MAV

Mars Ascent Vehicle

A Hybrid Mars Ascent Vehicle Concept for Low Temperature Storage and Operation

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MSFC

Marshall Space Flight Center

JPL

Jet Propulsion Laboratory
California Institute of Technology

LaRC

Overview

- Introduction
- FY2015 Hybrid MAV Design
- Updated Hybrid MAV Design
- Areas of Technology Investment
- Path Forward
- Conclusion

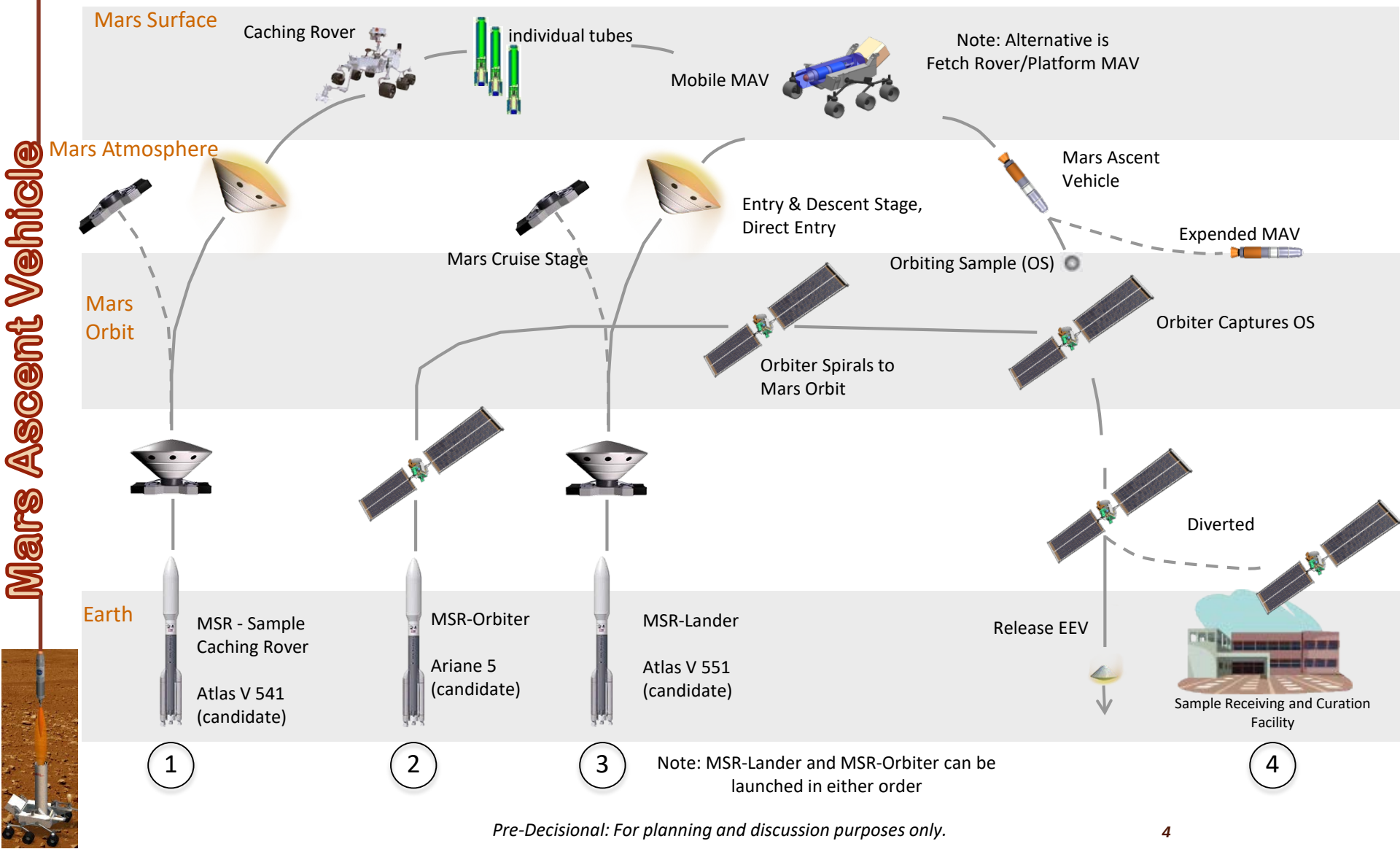
Mars Ascent Vehicle

Mars Sample Return

Mars Ascent Vehicle

- Mars science community would like to return samples from the surface of Mars to study on Earth.
  - Enables in-depth studies through multi-step processes
  - Paves the way toward human exploration of Mars – demonstrates feasibility of a round trip mission
- One of the perceived major technological challenges is the Mars Ascent Vehicle
  - Surface environment is cold and highly variable. Interested temperature range is -100 C to 20 C on Mars (up to 50 C for Earth launch)

