From the Moon to Mars

The Things We Most Need to Learn at the Moon to Support the Subsequent Human Exploration of Mars

Presented to the

LEAG Workshop on Enabling Exploration:

Lunar outpost and Beyond

Bret G. Drake

1 October 2007

Background of the Mars Design Reference Architecture 5.0

Mars Design Reference Mission Evolution

- **Purpose of Reference Architectures:**
  - Exploration mission planners maintain “Reference Mission” or “Reference Architecture”
  - Represents current “best” strategy for human Mars missions
  - Purpose is to serve as benchmark against which competing architectures can be measured
  - Constantly updated as we learn
  - Probably does not represent the way we will end up going to Mars

1988-89: NASA “Case Studies”

1990: “90-Day” Study

1991: “Synthesis Group”

1992-93: NASA Mars DRM v1.0

1998: NASA Mars DRM v3.0

1998-2001: Associated v3.0 Analyses

2002-2004: DPT/NExT

2007 Design Reference Architecture 5.0

Key Challenges of Human Exploration of Mars

1 EARTH VICINITY
- Multiple launches of large payloads
- Automated rendezvous & docking
- Long-term storage of systems in orbit

2 TRANSIT TO MARS
- Human health and performance in space (200 days to Mars) including radiation & zero-g
- Long-term system reliability, maintenance and operations of systems for long-periods
- Landing large payloads on Mars (Aero-Entry, and precision landing)
- Mars orbit insertion or aerocapture
- Extended periods of dormancy
- Communication time lag
- Abort to surface

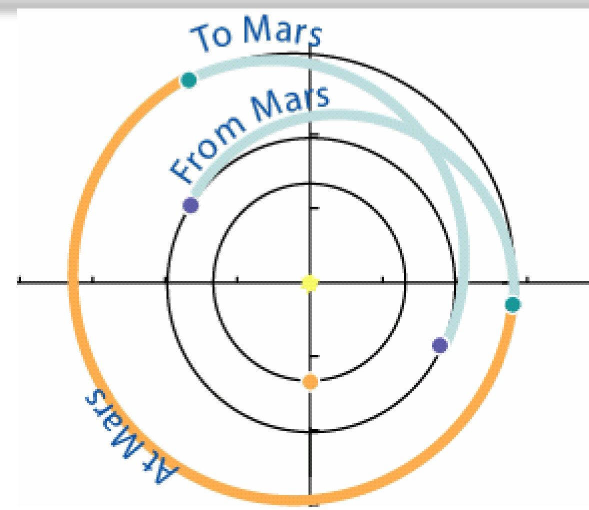
3 SURFACE EXPLORATION
- Human health and performance on Mars (500 days)
- Minimize surface assembly and associated operations
- Long-term system reliability, maintenance and operations of systems for long-periods
- No logistics resupply
- Communication time lag
- Robust exploration including long-range & routine EVA
- Extensive science operations & minimal sample return
- Environment of Mars: dust, dust storms, etc.
- Nuclear surface system operation and reliability
- Extended periods of dormancy
- Ascent & rendezvous
- Planetary protection

