



Presentation Outline

- Background of the 2007 Mars Architecture Study
- Mars Design Reference Architecture 5.0 Overview
- Decision Packages & Key Rationale
- Special Topics
 - Entry, Descent, and Landing Challenges
 - In-Space Transportation Systems
 - Launch Vehicle & Orion Assessments
 - Risk and Risk Mitigation
 - Key Driving Requirements and Challenges
 - Lunar Linkages
- Forward Work

December 4, 2008



2007 Study Objectives / Products

- Update NASA's human Mars mission reference architecture, that defines:
 - Long term goals and objectives for human exploration missions
 - Flight and surface systems for human missions and supporting infrastructure
 - Current Constellation systems and other systems updated since Mars DRM 4.0 (circa 1998)
 - Update and incorporate Mars surface reference mission into current strategy
 - An operational concept for human and robotic exploration of Mars
 - Key challenges including risk and cost drivers
 - Development schedule options (deferred)
- Assess strategic linkages between lunar and Mars strategies
- Develop an understanding of methods for reducing the cost/risk of human Mars missions through investment in research, technology development and synergy with other exploration plans, including:
 - Robotic Mars missions, Cis-lunar activities, ISS activities, Earth-based activity, including analog sites, laboratory studies, and computer simulations, additional research and technology development investment
- Develop a forward plan to resolve issues not resolved during 2007



Mars Design Reference Architecture 5.0 Study Approach

- Non-Science Requirements
- Systems Development
- Human Exploration
 Architecture

ESMD

- Science Requirements
- Integration with ongoing MEP
- Interpretation of science results

SMD

Mars Design Reference Architecture 5.0

•Science Community

ARMD

- Aeronautics research
- Mars atmospheric entry

SOMD

- Human Spaceflight Operations
- Tracking, navigation and communications
- Integrating all stakeholders while leveraging recognized subject matter experts
- Mission Directorates will assign and provide funding for personnel within their respective directorates

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Mars Design Reference Architecture 5.0 Refinement Process

- Phase I: Top-down, High-level Mission Design Emphasis
 - Focus on key architectural drivers and key decisions
 - Utilization of previous and current element designs, ops concepts, mission flow diagrams, and ESAS risk maturity approach information where applicable
 - Narrow architectural options (trimming the trade tree) based on risk, cost and performance
 - First order assessments to focus trade space on most promising options for Phase II
- Phase II: Strategic With Emphasis on the Surface Strategy
 - Refinement of leading architectural approach based on trimmed trade tree
 - Elimination of options which are proven to be too risky, costly, or do not meet performance goals
 - Special studies to focus on key aspects of leading options to improve fundamental approach
- Propose basic architecture decisions

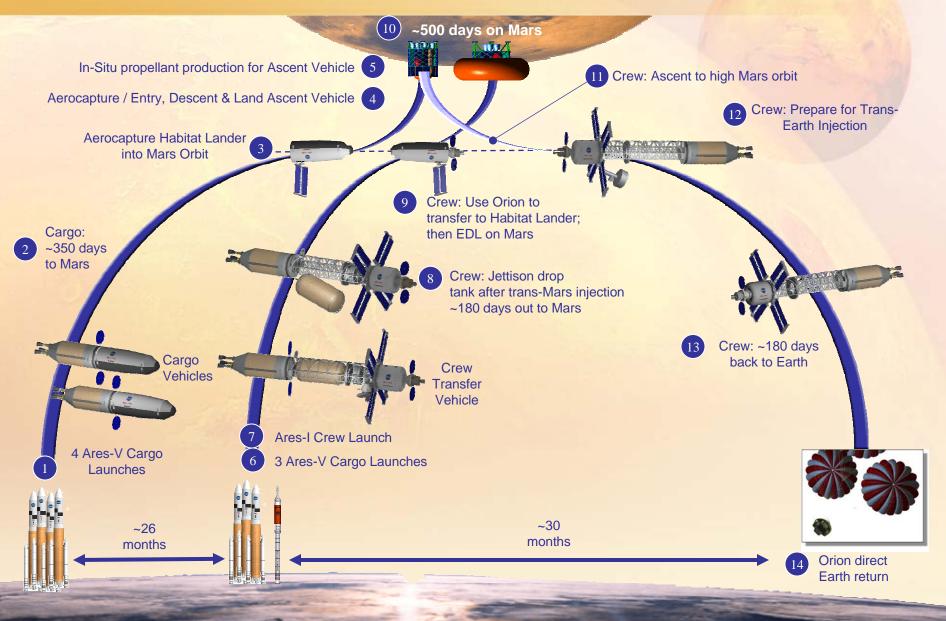


Human Exploration of Mars Key Decisions and Tenets

- Long surface stays with visits to multiple sites provides scientific diversity thus maximizing science return
- Mars systems pre-deployed to reduce mission mass and conduct system checkout prior to crew departure from Earth
- Enabling characteristics of human exploration of Mars:
 - Entry, Descent, and Landing of large payloads (40 t) Dual use Ares V shroud
 - Robust Ares V launch campaign: 7+ launches on 30-day centers
 - Nuclear Thermal Rocket (NTR) propulsion preferred transportation option (retain chemical/aerocapture as backup)
 - ISRU: Production of ascent propellant (oxygen) and crew consumables from the atmosphere
 - Nuclear surface power: Enables In-Situ Resource Utilization (ISRU) while providing continuous robust power
 - Mobility at great distances (100's km) from the landing site enhances science return (diversity)
 - A rich "Mars like" lunar Program which demonstrates key system behavior, operability, repair, and time on systems is necessary
 - Operation and maintenance of systems for long durations (500-1200 days) with no logistics resupply



Mars Design Reference Architecture 5.0 Mission Profile NTR Reference Shown





Possible Objectives Program of First Three Human Missions

Goals for initial human exploration of Mars organized into the following taxonomy:

Goal I	Potential for Life (MEPAG)	
Goal II	Current and ancient climate (MEPAG)	
Goal III	Geology & geophysics (MEPAG)	

Goal IV	Preparation for human exploration (MEPAG – update pending	
Goal IV+	Preparation for sustained human presence (ESMD)	
Goal V	Ancillary science (SMD)	

- Relationship between the resulting goals and proposed implementation approaches addressed:
 - Different exploration sites or same site?
 - Short stay (30-day) or long stay (500-days)
- Recommendation:
 - Long-stay missions overwhelmingly preferred
 - Multiple sites preferred from a science perspective
 - Same site probably better for sustained presence
 - Maximize mobility, on-Mars field (and field lab) science capability, and options for returned sample science



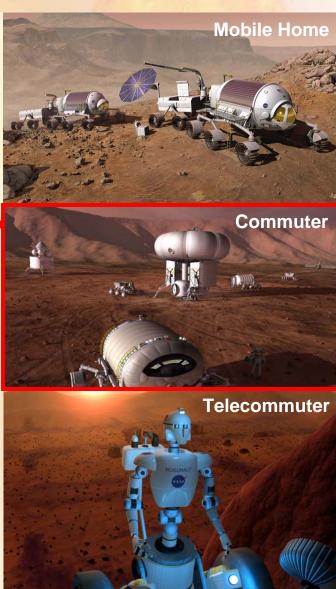


Mars Design Reference Architecture 5.0 Surface Strategy Options

- Multiple strategies developed stressing differing mixes of duration in the field, exploration range, and depth of sampling
 - Mobile Home: Emphasis on large pressurized rovers to maximize mobility range