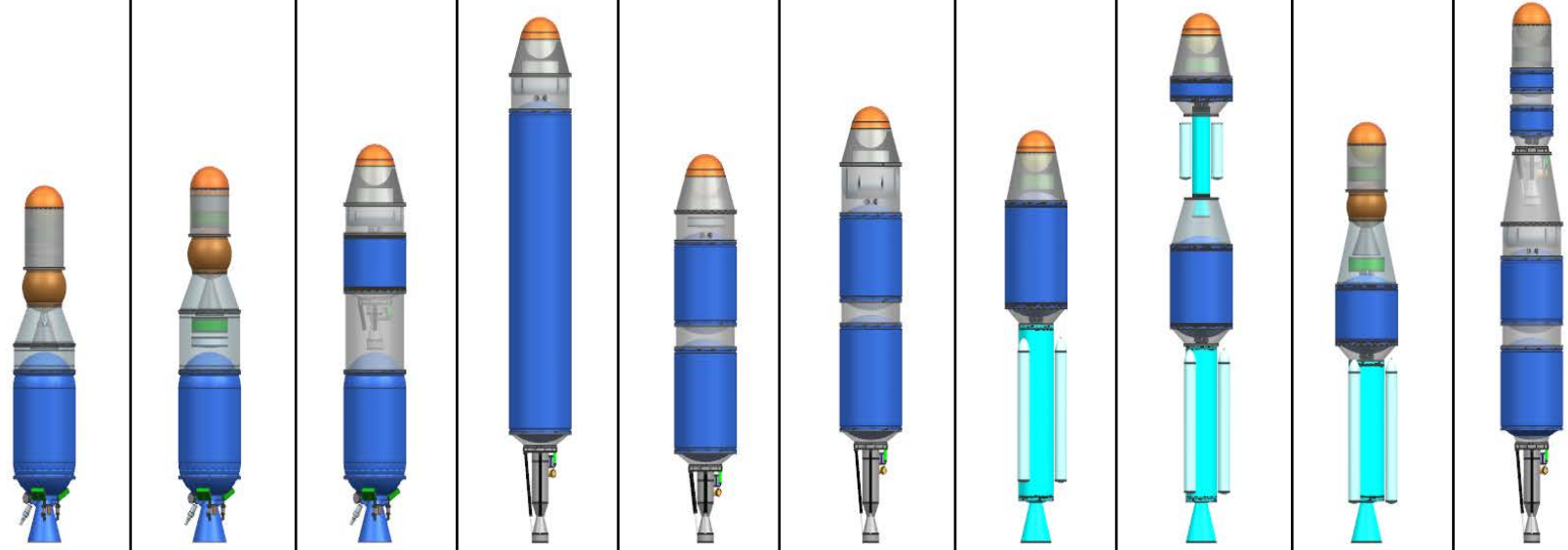
MSR Reference Architecture



FY 14 Comparison of MAV Propulsion Systems

Mars Ascent Vehicle

6.65kg Payload, 20cm Reference OS



	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9	Case 10
	Solid-Solid G-G	Solid-Solid G-U	Solid-Liquid G-G	SSTO Monoprop	SSTO Pump BiProp	SSTO Reg. BiProp	SSTO Hybrid	Hyb-Hyb G-G	Hyb-Solid G-G	BiProp-BiProp G-G
Score	0.60	0.54	0.32	0.52	0.79	0.76	0.76	0.621	0.52	0.57
GLOM	176	158	237	276	182	187	166	173	157	190
Length	1.88 m	1.98 m	2.09 m	2.76 m	2.04m	2.29 m	2.16 m	2.78 m	2.21 m	2.84 m
AFT	-40 C	-40 C	+17 C	+8 C	-37 C	-37 C	-66 C	-66 C	-40 C	-37 C

Pre-Decisional: For planning and discussion purposes only.

