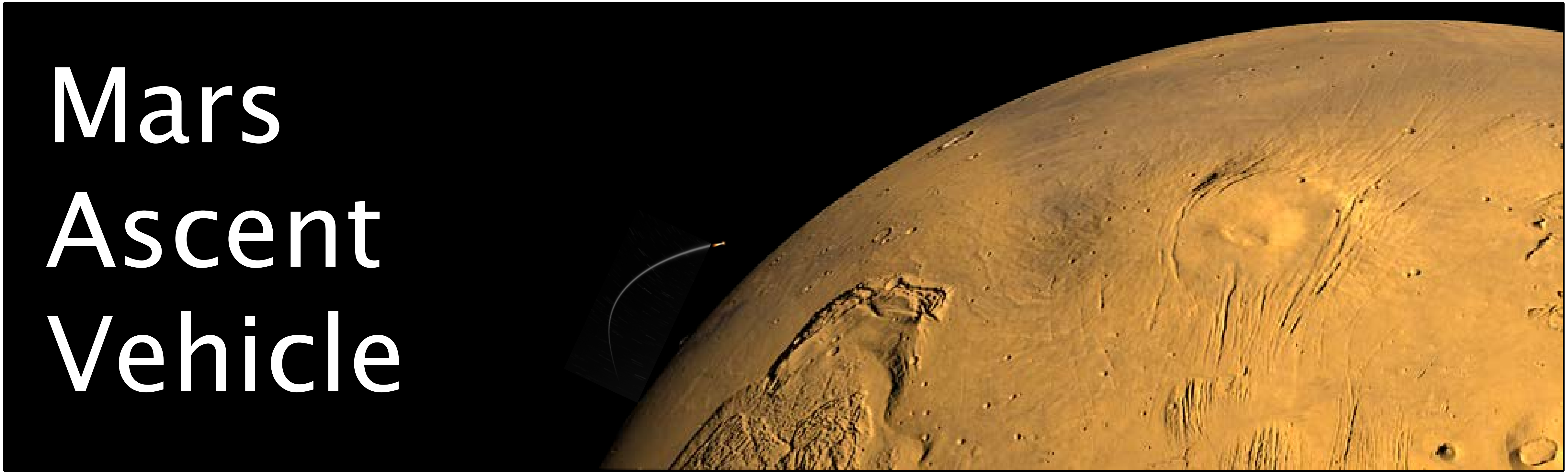

Jet Propulsion Laboratory
California Institute of Technology

MARSHALL
SPACE FLIGHT CENTER

MARS ASCENT VEHICLE HYBRID PROPULSION DEVELOPMENT

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June 2019

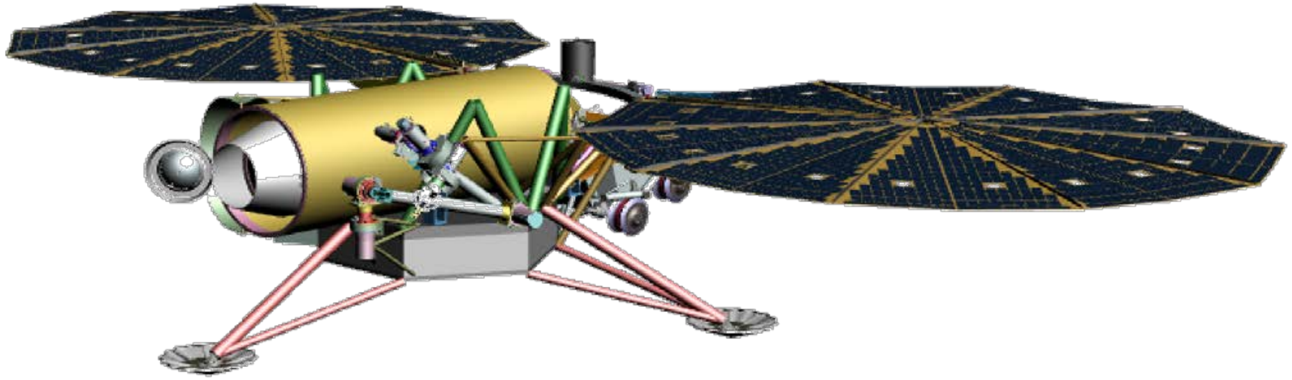
Pre-Decisional

Agenda

- *Potential Mars Sample Return (MSR)*
- *Potential Hybrid Design*
- *2019 Preliminary Architecture Assessment*
- *Propellant Combination: Fuel*
- *Propellant Combination: Oxidizer*
- *Full Scale Testing thru 2018*
- *Hypergolic Ignition*
- *TEA/TEB Ignition*
- *Solid Hypergolic Additives*
- *2018 test – longest duration test*
- *2019 test*
- *Liquid Injection Thrust Vector Control*
- *White Sands Test Facility*
- *FY19 and Future Work*
- *Summary*

Potential Mars Sample Return (MSR)

- A potential MSR campaign is being studied jointly by NASA and ESA for launch as early as 2026.
  - Technology development for a hybrid propulsion system that could meet this challenging schedule.
- Sample Retrieval Lander
  - Studying a Propulsive Platform Lander and Skycrane Delivered Lander
  - Notional requirements of 400 kg and <3 m