DRA 5.0 Reference

- Commuter: Balance of habitation and small pressurized rover for mobility and science
- Telecommuter: Emphasis on robotic exploration enabled by teleoperation from a local habitat
- Mobility including exploration at great distances from landing site, as well as sub-surface access, are key to Science Community
- In-Situ Consumable Production of life support and EVA consumables coupled with nuclear surface power provides greatest exploration leverage
- Development of systems which have high reliability with minimal human interaction is key to mission success





Design Reference Architecure 5.0 Summary

	NTR Reference	Chemical Option
Total Crew Flight Duration (approx. days) *	~900	~900
Crew Transit time LEO-Mars (approx. days)	~180	~180
Crew Mars Stay Time (approx. days)	~540	~540
Crew Transit time Mars-Earth (approx. days)	~180	~180
Total Initial MTV Mass in LEO (IMLEO) (t) **	825	1252
Crew Vehicle Mass	333	534
Inter-Planetary Transportation (t)	282	483
Crew Transit Payload (t)	51	51
Cargo Vehicle Mass (mt each)	246	359
Inter-Planetary Transportation (t)	144	257
Mars Surface Payload (t)	36	36
Propulsive Lander (wet, t)	23	23
Aeroshell Mass (t)	43	43
Launch Data †		
Ares-I Launches (crew)	1	1
Ares-V Launches (cargo)	7-9	10-12
Launch Campaign Duration (days)	300	390

^{*} Trip times are average durations across the synodic cycle

^{**} All mass data exclusive of Project and Program reserves

[†] Number of launches dependent on launch vehicle selected



Mars Design Reference 5.0

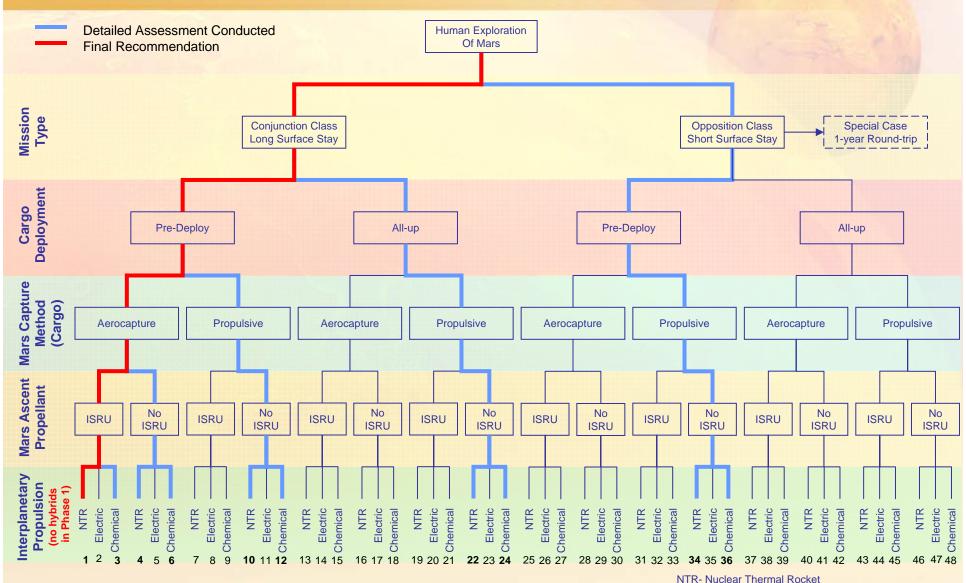
Decision Packages

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Mars Design Reference Architecture 5.0 Top-level Trade Tree





Mars Design Reference Architecture 5.0 2007 Key Decision Packages – Mission Type

Question	Which mission type, conjunction class (long surface stay) or opposition class (short surface stay) provides the best balance of cost, risk, and performance?	
Recommendation	Conjunction class (Long-stay) missions	
Notable Advantages of Conjunction Class (Long-Stay) Missions	 Best exploration value for cost Ample time for crew acclimation and planetary operations/contingencies and surface exploration Zero-g transits (~180 days) within our current experience base. Lunar Outpost will provide vital hypo-gravity data for human performance associated with long surface stays for feed forward to Mars Less total radiation exposure (as known today – surface radiation environment characterization needed). No other significant human performance factors identified. No close perihelion passage reduces radiation and thermal risks Lower total delta-v and less variation in delta-v across the synodic cycle Less sensitive to changes in propulsive delta-v and thus less architectural sensitivity Provides ability to maintain similar vehicle size for both crew and cargo vehicles 	
Necella	Orion Earth return speed "within Orion family" – 12 km/s (TPS implications)	
Notable	Longer total mission duration	
Disadvantages	 Slightly higher overall total mission cost (assuming opposition class missions do not require dedicated surface habitats 	

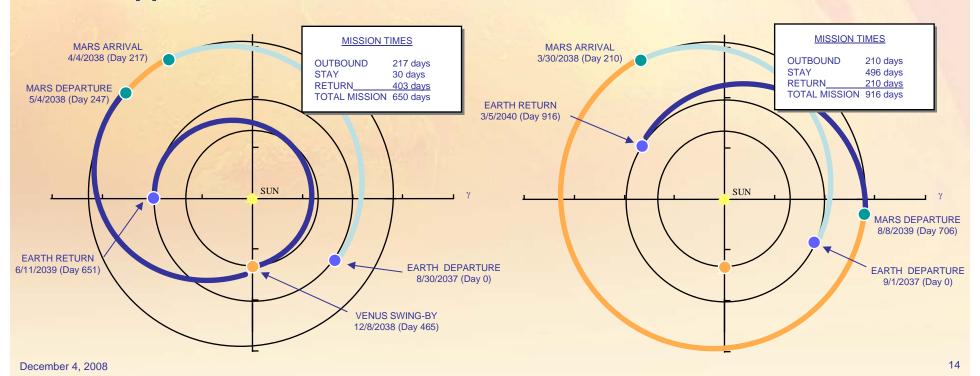
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Mars Design Reference Architecture 5.0 Mars Trajectory Classes

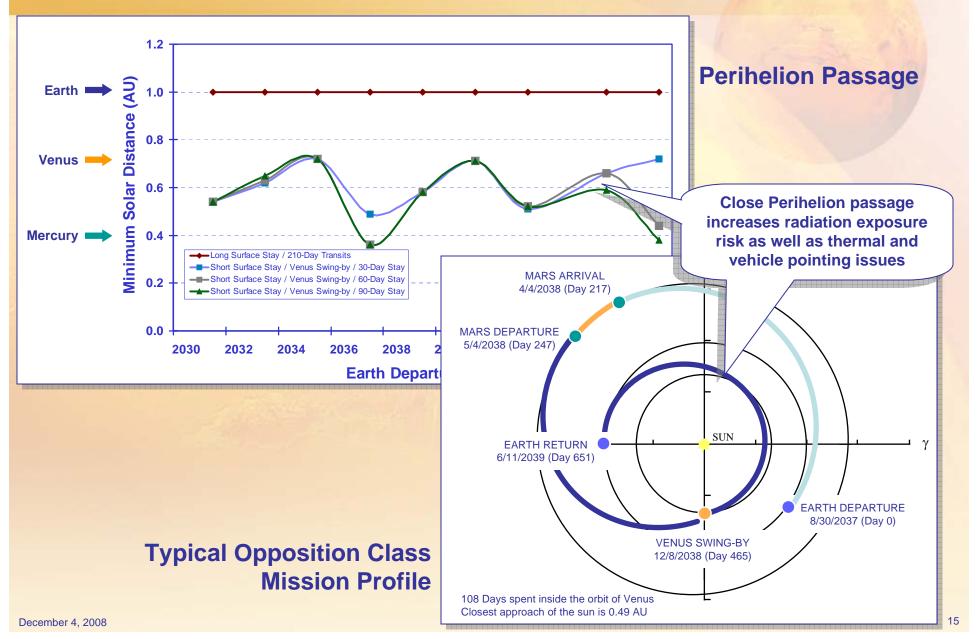
- Short-Stay Missions
 - Variations of missions with short Mars surface stays and may include Venus swing-by
 - Often referred to as Opposition Class missions

