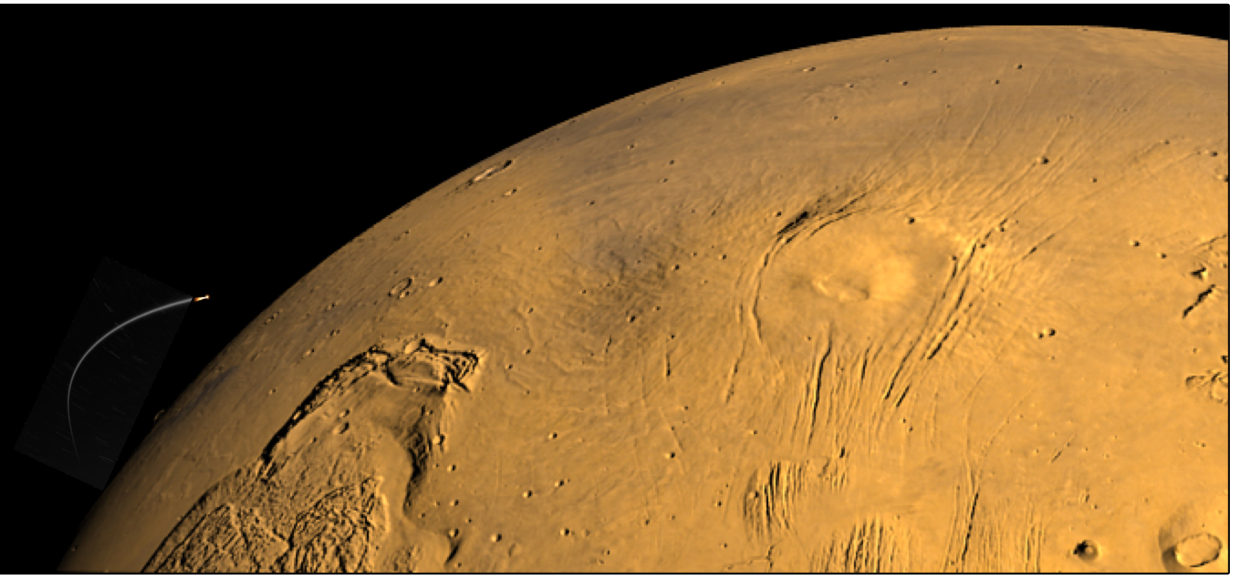
Mars Ascent Vehicle



Jet Propulsion Laboratory
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MARSHALL
SPACE FLIGHT CENTER

Mars Ascent Vehicle Propulsion System Solid Motor Technology Plans

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Summary

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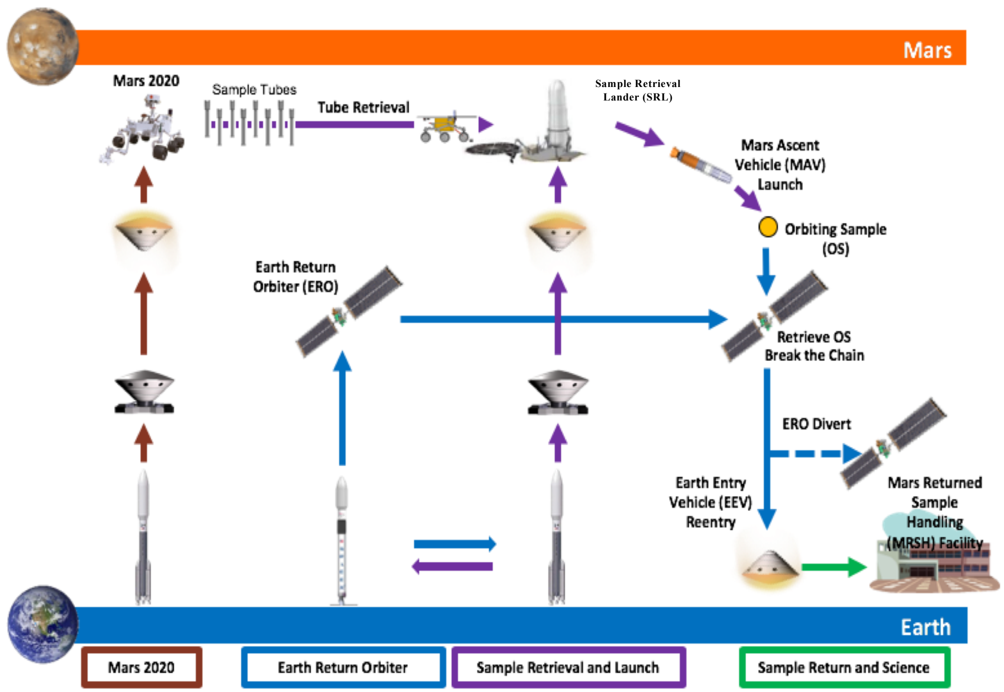
- Potential Mars Sample Return Campaign
- Assumptions
- Motor Sizing
- Propellant Selection
- Nozzle and Controls
- Development and Qualification Testing
- Future Work

