ReachMars 2024

A Candidate Large-Scale Technology Demonstration Mission as a Precursor to Human Mars Exploration

1 October 2014 | Toronto, Canada

Mark Schaffer
Senior Aerospace Engineer, Advanced Concepts Group
mark.schaffer@sei.aero | +1.770.379.8013

Introduction

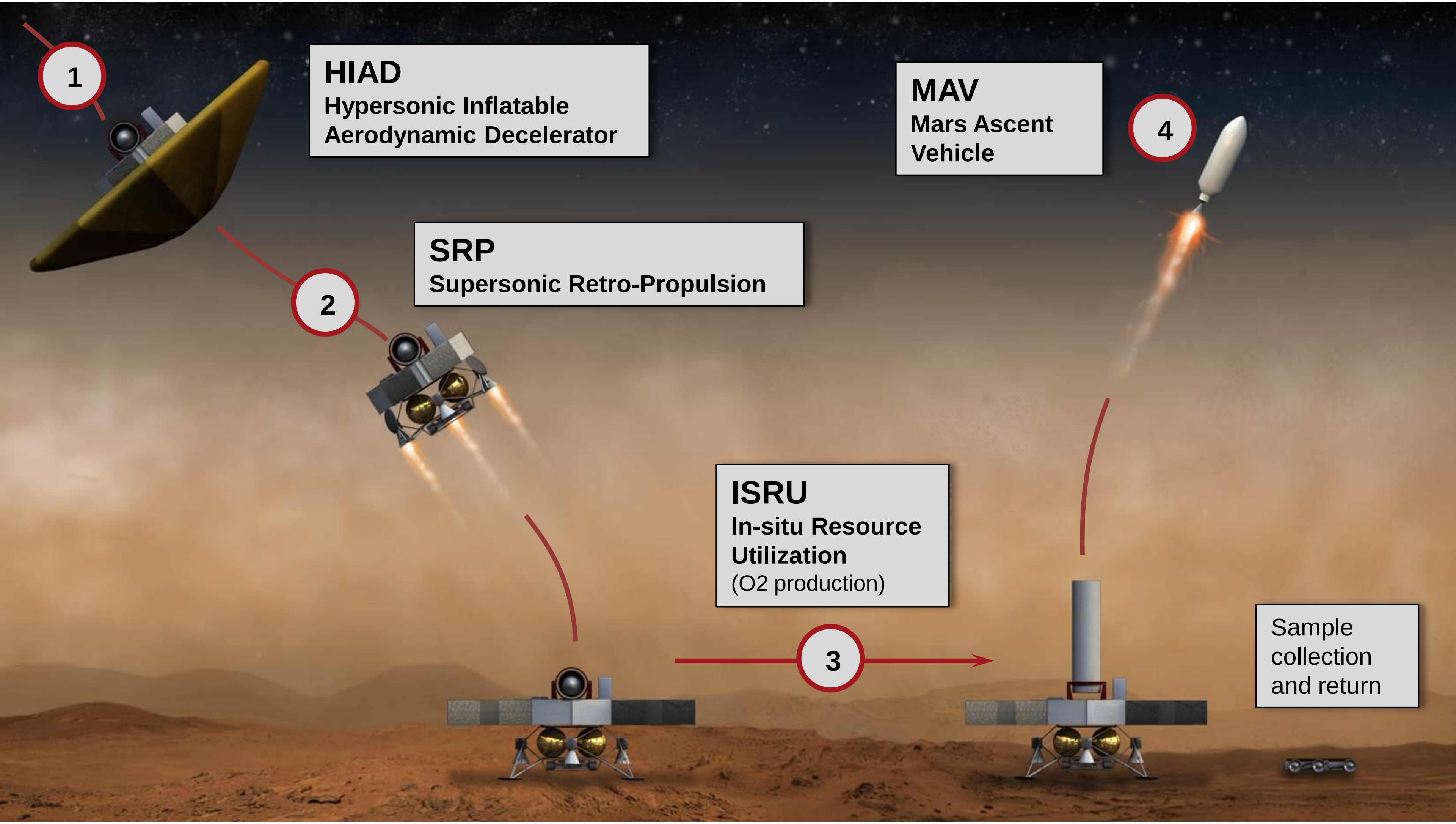
Project Overview

- Problem: Investigate robotic precursor Mars mission to demonstrate and mature key technologies required for future human Mars missions
  - 2024 or 2026 Mars mission opportunity
  - Launch on SLS Block 1 (ICPS provides TMI maneuver)

