Human Mars Missions

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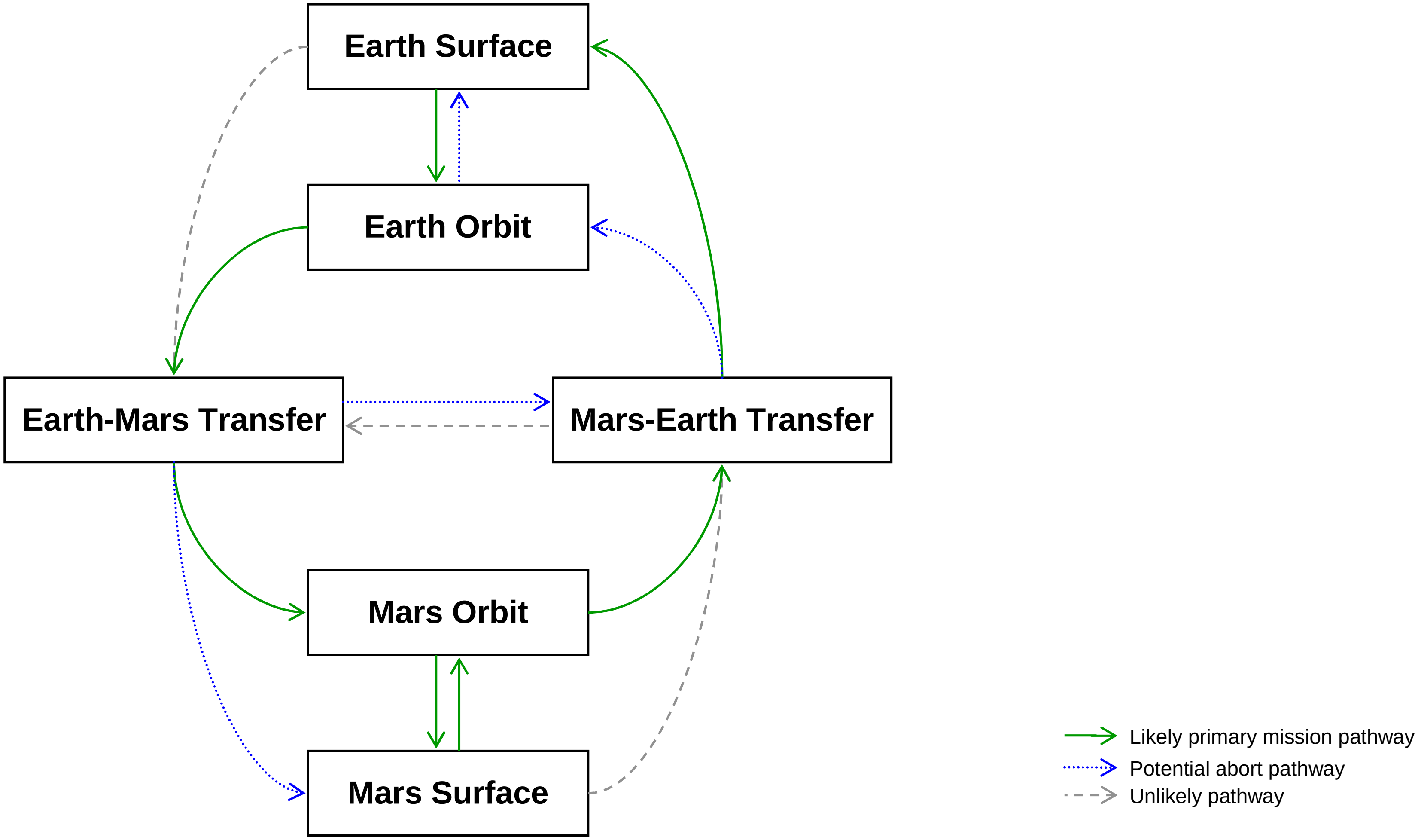
Getting to and from Mars

