
Technology Development for
Human Exploration of Mars
University of North Dakota
Space Studies Colloqium
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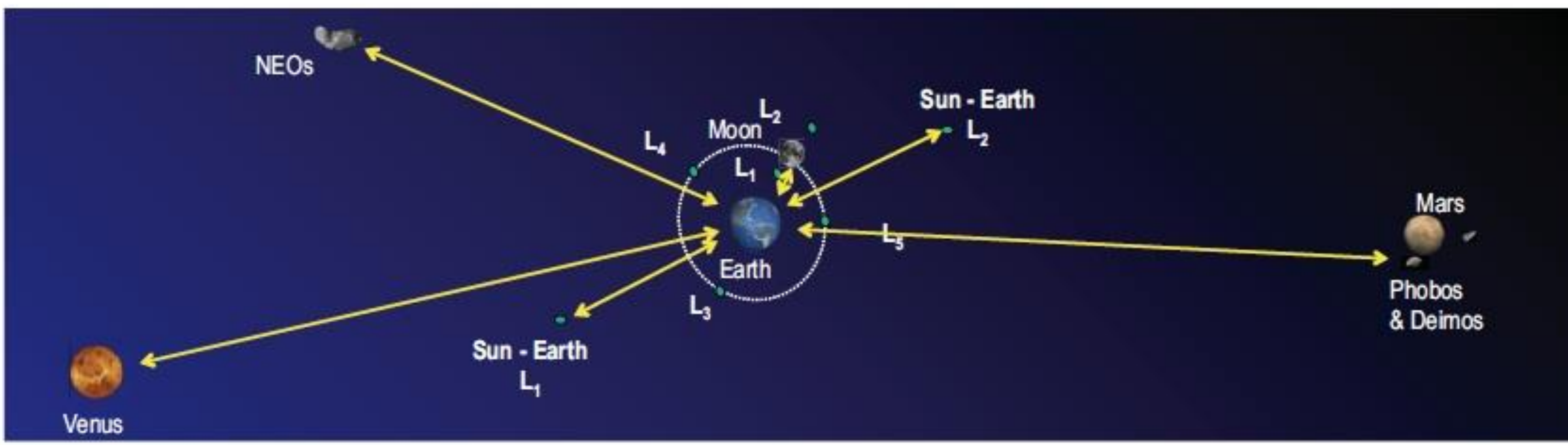
Exploration Strategy: Flexible Path to Mars and Moon

Goal – Understand how to live and work in free space under the conditions we will meet on the way to Mars, gather science knowledge and support science operations

A Flexible Path of Human and Robotic Exploration:

- **Crewed exploration missions to many places in the inner solar system**
- **Orbit planets with deep gravity wells, but do not land on the surface**
- **Rendezvous with small planetary bodies such as NEOs and Mars' moon Phobos**
- **Tele-robotically explore and sample planetary surfaces**

A fundamentally new mode of human exploration, in close cooperation with robotics



Value Proposition for Flexible Path

Destination	Public Engagement	Science	Human Research	Exploration Preparation
Lunar Flyby/ Orbit	Return to Moon, "any time we want"	Demo of human robotic operation	10 days beyond radiation belts	Beyond LEO shakedown
Earth Moon L1	"Onramp to the inter-planetary highway"	Ability to service ES L2 s/c at EM L1	21 days beyond the belts	Ops at potential fuel depot
Earth Sun L2	First human in "deep space" or "Earth escape"	Ability to service ES L2 s/c at ES L2	32 days beyond the belts	Potential servicing, test airlock
Earth Sun L1	First human "in the solar wind"	Potential for Earth/Sun science	90 days beyond the belts	Potential servicing, test in-space hab
NEO's	"Helping protect the planet"	Geophysics, Astrobiology, Sample return	190-220 day, similar to Mars transit	Encounters with small bodies, sample handling, resource utilization
Mars Flyby	First human "to Mars"	Human robotic operations, sample return?	440 days, similar to Mars out and return	Robotic ops, test of planetary cycler concepts
Mars Orbit	Humans "working at Mars and touching bits of Mars"	Mars surface sample return	780 days, full trip to Mars	Joint robotic/human exploration and surface ops, sample testing,
Mars Moons	Humans "landing on another moon"	Mars moons' sample return	780 days, full rehearsal Mars exploration	Joint robotic/human surface and small body exploration