- Long-Stay Missions
 - Variations about the minimum energy mission
 - Often referred to as Conjunction Class missions





Mars Design Reference Architecture 5.0 Mission Type Close Perihelion Passage

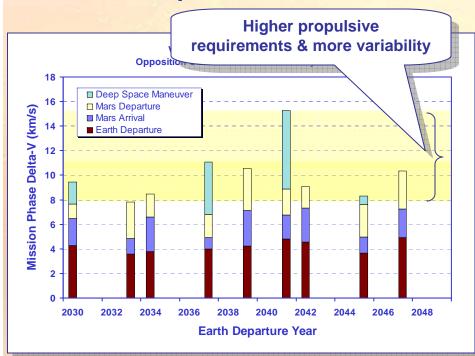




Mars Design Reference Architecture 5.0 Total Interplanetary Propulsion Requirements

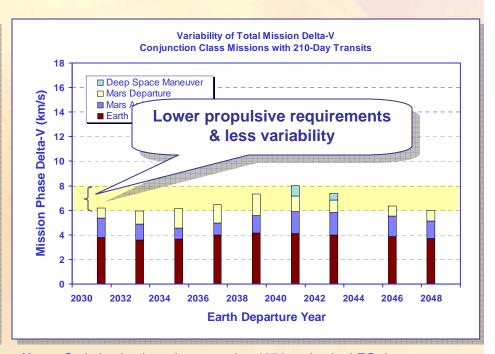
Opposition Class Missions (Short-Stay)

Propulsive Delta-V



Note: Optimized trajectories assuming 407 km circular LEO departure orbit, propulsive capture at Mars into a Mars 1-Sol orbit of 250 km x 33,793 km. 30 sols stat at Mars. Direct entry at Earth with an entry speed limit of 13 km/s.

Conjunction Class Mission
(Long-Stay)
Propulsive Delta-V



Note: Optimized trajectories assuming 407 km circular LEO departure orbit, propulsive capture at Mars into a Mars 1-Sol orbit of 250 km x 33,793 km. 210 day transits to and from Mars. Direct entry at Earth with an entry speed limit of 13 km/s.



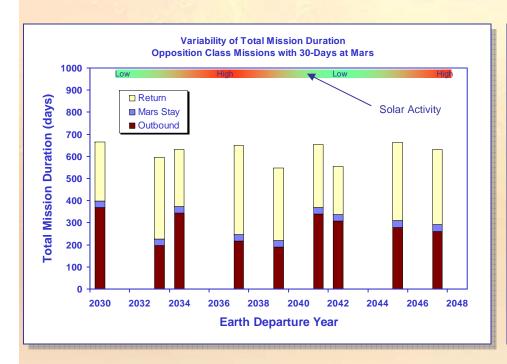
Mars Design Reference Architecture 5.0 Mission Type Total Mission Duration

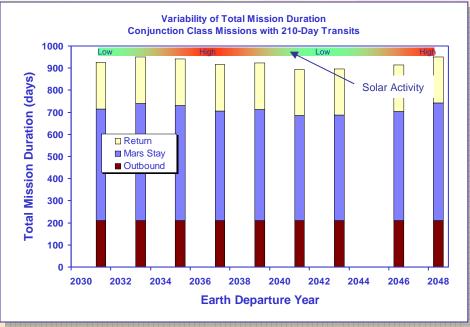
Opposition Class Missions
(Short-Stay)

Total Mission Duration

Conjunction Class Mission (Long-Stay)

Total Mission Duration





% of time at Mars: ~5% % of time at Mars: ~55%

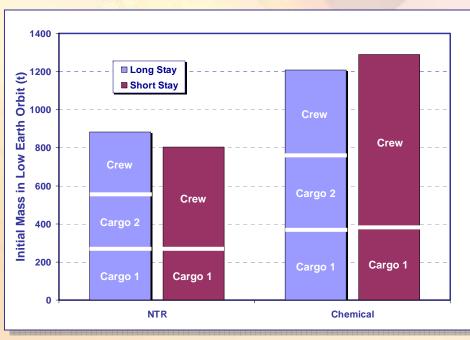
Advantage: Long-Stay – maximizes exploration return



Mars Design Reference Architecture 5.0 Mission Type Total Mass Comparison

- Total mission mass essentially the same when "hardest" short-stay opportunity not considered.
- Short-stay missions may require fewer elements (inclusion of surface habitat lander dependent on length of stay), but require more interplanetary propulsion (3-7 km/s extra)
- Long-stay mission utilizes more energy efficient trajectories, but requires more mission elements:
 - Surface Habitat Lander
 - Surface exploration systems

Total Mission Mass



Advantage: Long-Stay. Enables common vehicle design for both crew and cargo missions

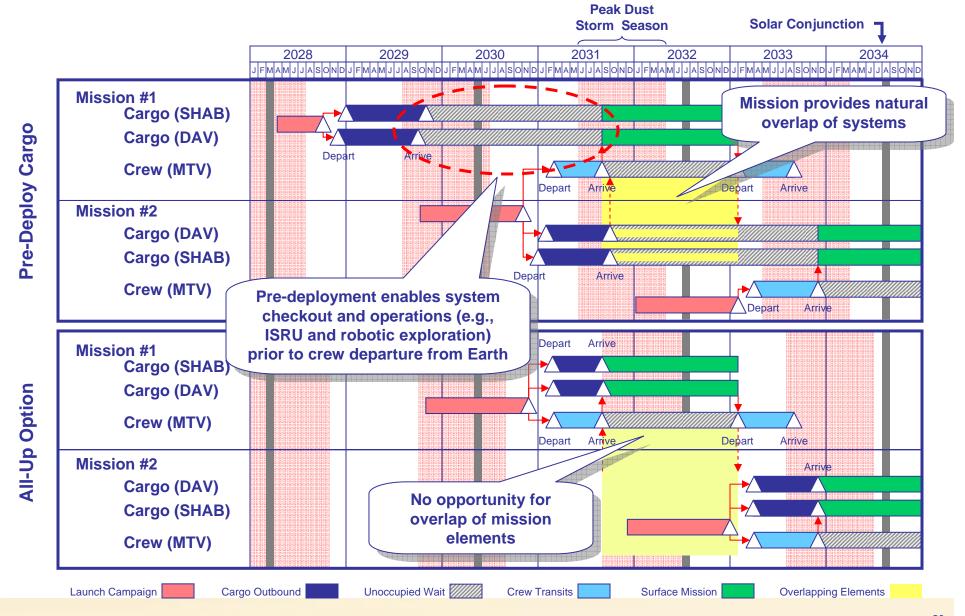


Mars Design Reference Architecture 5.0 2007 Key Decision Packages – Cargo Deployment

