MAV

Mars Ascent Vehicle

Technology Development and Design of a Hybrid Mars Ascent Vehicle Concept

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MSFC

Marshall Space Flight Center

JPL

LaRC

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Mars Ascent Vehicle FY 2015 Study

Mars Ascent Vehicle

	Case 1a	Case 1b	Case 2a	Case 2b	Case 5	Case 6	Case 7
	Solid-Solid G-G	Fixed Solid-Solid G-G	Solid-Solid G-U	Fixed Solid-Solid G-U	SSTO Pump BiProp	SSTO Reg. BiProp	SSTO Hybrid
Payload/OS	**14 kg, 30 cm OS taken as reference**						
GLOM	318.8	341.5	274.1	297.1	255.0	269.8	219.1
Length	2.64 m	2.96 m	2.51 m	2.87 m	3.21 m	3.39 m	2.89 m
AFT	-58 C	-58 C	-58 C	-58 C	-90/-44 C	-90/-44 C	-90/-66 C

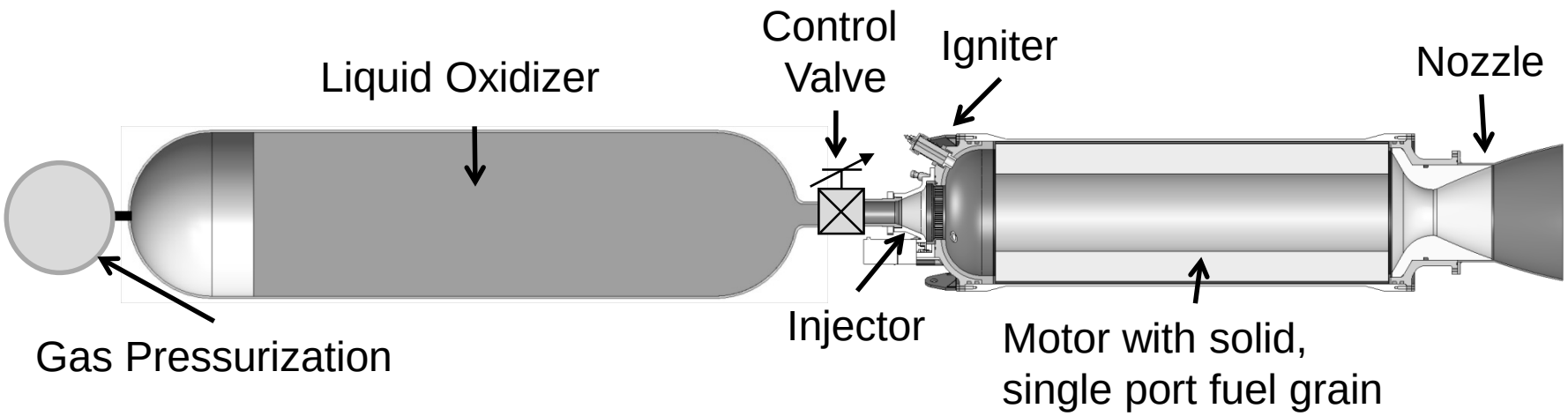
(Temp limit if frozen/temp limit if not frozen)

Pre-Decisional: For planning and discussion purposes only.

Overview

Mars Ascent Vehicle

- Hybrid rockets utilize solid fuel and liquid oxidizer.
  - MAV is interested in this option because of its high performance, minimum need for thermal control and capability for multiple starts.
- Technology development in FY15
  - New fuel formulation (wax-based, SP7) developed for extreme temperature swings on Mars. (Subcontract with Space Propulsion Group)
    - Hotfire tested with N_2O to determine parameters necessary for design.
    - Includes CTE work
  - Purdue – tested paraffin and SP7 with MON
  - Thermal cycling of new fuel – temperature range explored at JPL and long term testing has begun at MSFC
  - Igniter and thrust vector control options explored at MSFC



