National Aeronautics and Space Administration

The Moon as a Stepping Stone to Human Mars Missions

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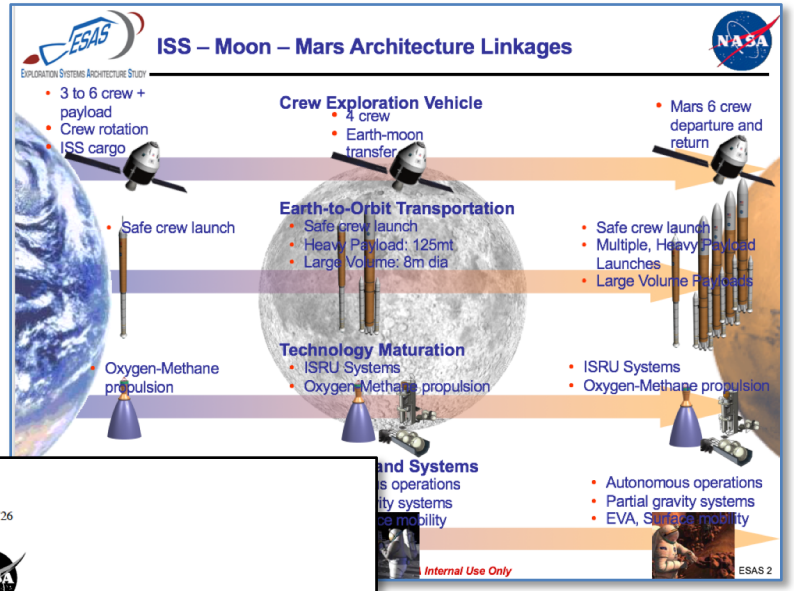
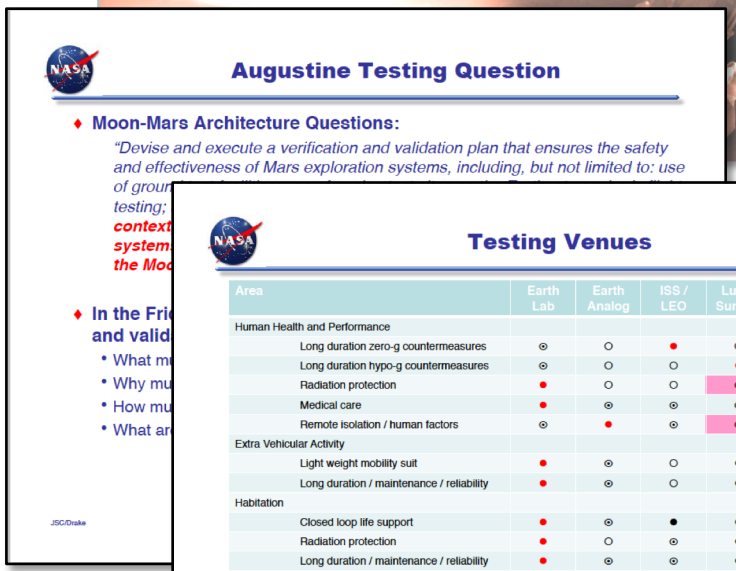
Goal

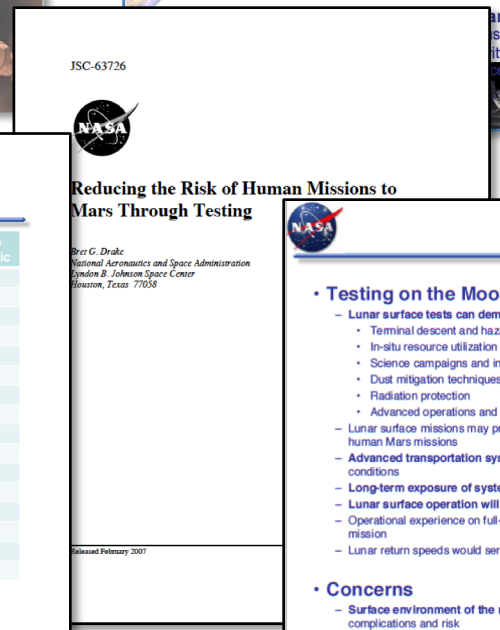
- ***Given that human lunar exploration activities will occur*, qualitatively identify areas where crewed lunar missions can provide applicability toward future human Mars missions**
  - "Natural overlaps" evaluated – no attempt to "force" Mars testbed activities into Lunar missions

