MAV

Mars Ascent Vehicle

Technology Development Plan and Preliminary Results for a Low Temperature Hybrid Mars Ascent Vehicle Concept

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Agenda

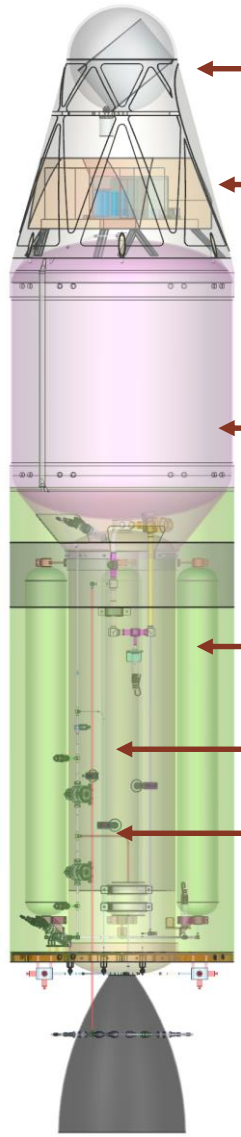
- Introduction
- Design
  - Point of Departure Review
  - Proposed MAVRIC flight test
- Technology Development Plan
- Propellant Combination
- Summary

Introduction

- Hybrid propulsion is being developed as a potential option for a future Mars Ascent Vehicle due to the following benefits
  - Promising low temperature behavior of fuel and oxidizer
  - Flexibility to design changes
  - Lowest GLOM
- The development would culminate with the Earth-based test of a MAV-like rocket
  - Mars Ascent Vehicle Research and Innovation Campaign (MAVRIC)

Point of Departure Review Concept

Mars Ascent Vehicle



- PoDR held in Dec 2016
- General requirements:
  - Survive one Martian year on the surface
  - Host agnostic
  - SSTO, 2 ignitions
  - LITVC
- More challenging requirements than past
  - Target orbit: ~479 km at 92.7 degrees, sun synchronous
  - Increased payload: 18 kg plus 5 kg of margin

346 kg GLOM, 57 cm outer diameter, 2.9 m long

Point of Departure Review Concept

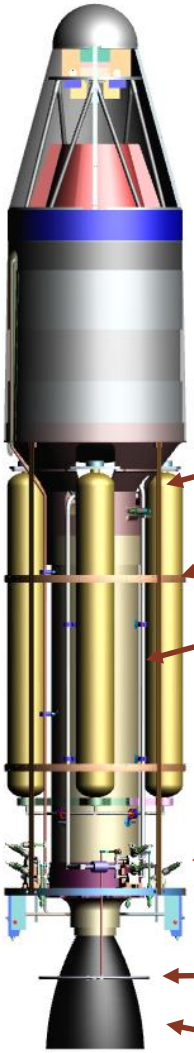
Mars Ascent Vehicle

PoDR Design	Units	Value
Payload mass (OS):	kg	18
Dry Mass Reserve	kg	5
GLOM	kg	346
Propulsion Dry Mass (includes RCS dry mass)	kg	35.0
Non-Propulsion Dry Mass	kg	18.0
Loaded Fuel Mass	kg	48.4
Loaded Oxidizer Mass (MON30, includes MON30 for LITVC)	kg	219.6
Pressurant and RCS propellant mass	kg	1.82
Thrust	N	7120
Specific Impulse (Isp)	s	314
O/F Ratio	-	4.45
Total ΔV	m/s	4250
Total Burn Time	s	112
Stack height	m	2.85
Hybrid Motor Outer Diameter	cm	28.5

MAVRIC Baseline Design

Differences from PoDR:

- Leverages commercially available components
  - Propulsion dry mass increase
  - ΔV decrease
- Oxidizer is MON3 instead of MON30.
  - Enables ambient temperature and pressure testing



448 kg GLOM, 57 cm outer diameter, 3.4 m long

MAVRIC Baseline Design

Mars Ascent Vehicle

MAVRIC Design	Units	Value
Payload mass (OS):	kg	18
GLOM	kg	448
Propulsion Dry Mass (includes RCS dry mass)	kg	106
Non-Propulsion Dry Mass	kg	43.2
Loaded Fuel Mass	kg	51.0
Loaded Oxidizer Mass (MON3, includes MON3 for LITVC)	kg	228
Pressurant and RCS propellant mass	kg	1.92
Thrust	N	7120
Specific Impulse (Isp)	s	314
O/F Ratio	-	4.25
Total ΔV	m/s	2650
Total Burn Time	s	112
Stack height	m	3.4
Hybrid Motor Outer Diameter	cm	28.5