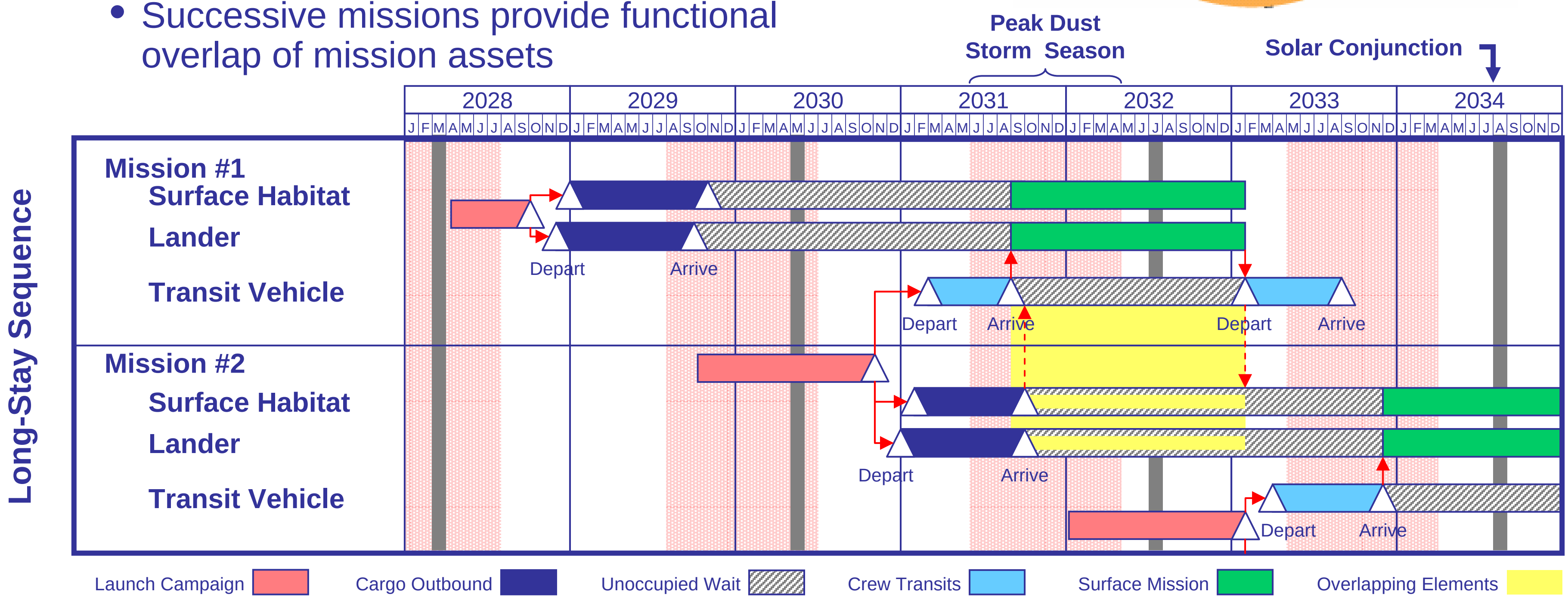
4 TRANSIT FROM MARS
- Human health and performance in space (200 days to Mars)
- Long-term system reliability
- Communication time lag

5 EARTH RETURN
- High-speed direct entry (12+ km/s)

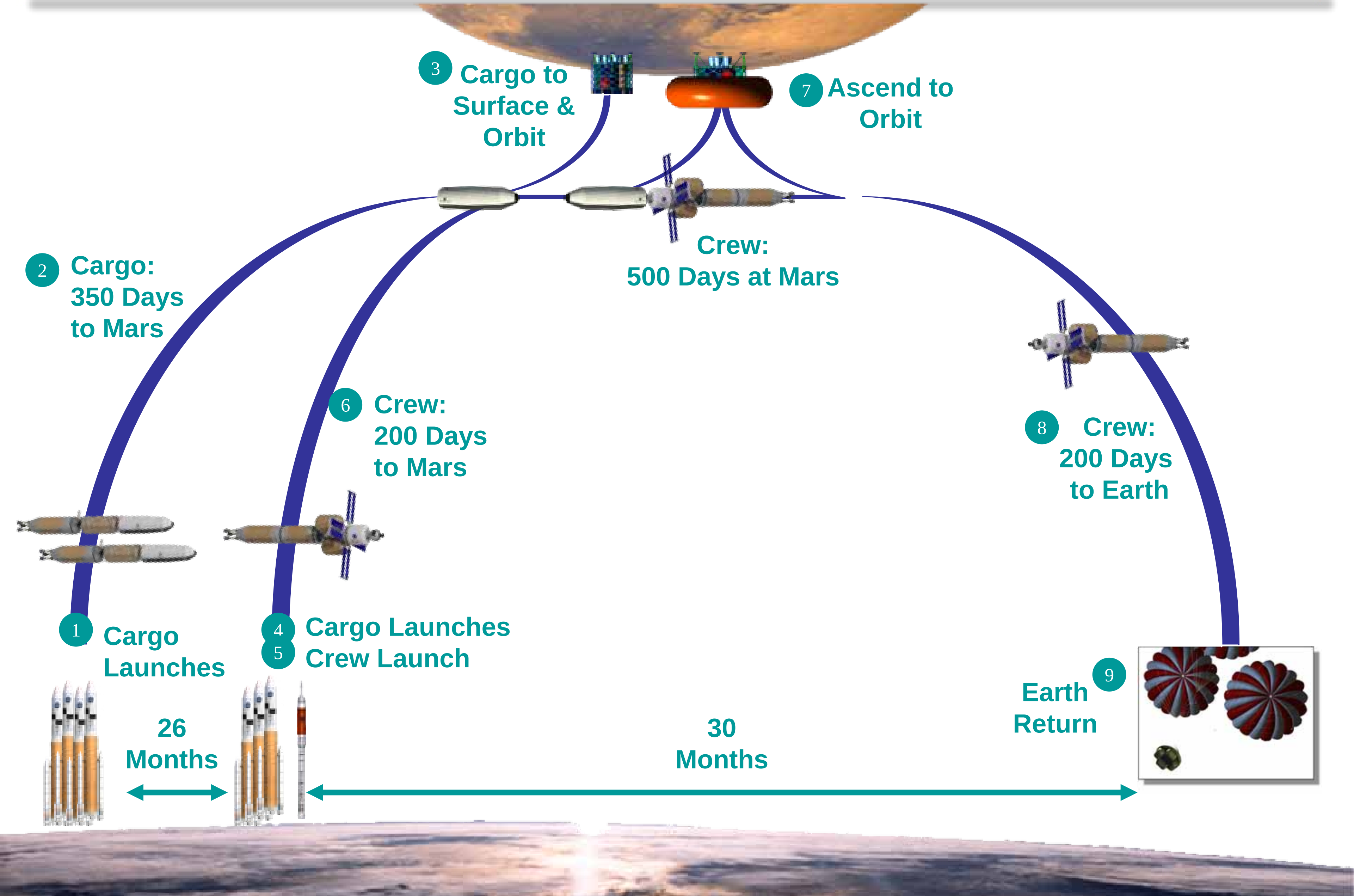
Design Reference Architecture 5.0 Flight Sequence