Earth-Mars-Earth Transportation Pathways



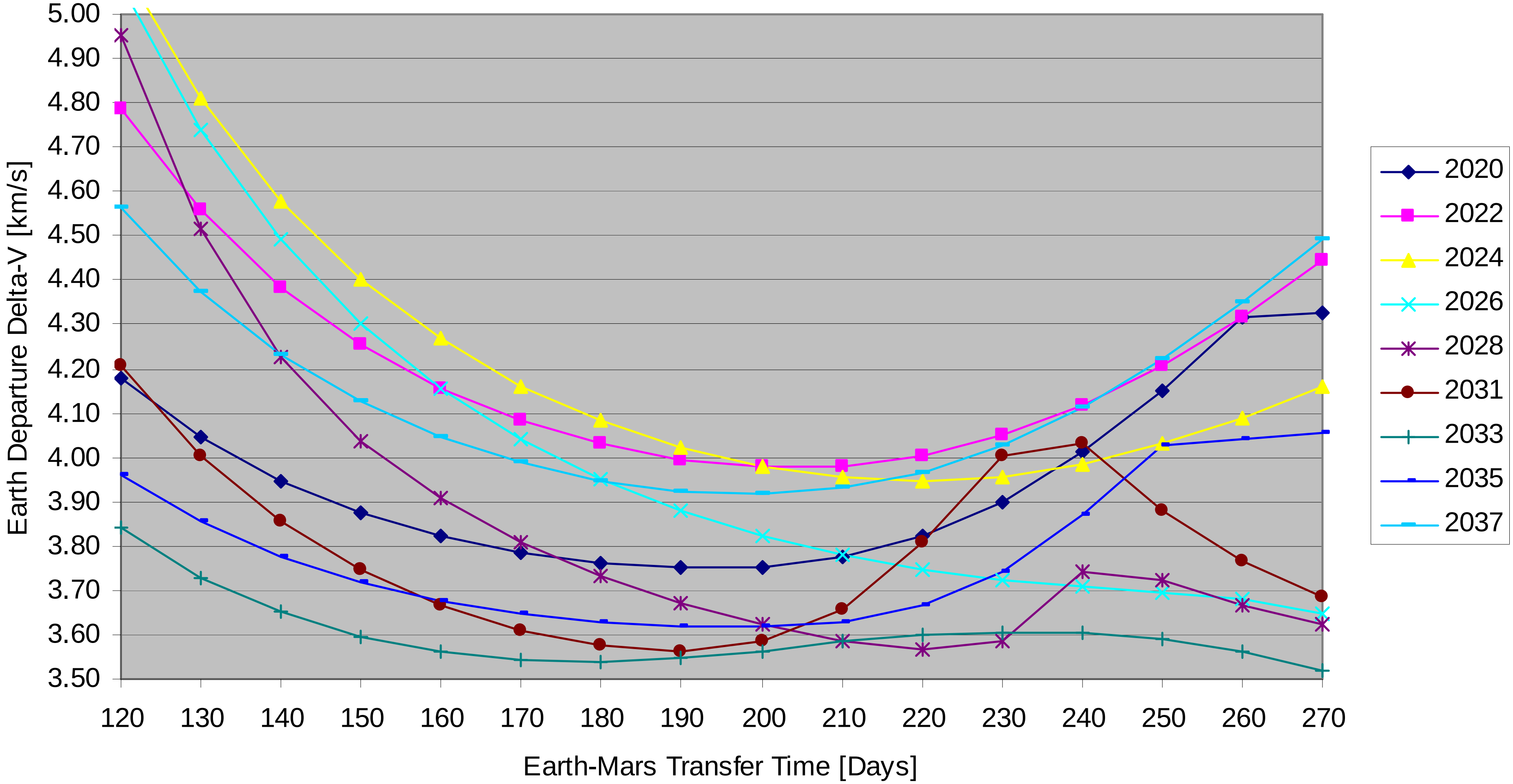
Mapping of Major Mars Elements to Mission Phases