Possible Test Architecture

- Balloon launch from a barge off Eglin Air Force Base.
  - Balloon lofts to 30 km (Mars-like surface atmosphere)
  - The rocket would ignite, exit the launch tube, coast to altitude, complete a LITVC test and then descend into the ocean.
  - Goal to recover avionics (high rate data)
  - Alternatives were considered: direct ground launch, rocket boosted ground launch

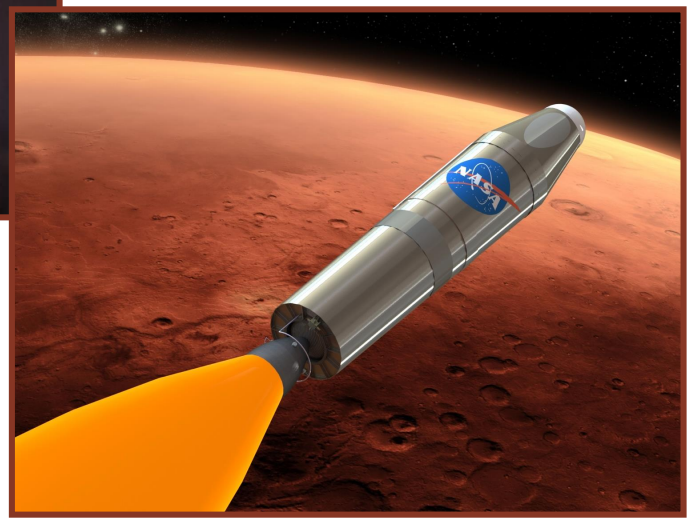
Challenges

- Slosh in the oxidizer tank during launch has been determined to require mitigation.
- Fuel grain production ended up being much more difficult than anticipated
  - Shrinkage during cooling makes process development a thermal management issue.
  - Cannot use simple, paraffin spin casting
- Program budget and schedule may be a forcing function on technical decisions
  - Heavier tanks and COTS propulsion components are being sourced

Technology Development Plan

Hotfire testing

Hypergolic ignition testing



Future work and flight demonstration

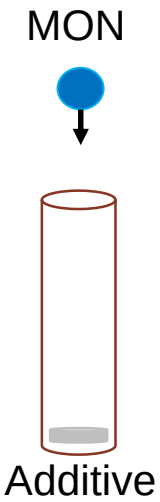
Hotfire Testing: SPG and Whittinghill

- Subscale 3 in (7 cm) testing completed over the last two years
  - N_2O (good analog for MON3 regression rate curve) - 2015
  - MON3 - 2016
- Full scale testing this summer at Space Propulsion Group and Whittinghill Aerospace.
  - The primary (ambitious) goals of this short test program:
    - Stable combustion (chamber pressure oscillations of +/- 5%)
    - High performance (combined efficiencies of 95%)
    - Complete a full duration burn
    - Complete a restart.

Subscale test at SPG with MON3

Hypergolic Ignition Testing

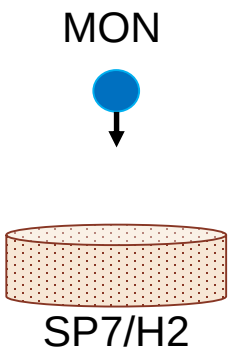
- Penn State and Purdue independently researched and tested tens of options and identified two top candidates with NTO/MON3

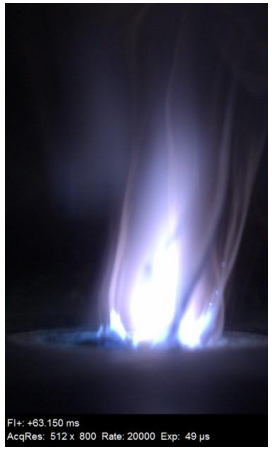


H1

H2

- Both then mixed the most promising additives with SP7 wax. The Purdue test is show at the left (H2 with SP7).
  - Hypergolic behavior exhibited with high loading and exposed reactants on surface (representative of second burn).