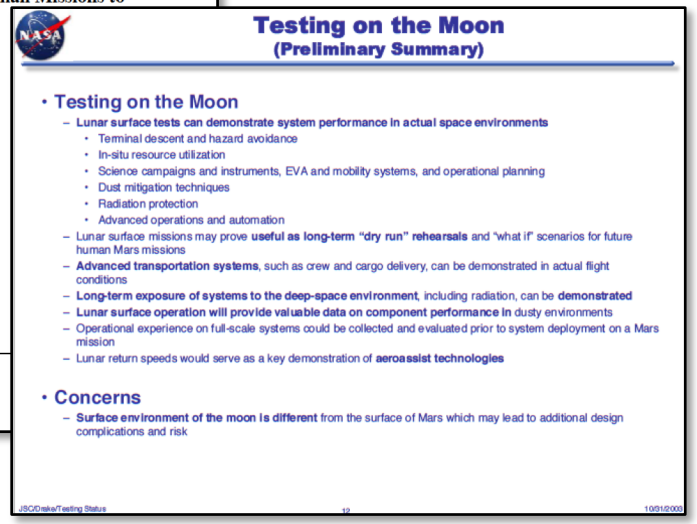
- **<u>Not</u> an attempt to *justify* a lunar "program" as *required* preparatory work for Mars**

Moon → Mars Linkages Have Been Well Studied









Approach

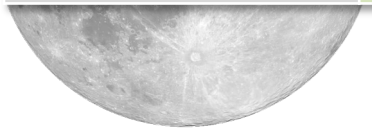
- **Four different classes of lunar activities were postulated**
  - "Gateway-Only"
  - "Apollo-Class"
  - "Global Exploration Roadmap (GER)-Class"
  - "Lunar Base"
- **Current MSC Mars "Basis of Comparison" (BoC) work used as basis for determining lunar applicability**
  - Applicability-level binned as little or none ○ , somewhat ◖ , or high ●
  - Applicability was viewed qualitatively from a system capability and risk reduction perspective. That is, how well does the assumed lunar system or fundamental knowledge feed forward to future missions.
  - Avoided questions like "*must* x be tested on the moon before it can be used for Mars?" – ultimately becomes system-by-system cost/risk trade
- **Different categories of lunar "Mars-forward" activities were identified**
  - Space Transportation Systems and Support
  - Human Health and Performance
  - Surface Activities and Systems

MSC's Mars Basis of Comparison (BoC) Attributes
Hybrid Solar Electric Propulsion / Chemical (O_2/CH_4 Option)

- **Cis-Lunar Operations**
  - Gateway serves as assembly and checkout node
  - Logistics and propellant refueling of transportation systems
  - Orion used for crew transport in cis-lunar space only
  - Crew on-boarding prior to final return in lunar-distant high Earth orbit
- **Transportation Systems**
  - SLS 2B (10 m diameter shroud) can inject 45 t TLI
  - Orion launched on SLS 2B + 13 t co-manifested payload
  - Hybrid SEP (500 kWe) / Chemical Propulsion (O_2/CH_4) for both crew and cargo missions
  - Hybrid vehicle reused 3 times
  - 22 t landed useful payload via Hypersonic Inflatable (HIAD) EDL
  - In-Situ propellants (O_2 from the atmosphere) for Mars ascent
- **Surface Exploration Strategy**
  - Surface outpost build-up at single site
  - Kilopower fission surface power (10 kWe each)
  - Modular habitation for logistics and outpost buildup
  - Regional mobility via small pressurized rovers
- **Mars Mission Operational Concept**
  - Mars payloads pre-deployed prior to crew departure
  - First crew mission to Mars orbit, subsequent all crew to the surface
  - Four crew to Mars surface every other Mars departure opportunity
  - Minimum energy transits (1,200 days round-trip crew mission)
  - High (5-sol) Mars parking orbit

Lunar Activity Categories Considered

Lunar Attribute	Gateway-Only	Sortie-Class	GER-Class	Field Station
All options assume Gateway staging, heavy lift, and 11 km/s return vehicles				
Human Surface Mission?	No	Yes, Multiple Sites	Yes, Multiple Sites	Yes, Fixed Base Site
Crew to Surface	0	2-4	4	4+
Surface Exploration Duration	n/a	3-5 Days	42 Days	6 Months
Pre-Deployed Surface Assets	No	No	Yes	Yes
Key Attributes	• Earth or Gateway tele-operated robotic science & demonstrations	• Unpressurized Rover • Cryogenic (O_2/CH_4) lander/ascent • Reusable ascent stage	• Pressurized Rover • Cryogenic (O_2/CH_4) lander/ascent • Reusable ascent stage • KiloPower	• Pressurized Rover • Cryogenic (O_2/CH_4) lander/ascent • Reusable ascent stage • KiloPower • Habitat • ISRU
Exploration Range	n/a	<10 km per site	100 km per site	100 km from base