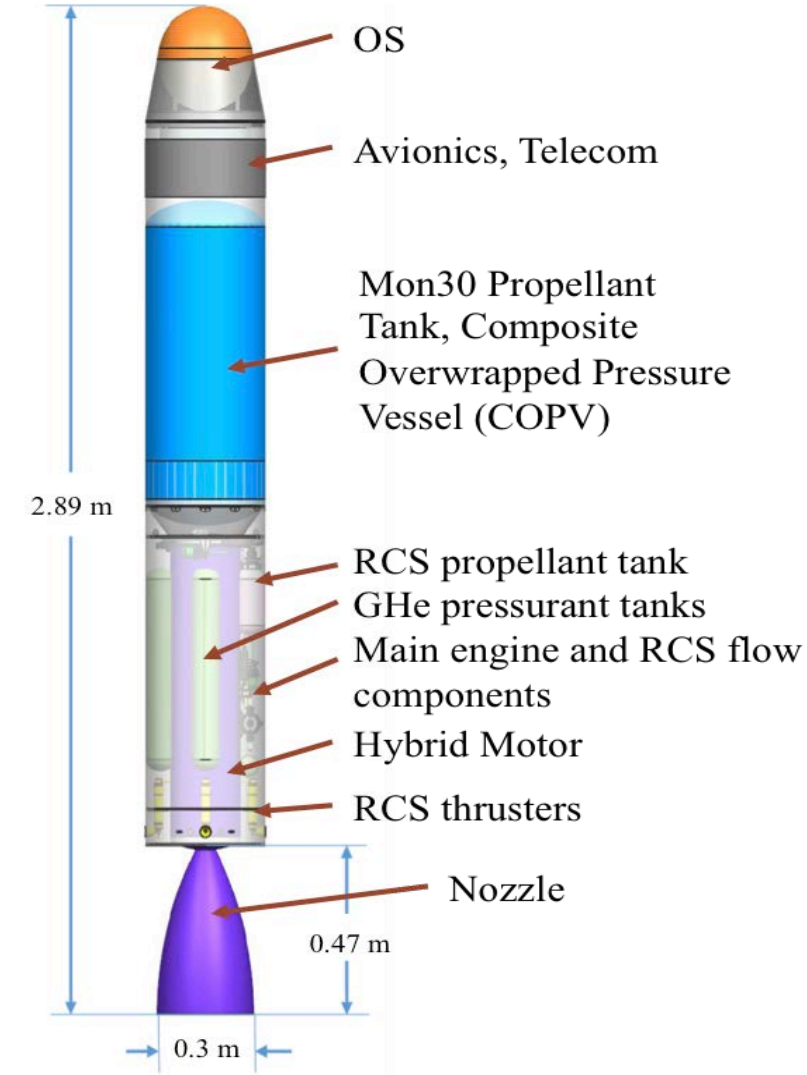
Key Goals for FY15

Mars Ascent Vehicle

1. Develop a high performance hybrid fuel that can survive and operate at Mars conditions (and during transport to Mars)
2. Alleviate any concerns due to low TRL of propellant combination
   - Test selected propellant combination at design temperature (currently as low as -20 C)
   - Study properties of new fuel, especially coefficient of thermal expansion
3. Evaluate multi-start ignition options and identify path forward.
4. Evaluate Thrust Vector Control (TVC) options and identify path forward for nozzle design.

Hybrid MAV Concept

Mars Ascent Vehicle



Hybrid MAV:

Wax based fuel (SP7) and MON25 hybrid motor
GHe storage pressure: 10 kpsia
MON Tank pressure: 400 psia
Chamber pressure: 250 psia
Thrust: 5800 N
O/F: 4.56
Length: 2.885 m
GLOM: 219.1 kg

Separate RCS operates at 1250 psia

- Currently: 4 x 22 N and 4 x 5 N thrusters
- Potential to reduce to 6 x 10N thrusters

Hybrid Assumptions and Trades

Mars Ascent Vehicle

- Chamber pressure: 250 psia
  - Minimum recommended chamber pressure for SP7 fuel is 120 psia
    - Operate above the supercritical pressure of the fuel (~50 psia)
  - Minimum wall thickness titanium chamber can support a pressure up to 400 psia
  - System optimization (in either direction) is possible
    - 160 psia chamber lowers GLOM by 2.7% but increases stack height by 8 cm
    - 400 psia chamber increases GLOM by 5.8% and decreases stack height by 2 cm
- Separate GN_2 RCS sub-system
  - Traded He RCS system (common tank), GN_2 pressurization of oxidizer tank at 400 psia) and having two separate systems resulted in lowest mass
- Hybrid motor combustion stability depends on oxidizer mass flux at end of burn
  - This results in a minimum recommended thrust based on the current fuel regression rate and fuel grain geometry.
  - Hybrid thrust has been set to this minimum to optimize GLOM and trajectory
- Complete optimization of thrust/trajectory, nozzle expansion ratio, chamber pressure and stack height should be performed.