Question	Should mission assets, which are not used by the crew until arrival at Mars, be pre- deployed ahead of the crew?	
Recommendation	Pre-deploy cargo one opportunity ahead of the crew	
Other Questions	 Is a lifeboat mode (e.g. Apollo 13) feasible/advantageous for human Mars missions? What are the architectural advantages of all-up versus pre-deploy mission modes? 	
Notable Advantages of Pre-Deployment	 Enables strategies such as In-situ Resource Utilization Mission design provides natural functional redundancy to reduce crew risk Verification of cargo arrival at Mars and operational condition prior to crew departure from Earth 	
	 Satisfies more exploration goals via robotic exploration prior to crew arrival Lower total initial mass in Low-Earth Orbit Reduces outbound vehicle size and complexity 	
Notable Disadvantages	 Longer cumulative time on systems Slightly higher costs (mission operations time) 	



Long and Short Mission Sequences Pre-Deploy Option





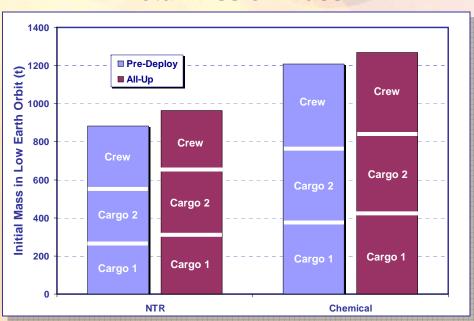
Mars Design Reference Architecture 5.0 Pre-Deploy Cargo vs. All-Up Mass Comparison

- Advantage: Pre-Deploy Option (but not significantly better)
 - Total mission mass consistently higher for the allup option since all vehicles fly faster "crew" trajectories
 - Sending Mars cargo on slower minimum-energy trajectories reduces mission mass for the pre-deploy option
 - All-up integrated vehicle approach is challenging
 - Requires assembly of all large vehicle elements in LEO prior to departure

or

 Hyperbolic rendezvous while in transit to Mars

Total Mission Mass





Mars Design Reference Architecture 5.0 2007 Key Decision Packages – Mars Orbit Capture

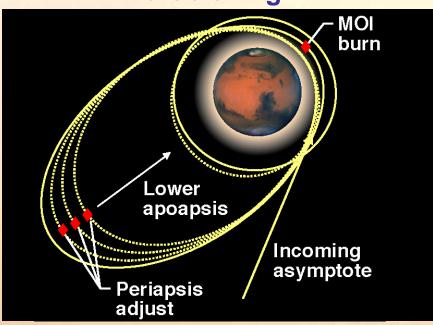
	Chould the atmosphere of Mare he used to centure mission assets into orbit		
Question	Should the atmosphere of Mars be used to capture mission assets into orbit (aerocapture) or propulsive capture?		
Recommendation	Retain aerocapture for Mars cargo elements		
Notes	 Benefit of aerocapture is dependent on the interplanetary propulsion used (If NTR is used, the issue becomes one of risk. If chemical is used, aerocapture was considered enabling) 		
	 Aerocapture for the crew transfer vehicle was eliminated from consideration due to the physical size of that element 		
Notable	Aerocapture reduces total architecture mass		
Advantages of using Aerocapture	Less architecture sensitivity to changes in payload mass		
for Mars Orbit Insertion	 Minimal thermal protection system impacts. Both heat rate (factor of 3) and heat load (factor of 2) are less than those that will be experienced for Orion Earth return 		
	 Aerocapture guidance techniques are subsets of Orion skip trajectories 		
Notable	Dual use of TPS (aerocapture followed by EDL) increases overall risk		
Disadvantages	 Heat rejection and thermal load on primary structure yet to be assessed and will add mass and complexity 		

Entry, Descent, and Landing large payloads on the surface of Mars remains a critical challenge for human exploration of Mars



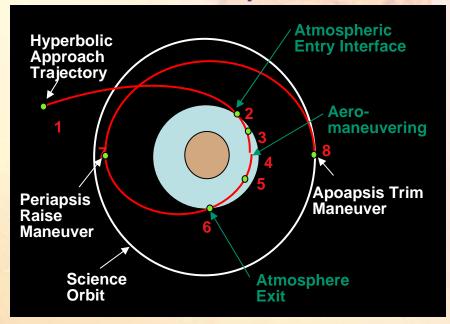
Aeroassist Reference Terminology

Aerobraking



- Mature approach: Magellan-1993 experiment at Venus. Used on last 3 Mars Orbiters (MGS-1996, Odyssey-2001, MRO-2005).
- Spacecraft performs multiple atmospheric passes, in very thin upper atmosphere, which lowers apoapsis on successive orbits
- Labor intensive operations, typically lasting 4-6 months
- May or may not require special adaptations (e.g. TPS, aeroshell, drag devices) depending on the depth, number and duration of the aerobraking mission phase
- Not considered a viable option for Mars Orbit Insertion

Aerocapture



- Direct capture into Mars orbit from arrival trajectory using single, atmospheric aerodynamic drag pass
- Requires an aeroshell with TPS, and an atmospheric flight guidance and control algorithm
- This technique not yet demonstrated on an operational mission
- TPS challenges are thought to be no more demanding than direct entry TPS (but are configuration specific to new shapes)
- Guidance requirements are similar to those for a skip reentry maneuver (used for CEV/Orion lunar return & MSL)

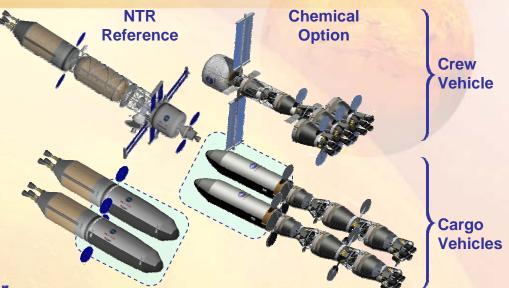


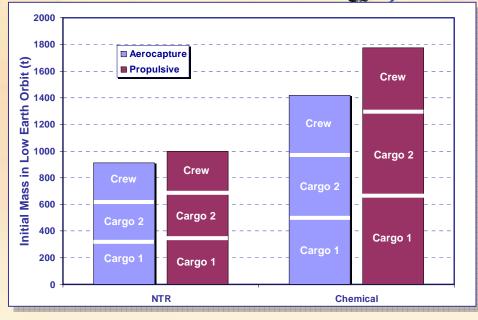
Mars Design Reference Architecture 5.0 Aerocapture versus Propulsive Capture Mass Comparison

Advantage: Aerocapture

 Total mission mass consistently higher for all-propulsive option

- Aerocapture savings are dependent on the in-space transportation system used
- Significant aerocapture savings for chemical transportation system (aerocapture is an enabler for the chemical propulsion option)
- Further assessments of aerocapture and EDL options are required
- Note: Aerocapture for the crew transfer vehicle was eliminated from consideration due to the physical size of that element





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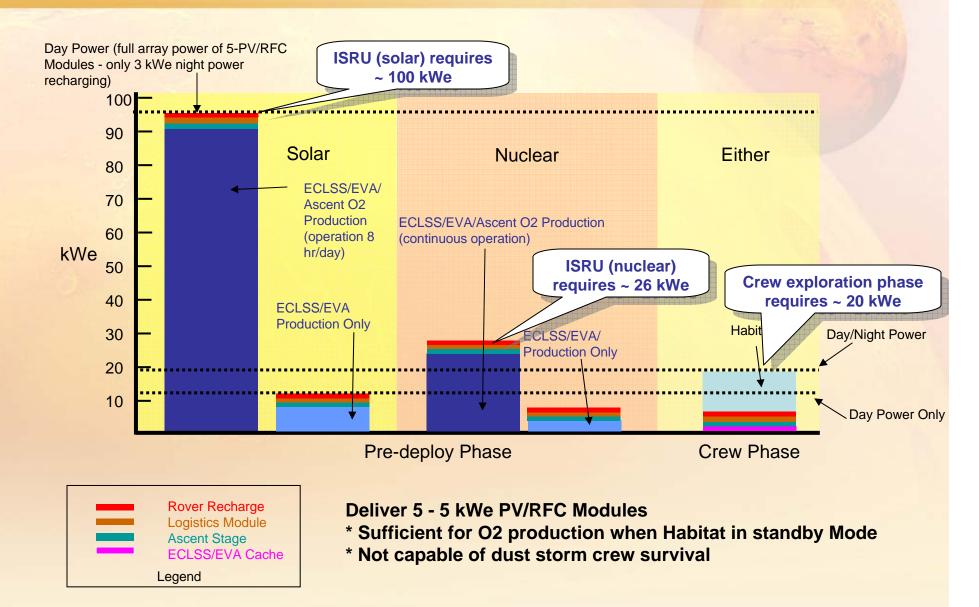