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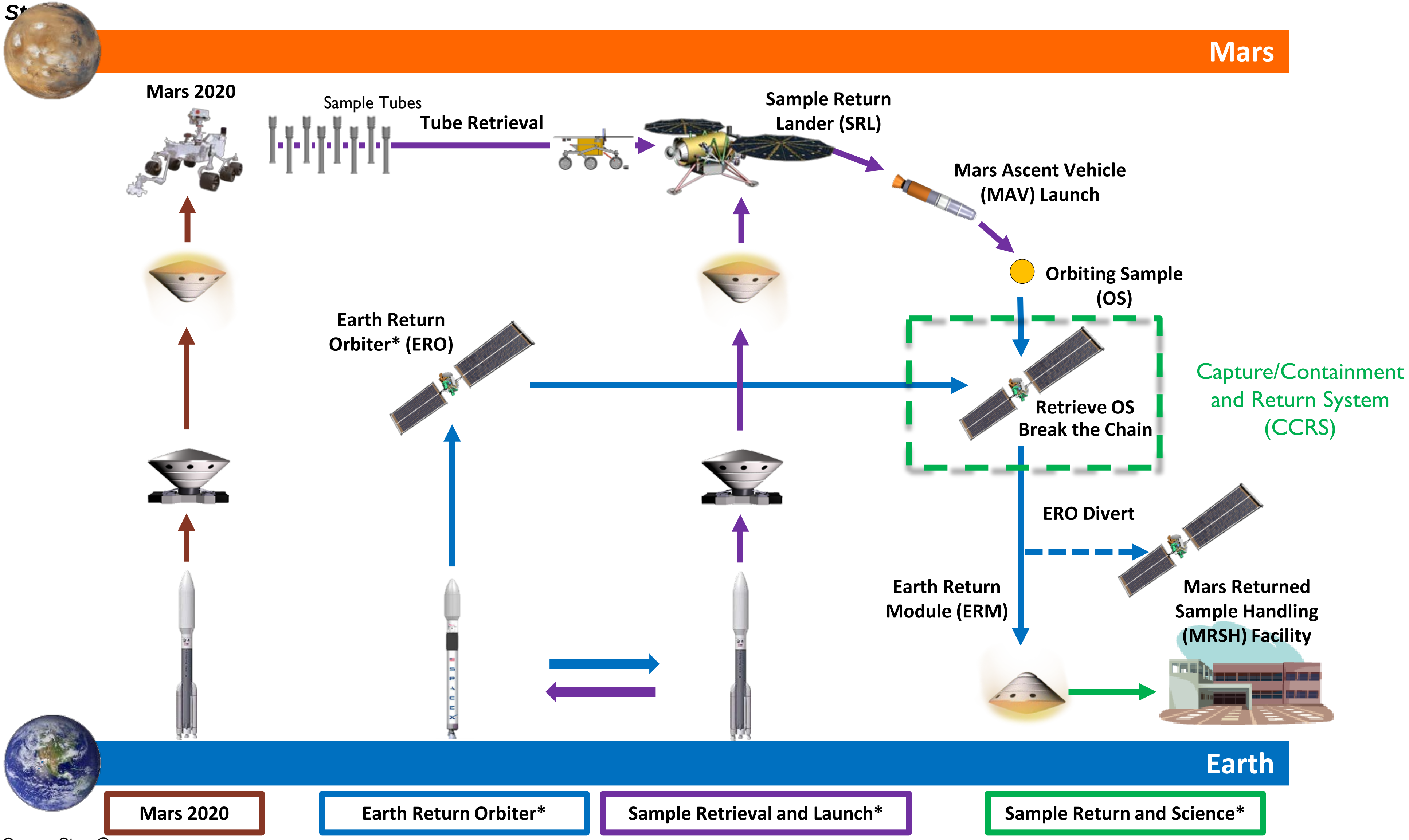
Mars Ascent Vehicle St

Potential Mars Sample Return Overview



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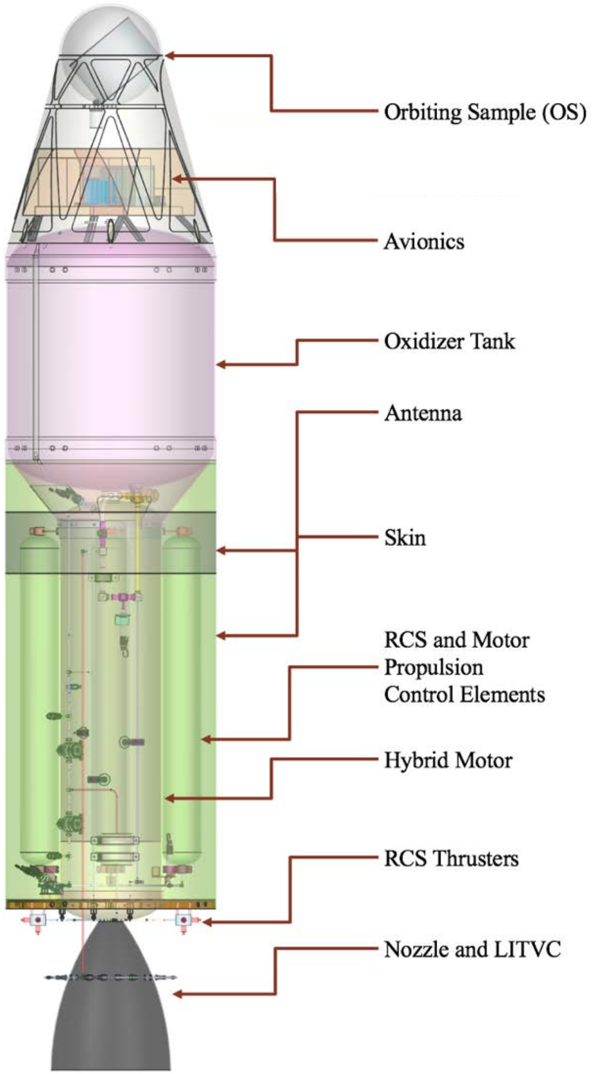
*Concepts under study

Potential Hybrid Design

- The main focus for the hybrid propulsion team has remained on the technology development of the novel propellant combination and the design has matured along with the tests.
- Additionally, preliminary work on the Sample Retrieval Lander has started to drive mass and geometric constraints.
  - Mass: maximum of 400 kg GLOM for a payload of 14 kg(30 samples).
  - Geometry: 2.8 m by 0.57 m