Fuel Formulation

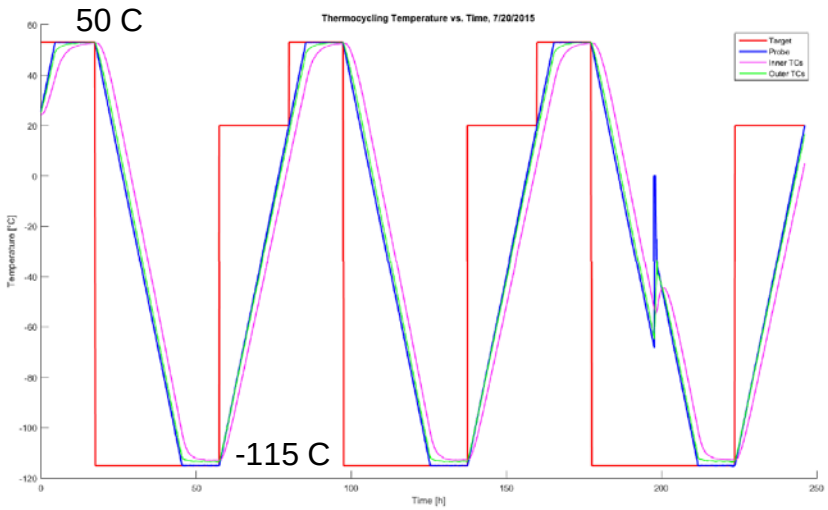
Mars Ascent Vehicle

- Worked with Space Propulsion Group, Inc. to developed new fuel (SP7) for operation in Mars-like temperatures
  - Tested paraffin (SP1) and SP7 with N_2O (non toxic analog to MON) to determine performance and behavior of new fuel.
  - Determined material properties of SP7
  - Matured processing of SP7
  - Initiated study into fuel/casing thermal mismatch

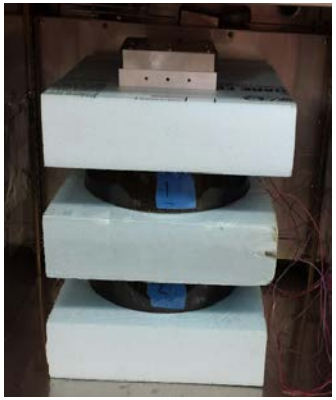
Preliminary Thermal Cycling

Mars Ascent Vehicle

- Thermal cycling of SP7 and SP7Al20 at JPL over wide range of temperatures
  - Delamination between fuel grain and insulation has been observed, however, believed it is acceptable as long as oxidizer flow is not allowed through the gaps.



Set Up



Delamination

- Started long term test at MSFC (100 day, 200 cycle)
  - EDL (one cycle)
  - Seasonal tests (winter x 50, spring/fall x 100, summer x 50)

Ignition

Mars Ascent Vehicle

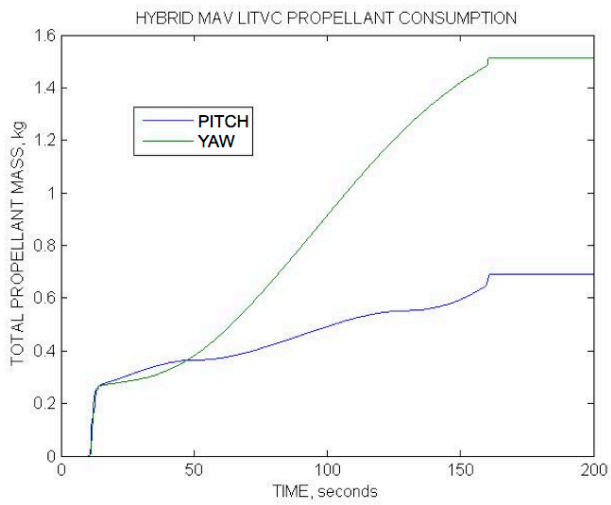
- Ignition option space evaluated, with the following recommendations:
  - Top choice: incorporating additives into the fuel to make it hypergolic with the selected oxidizer (MON). This is the simplest solution.
  - Other options, including electrically controlled solids need to be pursued as back up
  - Results of trade study in ranked order are below