Mars Design Reference Architecture 5.0 2007 Key Decision Packages – ISRU

Question	Should locally produced propellants be used for Mars ascent?	
Recommendation	ISRU is enabling for robust human Mars missions	
Notable Advantages of In- Situ Resource Utilization	 Production of oxygen from the atmosphere for ascent from Mars as well as consumables (oxygen, buffer gases, water) for the crew enables robust exploration Atmospheric based ISRU processes less operationally complex than surface based Reduced total initial mass in Low-Earth Orbit and subsequent number of launches Reduced lander vehicle size and volume Greater surface exploration capability (EVA, roving, etc.) Life support functional redundancy via dissimilar means Lower mission risk due to fewer launches 	
	Lower life cycle cost through third mission (if same landing site)	
Notable Disadvantages	 Requires slightly more peak power Longer cumulative time on systems Rendezvous with surface ascent vehicle required for crew return to orbit (see note). 	
Notes	 Abort to orbit during EDL deemed not feasible. Thus, for human exploration of Mars emphasis should be placed on abort to surface and landing accuracy. 	



Mars Design Reference Architecture 5.0 Power Requirement Estimate



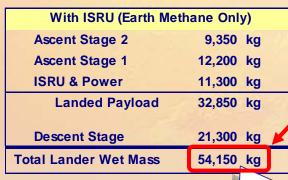


Mars Design Reference Architecture 5.0 Lander Size Comparison for ISRU

Mars Ascent Vehicle Trade

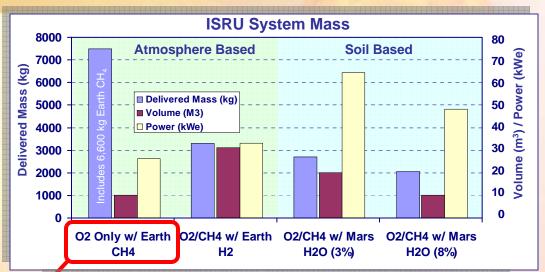
- Assumes ascent to a 1-sol orbit
- LO₂/LCH₄ pump-fed propulsion
- Large delta-V margin on descent stage

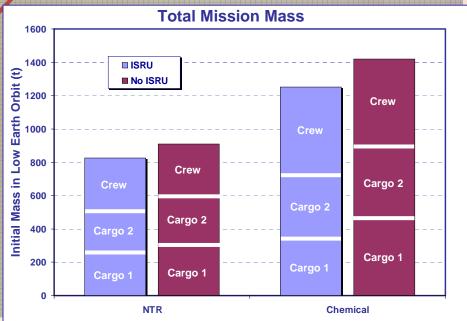
No ISRU (Earth Propellants)			
Ascent Stage 2	18,550	kg	
Ascent Stage 1	27,900	kg	
Minimal Habitat	5,700	kg	
Landed Payload	52,150	kg	
Descent Stage	27,300	kg	
Total Lander Wet Mass	79,450	kg	



* Wet mass; does not include EDL System † Packaging not yet addressed

Significant mass (32%) and volume savings by producing ascent oxygen from the atmosphere of Mars







Mars Design Reference Architecture 5.0 2007 Key Decision Packages – Surface Power

Question	Which surface power strategy provides the best balance of cost, risk, and performance?
Recommendation	Fission Surface Power System is enabling for human exploration of Mars
Notable Advantages of Nuclear Surface Power	 Enables in-situ resource utilization strategies Reduced power system mass and corresponding total mission mass Less sensitive to increase in power loads Continuous high-power generation Low sensitivity to environmental effects such as dust storms No restrictions to landing site location Less complex autonomous system deployment Potential for synergism with lunar power approach and testing to reduce risk Lower overall cost (assuming lunar development)
Notable Disadvantages	 Inability to repair power generation system Increased crew radiation dose as well as operational keep-out zones Increased development and testing complexity

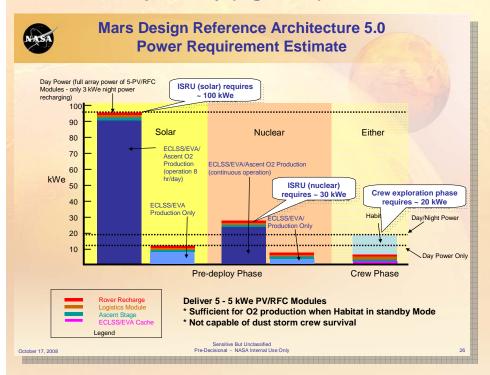


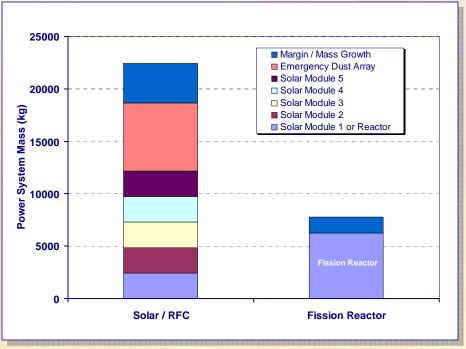
Mars Design Reference Architecture 5.0 Power Requirement Estimate

- Crew exploration phase requires
 - ~ 20 kWe continuous
- ISRU power requires
 - ~ 26 kWe continuous (e.g. fission)
 - ~100 kWe peak-day (e.g. solar)

Fission surface power system provides continuous power for less mass (35%)

Total System Mass







Mars Design Reference Architecture 5.0 Surface Power Special Considerations

Dust Accumulation

- MER, Pathfinder ~0.2%/day output drop
- "Cleaning Events" provide temporary amelioration

Spirit sol 357 (Jan. 3, 2005) Spirit sol 418 Spirit sol 9 (Jan. 11, 2004) ф 9.7 aro Array Gean Cleaning **Events** E 0.3

Dust Storms

- MER dust storms dropped daily output to as low as ~15% of pre-storm capability
- Dust storms can last for one to two months, with varying degrees of obscuration at regional and sometimes global scale



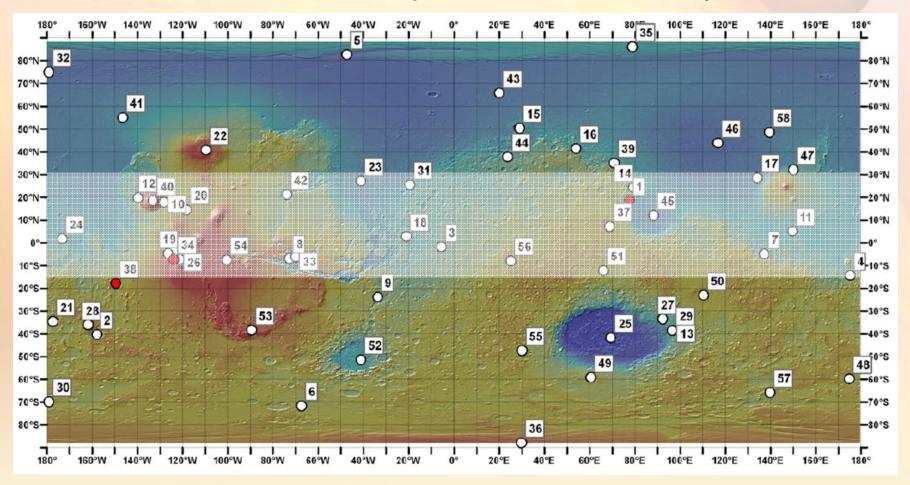


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Special Consideration: Latitude Constraints