For More Information, Contact: andrew.s.prince@nasa.gov

Potential Mars Sample Return Campaign

- Mars 2020 rover
  - Collect and cache samples
- Earth Return Orbiter (ERO)
  - Enter Mars orbit ready to receive samples and transport back to earth
- Sample Retrieval Lander
  - Places Mars Ascent Vehicle (MAV) on Mars for sample stow and launch to ERO



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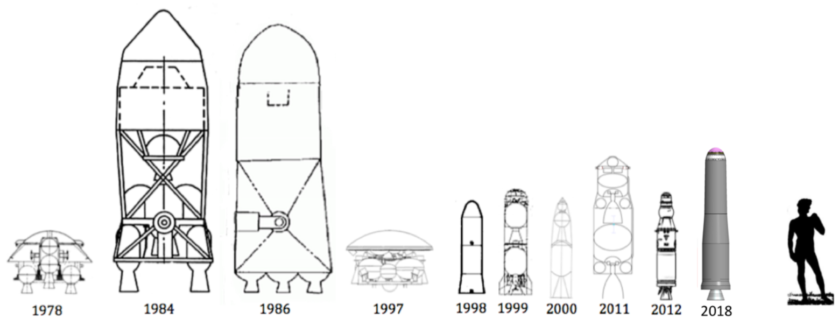
MAV Propulsion



MAV Concept History

- Currently MAV is trading between hybrid and solid propulsion with a selection to be made in September 2019
- This presentation is about the methodologies and progress toward developing the solid propulsion vehicle

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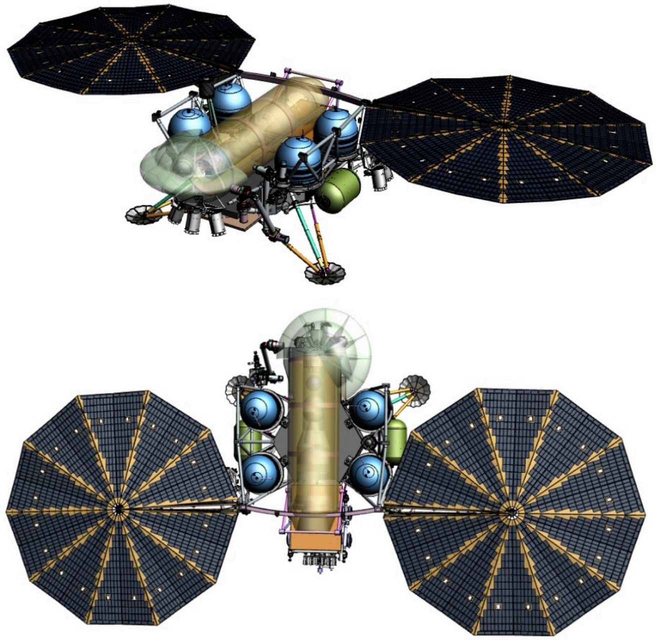
Ground Rules and Assumptions

- Mass, length and diameter are driven by the lander
  - Length is shared with payload, avionics and Reaction Control System (RCS)
- Landing site selection will affect low temperature requirements
- Maximum shock will be parachute snap



Assumption	Value
Maximum GLOM (kg)	400.0
Maximum Vehicle Length (m)	3.0
Vehicle Diameter (m)	0.57
Payload Length Length (m)	0.5
Altitude (m)	343,000.0
Maximum Angle of Attack (degrees)	4.0
Launch PBMT (◦C)	-20 (+/-2)
Storage Temperature Min/Max (◦C)	-70/40