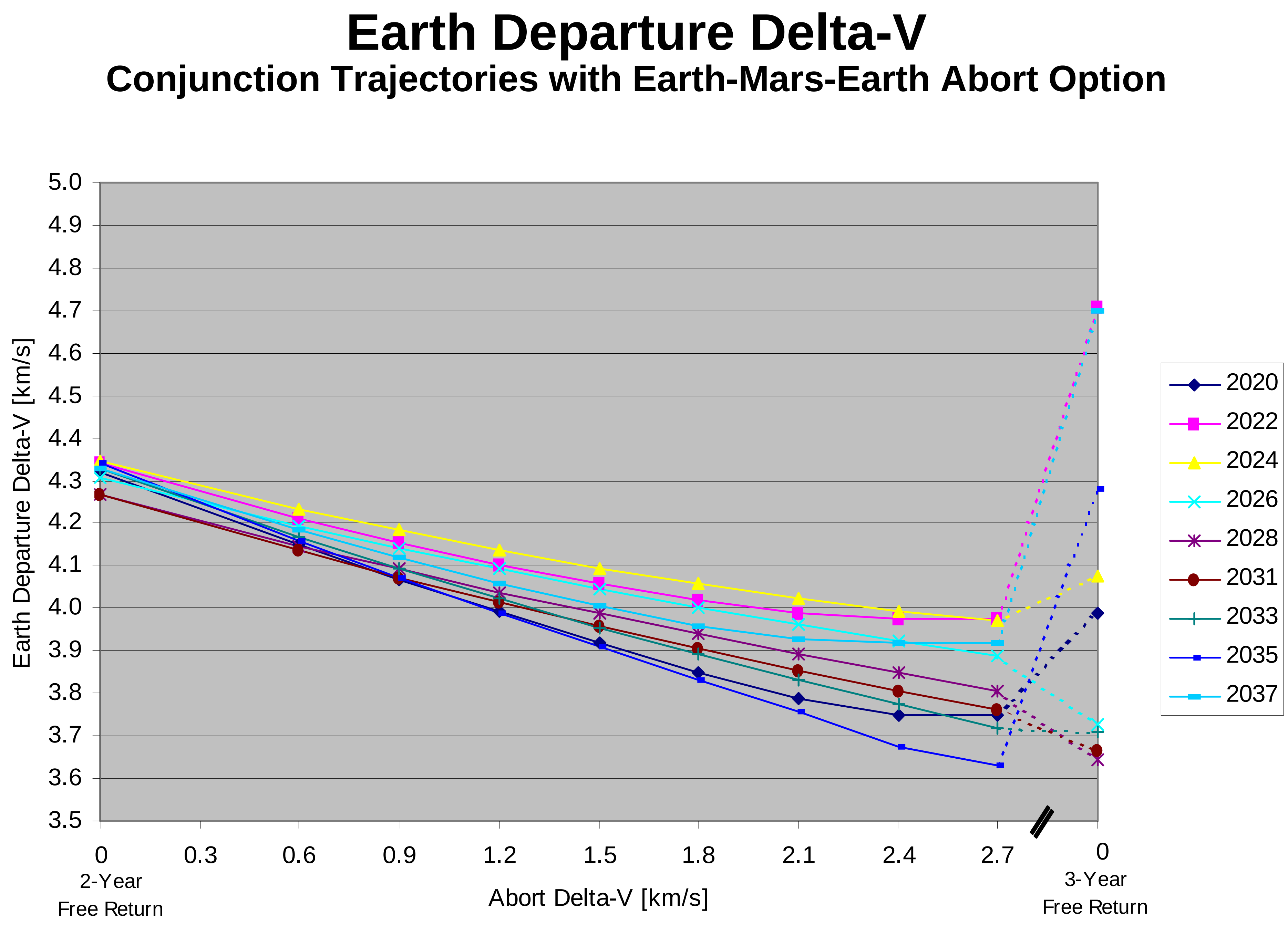
Major Mars Systems and Phases	ES->EO	EO	EO->EMT	EMT	EMT->MO	MO	MO->MS	MS	MS->MO	MO	MO->MET	MET	MET->ES
In-space and Surface Habitation		x	x	x	x	x	?	x	?	x	x	x	
Ascent Crew Compartment							?		?				
Crew Earth Ascent and Entry Vehicle	x						?		?				x
Earth Launch and Departure Propulsion	x		x										
Mars Aero-systems					x		x						
Descent and Landing Systems							x						
Mars Ascent and Departure Propulsion									x		x		
Surface Exploration Systems								x					
Surface Power Systems								x					
ISRU Systems								?					