- Study Timeframe: July 2013 through Sept 2013

- Design Team: Joint partnership between NASA MSFC and SpaceWorks Enterprises, Inc.
  - Mark Schaffer, SpaceWorks Enterprises, Inc.
  - Brad St. Germain , SpaceWorks Enterprises, Inc.
  - Tara Polsgrove, NASA MSFC
  - Kendall Brown, NASA MSFC

Demonstrated Technologies



Summary Results

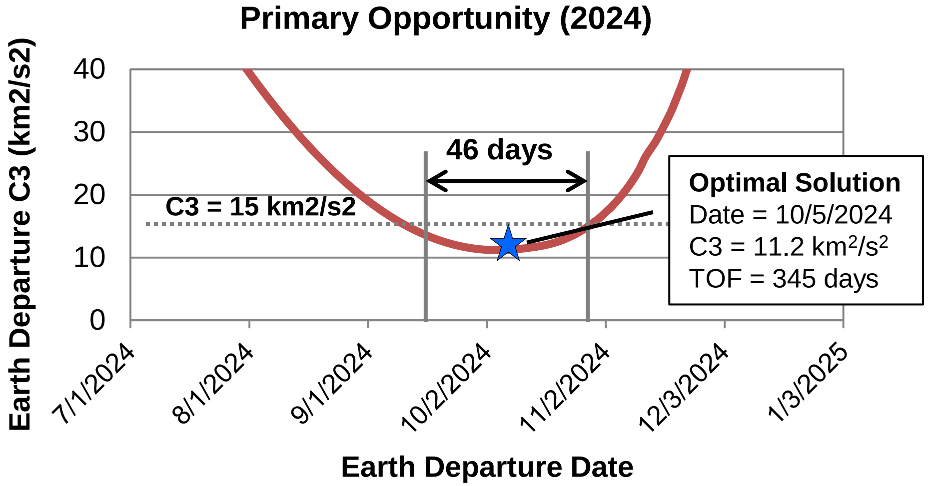
- System Masses
  - Launch Mass = 18.0 t
  - Payload Mass = 7.4 t
- Vehicle Dimensions
  - Height = 5.5 m
  - Rigid Diameter = 5.0 m
  - HIAD Diameter = 12.5 m
- Launch C3 = 15.0 km2/s2
  - Primary Opportunity: 9/12/2024 to 10/28/2024
  - Secondary Opportunity: 10/1/2026 to 11/25/2026

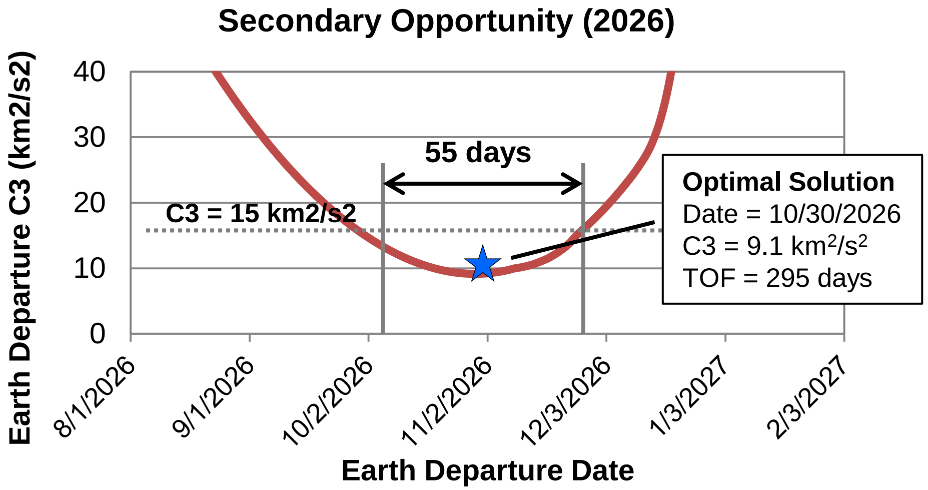
Mass Breakdown Statement	
Lander Vehicle	**10.6 t**
Inert	4.7 t
Propellant	3.4 t
HIAD	2.4 t
Delivered Payload to Surface	**7.4 t**
ISRU	0.5 t
Nuclear Power for ISRU	3.3 t
MAV	2.1 t
MAV Deployment	0.4 t
Rover	0.9 t
Integration	0.1 t
Total	**18.0 t**