- **Long-surface Stay + Split Cargo Mode Adopted**
  - Mars mission elements pre-deployed to Mars prior to crew departure from Earth
    - Surface habitat and surface exploration gear
    - Mars lander for transportation to/from the surface of Mars
  - Conjunction class missions (long-say) with fast inter-planetary transits
  - Successive missions provide functional overlap of mission assets

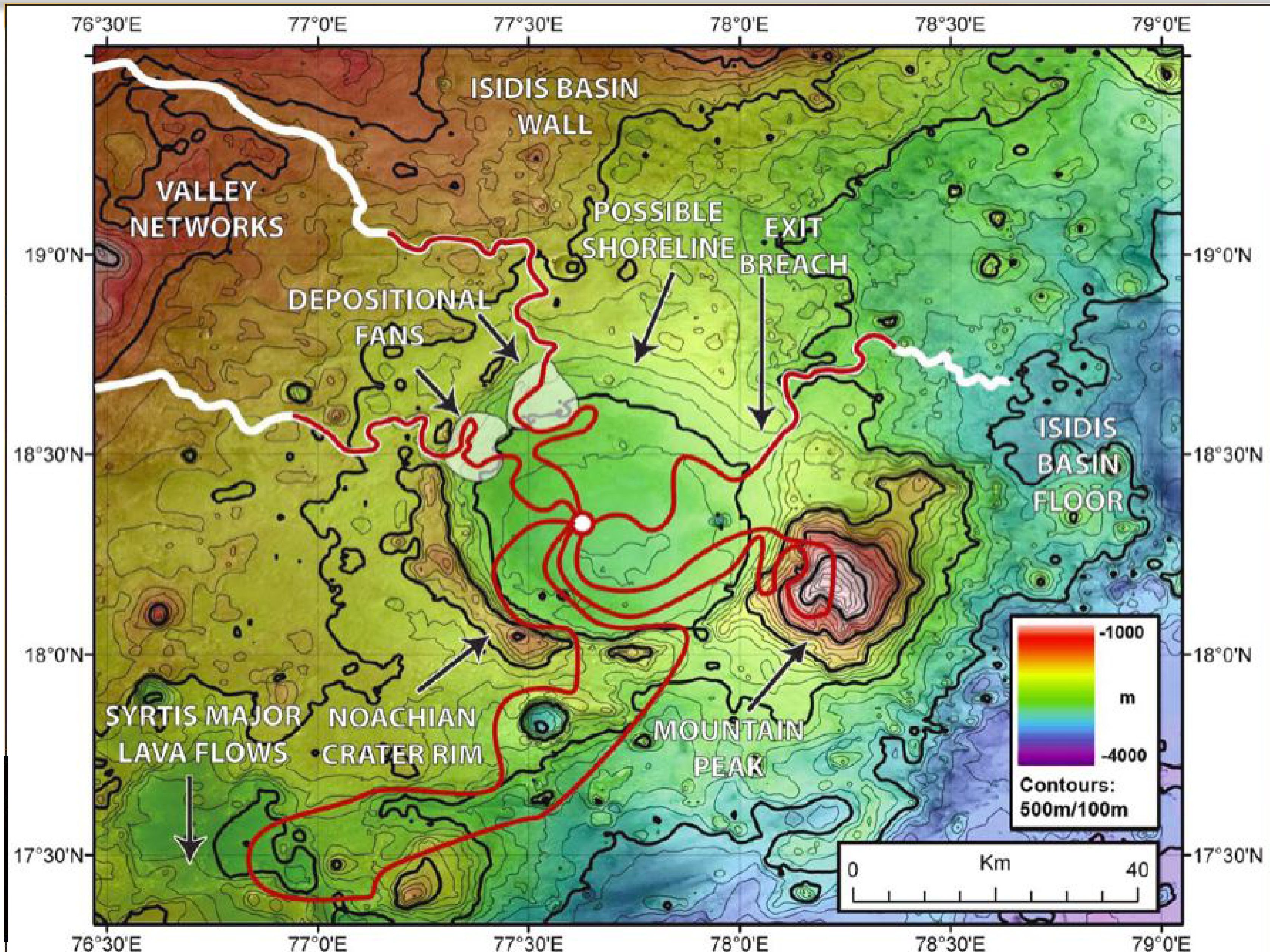




Design Reference Architecture 5.0
Mission Profile



Example Long-Range Exploration



Key Moon / Mars Mission Comparisons

Category	Moon	Mars
Initial Mass in LEO per Mission (mt)	~140	~400+
# of Ares-V launches per crew mission # of Ares-I launches per crew mission	1 1	6 1
Ares-V Needs	65+ mt to TLI 8+ m dia shroud	125+ mt to LEO 10+ m dia shroud
"Typical" Mission Timeline (days out, at destination, and return)	4 / 7 / 4 (Sortie) 4 / 180 / 4 (Outpost)	180 / 550 / 180
Injection Opportunities	Weekly (Outpost)	Every 26 months
Round-trip Interplanetary Delta-v (km/s)	~ 5	6-7 (w A/B), 9-13 (w/o A/B)
Descent & Landing Delta-v (km/s)	~ 2 Powered	<1, Aerodynamic, Powered
Ascent Delta-v (km/s)	~2	6.0 (with ISRU)
Surface Environment (location dependent)	Vacuum, 1/6-g, 27 days, etc.	Near-vacuum, 95.5% CO_2 3/8-g, 24.6 hr days, dust storms, etc.
Communications	2-3 second latency	8-40 minute latency
Operations	Earth, near real-time	Autonomous, Asynchronous
Abort Options / Strategy	All-phases. Return to Earth	Limited/none. To Mars Surface
Surface Strategy	Multiple / Buildup	Few / Monolithic
Surface Payloads	Crew: 0.5 – 6 mt (under study) Cargo: 15-20 mt (under study)	Crew: Minimal Cargo: 30 – 50 mt