2016 PODR

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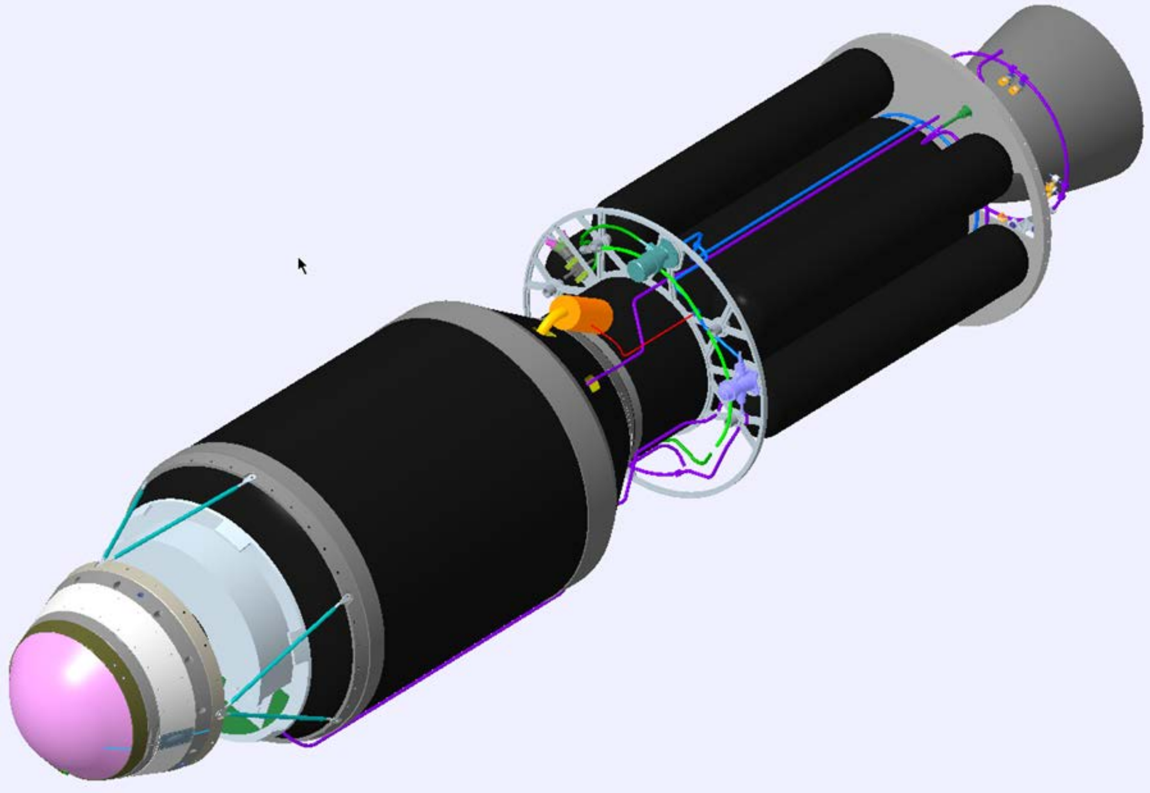
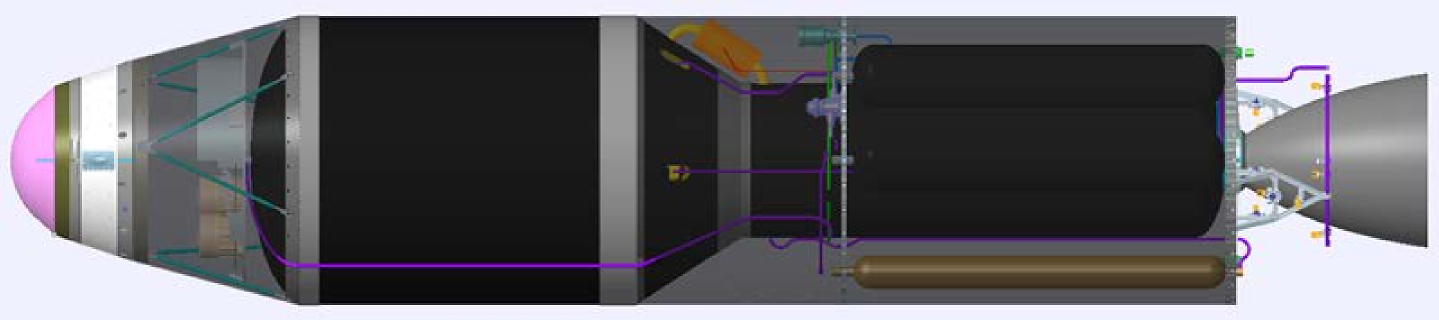
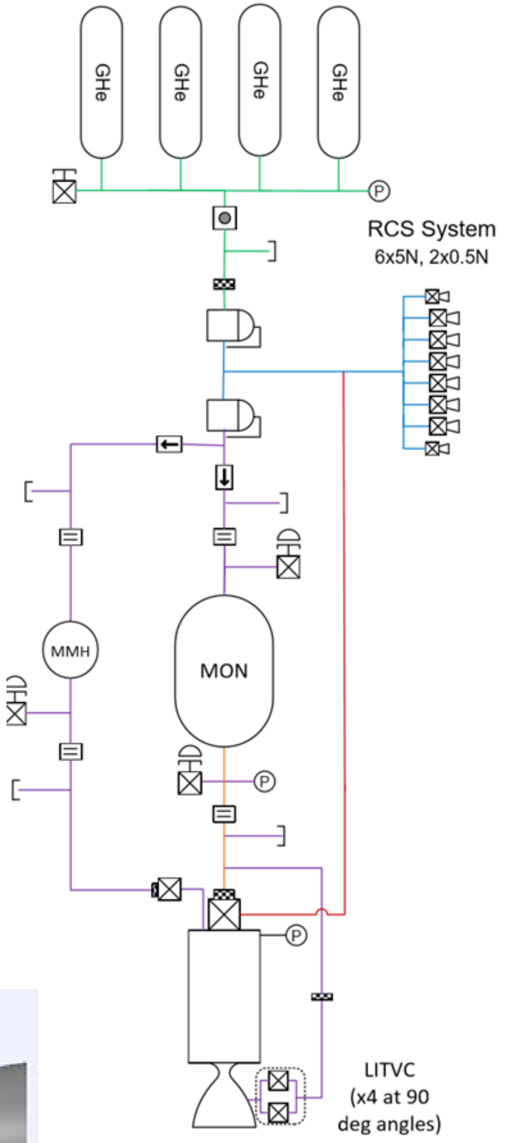
2019 Preliminary Architecture Assessment





