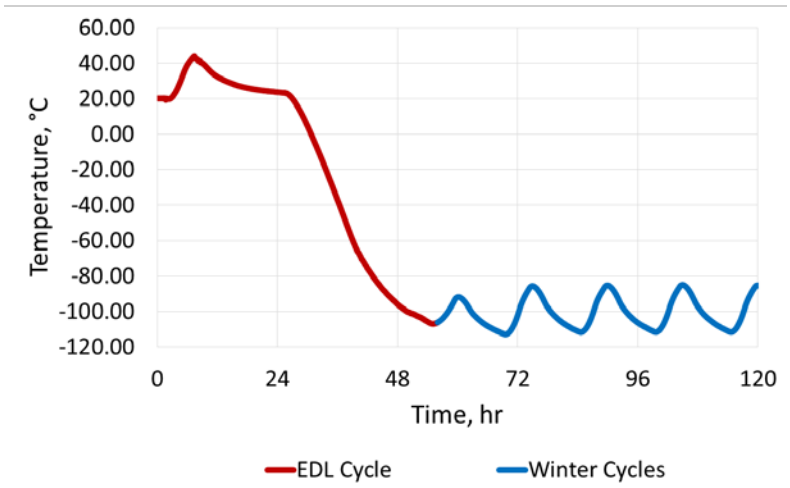
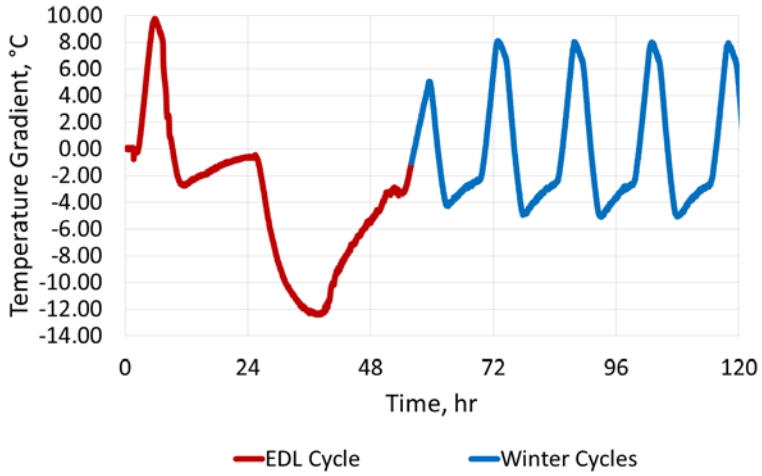
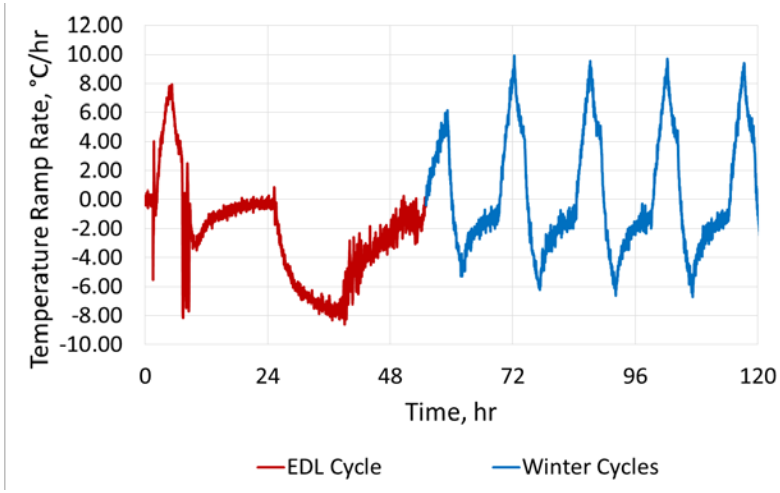
EDL and Winter Test Data

- Snapshot of EDL and Winter data for a single fuel sample







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EDL and Winter Test Data

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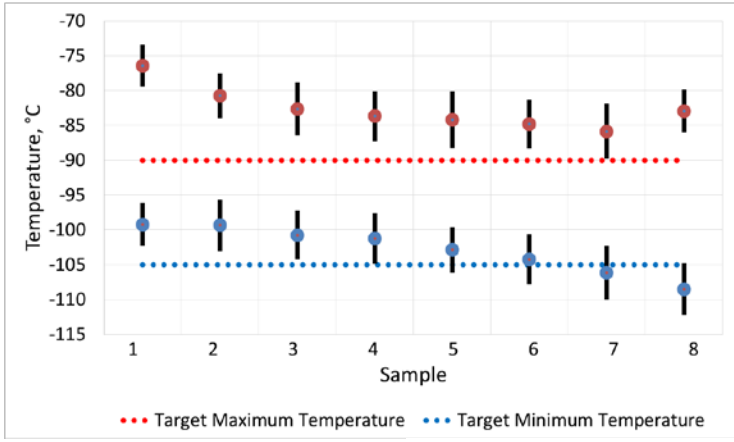