Analysis

Launch Opportunities

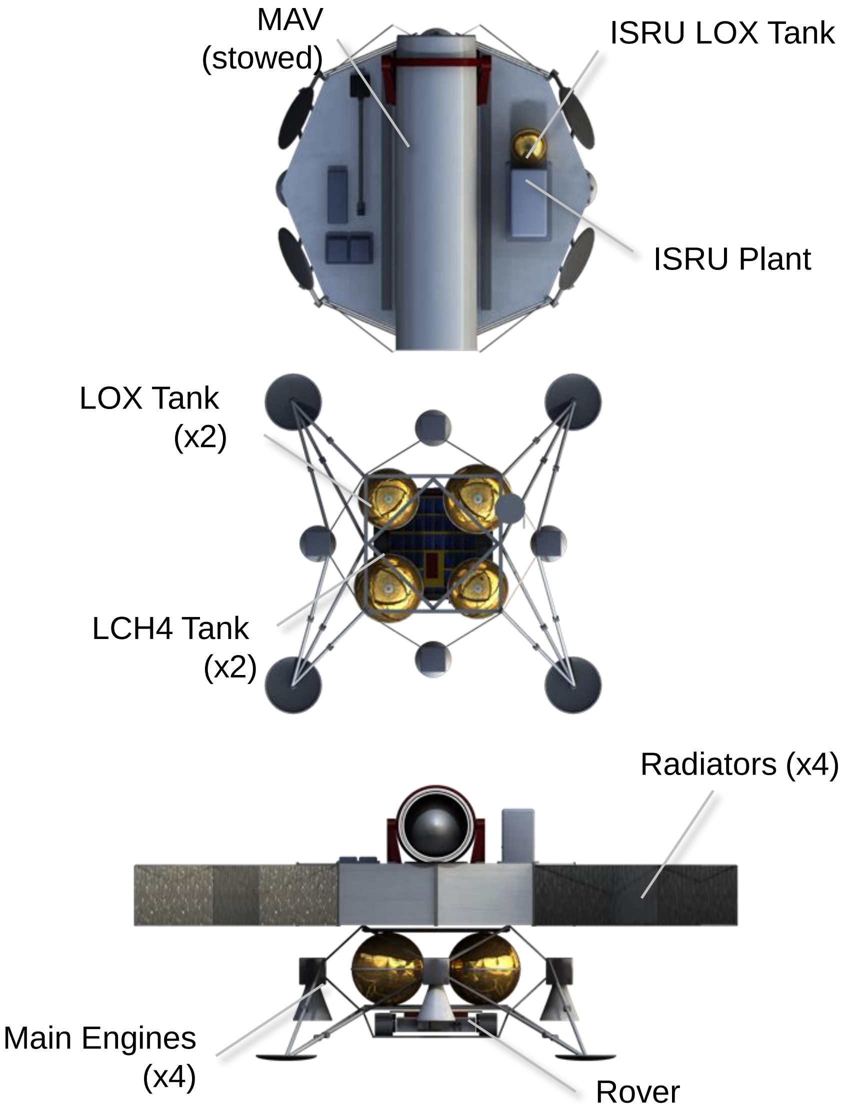
- Selected launch C3 = 15.0 km2/s2
- Identified two mission opportunities
  - Primary opportunity: 46 day window in 2024 between 9/12 and 10/28
  - Secondary opportunity: 55 day window in 2026 between 10/1 and 11/25