Surface Power	Solar Nulcear – ISRU	Nuclear
Reliability / Maintainability	Logistics resupply possible	Resupply very limited

From the Moon to Mars

The Things We Most Need to Learn at the Moon to Support the Subsequent Human Exploration of Mars

Human Health and Performance

- **Mars Challenges: Provide for a safe and effective long-duration (30 month) remote mission**
  - Radiation environment and protection strategies
  - Long-duration performance of countermeasure equipment and protocols
  - Medical diagnosis and treatment equipment
  - Food nutrition and long-term storage
  - Human factors and human-machine efficiency

- **The Moon as a Proving Ground: Long-duration lunar missions serve as a vital venue to:**
  - Validate efficacy and performance of countermeasure equipment
  - Validate and demonstrate medical equipment
  - Validate food systems and habitat human factors on a planet

Advanced Life Support Systems

- **Mars Challenges: Long-duration, limited resupply, and need for low-mass systems requires advanced closed-loop life support systems**
  - Air closure
  - Water closure
  - High reliability and maintainability
  - Plant growth for nutrition and psychological health

- **The Moon as a Proving Ground**
  - Long-duration testing with humans in the loop to understand optimal system performance and crew operation
  - Integrated testing of multiple systems
    - Trace contaminant control
    - Oxygen generation
    - CO_2 removal and nutrient recovery
    - Long-term sustainability / reliability of crop production systems