Hybrid MAV

Ashley Karp, v. 4/19/2019



Legend

- Tank
- Fill & Drain Valve
- F&DV with Cap
- Pyro Valve
- Latch Valve
- Solenoid Valve
- Check Valve
- Regulator
- Filter
- Burst Disk
- Cavitating Venturi
- Test Port
- Pressure Transducer
- Pyro Igniter
- RCS
- Hybrid Motor

Ti 3Al2.5V Tube Pressure Levels & Sizes

- 10,000 psia, 1/4"
- 1,000 psia, 1/4"
- 430 psia, 3/4"
- 430 psia, 1/4"
- 430 psia, 1/8"

Propellant Combination: Fuel

- SP7 is a wax-based (but higher melt temperature/viscosity than paraffin)
- *Residual stresses*
  - SP7 shrinks 15-20% in the liquid to solid phase transition
  - The material cools from the outside inward, leaving residual stresses within the segment.
  - Grains were first allowed to cool at ambient conditions → cracking
  - Later grains were cooled at a controlled rate with success, however minor changes to the cooling process have resulted in issues, implying residual stresses are still high.
  - Southern Research is carrying out material testing on SP7 to obtain material properties for modeling
- Reformulated SP7 to get 85% regression rate version, called SP7A

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Propellant Combination: Oxidizer

- Mixed Oxides of Nitrogen (MON) is a common space storable oxidizer, but has not been used for a hybrid motor in the past.
  - Most existing propulsion systems use MON-0.5 to MON-25, where the number stands for the percentage of NO in the mixture (by mass).
  - Previous hybrid MAV concepts used MON-30 because of it’s low freezing point, <-80C.
    - The curve relating freezing temperature to the amount of NO in the mixture is very steep, with a difference of about 25 C between MON-25 and MON-30.
  - The current mission design indicates that the MAV and oxidizer could be kept above -40 C (the updated mission timeline does not require the MAV to be on Mars in winter)
  - A move to MON-25 was made in 2018 based on the new mission timeline and the availability of the oxidizer.
- One of the challenges (and benefits) of MON is that it is reactive with many materials. All potential components are being evaluated for compatibility and hypergolic ignition.

Hypergolic Ignition

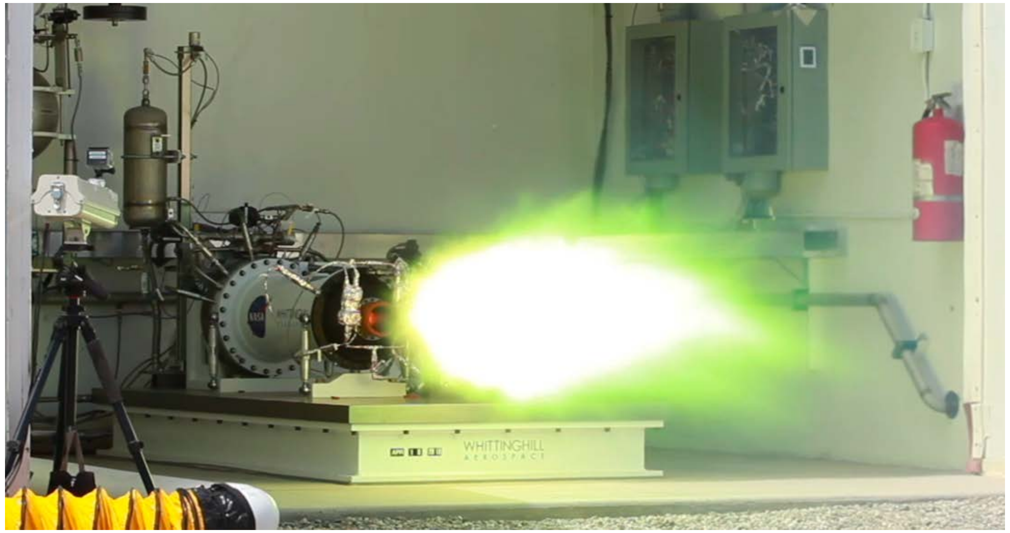
- Previous studies suggested that hypergolic ignition, with solids mixed in the SP7, would be the lightest mass option for MAV.

- Two methods of hypergolic ignition are currently being considered.

  - Liquid: Triethyl Aluminum and Triethyl Borane (TEA/TEB) with the MON oxidizer.
    - Commonly used (with oxygen) in rocket applications
    - Purdue completed a drop test with N_2O_4 that indicated it is hypergolic with TEA
    - Other hypergolic liquids are available and some have been tested in ignition tests

  - Solid: Solid materials are added to the hybrid fuel grain that are hypergolic with MON.

TEA/TEB Ignition



- *TEA/TEB* is currently being used with a small amount of GOx to ignite the motor and maintain stable combustion throughout the burn (vaporize the MON)
- Disadvantages:
  - The TEA/TEB system accounts for nearly 20% of the total component count in the feed system.
  - Safety considerations of carrying a hypergolic liquid
  - Performance at low temperatures may not be sufficient
- Using TEA/TEB and GOx for current testing until a different hypergolic, MMH, can be tested with MON-25. Historical data shows MMH/MON-25 thruster firings at -40C.