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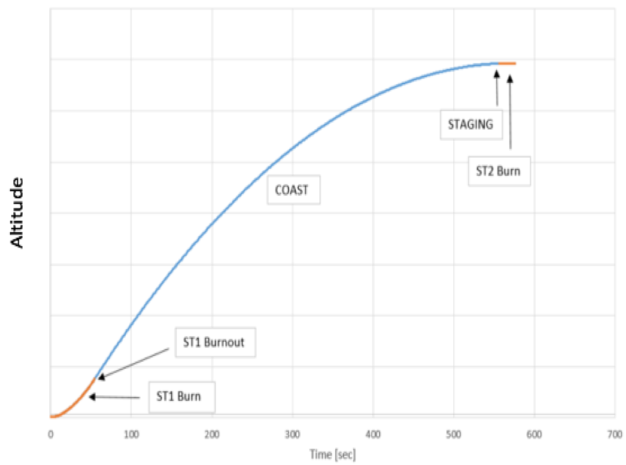
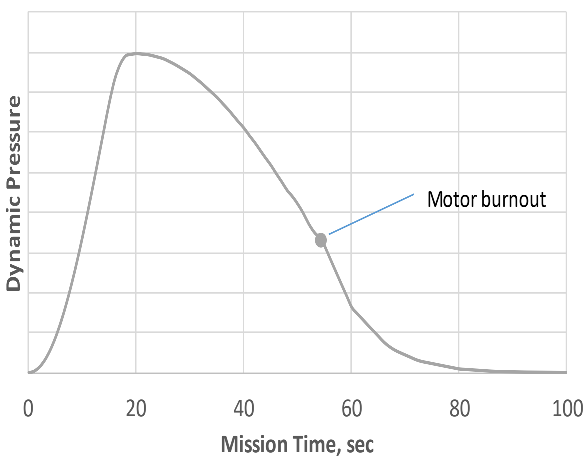
Design Methodology

- First Stage: High initial thrust to overcome gravity losses; Burn time and throttling to minimize max Q (Boost-Sustain)
- Second Stage: Insensitive to burn time variation; Sensitive to I_{sp} variation



Mission Flight Profile



First Stage Dynamic Pressure

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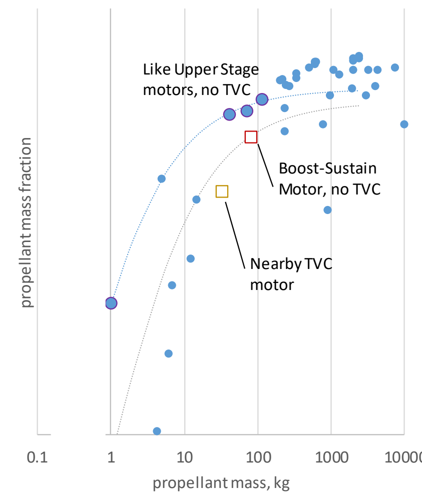
Propellant Mass Fraction Model

- A non-dimensional relationship was derived for propellant mass fraction (pmf)
  - Like sized motors were surveyed based on pmf and propellant mass
  - A subset of boost-sustain motors yields a slightly lower curve due to added insulation for the longer burn times

$$f_i = f_{i_{min}} + C_{ref}\left(\frac{m_{p_{ref}}}{m_p}\right)^{\frac{2}{3}}$$

$$pmf = \frac{1}{1+f_i}$$



- Where,
  - $f_{i_{min}}$ = minimum inert mass or the limit as propellant goes to infinity
  - C_{ref} = slope of data
  - $m_{p_{ref}}$ = a reference propellant mass driving the location of inflection

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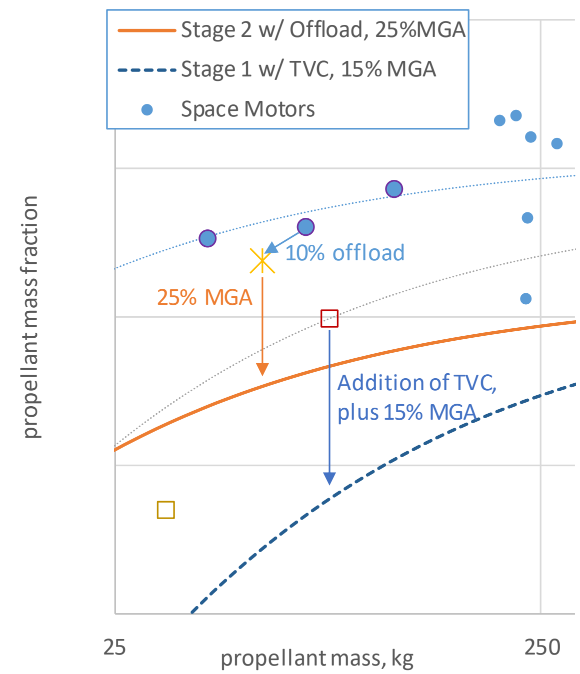
MAV Motor Model