A range of lunar missions were considered in order to help drive key capability and technology needs and potential applicability toward future Mars missions

Space Transportation Systems and Support Applicability to Mars

- **Gateway** missions can provide good in-space transportation feed forward to human Mars missions
  - Demonstrates higher power SEP
  - Deep-space operations
  - But challenges remain due to lack of surface component
- **Sortie, GER, and Lunar Field Station** class missions provide additional Mars applicability due to surface component, Gateway staging, and lander reuse
  - Cryogenic propulsion and fluid management (assuming O_2 with either CH_4 or H_2 propellants)
  - Higher power SEP and fuel transfer
  - Terminal landing dynamics (hazard avoidance, precision landing, plume ejecta)
  - Deep space operations

Capability	Applicability to Mars Missions			
	Gateway Only	Sortie-Class	GER-Class	Lunar Field Station
Elliptical Orbit Rendezvous	●	●	●	●
Deep Space Logistics & Operations	●	●	●	●
Heavy-Lift Launchers	●	●	●	●
Earth Entry at Lunar-Return Velocities	●	●	●	●
High-Power Electric Propulsion	◖	◖	◖	◖
In-Space Refueling (Xe)	●	●	●	●
Cryogenic Propellant Descent/Ascent Stage	○	●	●	●
Lander Cryogenic Propellant Management	○	●	●	●
In-Space Refueling (O_2/CH_4)	○	●	●	●
Hazard Avoidance / Precision Landing	◖	●	●	●
Deep Space & Surface Navigation & Communication	◖	◖	●	●

Moon-Mars Relevance Rating: ○ Little or none ◖ Somewhat ● High

Human Health and Performance Applicability to Mars

- **Gateway –** operations in deep-space can help mitigate risks associated with key human health
- **Sortie –** expected manifested medical capability will be significantly different than for a Mars mission, making the feed-forward applicability low

Capability	Applicability to Mars Missions			
	Gateway Only	Sortie-Class	GER-Class	Lunar Field Station
Flight Medical Capabilities	◖	○	◖	◖
Radiation Exposure	◖	○	◖	●
Cognitive or Behavioral Conditions	◖	○	◖	●
Long-Term Medication Storage	●	○	◖	●
Food System	◖	○	◖	●

Moon-Mars Relevance Rating: ○ Little or none ◖ Somewhat ● High

- **GER –** medium duration of GER-class missions increases Mars mission applicability, but challenges remain
- **Lunar Field Station –** Longer durations of lunar Field Station mission provides the best Mars mission feed forward of all lunar mission considered

Surface Systems and Activities Applicability to Mars

- **Gateway –** Lack of surface component limits applicability to robotic components
- **Sortie -** Short duration of this class includes only EVA and some mobility enhancements
- **GER –** medium durations provide more value in reducing future Mars risks and developing key capabilities
  - May provide better return on investment of the lunar mission concepts considered here
- **Lunar Field Station –** provides the broadest Mars surface system and activity feed forward due to the scope and scale of activities
  - Challenges due to difference in lunar environment remain
  - ISRU demonstrations, especially cryogenic propellant management, could feed forward

Capability	Applicability to Mars Missions			
	Gateway Only	Sortie-Class	GER-Class	Lunar Field Station
Routine Surface EVA & Local Mobility	○	◖	◖	●
Regional-Scale Surface Mobility	○	○	●	●
Dust Mitigation (Equipment)	○	◖	◖	◖
Fission Nuclear Surface Power (kWe-class)	○	○	◖	●
Robotic Teleoperation, Site Preparation	◖	◖	●	●
Modular Habitation Systems	◖	○	○	●
Surface Science Operations & EVA Support	○	◖	●	●
Planetary In-Situ Resource Utilization	○	○	○	◖

Moon-Mars Relevance Rating: ○ Little or none ◖ Somewhat ● High

Conclusion

- As we venture back to the Moon with a longer term goal of future Mars missions, lunar missions can provide an important testbed for technologies, systems and operations that directly feed forward to future Mars needs.
- Gateway missions can provide good in-space transportation feed forward to human Mars missions
- Modest operations on the Moon such as the GER-class missions, can provide key Mars human performance and surface mission capability development and risk reduction.

A human return to the Moon can, if done correctly, serve as an excellent down payment to Mars.