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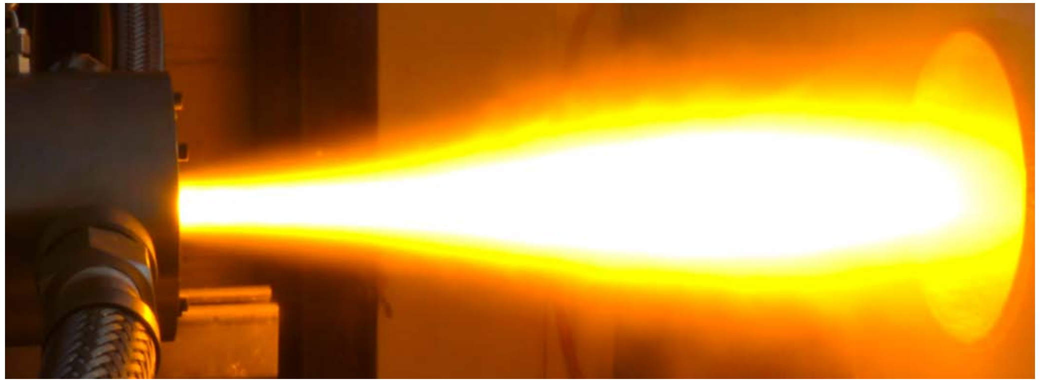
Solid Hypergolic Additives

- Solid hypergolic materials simplify the design by not requiring additional tanks/plumbing
- Subscale hotfire testing (2 inch scale) at Purdue confirmed the performance of several solid hypergolic options using different amide formulations and MON.
- Unique processing steps were developed by Purdue to incorporate the material into SP7.
- The main disadvantage of this option is the additives sensitivity to moisture, complicating handling of the otherwise inert motor.



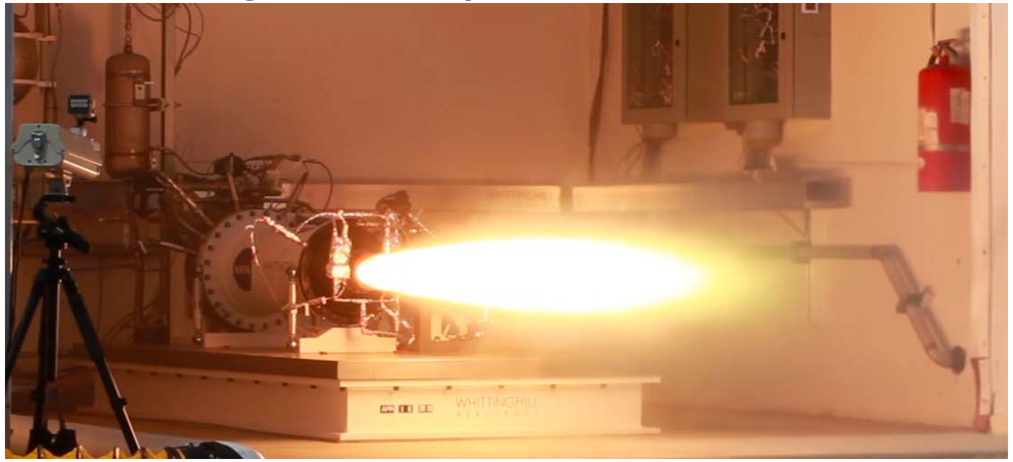
2" motor test at Purdue

Full Scale Testing thru 2018

- Two vendors have completed hybrid motor testing at full scale over the past year and a half.
  - Duration: almost full mission duration testing with a motor shutdown and restart without human intervention.
  - Performance: C* efficiency ~ 90% (goal 95%)
  - Concerns
    - Stability: using TEA/TEB to vaporize MON
    - Nozzle erosion
  - All testing was with MON-3 because it is less expensive, easier to acquire and is has similar vapor pressures at atmospheric conditions to MON-25 at -20 C.