Starting Point for FY15 Study

Mars Ascent Vehicle

6.65kg Payload, 20cm Reference OS

	Case 1 Solid-Solid G-G	Case 2 Solid-Solid G-U		Case 5 SSTO Pump BiProp	Case 6 SSTO Reg. BiProp	Case 7 SSTO Hybrid	
Score	0.60	0.54		0.79	0.76	0.76	
GLOM	176	158		182	187	166	
Length	1.88 m	1.98 m		2.04m	2.29 m	2.16 m	
AFT	-40 C	-40 C		-37 C	-37 C	-66 C	

Pre-Decisional: For planning and discussion purposes only.

FY15 Comparison of MAV Propulsion Options

14kg Payload, 30cm Reference OS

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
Max OS	**OS can grow up to ~ 30 cm diameter without fairing (stay under max case diameter)**						
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.

FY2015 MAV Study

Mars Ascent Vehicle

- Solid, liquid bi-propellant and hybrid MAV options were studied using a parametric approach.
  - The Payload, aka Orbiting Sample (OS), was varied from 6.65 to 20 kg.
  - The avionics, telecom, etc. are varied from a single-string to conservative approach.
- Nearly 40 options were considered
- Hybrid determined to have the most promise: lowest GLOM, potential for lowest system mass due to low temperature capability. However, lowest TRL

The hybrid was selected for further study and technology development in FY16.

FY2015 Hybrid MAV

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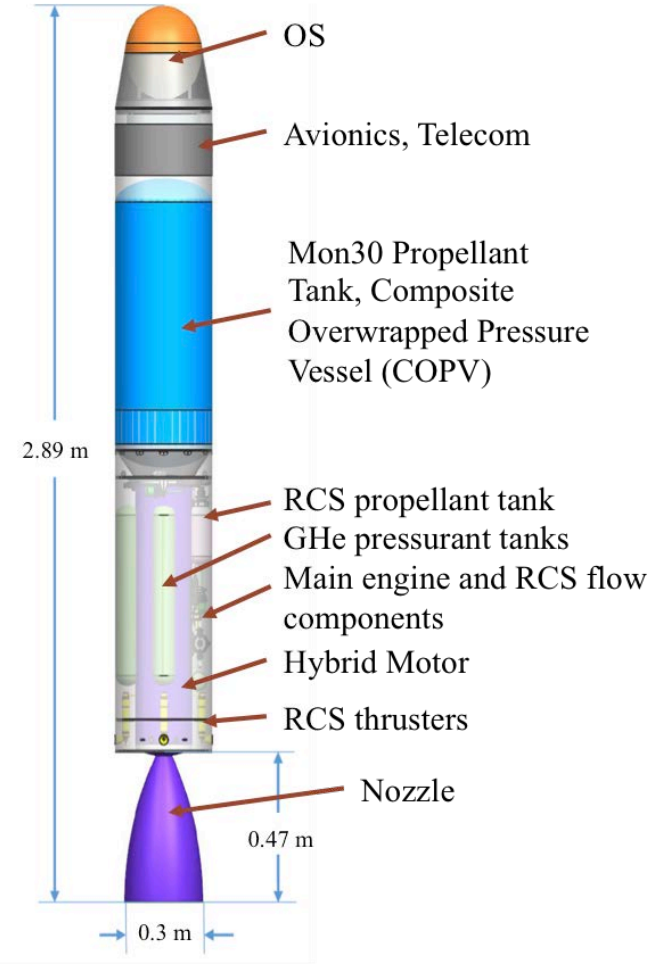
- The hybrid option was chosen for further study at the end of the FY15 study

	Value
Fuel/Oxidizer	SP7/MON30
Oxidizer to Fuel Ratio	4.56
Isp (assumes 95% efficiency)	317 s
Chamber Pressure	250 psia
Reaction Control System (RCS)	N_2 Cold Gas (8 thrusters)
Nozzle Area Ratio	40
Thrust Vector Control (TVC)	Liquid Injection TVC



FY2015 MAV Study

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- Results of parametric study (hybrid case only)
  - Payload and non-prop dry mass kept constant between subcases for different propulsion options.