Path Forward – Demo Launch

- Technology development to culminate with proposed Earth-based demonstration flight (TRL 6)
- Would demonstrate:
  - Hybrid propulsion system
  - Multiple ignitions (two)
  - LITVC
  - RCS control during transitions
- Two vendors are currently doing ground tests of a full scale motor. Results of these tests and their MAVRIC designs will be used to select a single vendor for the test motor.

Propellant Combination

- New wax-based fuel, called SP7
  - Developed specifically for Mars storage
  - Can temperatures as high as 50C and as low as about -100C.
  - Not much data exists on this fuel since it was developed recently.
    - Chemical and mechanical testing was completed this year.
    - CTE data was gathered previously
- Oxidizer: Mixed Oxides of Nitrogen (MON)
  - MAVRIC would utilize MON3 because it can be tested at ambient Earth conditions.
    - MON3 is more readily available (and less expensive) than MON30.
    - It is a different oxidizer than that desired for Mars use, but should serve as a good analog for the suspected more reactive MON30.
    - N_2O was proven to show similar behavior to MON3 through subscale testing, we anticipate the trend in regression rate vs oxidizer mass flux will also be similar from MON3 to MON30

SP7 Chemical Analysis

- Many chemical analyses were carried out this year to improve the designs
- Some fundamental values were determined:

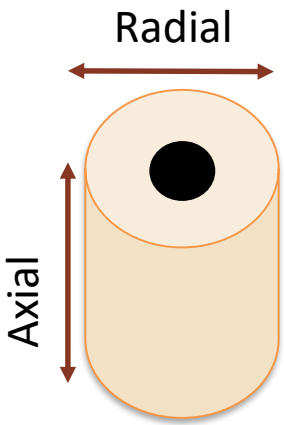
- Density: 0.9590 g/cm^3
  - This was actually a departure from original estimates leading to a redesign of the motor geometry.

- Heat of Combustion: 11.01 kcal/g (46.10 kJ/g)
  - Four samples were averaged to get this value
  - Future work: validate heat of formation

SP7 Mechanical Pull Tests

- Testing done to ASTM D638, Type I (for plastics) at ambient and -20C.
  - Samples from radial and axial directions to see if casting makes a difference –
  - The casting process is still evolving and this test will likely need to be repeated after the final processes have been determined.

	Sample	Modulus (x 10^6 MPa)	Average Modulus (x 10^6 MPa)	Std. Dev. (x 10^6 MPa)	Cov (%)	Ultimate Stress (MPa)	Average Ultimate (MPa)	Std. Dev. (MPa)	Cov (%)
Radial / 22 C	R001	1.798	1.739	0.101	5.787	4.332	4.15	0.258	6.218
	R002	1.850				3.998			
	R003	1.658				4.413			
	R004	1.649				3.876			
Axial / 22 C	A002	1.504	1.597	0.0875	5.479	4.807	4.65	1.316	28.277
	A003	1.603				4.551			
	A004	1.659				4.884			
	A005	1.516				4.373			
Radial / -20 C	R006	3.106	3.083	0.0325	1.055	3.586	3.19	0.566	17.774
	R007	3.060				2.785			
Axial / -20 C	A006	3.672	3.786	0.162	4.268	2.305	2.65	0.488	18.426
	A007	3.901				2.996			



SP7 Fuel Grain Manufacture

- Fuel grains process development is ongoing
  - Currently making grains out of multiple wafers: cast in cake pans and post processed
  - Future grains to use an oven cooled grain process
  - MSFC solid fuel torch testbed (Shuttle/SLS) being used to validate wafer method doesn't have an intolerable regression rate impact
  - Stress analysis indicates multiple wafer grain will have lower stresses due to CTE over MAV temperature range
  - Residual stresses being studied – seeing some cracking in post processing/shipping

Summary

- Substantial technology investment is ongoing to develop hybrid propulsion technology for this application with an anticipated increase in TRL to 4 this summer
- Plans for MAVRIC are currently underway with a flight test proposed for the early 2020's (TRL 6)
- Several of the goals of this test are to mitigate potential risks for the MAV and demonstrate hybrid propulsion technology such that it could be adopted for a Mars application in the future.

Questions?

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