Vehicle Design

- Mass and sizing
  - Parametric sizing model built from historical MERs, physics-based equations, and empirical data
  - 30% mass growth allowance on all dry masses
- Design assumptions
  - LOX/CH4 propellants
  - Electrical power provided by Advanced Stirling Radioisotope Generator (ASRG)
    - ISRU uses independent power supply
  - Total Descent DV = 820 m/s based on NASA DRA 5.0



Propulsion

- Common Extensive Cryogenic Engine
  - In development by Aerojet Rocketdyne
  - Derived from RL-10 engine family
  - Deeply throttlable for lunar and Martian surface missions
  - Assumed shortened nozzle (Area Ratio = 40:1) to support SRP
- Total thrust requirement
  - 4 engines required
  - Ignition Thrust-to-Weight
    - 1.5 (Earth)
    - 4.5 (Mars)
    - Based on NASA DRA 5.0 lander thrust-to-weight (Mars)

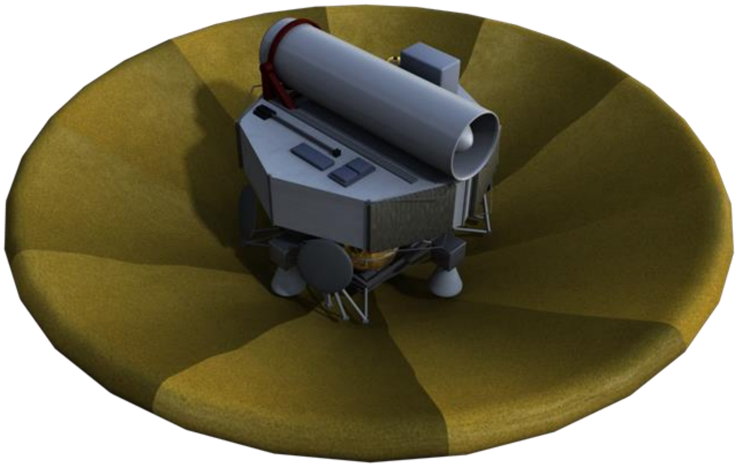
Propellants	LOX/CH_4
Engine Cycle	Expander
Vacuum Thrust	66.7 kN (15.0 klbf)
Vacuum Isp	340 sec
Area Ratio	40:1
Exit Area	0.37 m^2 (4.0 ft^2)
Chamber Pressure	39 bar (570 psi)
Mass	160 kg (350 lbm)

Engine data based on published information on Aerojet Rocketdyne website and augmented by analysis with SpaceWorks Software's REDTOP-Lite engine analysis software

Image Source: http://www.rocket.com/common-extensible-cryogenic-engine-0

Hypersonic Inflatable Aerodynamic Decelerator

- HIAD designs from previous studies used to approximate HIAD mass and dimensions
- Results:
  - Total Mass = 2.4 t
  - Inflated Diameter = 12.5 m
  - Cone half angle = 63.5 deg
  - Entry areal bulk density = 200 kg/m^2



	EFF-2 Ablator	EFF-2 Insulator	EFF-4 Ablator	EFF-4 Insulator	DRA-5 Addendum 2
Entry Type	Aerocapture	Aerocapture	Direct	Direct	Aerocapture
Rigid Diameter	4.3 m	4.3 m	4.3 m	4.3 m	9.0 m
HIAD Diameter	8.0 m	14.0 m	8.0 m	8.0 m	23.0 m
Entry Mass	7.2 t	7.2 t	7.2 t	7.2 t	94.0 t
Areal Bulk Density	140 kg/m^2	50 kg/m^2	140 kg/m^2	140 kg/m^2	230 kg/m^2
HIAD Mass	1.1 t	1.8 t	0.9 t	0.7 t	21.0 t

In-Situ Resource Utilization

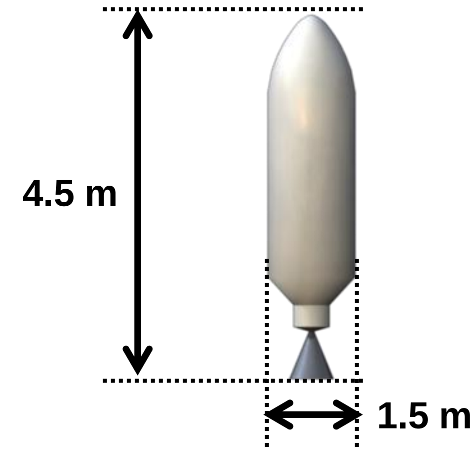
- ISRU through collection of atmospheric CO_2 and generation of O_2 from CO_2 Electrolysis is a power-intensive process
  - ISRU design limited by high power requirements
  - Nuclear fission power likely required for human missions, can be demonstrated in precursor mission with ISRU