Mars Design Reference Architecture 5.0

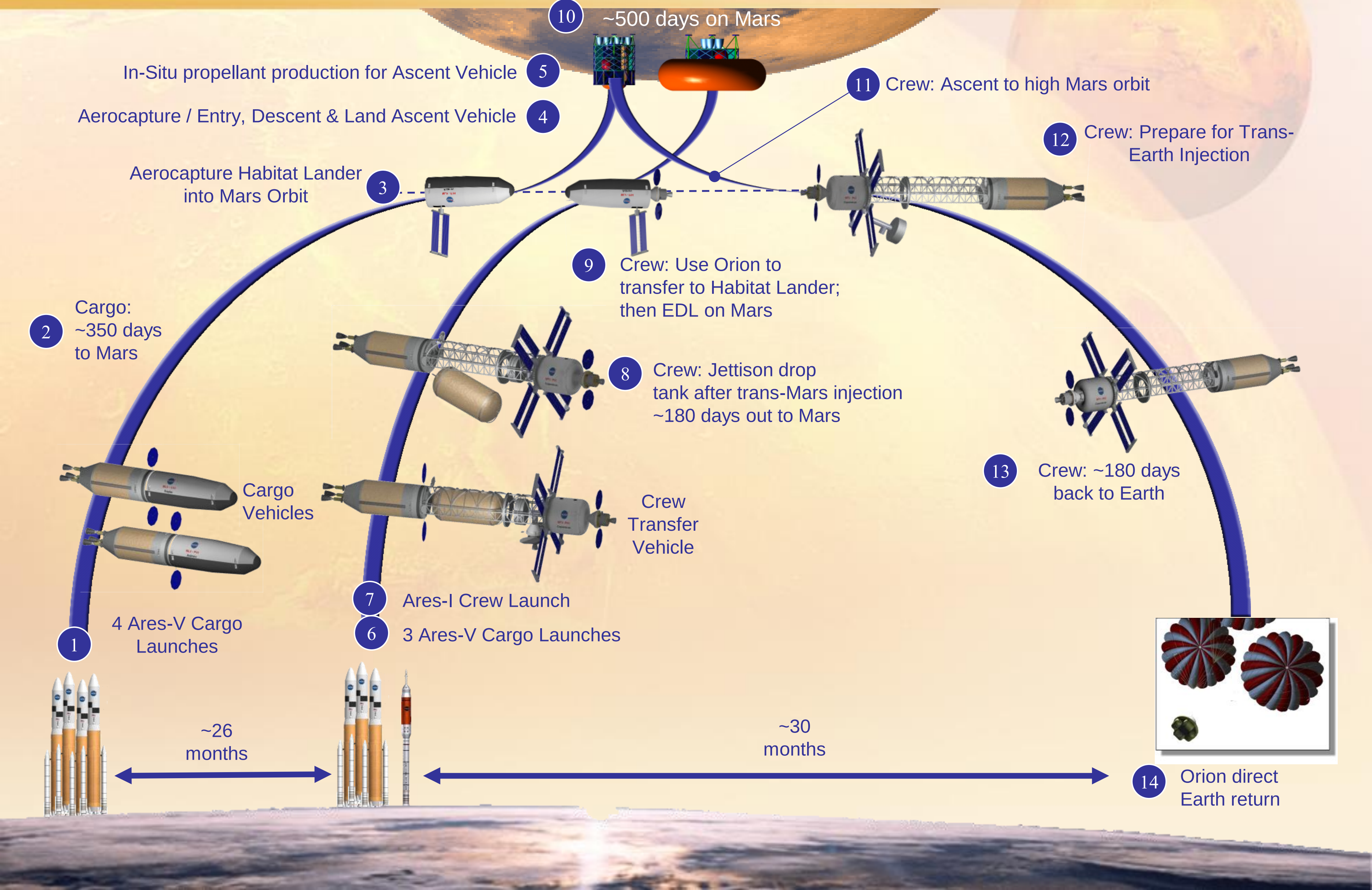
Mars Exploration Architecture Studies

- NASA has conducted a series of studies to define a conceptual mission architecture and to identify enabling technologies for human exploration of Mars.
- The Mars Design Reference Architecture 5.0 was completed in 2009.