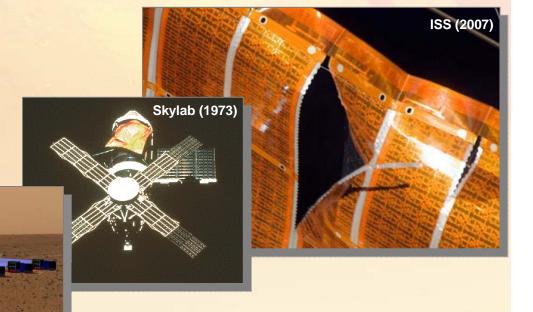
- Solar power applicability best between 15°S and 30°N latitudes
 - System efficiency drops quickly beyond outside this band
 - Covers 26-28 of the 58 sites of potential interest identified by HEM-SAG





Special Consideration: Deployment

- Autonomous deployment of large structures is inherently complicated, especially in a gravity field
 - Solar array deployment is relatively straightforward, but the sheer size of the arrays makes this task problematic
 - It is of note that Skylab, Mir and Space Station have experienced serious problems with solar array deployment requiring crew intervention
 - Deployment of the large FSPS radiators is a similar operation, with the additional complexity of jointed fluid lines
 - ~5,7500 M² total area required for solar approaches





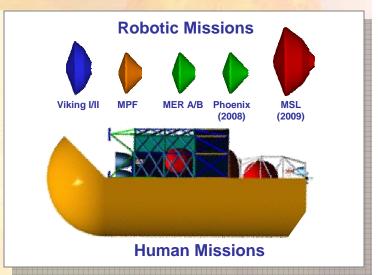
Mars Design Reference 5.0 Special Topics

- Entry, Descent, and Landing Challenges
- In-Space Transportation Systems
- Launch Vehicle and Orion Assessments
- Risk and Risk Mitigation
- Key Driving Requirements and Challenges
- Lunar Linkages



Mars Entry, Descent, and Landing (EDL) History

- Total of six successful robotic landings on Mars:
 - Vikings I and II (1976)
 - Mars Pathfinder (1997)
 - Mars Exploration Rovers Spirit and Opportunity (2004)
 - Phoenix Polar Lander (2008)
- All of these successful systems:
 - Had landed masses of less than 0.6 t
 - Landed at low elevation sites (below –1 km MOLA)
 - Had large uncertainty in landing location (uncertainty in targeting predetermined landing site of 100s km)

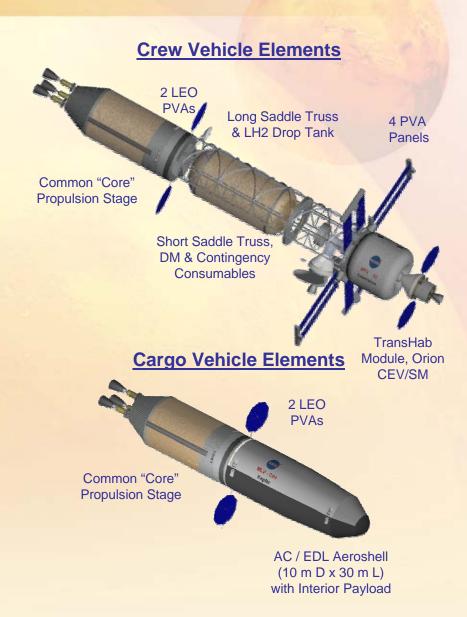


- Mars Science Laboratory (MSL) has reached the limits of the current EDL technology set, with very limited extension available
 - 0.9 t landed mass
 - Largest aeroshell (4.5m) ever flown
 - Largest ballistic coefficient (140+ kg/m2) ever at Mars
 - Highest heat rate (250 W/m2, using PICA TPS)
 - Largest supersonic disk-gap-band parachute ever flow (21.5m); deployed at highest Mach number (2.2)
 - 10 km radius landing uncertainty ellipse
- Estimated landed payload mass extensibility of the MSL EDL architecture: ~2 t (max)
- Robotic Mars Sample Return (MSR) will likely require 1-3 t of landed payload mass
- Human scale mission will likely require one to two orders of magnitude in landed mass capability over current MSL capability (30-60 t landed payload mass)



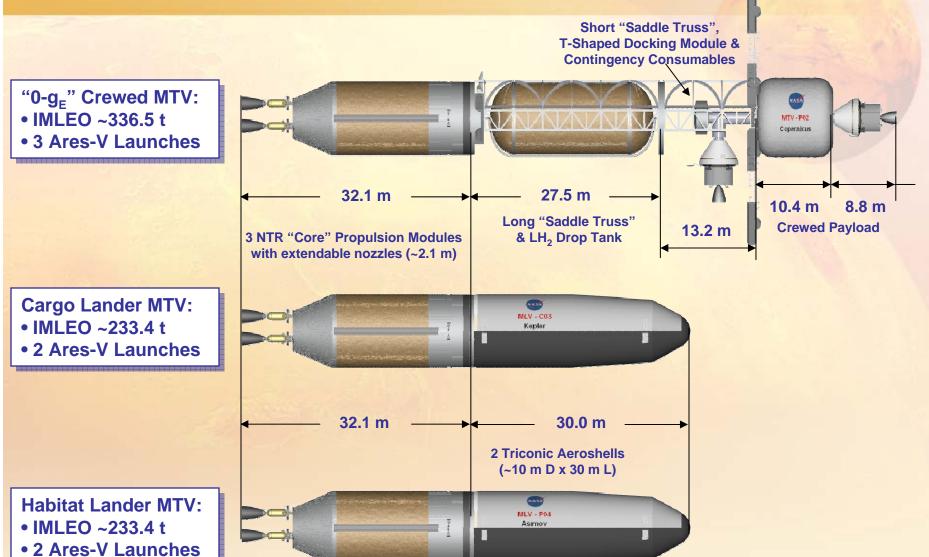
Mars Design Reference Architecture 5.0 Nuclear Thermal Rocket (NTR) Reference

- The crewed vehicle elements include:
 - Common "core" propulsion stage with 3 - 25 klbf NTR engines (Isp ~900 s)
 - "In-line" LH2 tank, 4-sided truss and 2 LH2 drop tanks
 - TransHab module, PVAs, & Orion CEV/SM
 - Crewed vehicle utilizes propulsive capture (PC) at Mars; also carries contingency consumables
- The cargo vehicle elements include:
 - Common "core" propulsion stage with 3 - 25 klbf NTR engines (Isp ~900 s)
 - Core stage propellant loading augmented with "in-line" LH2 tank for TMI maneuver
 - Dual-use aeroshell used to aerocapture (AC) lander payloads into Mars orbit, then for entry, descent and landing (EDL) on Mars
- NTR cargo & crewed vehicle elements are delivered to LEO and assembled via autonomous EOR&D
- NTR stage used for R&D propulsion, orbit maintenance & electrical power (via PVAs) for the vehicle elements during LEO assembly