- Modification to the pmf model were made to account for MAV specifics
  - Additional interstage structures were accounted for by assuming 10% propellant offload
  - A 25% MGA assumed for the second stage
  - Additional inert mass added to the larger first stage for increased TVC
  - The first stage is similar to a commercially available system allowing a 15% MGA to be assumed



First and Second Stage Adjusted Trends

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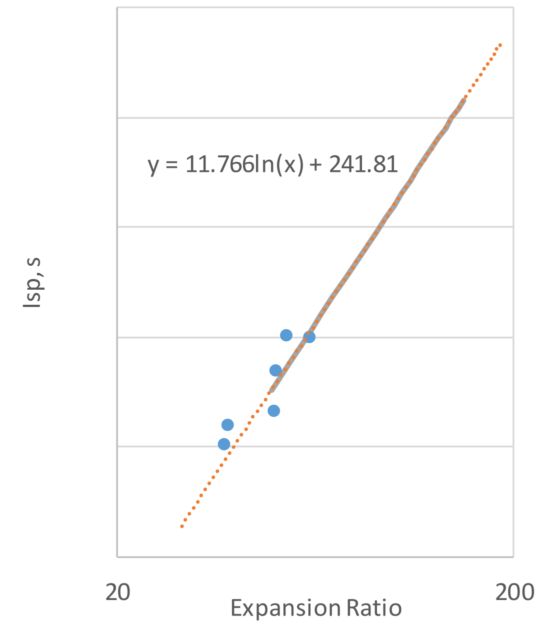
Motor Sizing

- Modified COTS solution:
  - Minimize Gross Lift Off Mass (GLOM)
  - I_{sp} assigned to each motor based on Commercial Off The Shelf (COTS) motors and 3 DOF analysis
  - Propellant mass allowed to vary to meet orbital assumptions while minimizing GLOM
- Optimum solution:
  - GLOM limited to 400 kg
  - I_{sp} allowed to move along trend as required to meet orbital assumptions



I_{sp} of COTS Products

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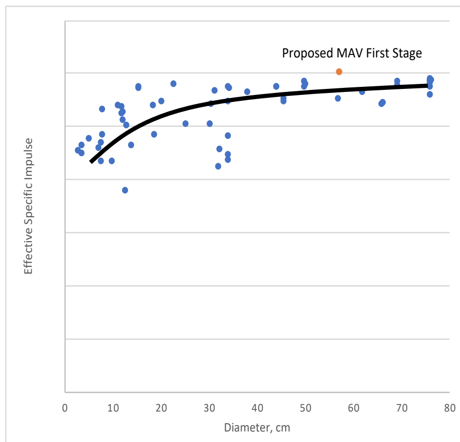
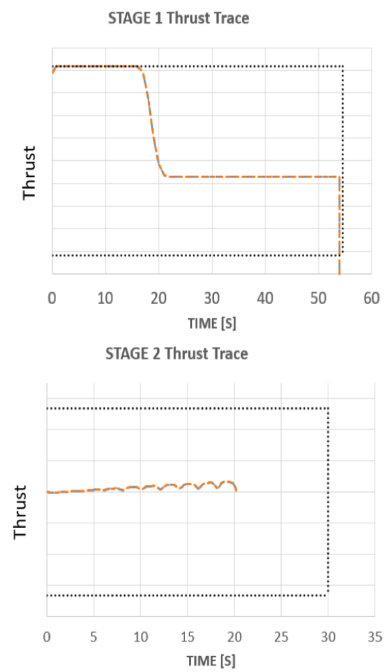
Thrust Traces for Both Solutions

- The optimum solution requires challenging I_{sp} values that are above the trend of other COTS products