		Subcase (Based on Payload and Non-Prop Dry Mass Allocation)					
Subcase:		1	2	3	4	5	6
Payload mass (OS):	kg	6.65	9	14	14	17	20
GLOM:	kg	171.4	187.3	219.1	257.3	283.6	300
Total Mass	kg	164.3	177.9	204.6	242.8	266.1	279.5
Propellant Mass	kg	122.8	134	156.3	183	202.3	214.3
Prop Dry Mass	kg	21.0	21.9	23.6	25.8	27.3	28.3
Non-Prop Dry Mass	kg	20.5	22.0	24.6	34.0	36.5	36.9
RCS Mass	kg	2.02	2.02	2.02	2.02	2.02	2.02
Thrust	N	4885	5150	5679	6312	6768	7053
Stack height:	m	2.6	2.6	2.9	3.1	3.3	3.4
Hybrid Motor Outer Diameter	cm	18.35	18.8	19.69	20.76	21.53	22.01

FY2015 MAV Study

Mars Ascent Vehicle

- Results of parametric study study (hybrid case only)
  - Case 7.3 selected for further study, model refinement, etc.

		Subcase (Based on Payload and Non-Prop Dry Mass Allocation)					
Subcase:		1	2	3	4	5	6
Payload mass (OS):	kg	6.65	9	14	14	17	20
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Hybrid MAV 2016

Mars Ascent Vehicle

Updated FY2016 Design	Units	Value
Payload mass (OS):	kg	14
GLOM	kg	229
Propulsion Dry Mass (includes RCS dry mass)	kg	23.1
Non-Propulsion Dry Mass	kg	19.99
Loaded Fuel Mass	kg	30.6
Loaded Oxidizer Mass (includes MON for LITVC)	kg	139.4
Pressurant and RCS propellant mass	kg	1.62
Thrust	N	5430
Specific Impulse (Isp)	s	320
O/F Ratio	-	4.56
Total ΔV	m/s	3944
Total Burn Time	s	93.4
Stack height	m	2.9
Hybrid Motor Outer Diameter	cm	23.6

Areas of Technology Development

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- New propellant combination
- Hypergolic Ignition
- Thrust Vector Control
- Pump Trade

MON25 Pump, Image: Ventions

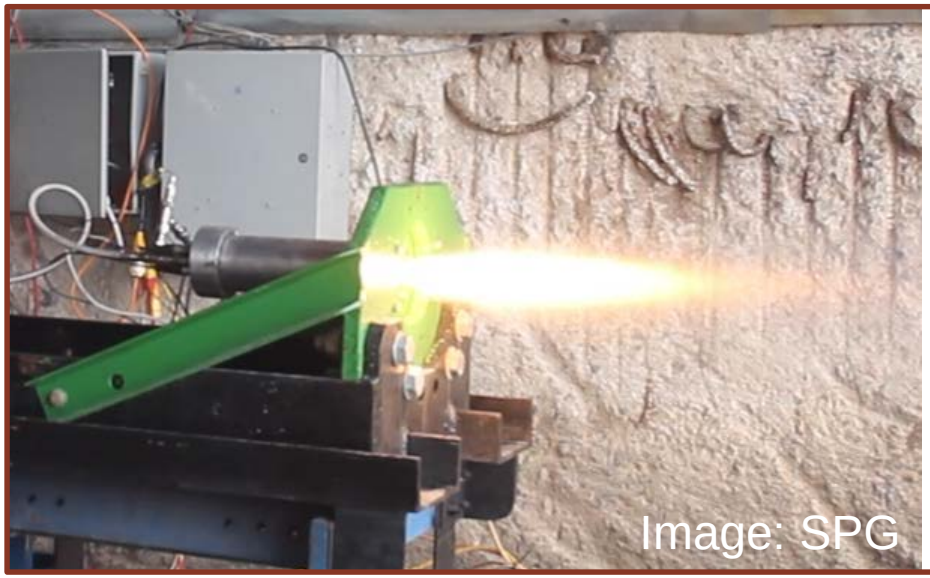

Image: SPG

Left: 3” SP7/N2O test
Right: SP7 10” fuel grain

New Propellant Combination (1/2)

Mars Ascent Vehicle

- Hybrid MAV Propellant Desires:
  - Low temperature capability for fuel and oxidizer to minimize thermal control in route to and on the surface of Mars
  - Operation at low temperature (demonstrated -20C operation with N2O)
  - High performance
- Selected propellant combination: SP7/MON3
  - SP7 is a wax-based fuel with very good low temperature capabilities, developed by Space Propulsion Group.
  - MON3 is a good, room temperature surrogate for MON30 proposed for flight.