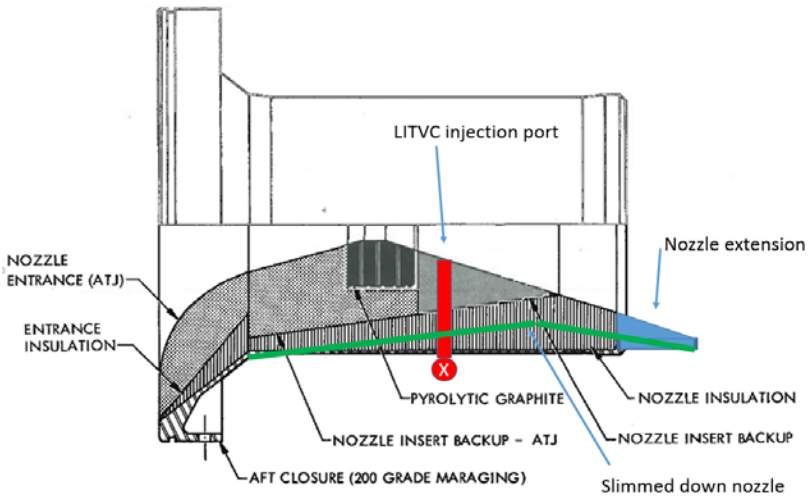
Category	Features	Total Score
Hypergolic	Hypergolic fuel	4.7
Multiple Solid igniters	Pyrotechnic or Pyrogen	4.2
Pyrogen	Solid Barrier/Pulse Igniter	4.2
Solid	Electrically controlled solid	3.9
Pyrotechnic	BKNO3	3.6
Hypergolic	Hypergolic liquid injection igniter	3.3
Electric	Electric arc discharge igniter	3.0

Work completed at MSFC

Thrust Vector Control

- TVC option space evaluated and the recommended Liquid Injection Thrust Vector Control (LITVC) for the hybrid option
  - Oxidizer is injected into the nozzle expansion area
  - Data from the Sandpiper hybrid (MON25, PMMA/Mg) was used for nozzle erosion information





Work completed at MSFC

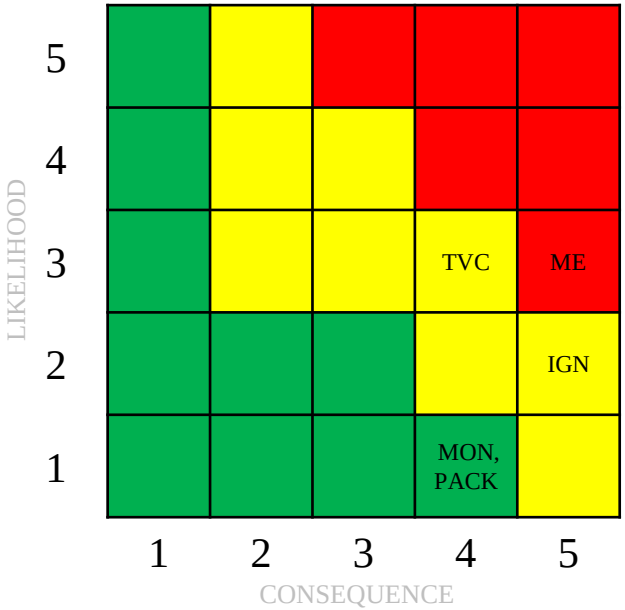
Key Challenges

Mars Ascent Vehicle

- Comparatively low TRL of propulsion system
  - A new fuel formulation was developed to survive the Mars environment and first tests were done this FY
  - Just started MON testing at the end of FY15
- Operation in the Mars environment
  - CTE thermal mismatch of fuel and liner/case
  - Soakback during coast before second start
- Optimal packaging / configuration
- Ignition/Restart
- Nozzle survivability, TVC and erosion

MAV Tech Area Risk Matrix

Mars Ascent Vehicle



Rank	ID	Title	Disposition
1	ME	Validation in the Mars Environment	Testing (FY15-16+)
2	TVC	Thrust Vector Control	Testing (FY16+)
3	IGN	Multiple Ignition	Testing (FY16+)
4	MON	New Oxidizer with Liquefying Fuel	Testing (FY15-16+)
5	PACK	Packaging/Configuration	Design (FY16+)

Likelihood %		
5	Very High	>70%
4	High	>50%
3	Moderate	>30%
2	Low	>1%
1	Very Low	>0%

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Future Work

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- Completely characterize newly developed fuel (SP7)
  - Hotfire testing with SP7/MON
  - Determine the material properties and processing of SP7 fuel
  - Complete thermal cycling
- Complete study on CTE mismatch of insulator/case and fuel grain
- Ignition testing
  - Hypergolic ignition method strongly desired
  - Quantify the amount of heat needed to ignite the hybrid.
- Nozzle and TVC testing – potential for regenerative nozzle using oxidizer
- Trade study to determine if the electric pump (studied for the liquid bi-propellant case) would enhance the design more than added risk.