Space Propulsion Group, of Butte, MT

Whittinghill Aerospace, of Camarillo, CA



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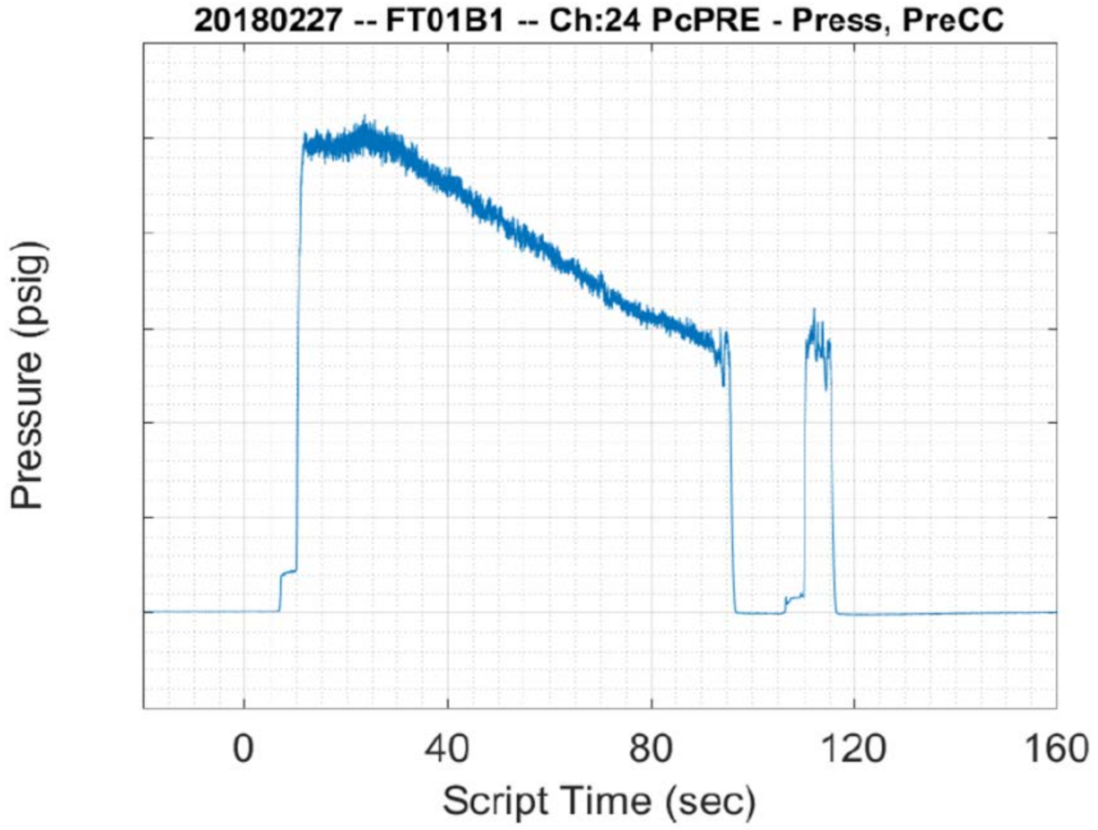
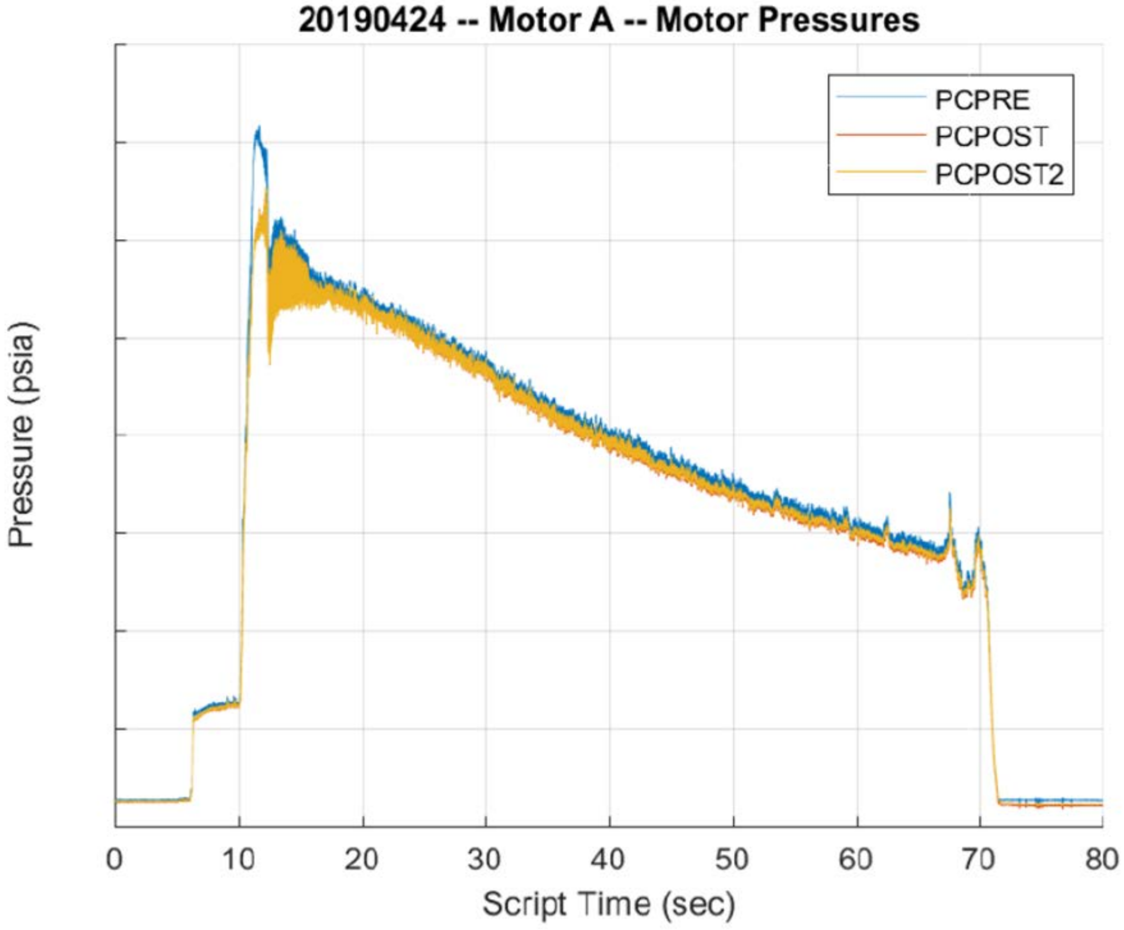
2018 test – longest duration test



- SP7 MON-3
- Ambient Temp
- Ignition source TEA/TEB w/ GOx
- Restart of the motor