SP7 Wax-based Fuel

Mixed Oxides of Nitrogen

MON3 = 0.97 N_2O_4 + 0.03 NO

New Propellant Combination

Mars Ascent Vehicle

- Preliminary testing (FY15)
  - Thermal testing of SP7 at SPG, JPL and MSFC*
  - SP7 with N_2O at SPG: determined regression rate correlation, currently being used for design.
    - SP7 regression rate is about 60-70% that of paraffin
  - SP7 and paraffin with MON3 and MON25 at Purdue
    - Other propellants used as well

- Current Test Programs
  - Two subcontracts have been awarded to test SP7/MON3
    - Space Propulsion Group (3” subscale motor)
    - Parabilis Space Technologies (10” full scale motor)

*Carried over into FY16

Hypergolic Ignition

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- Hybrid MAV Ignition Desires:
  - Multiple, reliable ignitions (3-5)
  - Low temperature capability
  - Ability to mix hypergolic additive into fuel without inhibiting reaction
  - Reactivity with MON3 and MON25-MON30

- Current Test Programs
  - Two subcontracts have been awarded to test solid hypergolic (with MON3) additives to SP7. Droplet testing
    - Purdue University (MON3 & MON25)
    - Penn State University (MON3)

Thrust Vector Control

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- A previous trade study determined Liquid Injection Thrust vector control to be the best option for the hybrid MAV
- Current LITVC requirements:
  - TVC capability of $\pm 5^{\circ}$
  - Conservative analysis suggests that about 2 kg of oxidizer would be necessary to complete the TVC required by a hybrid MAV using LITVC. This is being refined.
- Ongoing research at NASA MSFC is focusing on the design of the LITVC system.

Electronic Pump – Trade Study

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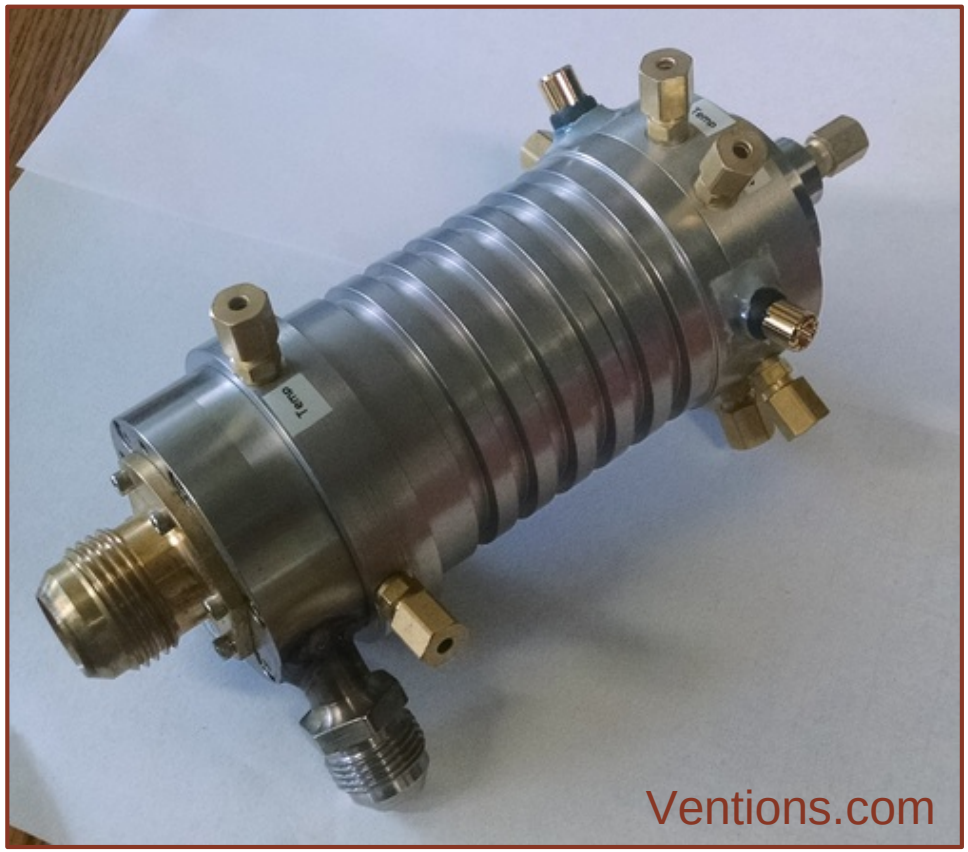
- GLOM could be decreased by 10 kg with conventional batteries or 15 kg with new battery technology (250 W/kg)
  - Alternatively, the pump could be used to decrease system length instead of GLOM
- The pump could be used to throttle hybrid motor
- RCS system is integrated with the pressurant system
  - He RCS instead of N_2
  - Combined residuals may enable OS avoidance maneuver.