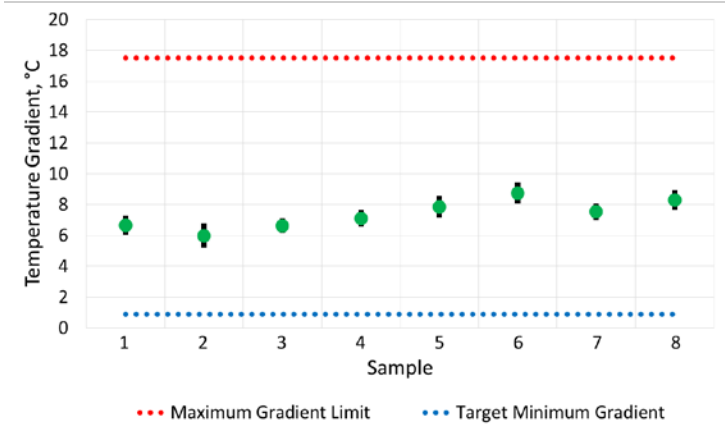

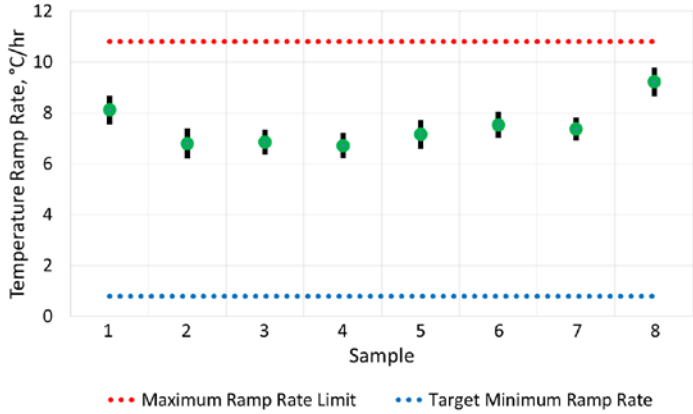

	Sample							
	1	2	3	4	5	6	7	8
Max Temperature, °C	39.2	38.3	38.1	38.4	40.5	41.6	42.1	44.1
Min Temperature, °C	-96.3	-96.3	-96.7	-97.4	-98.9	-101.3	-104.2	-107.1
Max Radial Gradient, °C	10.2	10.6	11.4	11.7	13.7	15.7	14.1	12.4
Max Ramp Rate, °C/hr	7.5	7.5	6.9	7.1	7.2	7.9	8.1	8.6

EDL and Winter Results

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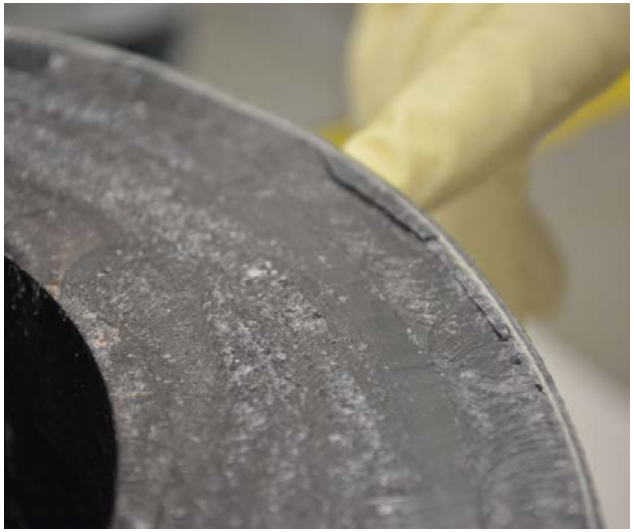
- These two portions of the testing were <u>successful</u>
  - The fuel experienced a simulated EDL cycle and 50 winter cycles with no radial cracking
  - Small circumferential cracks were observed, but this is a known issue due to CTE mismatch with the fuel's outer liner

<u>Before</u>

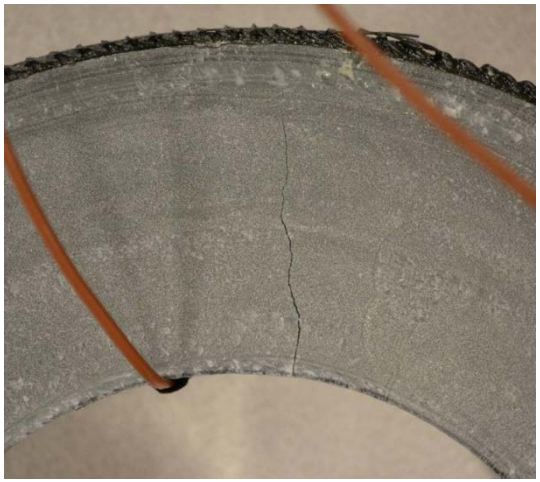
<u>After</u>



Testing Anomalies

- Some of the testing resulted in cracked samples (either through planned or unplanned scenarios)
- Thermal gradient may be responsible for the fuel cracking

Scenario	Sample	Radial Gradient	Ramp Rate	Cracking
Power outage	1	19.6	36	No
	2	20.7	33	No
15 °C/hr ramp rate	1	21.1	18.4	No
	2	25.9	18.5	Yes
Solenoid failure	1-8	20.0 to 27.7	27.3 to 37.2	Six of Eight
Contact relay failure	1-8	11.6 to 17.3	25.8 to 36.1	Zero of Eight



Future Work

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- Analyze data from the Spring and Summer cycles
- Analysis and testing to better understand the cracking of the fuel
- Study the implications of cracked fuel to determine their effects during combustion
  - AIAA-2016-4656: *Hybrid Propulsion In-Situ Utilization Test Facility Results for Performance Characterization*. F.S. Mechentel

Summary

Mars Ascent Vehicle

- Challenging requirements would be placed on a MAV mission concept
  - Winter ambient temperatures can reach -130°C
- A fuel capable of surviving at low temperatures would reduce the necessary survival heating energy as well as necessary insulation
- A 100-day thermal cycling test was designed to simulate Mars EDL, winter, fall, and summer
- All cycling has been completed with no observed cracking
  - The only cracking that occurred was under extreme thermal gradients that are not representative of what the fuel could see in a MAV mission concept