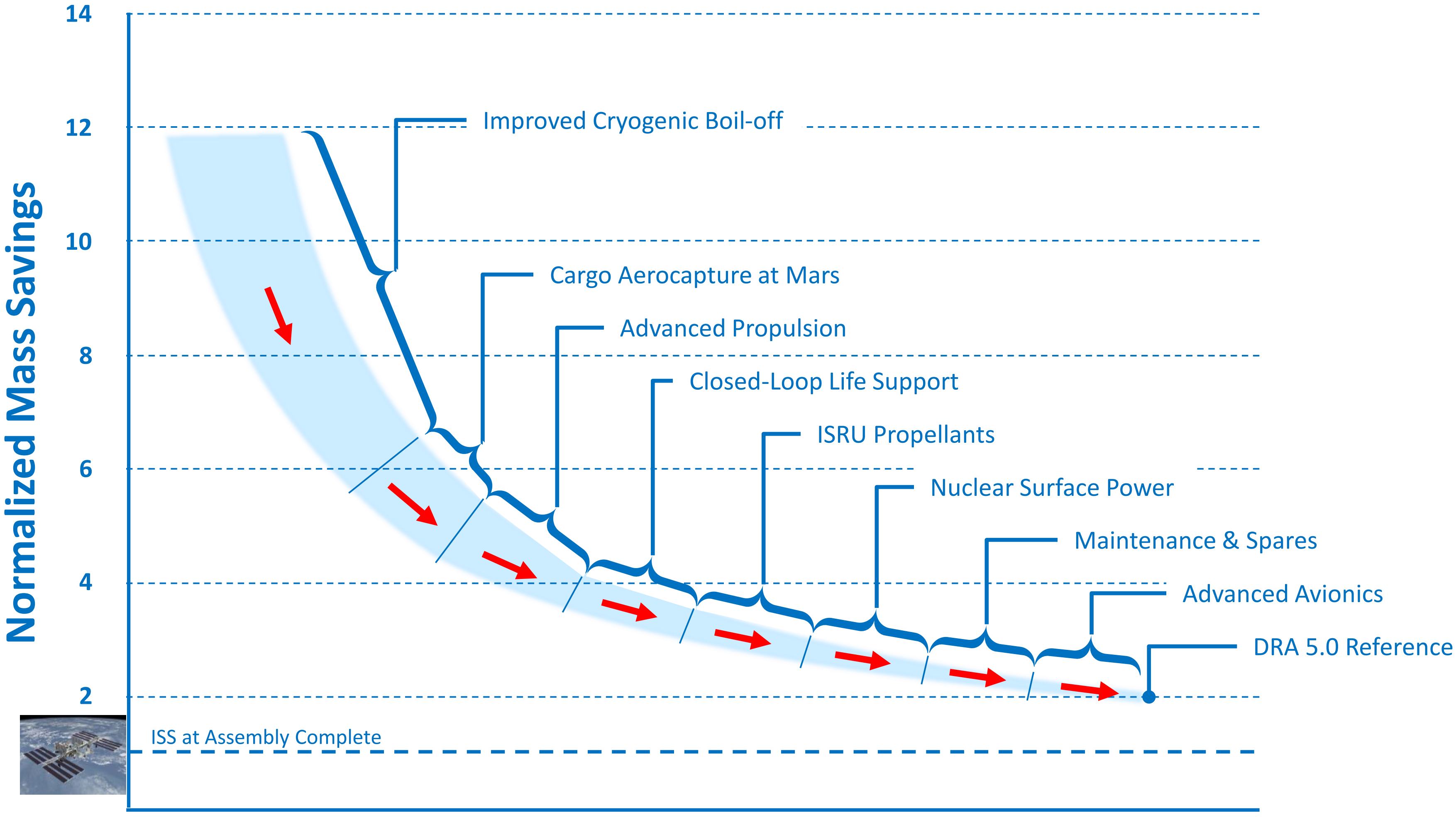
Main Features:

- Minimum energy conjunction class architecture.
- Mars habitat and ascent/descent vehicle are pre-deployed for checkout before crew arrives.
- Crew launches 26 months after cargo elements and stays 500 days on Mars surface.
- Nuclear thermal rocket for in-space propulsion.
- Aerocapture for Mars orbit entry.
- Surface mobility systems enable the crew to explore hundreds of kilometers from the landing site to enhance science return.
- In-situ propellant production for ascent vehicle.
- Requires 7 Heavy Lift Launch Vehicles to assemble systems in Earth orbit.
- Total mission duration for crew is about 900 days.

Mars Design Reference Architecture 5.0



The Value of Technology Investments
Mars Mission Example



Critical Technology Needs for Human Mars Exploration

NASA has begun long-range development of critical technologies:

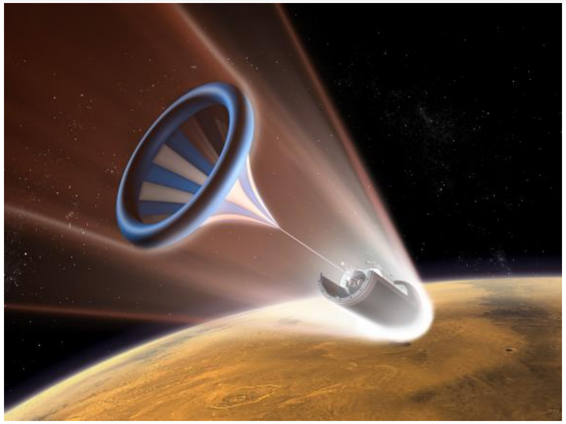
- Entry, Descent, and Landing Technology
- Nuclear Propulsion and Power
- LOX-Methane Propulsion and Cryogenic Propellant Storage
- Closed-Loop Life Support
- Surface Mobility Systems
- In-Situ Resource Utilization Systems
- High Bandwidth Communications
- Radiation Protection

Entry, Descent, and Landing Technology

Desired Capabilities
- Aerocapture for Mars orbit entry to reduce propellant mass.
- Landing payloads greater than 50 metric tons on surface of Mars.

Technology Development
- Thermal protection system materials for rigid and inflatable aeroshells
- Aerothermal modeling and analysis tools
- Supersonic parachutes and aerodynamic decelerators
- Supersonic retro-propulsion

Flight Experiments
- Inflatable Re-entry Vehicle Experiment (IRVE) successfully flight tested in 2009.
- MEDLI experiment on Mars Science Laboratory mission in 2011 will acquire temperature and pressure data on aeroshell during atmospheric entry.



Ellipsled rigid aeroshell with inflatable decelerator

Inflatable Re-entry Vehicle Experiment (IRVE)

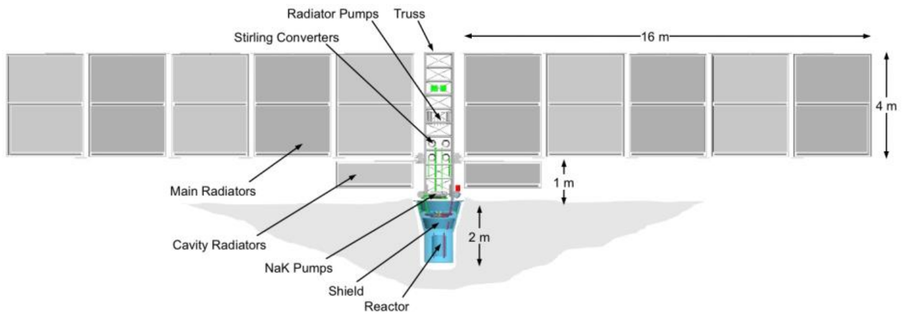
Nuclear Propulsion and Power

Desired Capabilities

- High specific impulse nuclear thermal propulsion (Isp ~900 s)
- Fission surface power system enables in-situ resource utilization.