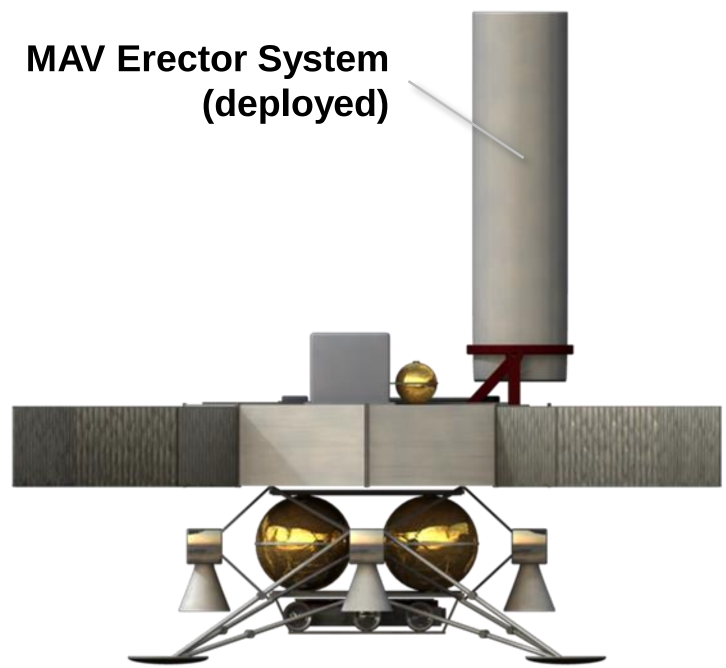
- Nuclear fission power generation:
  - Power generated = 10.0 kWe
  - Comparable to individual mobile unit considered for human missions to Moon and Mars
  - System mass (including thermal control) = 3,300 kg

- Resulting ISRU system:
  - Oxygen production = 0.65 kg per hour
  - Operating power = 9.2 kWe
  - Operating time = 30 days
  - System mass = 520 kg

Mars Ascent Vehicle

- Point design from 2013 Mars Sample Return Study
  - Single stage NTO/MMH rocket
  - XLR-132 gas generator engine
- Launches 200 kg Earth Return Vehicle (ERV) to direct Earth return trajectory



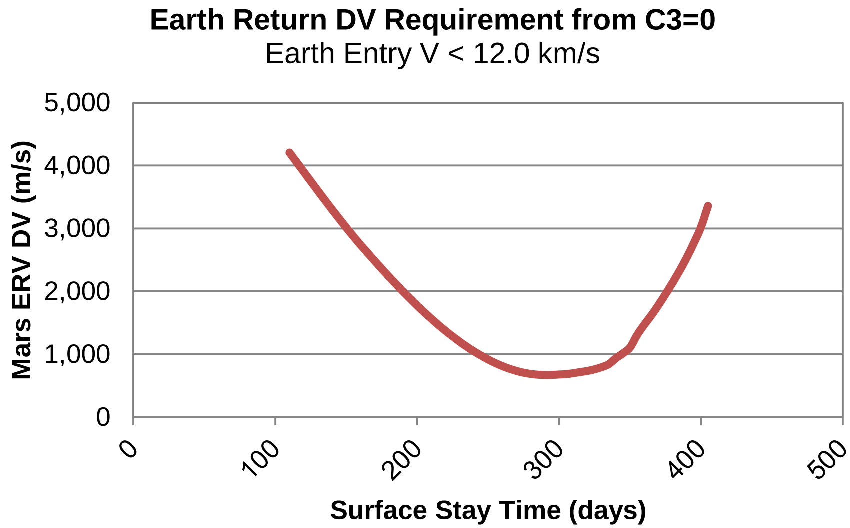


Mass Breakdown Statement	
Payload (ERV)	200 kg
Dry Mass	170 kg
Propellant	1,730 kg
Mars Ascent Vehicle	**2,100 kg**
Erector System	420 kg
Total MAV System	**2,520 kg**