Air Revitalization

Plant Growth

Water Recovery

Mobility Systems

- **Mars Challenges: Long-duration surface missions provide the opportunity for robust exploration. Robust exploration is enabled through advanced mobility capabilities including:**
  - Space suit mobility & dexterity performance
  - EVA communications / information systems
  - Life support system component operation
  - Space suit thermal protection & operation
  - Dust protection and radiation protection
  - EVA traverse mapping & route planning
  - Surface mobility systems “trafficability”
  - EVA system maintenance strategies

- **The Moon as a Proving Ground**
  - The moon can serve as a vital planetary venue for demonstration of:
    - Surface EVA in greater numbers & durations for system validation
    - Validate EVA traverse mapping & route planning techniques
    - System performance and reliability
    - Lunar surface conditions similar, but not truly “Mars-like”

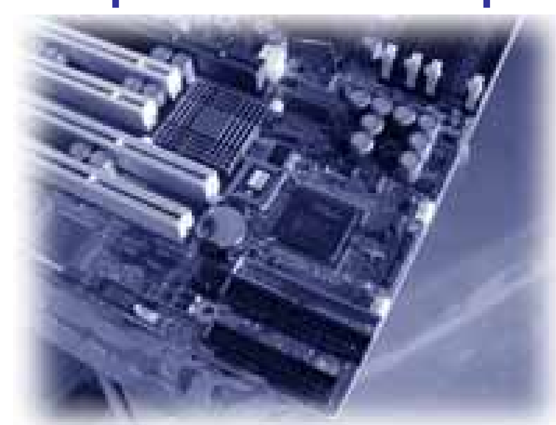
System Reliability and Maintenance

- **Mars Challenges: Long mission durations and lack of logistics / resupply capability necessitates advanced supportability concepts**
  - Concepts for effective supportability
    - Maintenance
    - Repair
    - Integrated logistics support
    - Crew autonomy and training concepts
  - Component level repair
  - Fabrication concepts

In-Situ Repair / Maintenance

- **The Moon as a Proving Ground**
  - Systems must be designed with supportability in mind
  - Supportability concepts can be tested on lunar missions, especially on missions of extended duration

Component Level Repair



Dust Mitigation

- **Mars Challenges: All components and systems will be exposed to planetary surface dust**
  - Electronic components
  - EVA systems and rovers
  - Lander and surface systems
  - Mars missions will need effective dust mitigation techniques
    - Operational procedures
    - EVA to IVA dust management
    - Cleaning and filtering
    - Component and system design

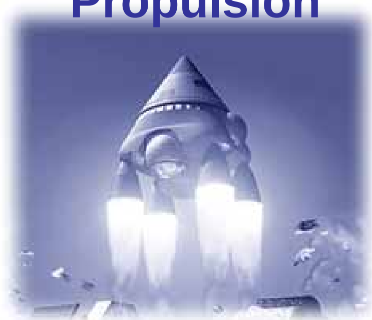
- **The Moon as a Proving Ground**
  - Although the lunar surface environment is not truly "Mars like," lunar surface missions can serve as a test bed for future Mars dust mitigation procedures and techniques
  - Lunar surface operation will provide valuable data on component performance in dusty environments

Transportation Systems

- **Mars Challenges:**
  - Routine, reliable launch of large payloads into Earth orbit (6+ launches per Mars opportunity)
  - Automated rendezvous and docking
  - Earth return at high speeds
  - Advanced cryogenic propulsion
- **The Moon as a Proving Ground**
  - Transportation system reliability and performance
    - Launch Vehicle (Ares-V)
    - Lunar Lander
  - Cryogenic fluid storage and management
    - Long-term pressure control with flight type system
    - Zero-boiloff control with integrated vehicle concept
    - 0-g & Low-g liquid acquisition and mass gauging data
  - Rendezvous and docking
    - Single-sensor technology for long, medium, and close range pursuit of spacecraft
    - Navigation and proximity operations with little direct Earth support
    - Intelligent flight software

Rendezvous & Docking

Cryogenic Propulsion



Autonomous Operations

- **Mars Challenges: Advanced autonomous capabilities are required due to long communications latency, lack of routine resupply**
  - Identification of system failure modes
  - Model Based Reasoning techniques
  - Software verification and validation
  - Fault detection a reconfiguration
  - Trends identification and predictions

- **The Moon as a Proving Ground**
  - Long-duration (180+) lunar missions allows automation technologies to be used and tested over a long period of time, under actual operational conditions, in an environment where their performance is not critical to mission success or crew safety, as it would be during a human mission to Mars.

"We leave as we came, and God willing, as we shall return, with peace and hope for all mankind"

Eugene Cernan,
Commander of the last Apollo mission