- Higher than desired nozzle erosion
- Stable test
- 90 secs

2019 test

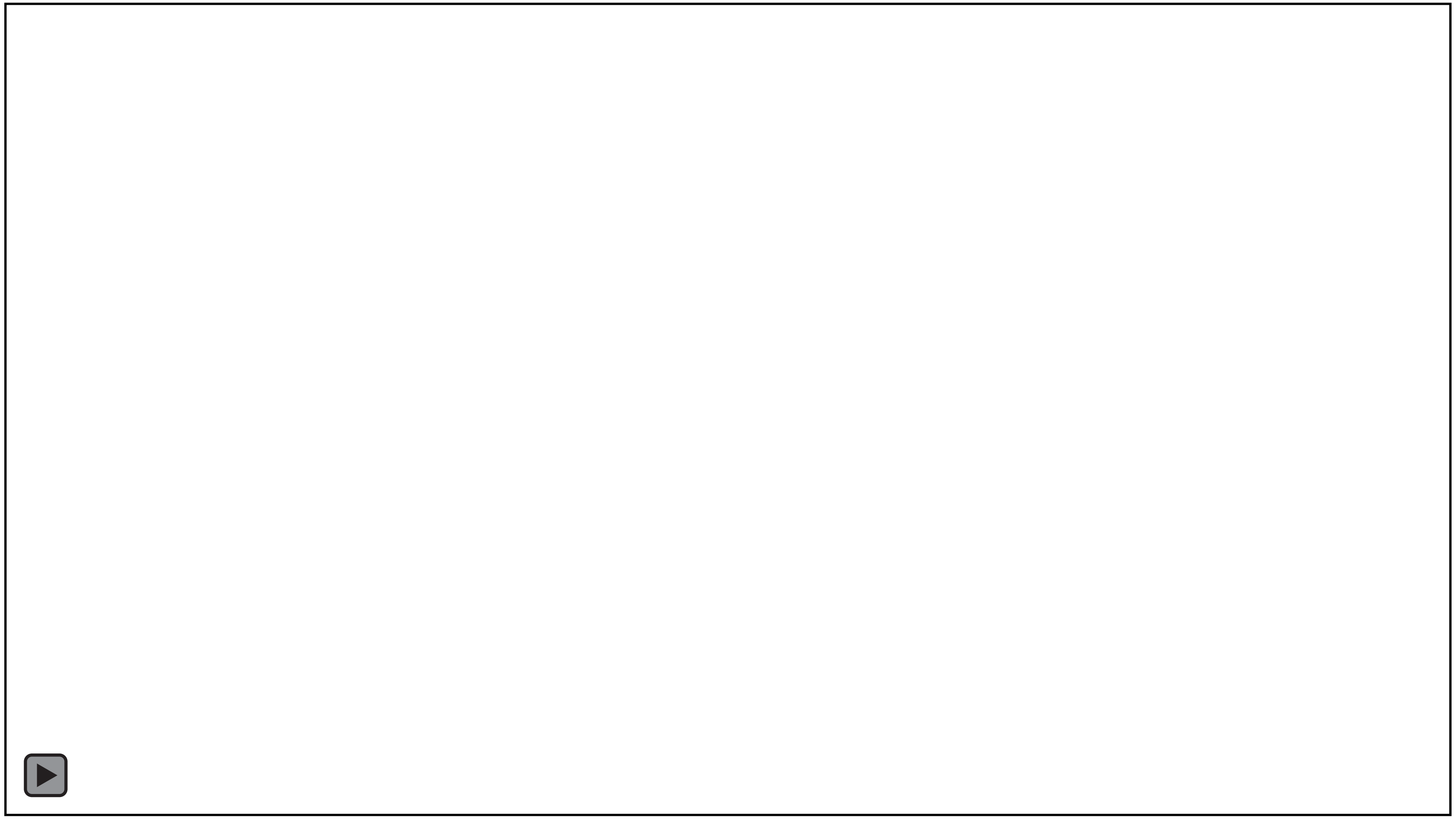


- Grain assembled into cartridge/liner and case at -20C
  - Keep the grain in compression at cold temperatures

- SP7 MON-25
- Conditioned to -20C
- Ignition source TEA/TEB w/ Gox

- Higher than desired nozzle erosion
- Stable test
- 60 secs

2019 test



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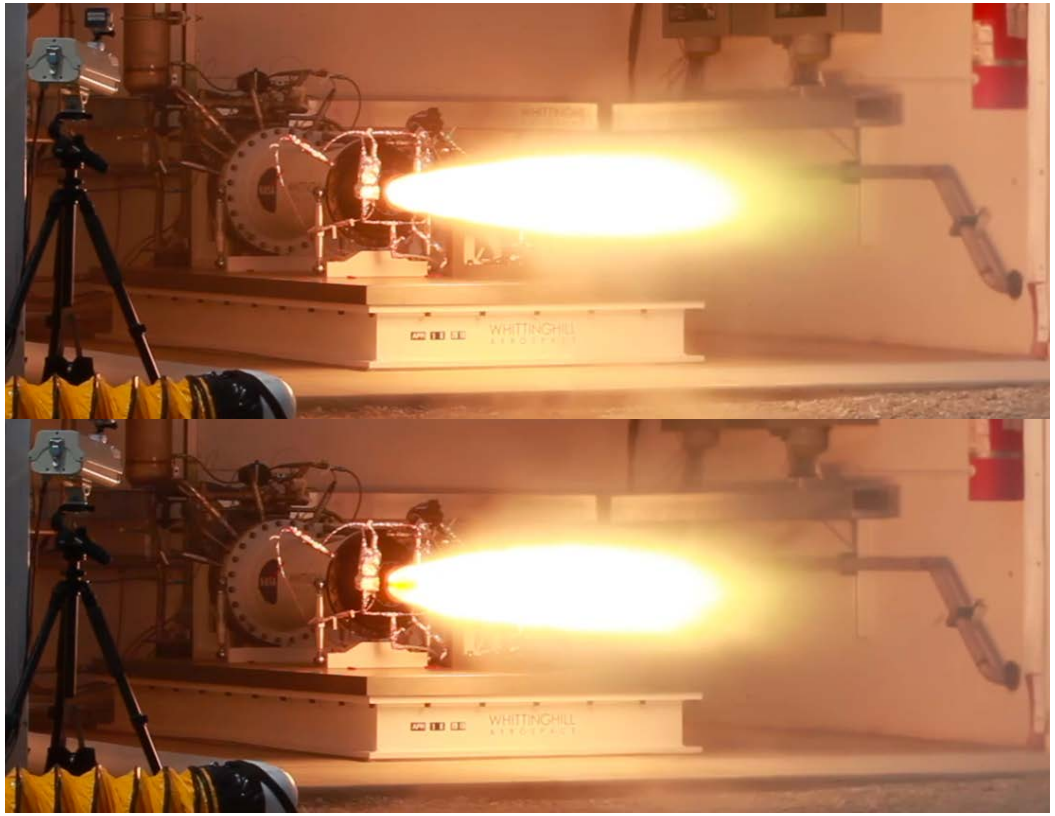
Liquid Injection Thrust Vector Control

- Benefits led to selection
  - Low mass and small deflection required: 1-2°.
- Design: Four pairs (90° around the nozzle)
  - One valve would provide sufficient flow for a ±1° deflection and both valves would provide ±2°.
  - Currently modifying a light weight, fast acting valve for MON service.
- This test (and all full-scale tests to date) have been completed at Earth ambient pressure and temperatures. X/L is different, but using this data to anchor modeling.
- Testing at WSTF will confirm vacuum performance.