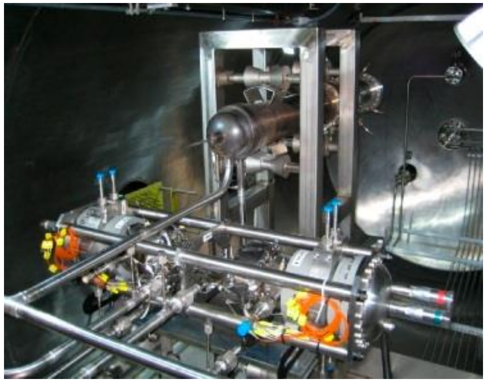
Technology Development

- Nuclear thermal propulsion demonstrated in 1970s.
- Concepts and technologies for 40 kWe fission power system for lunar and Mars surface applications
- Low temperature, liquid-metal (NaK) cooled reactor with UO_2 fuel and stainless steel construction
- Demonstrated 2kW Stirling power conversion system integrated with liquid metal coolant loop.



Fission surface power system

NERVA nuclear rocket engine



Stirling power conversion system

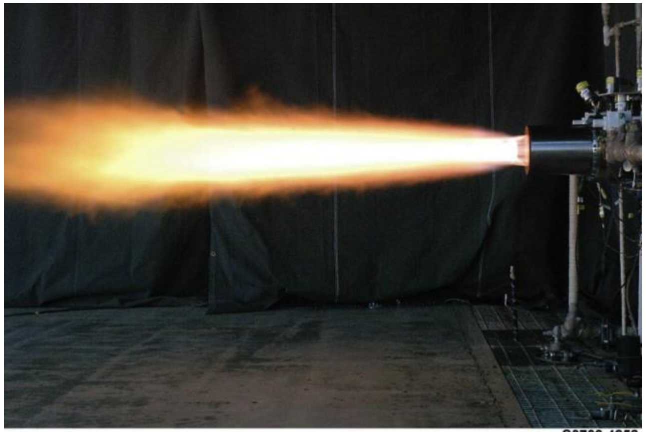
LOX-Methane Propulsion and Cryogenic Fluid Management

Desired Capabilities

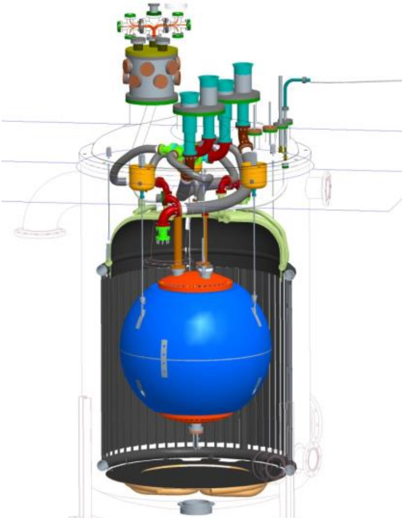
- Cryogenic propulsion system for ascent vehicle that uses non-toxic propellants produced from Mars atmosphere.
- Zero boil-off storage of cryogenic propellants on Mars surface for up to 1200 days.

Technology Development

- Prototype 5,500 lbf thrust LO_2-LCH_4 engine for lunar lander ascent stage.
- 100 lbf LO_2-LCH_4 thrusters for attitude control
- Broad area cooling of propellant tanks
- Thermodynamic vent systems to control tank pressure and temperature
- Liquid acquisition devices
- Propellant mass gauging



LOX-methane engine for lunar lander (Aerojet)



Cryogenic fluid management test bed

Closed-Loop Life Support

Desired Capabilities

- Recycle greater than 95 percent of air, water, and solid waste to minimize life support system consumables.

Technology Development

- Carbon dioxide and moisture removal systems for air revitalization.
- Sabatier reactor to produce water from carbon dioxide and methane.
- Water recovery system to recycle urine and sweat condensed from cabin atmosphere.
- Recovery of water from solid waste.
- Instruments to monitor atmospheric contaminants.