NTR Crewed & Cargo Mars Transfer Vehicles (MTVs) for DRA 5.0: "7-Launch" Strategy



Source: Glenn Research Center



Nuclear and Solar Electric

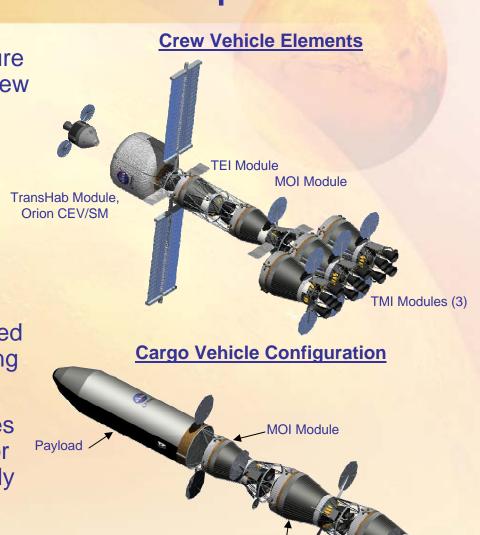
- Direct NEP missions require megawatts of electrical power (8-20 MW)
 - Solar arrays generating this much power may not be feasible
- Direct NEP requires very high-power, high-specific impulse EP thrusters (5,000 -10,000 sec lsp)
- Using Aero-assist reduces required power to 4-5 MW and decreases optimal lsp to 4,000-7,000 sec
- Using NEP or SEP for LEO to HEO staging reduces power to < MW and decreases optimal lsp to ~3000 sec
- 100 kW class electric propulsion thrusters have seen recent developments as a result of the Prometheus & ESR&T programs
- Ground testing & propellant selection are important consideration
- Significant technical risks exist with each approach and they were thus dropped for further consideration





Design Reference Architecture 5.0 Chemical/Aerocapture Vehicle Option

- The chemical/aerocapture architecture consists two cargo vehicles and a crew vehicle
- Vehicle elements include:
 - TMI Propulsion Modules
 - MOI/TEI Propulsion Modules
 - Cargo Payloads
 - Crew Transit Habitat
 - LEO Assembly Reboost Modules
- Vehicles elements are fully assembled and deployed in Low earth Orbit using autonomous docking and assembly
- The LEO Assembly Reboost Modules provide orbit altitude maintenance for the vehicle elements during assembly
- Synergism of Ares V EDS for Mars mission application possible

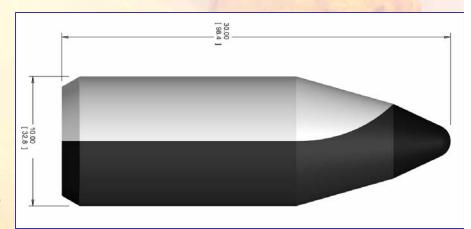


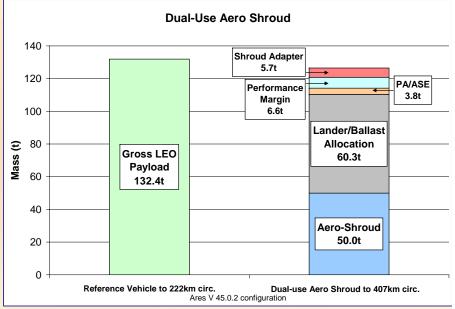
TMI Modules (2)



Mars Design Reference Architecture 5.0 Launch Vehicle Shroud

- Minimum of 10 m payload shrouds are necessary for packaging of Entry, Descent & Landing (EDL) system and lander
- Dual Use Shroud:
 - Preliminary assessments indicate launch vehicle shroud can be used for both ascent to low-Earth orbit as well as EDL aeroshell structural element
- Ares-V (Dual Use Shroud)
 Performance to 407 km LEO orbit
 - 110.3 t for Shroud/EDL and payload
 - 16.1 t additional allocation for payload adapter, airborne support equipment and margin

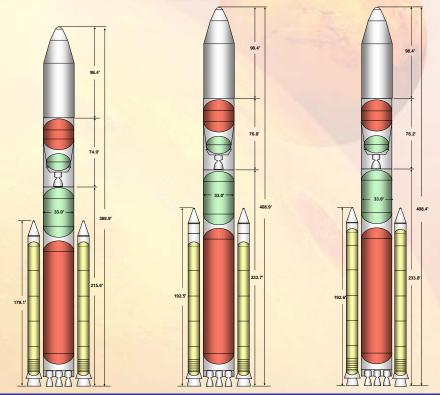






Ares-V 51.xx Series Performance

- Follow-on analysis of CxAT_Lunar launch concepts applicability to Mars
- 51 series of Ares-V launch vehicles provides better performance to LEO
- Use of off-loaded lunar-derivative EDS reduces available shroud volume
- Payload shroud volume limits inhibit maximum performance to Mars
- Forward Work: Optimize EDS for LEO delivery missions and reduce stack height

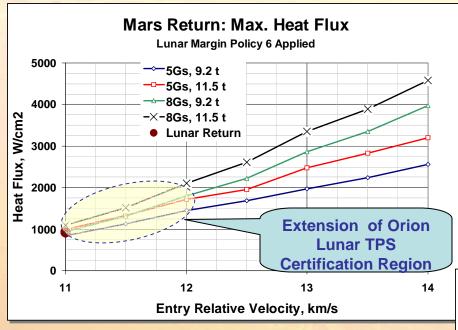


Assumed Shroud: Outer Diameter: 10 m Barrel Length: 18 m Overall Length: 30 m

	51.00.40	51.00.47	51.00.48
Jettison Shroud			
Payload to LEO (t)	126.4	136.9	130.8
Dual-Use Shroud			
Payload (lander) to LEO (t)	79.0	89.6	83.6
Shroud to LEO (t)	50.0	50.0	50.0

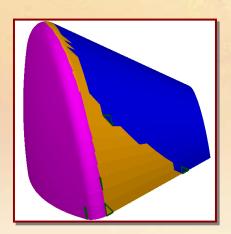


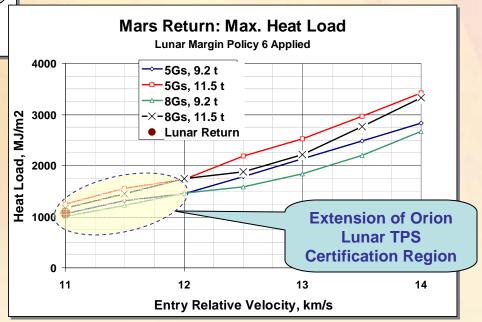
Orion Earth Return Speeds Drive Block 3 TPS Development Requirements



- Limiting Earth return velocities to <12 km/s keeps TPS requirements "within Orion family".
- At 12 km/s, peak margined heating rates are ~1,700 W/cm² (current ground test capability is limited. Comfort zone for ADP is 1,000 W/cm²)
- At and beyond 12 km/s, radiative heating is a major driver for TPS mass (need to continue to pursue coupled convective/radiative heating modeling and work on advanced TPS)









Mars Design Reference Architecture 5.0 Risk Assessments and Mitigation

- Focused on top-level risk assessments to drive out relative architectural differences
- Key Risk Drivers Identified to Date (not in priority order):
 - Entry Descent and Landing
 - Other dynamic events: Trans-Mars Injection, Mars Ascent, Trans-Earth Injection
 - Time on systems and reliability
 - Failure of systems which must operate without crew repair ability (e.g. crew Mars Transfer Vehicle during surface mission)
 - Development risk of nuclear propulsion and power and In-Situ Resource Utilization
 - Radiation protection and radiation environment on Mars
- Key Risk Mitigation Strategies
 - A rich, "Mars Like" lunar program which demonstrates key system behavior, operability, repair (life support, propulsion, power, etc.) and time on systems
 - A Mars Robotic Program which obtains key engineering data and demonstrates scalable human exploration systems and concepts
 - Supportability and Commonality concepts for in-flight maintenance and repair of low-level component and systems
- Refinement of risk assessments will require greater understanding of the Mars systems designs. Recommend further refinement of all Mars systems to improve our understanding.