Summary

Mars Ascent Vehicle

- A conceptual design for a hybrid Mars Ascent Vehicle is presented as a potentially promising alternative to conventional propulsion systems.
  - Lowest GLOM and lowest relative TRL, requires technology maturation.
- A new hybrid fuel was developed
  - Thermal cycling of the fuel (both aluminized and virgin) over a range of +50 °C to -110 °C was successfully completed at JPL.
  - Hotfire testing with N_2O successful, some preliminary testing with MON, but major are for future work.
- Hypergolic additives to the fuel grain were deemed the most favorable ignition technique and development in this area is recommended.
  - Currently initiating testing in this area
- Liquid injection thrust vector control traded the most favorably, since the Mars environment presents a substantial challenge to many of the more common TVC systems
  - Further study required to refine design and amount of “liquid” required
  - e.g. flex seals cannot operate at low temperatures
- While several technological challenges remain, significant development and risk mitigation has already been accomplished in this short time period.

Questions?

Mars Ascent Vehicle

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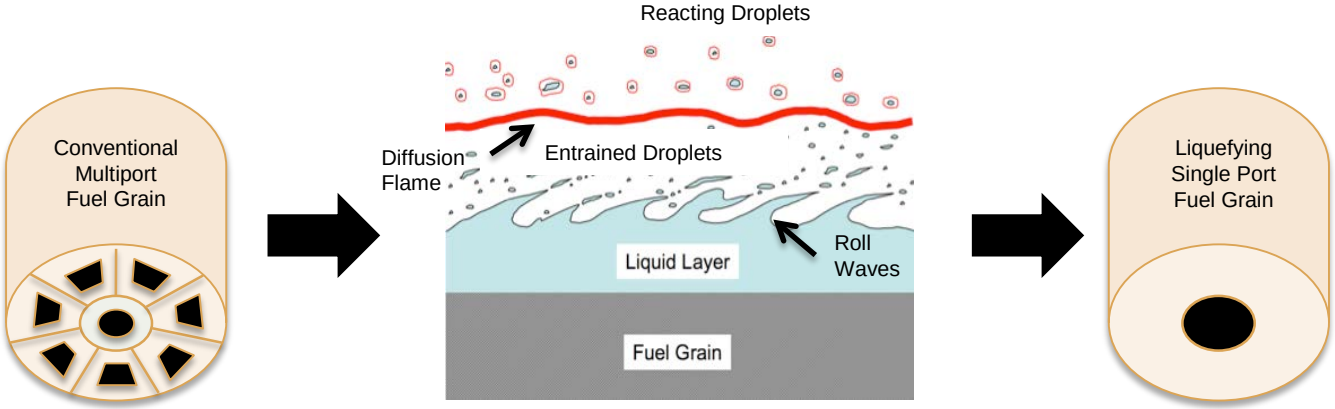
BACK UP

Mars Ascent Vehicle

Hybrid evolution over the last 15 years

Mars Ascent Vehicle

- The many benefits of hybrid rockets using liquefying fuels (discovered in the late 1990's) make them excellent candidates for a MAV
  - High performance comparable to liquid engines (Isp ~ 320 s)
  - Wide temperature range capability (at least -100 C to +60 C)
  - Capable of multiple restarts
  - Simply throttled with only a single valve
  - Fuel grain is mechanically simple (single port) and non toxic
  - Higher regression rate (thrust) capability than conventional hybrids
- Conventional hybrids (SOA up to the late 1990's)
  - Excessive unburned mass fraction (5-10%)
  - Web support requires complex design/fabrication
  - Compromised grain structural integrity at end of burn
  - Poor volumetric loading
  - Potential uneven burning of individual ports
  - Requirement for substantial pre-combustion chamber or individual injectors for each port



Cantwell, Karabeyoglu, &
Altman, 8th ISICP Cape Town, SA, 2009