Flight Demonstrations

- ISS will be used to test Sabatier reactor and water recovery system.

ISS Water Recovery System

Surface Mobility Systems

Desired Capabilities

- Maximize opportunities for scientific discovery by exploring the surface of Mars hundreds of kilometers from the landing site on excursions lasting up to 14 days.
- Prepare for EVA in less than 15 minutes.
- Robotics to enable deployment, assembly, and checkout of surface systems.

Technology Development

- Small pressurized rover capable of transporting a crew of two.
- Suit-ports to enable rapid EVA.
- Tri-ATHLETE rover to unload large payloads from lunar lander and transport them to outpost assembly site.

Tri-ATHLETE rover for transporting large payloads.

Lunar Electric Rover

EVA suit-port

Tri-ATHLETE Rover Video

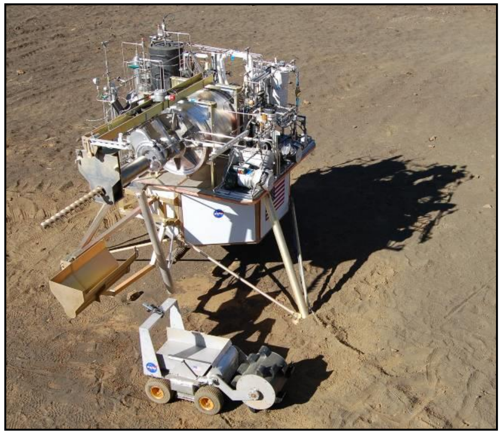
In-Situ Resource Utilization Systems

Desired Capabilities

- In-situ production of methane and oxygen propellants from Mars atmosphere for ascent vehicle.
- In-situ production of water and oxygen from Mars resources to replenish life support system consumables.

Technology Development

- Prototype ISRU systems to prospect for lunar resources, excavate lunar regolith, and process regolith to produce oxygen.
- Integration of ISRU, life support, energy storage, and propulsion systems to use common reactants.



Prototype ISRU system for producing oxygen from lunar regolith (Lockheed Martin)

Scarab rover designed to prospect for ice in lunar craters (CMU)

High Bandwidth Communications

Desired Capabilities

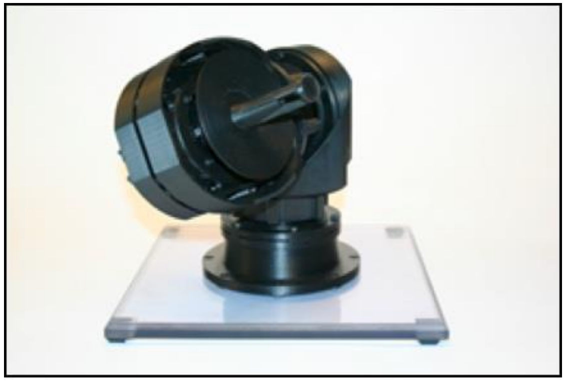
- High data rate communications link between Mars and Earth for HDTV.
- Surface communications between outpost and distant rovers.

Technology Development

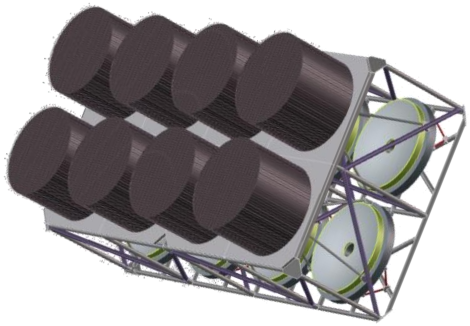
- Compact optical communications systems.
- Superconducting photon counting detectors.
- Multi-aperture ground receiver arrays.
- Portable communications relay terminal to link rovers with outpost or communications satellite in Mars orbit.

Flight Demonstrations

- NASA is planning to demonstrate a 622 Mbps optical communications system to downlink data from the Lunar Atmosphere & Dust Environment Explorer (LADEE) mission in 2012.