Mars Design Reference Architecture 5.0 Testing on the Moon

- Lunar surface tests can demonstrate system performance in actual space environments
 - Advanced power, habitation, life support systems
 - Science campaigns and instruments, surface mobility systems, and operational planning
 - Dust mitigation techniques
 - Radiation protection
 - Advanced operations and automation (minimal/no surface assembly)
 - In-situ resource utilization
 - Terminal descent and hazard avoidance
 - Science and operational concepts
- Lunar surface missions will prove useful as long-term "dry run" rehearsals and "what if" scenarios for future human Mars missions
- Long-term exposure of systems to the deep-space environment, including radiation, can be demonstrated
- Lunar surface operation will provide valuable data on component performance in dusty environments
- Demonstration of in-situ repair and maintenance techniques and technologies
- Operational experience on full-scale systems could be collected and evaluated prior to system deployment on a Mars mission



Mars Design Reference Architecture 5.0 Key Driving Requirements (KDR) & Challenges

Ground Ops

- 7+ launches per mission
- 30 day launch centers (300 day launch campaign)
- Processing of nuclear systems
- Ares-V launch vehicle configuration
- Production and storage of cryogenics and helium

Ares-V

- 10-m dia x 30 m total length launch shroud
- Dual use shroud (EDL)
- 125+ t to LEO
- Launch to higher inclinations
- EDS evolution to long-duration (option)

Cross-cutting

- Automated Rendezvous & Docking (in Earth orbit)
- Cryogenic fluid management (H₂, O₂, CH₄)
- Commonality & lowest level maintenance & repair
- Long-term system operation (300-1200 days)
- Low-Earth Orbit loiter for 300+ days
- Planetary protection
- Dust mitigation

Mobility and Exploration

- 100+ km roving range
- 10+ m depth access
- Light-weight, dexterous, maintainable EVA
- In-situ laboratory analysis capabilities

Human Health & Support

- Support humans in space for 900 days
- Radiation protection & forecasting
- Zero-g countermeasures
- Closed-loop life support (air & water)

In-Space Transportation

- ~50 t roundtrip (LEO to Mars orbit return)
- 110 125 t to Trans-Mars Injection
- Assembly via docking only
- ISRU compatible lander propulsion (oxygen)
- Integrated transportation flight experience
- Advanced Inter-planetary Propulsion

Aeroassist

- 40-50 t payload to the surface
- Aerocapture + EDL for cargo
- Abort-to-Mars surface
- 12 km/s Earth return speed

Surface Related

- Auto-deployment and checkout of systems 30+ kWe continuous power
- Reliable back-up power system

ISRU

- Extraction, storage and use of consumables from the martian atmosphere
- Production of 24 t of oxygen for ascent
- Production of life support oxygen (2 t) and water (3.5 t)



Mars Design Reference Architecture 5.0 Moon – Mars Transportation Linkages

System	Lunar / ISS	Mars
Ares I	◆ Launch Orion and crew to LEO	◆ Launch Block 3 Orion and crew to LEO
Ares V	→ 71.1 t to TLI (130 t to LEO)	+ 125+ t to LEO
	 10 m diameter x 9.7 m barrel length shroud 2-4 launches per year 	 ◆ 10 m diameter x 30 m barrel length shroud, dual use shroud
		• 7+ launches on 30-day centers
Orion	6 crew to LEO or 4 to/from LLO	• 6 crew direct Earth return (3 days active)
	→ 11 km/s entry speed	◆ Advanced TPS for 12 km/s entry speed
	• 180 day dormancy	• 900- day dormancy
Altair Descent	• All propulsive descent and landing	Aerodynamic entry, propulsive landing
Stage	◆ 2030 m/s delta-v with hazard avoidance	• 700 m/s delta-v with hazard avoidance
	◆ LO₂/LH₂ propellants	◆ LO ₂ /LCH ₄ propellants
Altair Ascent	◆ 4 crew to Low-lunar orbit	→ 6 crew to high-Mars orbit
Stage	→ 1900 m/s ascent delta-v	→ 6500 m/s ascent delta-v
	◆ Vacuum ascent	Aerodynamic ascent
	• N ₂ O ₄ /MMH or LO ₂ /LCH ₄ propellants	◆ LO₂/LCH₄ propellants
	• Earth propellants for ascent	• Mars produced oxygen for ascent
	→ 210 days on lunar surface	→ 1200 days on martian surface
	• 14.5 t payload (cargo mode)	• 40+ t payload capability (cargo mode)
	Descent abort: Abort to orbit	Descent abort: Abort to surface



Mars Design Reference Architecture 5.0 Moon – Mars Surface System Linkages

System	Lunar	Mars
EVA	◆ Lunar environment	Mars environment
		Minimized contamination
Small Pressurized	→ 100+ km surface range	◆ 100+ km surface range
Rovers	◆ 2 crew for 1-2 week duration	◆ 2 crew for 1-2 week duration
Surface	◆ 4 crew for up to 180 days => Continuous	◆ 6 crew for up to 550 days
Habitation	◆ Multiple elements, surface assembly	Single element, deployment
Environmental	◆ Partially closed air and water	Closed-loop air and water
Control & Life Support	• ISRU (Oxygen) enhancing	 ISRU (O₂, H₂O, N₂, Ar) enabling for robust exploration
In-Situ Resource	Architecture enhancing, Soil based	Architecture enabling, Atmospheric based
Utilization	 Utilized for life support make-up Potential H₂O from cold traps 	 Oxygen for Mars ascent, H₂O, O₂, N₂, Ar for EVA and life support
		Option for hydrated minerals or sub- surface water
Surface	◆ 35 kWe daytime total load	→ 30 kWe continuous load
Stationary Power	◆ Solar PVA/RFC primary, Multi unit	→ Fission surface power system primary
	◆ Fission surface power system option	Must accommodate dust and dust storms
Operations	◆ Semi-autonomous – minimal time delay	• Fully autonomous – long time delay
	• Limited logistics resupply	No logistics resupply



Forward Work

- Further integration, assessment and refinement of lunar surface systems and strategies which can feed forward to Mars
 - Habitation systems and life support
 - EVA and surface mobility
 - Nuclear surface power
 - In-situ Resource Utilization
 - Lander oxygen-based propulsion
 - Commonality and in-flight maintenance & repair approaches
 - Science and operational concepts
- Further refinement of Ares-V launch approach
 - Dual-use shrouds
 - Ground operations processing concepts and campaign assessments
- Coordinated, Agency-wide, EDL development effort for landing large payloads (fundamental aero, integrated Ares V shroud/lander design, etc.)
- Deepen understanding of risk drivers and methods to obviate risks
 - Reliability Drivers
 - Maturity Process
 - Precursor Activities
- Technology development roadmaps and precursor assessments
- Address options for reducing total mission mass and thus number of launches
- Quantitatively tie precursor program and flight tests to risk mitigation
- Maximize synergy with Mars robotic program including landing large payloads