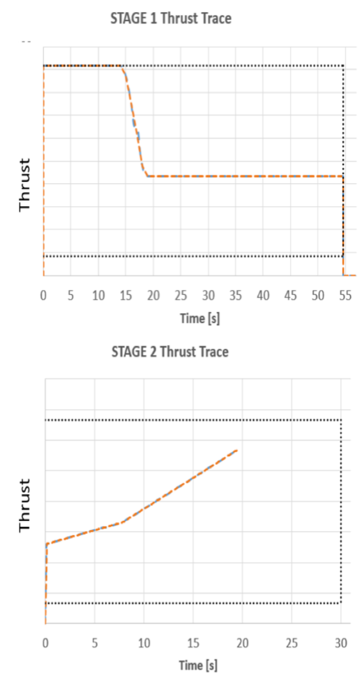
Parameter	Isp, sec		GLOM, kg
Stage	1	2	
Modified COTS	288	291	419
Optimum	300	293	399



COTS Isp vs. Diameter



Modified COTS



Optimum

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Propellant Selection

- A set of COTS propellants were surveyed based on a set of specific assumption
  - -70 ºC/ +40 ºC storage and -20 ºC Operation
  - Ranked density-impulse
  - Effects of Planetary Protection procedures
    - Bio-reduction (heat or radiation)
    - Bio-barriers
    - End-of-mission procedures
  - TRL level – Similar mission histories

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Nozzle and Controls

- With low operational temperature assumptions freezing slag is concern
  - Subsonic splitline vectorable nozzle could get entrained with slag and freeze up
  - Therefore a super sonic splitline was selected

- RCS sizing will rely on 6 DOF results when received
  - Cold gas vs hydrazine
  - Minimize mass
  - Favors minimal Q at first stage burnout

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Development and Qualification Testing Planning

- Defining a development/qualification is important for planning purposes
- More motors can reduce risk and increase cost requiring these to be balanced
- A qualitative matrix of risk with varied numbers of motors was derived based or assumption parameters qualified
- A set of 3 development and 3 qualification motors were selected by the project
  - Flight test is considered a qualification motor in Dev/Qual Plan

OPTION	SUB-SCALE TESTING			FULL-SCALE TESTING				LIKELIHOOD X CONSEQUENCE	FINAL RISK SCORE
	PLANETARY PROTECTION	THERMAL CYCLING	COLD-SOAK	PLANETARY PROTECTION	THERMAL CYCLING	COLD-SOAK	FLIGHT TEST OR FLIGHT-LIKE TEST		
1	X	X	X	3 DMs + 8 QMs	3 DMs + 8 QMs	3 DMs + 8 QMs	5 QMs	1X2	3
2	2X	2X	2X	3 DMs + 6 QMs	3 DMs + 6 QMs	3 DMs + 6 QMs	4 QMs	2X2	6
3	3X	3X	3X	3 DMs + 4 QMs	3 DMs + 4 QMs	3 DMs + 4 QMs	3 QMs	3X2	9
4	X	X	X	3 DMs + 4 QMs	3 DMs + 4 QMs	3 DMs + 4 QMs	3 QMs	3X2	9
5	2X	2X	2X	3 DMs + 3 QMs	3 DMs + 3 QMs	3 DMs + 3 QMs	2 QMs	2X3	11
6	3X	3X	3X	2 DMs + 2 QMs	2 DMs + 2 QMs	2 DMs + 2 QMs	1 QM	2X4	14

Dev/Qual Risk Matrix

	Stage 1	Stage 2
Development	3	3
Qualification	3	3
Flight Test	1	1
Inert Mass Simulator	1	1
Flight	2	2
Total Motors	10	10

Dev/Qual Plan

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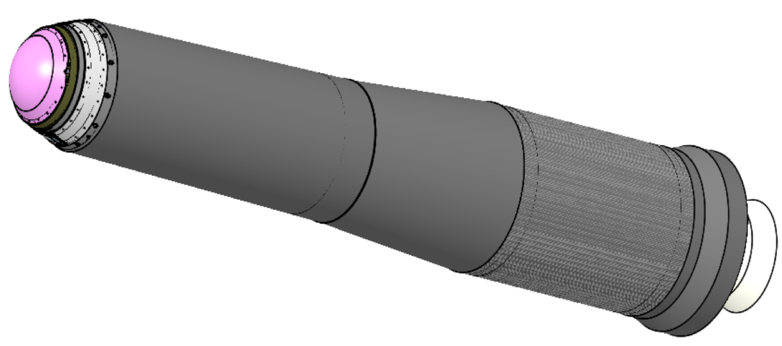
Future Work

- Refine and iterate with other subsystems
  - Trade Isp (expansion ratio) with vehicle mass (interstage)
  - Trade aero stability with flow feature mass and location and design
- Refine design models (CAD) for minimum mass



Current MAV Solid Vehicle Concept

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