LITVC Testing at Earth Ambient Pressure

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White Sands Test Facility

- Vacuum test for LITVC performance
  - Full nozzle length and area ratio

- Before it gets to WSTF, motor will be Computed Tomography (CT) inspected, thermally cycled and CT inspected again.

- Test planned for late 2019
  - SP7A and MON-25
  - Conditioned to -20C
  - Ignition source TBD

WSTF Test Stand 403
Vacuum Chamber

FY19 and Future Work (1/2)

- The goal of this technology development program is to have demonstrated the major milestones required for a hybrid MAV design that closes under the current assumptions for Mars Sample Return by the end of 2019.
- The highlight of this effort will be testing of a thermal cycled, full-scale hybrid motor under relevant (low pressure and cold) conditions at White Sands.
  - Up to five additional hotfire tests are planned to prepare for the WSTF test.
    - Two more tests focus on motor development for the wax-based fuel and MON-25 oxidizer and achieving performance and burn time goals. (Whittinghill)
    - Two tests will demonstrate a light weight motor case under relevant thermal conditions with SP7 and MON-3 (SPG)

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FY19 and Future Work (2/2)

- Purdue will test hypergolic ignition of SP7 with solid additives and MON-25 under low pressure conditions this year.
  - Full-scale testing will continue to use a liquid hypergol for ignition this year
  - The potential for adding solid additive to a hybrid MAV will be evaluated and a decision should be made by the end of the fiscal year.
- A qualification program for a hybrid motor will continue to be refined.
- MSFC is doing a Preliminary Architecture Assessment, a study to design complete concepts for both a hybrid and solid version of a MAV vehicle, working closely with the MSR and SRL studies being led by JPL to make sure the MAV concepts fit within study constraints for the higher level architecture.

Summary

- A technology development program is underway to determine feasibility of the hybrid option for a potential Mars Ascent Vehicle as part of a potential robotic Mars Sample Return Campaign.
- Substantial strides have been taken in the propulsion system development.
- Full scale hotfire testing has been completed at two vendors and the development is ongoing with both vendors joining their efforts.
- Hypergolic ignition has been researched and demonstrated using multiple options.
- The potential design is continually updated based on the developments of the development program.
- The goal is to demonstrate a design that closes by the end of 2019.

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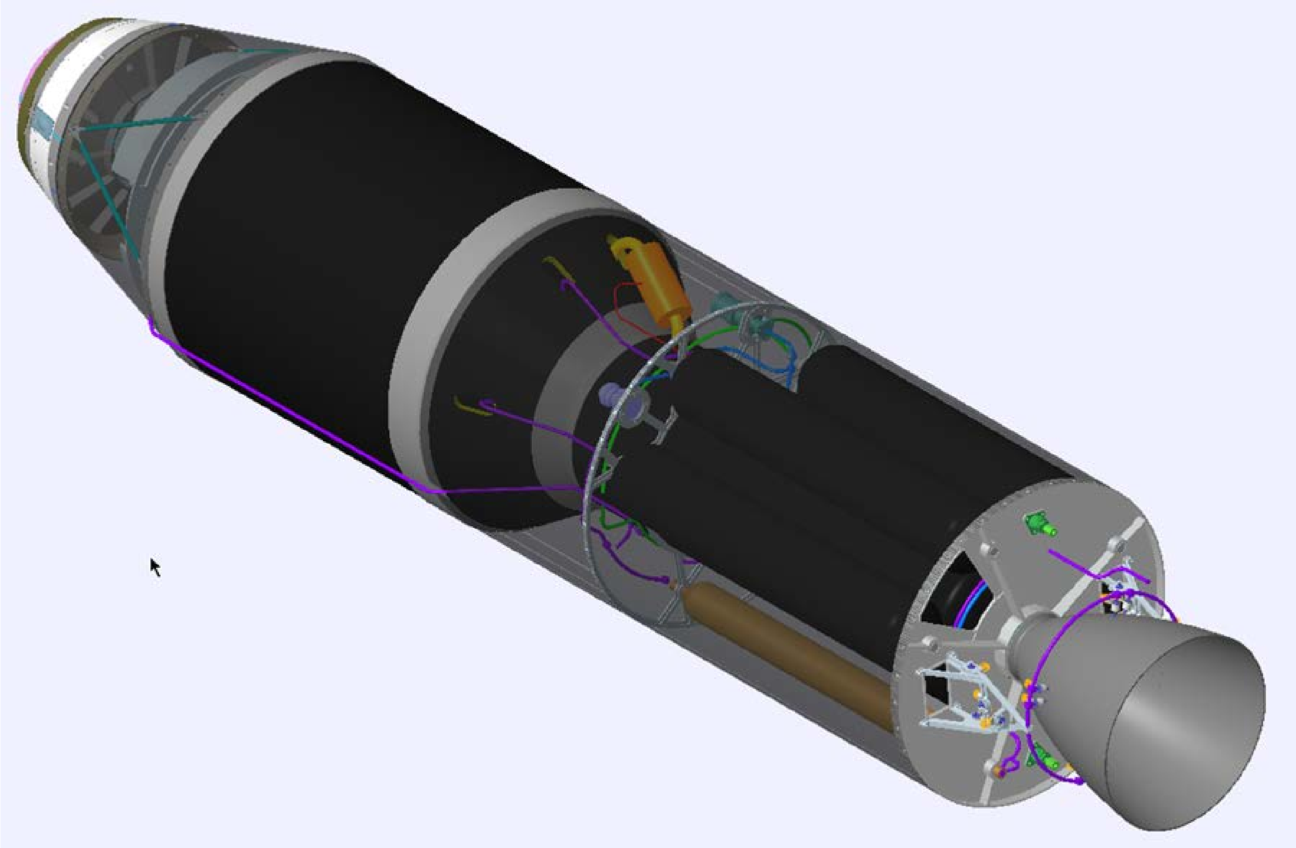
Questions?



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