Path Forward – Demo Launch

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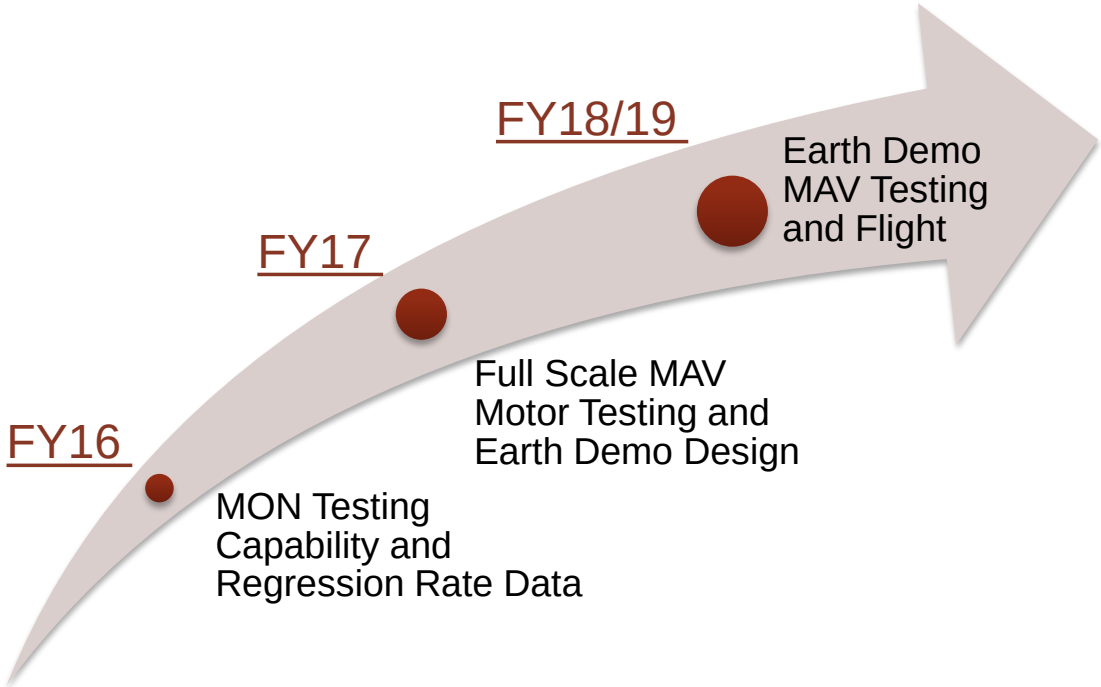
- Technology development to culminate with Earth-based demonstration flight
  - Earth based launch of a hybrid MAV is currently in the planning stages, target mid FY2019
  - Cannot match all Mars parameters with Earth based flight
  - Goal is overall risk reduction for MAV system



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Path Forward – System Design

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- Optimization of system variables
  - A complete optimization of all system variables has yet to be completed including
    - Diameter
    - MAV length
    - Oxidizer mass flux
    - Chamber pressure
    - Tank pressure
    - Thrust
    - Nozzle length/area ratio
  - Infusion of technology development programs
  - Final trades

Conclusions

Mars Ascent Vehicle

- A viable design for a potential hybrid Mars Ascent Vehicle has been presented with a GLOM of 229 kg and system length of 2.9 m.
  - The hybrid MAV is very promising because of its high performance, ability to restart and storability under Mars ambient conditions.
- Great strides in technology development are being made for a hybrid MAV that could also be applied to other in space propulsion applications.
  - Low temperature propellant combination
  - Potential hypergolic additives for multiple starts
  - The excellent potential performance of the hybrid MAV is driving technology development instead of relying on heritage.
- MAV technology demonstrator is currently in the planning stages for launch in 2019.

Questions

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