Earth Return Vehicle

- Sample Return Canister
  - Scaled from reference document
  - Direct Earth entry
- Earth Transfer Return Stage
  - Monopropellant hydrazine
    - Thrust = 400 N
    - Isp = 214 sec
  - Total DV = 1,000 m/s
- Total Mars surface sample return to Earth = 5 kg

Mass Breakdown Statement	
Sampler Return Canister	40 kg
Surface sample	5 kg
Structures and subsystems	10 kg
Aerobrake and heat shield	20 kg
Parachute	5 kg
Earth Transfer Return Stage	160 kg
Structures and subsystems	80 kg
Propellant	80 kg
Total	**200 kg**



Programmatic Factors

De-Scope Options

- Reduce ISRU plant power requirement to remove nuclear fission requirement and rely solely on ASRG-based power supply
  - Reduces total mission cost
  - Reduces political sensitivity

- Replace mobile rover with static sample collection package on lander
  - Reduces total mission cost
  - May be opportunity to repurpose existing rover design to reduce cost and risk

- Remove ERV from MAV; demonstrate ascent to Mars orbit or Mars escape only
  - Reduce mission complexity
  - Avoid Earth planetary protection concerns

Mission Dependencies

This mission will require **separate development** of several enabling hardware elements including:

- Throttlable exploration-class liquid rocket engine (i.e. methane-fueled CECE)
- Low boil-off technologies for liquid oxygen and liquid methane for long duration mission (> 1 year)
- Advanced dynamic radioisotope power sources (i.e. ASRG)

Conclusions

Key Findings

- SLS Block 1 can deliver an **18.0 t vehicle** to Mars to support a 2024 or 2026 robotic precursor mission, which can deliver **7.4 t payload** to the Martian surface

- Lander vehicle can demonstrate **two key EDL technologies** for human missions: HIAD and SRP

- Delivered payload is sufficient to support several cross-cutting technology demonstrations:
  - An **ISRU O2 production** demonstration
  - **Mars Ascent Vehicle** capable of **5 kg Mars surface sample return** to Earth supported by Curiosity-class rover for sample collection and scientific exploration

SPACE IS GO

SpaceWorks Enterprises, Inc.

SPACEWORKS ENTERPRISES, INC. (SEI) | www.sei.aero | info@sei.aero

1040 Crown Pointe Parkway, Suite 950 | Atlanta, GA 30338 USA | +1.770.379.8000

References

1. Yeomans, Donald (Site Manager), “HORIZONS System”, Visited 9 Sept 2014, http://ssd.jpl.nasa.gov/?horizons

2. NASA Facts, "Space Launch System", NASA Marshall Space Flight Center, NASA FS-2012-06-49-MSFC, June 2012.

3. Brown, K., Lepsch, R., "Mars Lander Analyses Summary and Forward Work", Human Architecture Team (HAT) Technical Integration Forum, NASA, March 2013.

4. Aerojet Rocketdyne, “Common Extensible Cryogenic Engine”, Visited 9 Sept 2014, http://www.rocket.com/common-extensible-cryogenic-engine

5. Drake, et. al., “Human Exploration of Mars, Design Reference Architecture 5.0”, Mars Architecture Steering Group - NASA Headquarters, NASA SP-2009-566, July 2009.

6. Cianciolo, A. (Editor), "Entry, Descent, and Landing Systems Analysis: Exploration Feed Forward Internal Peer Review Slide Package", NASA Langley Research Center, NASA/TM-2011-217050, February 2011.

7. Bowles, J., Huynh, L., Hawke, V., Mars Sample Return: Mars Ascent Vehicle Mission & Technology Requirements, NASA/TM-2013-216511, March 2013.

8. Coons, S., Curtis, R., McLain, C., Williams, J., Warwick, R., Bruckner, A., In-Situ Propellant Production Strategies and Applications for a Low-Cost Mars Sample Return Mission, AIAA 95-2796.