Model of optical communications system for LADEE mission (MIT Lincoln Laboratory)



Multi-aperture receiver array

Radiation Protection

Desired Capabilities

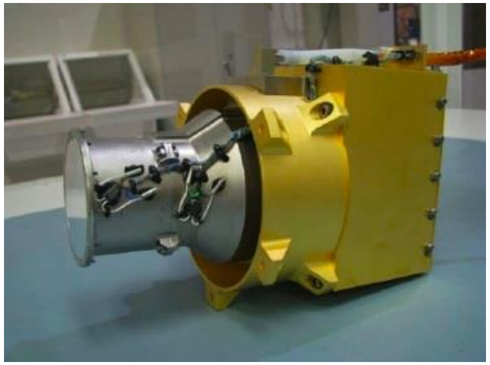
- Protect crew from hazardous effects of galactic cosmic rays and solar particle events on long-duration missions.

Technology Development

- Particle accelerator experiments to investigate the biological effects of space radiation and reduce the uncertainty in radiation risk models.
- Radiation transport models for use in spacecraft design.
- Lightweight radiation shielding materials.

Flight Demonstrations

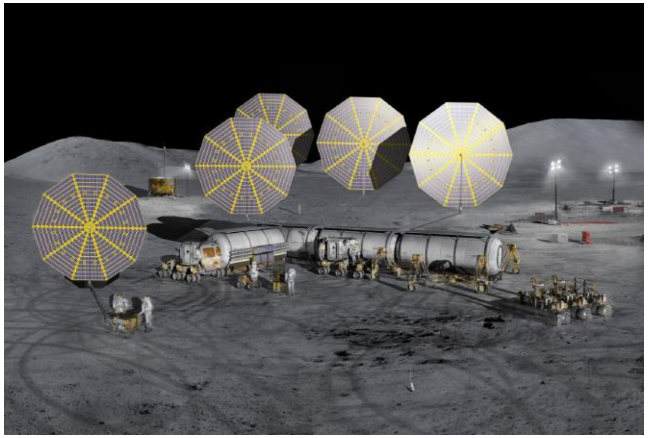
- The Radiation Assessment Detector (RAD) will be flown on the Mars Science Laboratory rover in 2011 to characterize the Mars surface radiation environment.

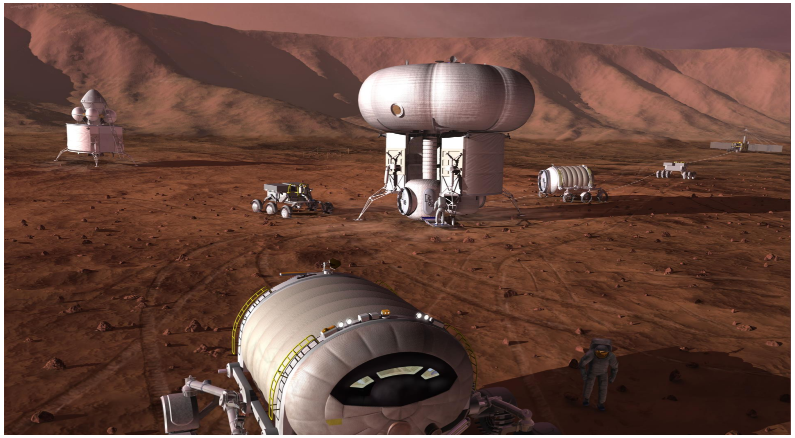


Radiation Assessment Detector for MSL Mission (Southwest Research Institute)

Preparing for Mars Exploration on the Moon

- **Many of the systems, technologies, and operational scenarios needed for human missions to Mars can be tested on the Moon:**
  - Surface mobility systems
  - Habitation systems
  - In-situ resource utilization systems
  - LOX-methane propulsion systems for ascent vehicle
  - Cryogenic fluid management systems
  - Fission surface power systems
  - Dust mitigation technologies
  - Planetary protection techniques





Summary

- NASA has begun long-range development of critical technologies needed to enable future human exploration missions to Mars.

- By developing and testing technologies for lunar exploration that are extensible to human missions to Mars, we will learn how to operate more effectively and safely on long missions far from Earth.