Major Drivers of Selected Mars Systems

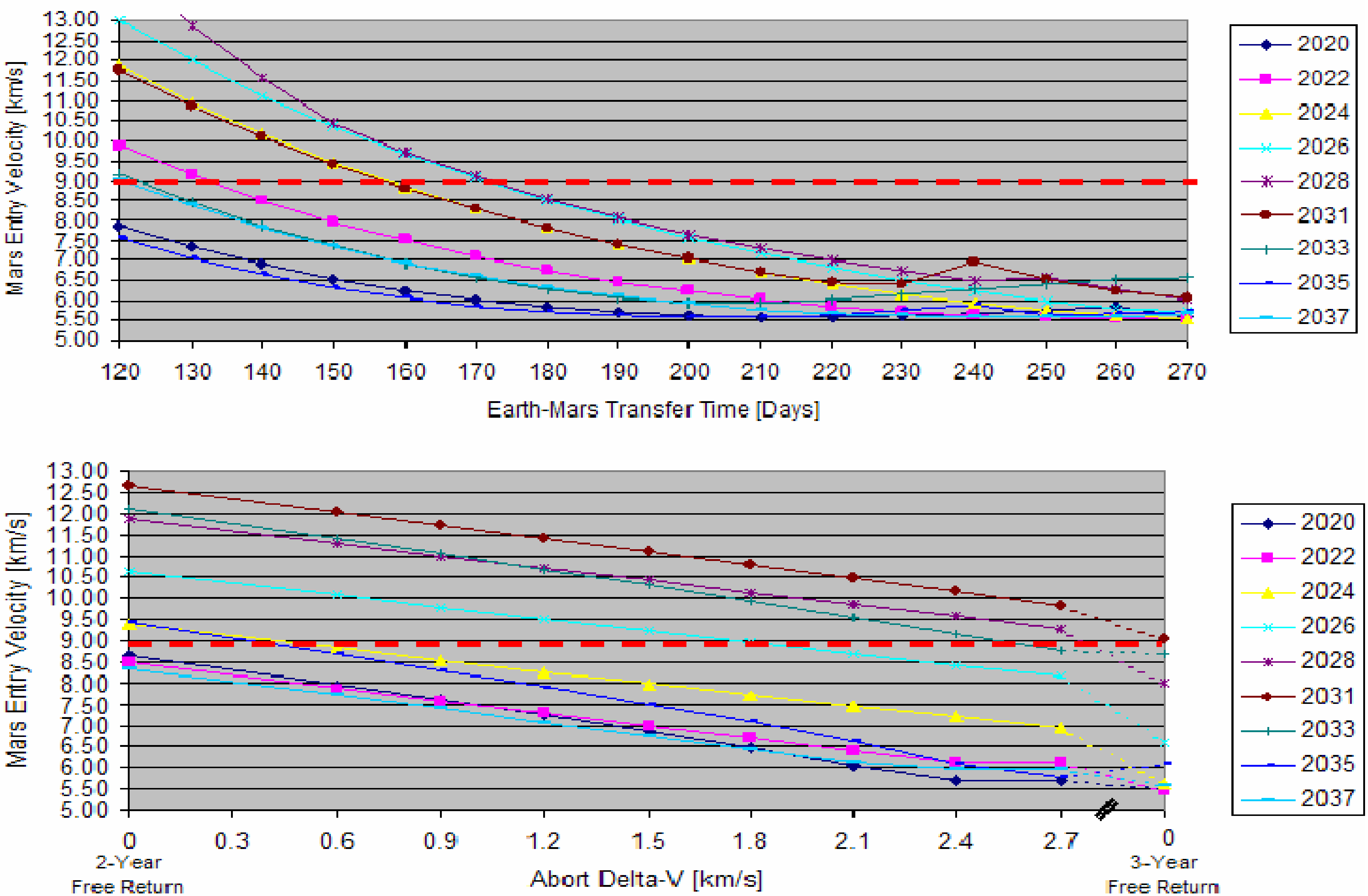
- **Earth Launch and Departure Systems are driven by the total payload which must be launched towards Mars and the Delta-V associated with the required Earth-Mars transfer trajectory.**
- **In-Space Habitation Systems are driven by crew size and the duration of the Earth-Mars transfer trajectory**
- **Mars Aero-Systems for Mars orbit capture and Mars entry and descent are driven by the payloads they must support and the Mars atmospheric entry velocities of the Earth-Mars transfer trajectories they must withstand**
- **Mars Landing Systems are dependent upon the payload they must deliver to the surface and the state (velocity and altitude) at which they must begin operation**

Earth Departure Delta-V
Standard (no abort option) Conjunction Trajectories

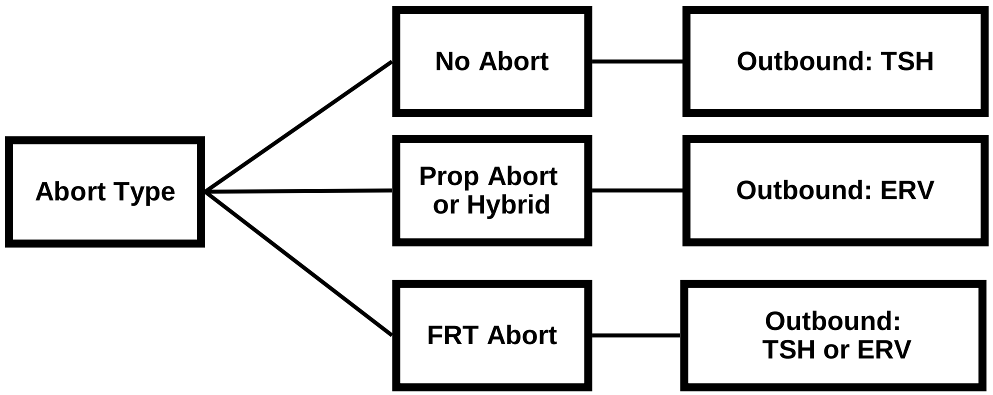



Earth Departure Delta-V
Conjunction Trajectories with Earth-Mars-Earth Abort Option
Earth Departure Delta-V [km/s]
5.0
4.9
4.8
4.7
4.6
4.5
4.4
4.3
4.2
4.1
4.0
3.9
3.8
3.7
3.6
3.5
0
0.3
0.6
0.9
1.2
1.5
1.8
2.1
2.4
2.7
0
2-Year Free Return
Abort Delta-V [km/s]
3-Year Free Return
2020
2022
2024
2026
2028
2031
2033
2035
2037

Mars Entry Velocity

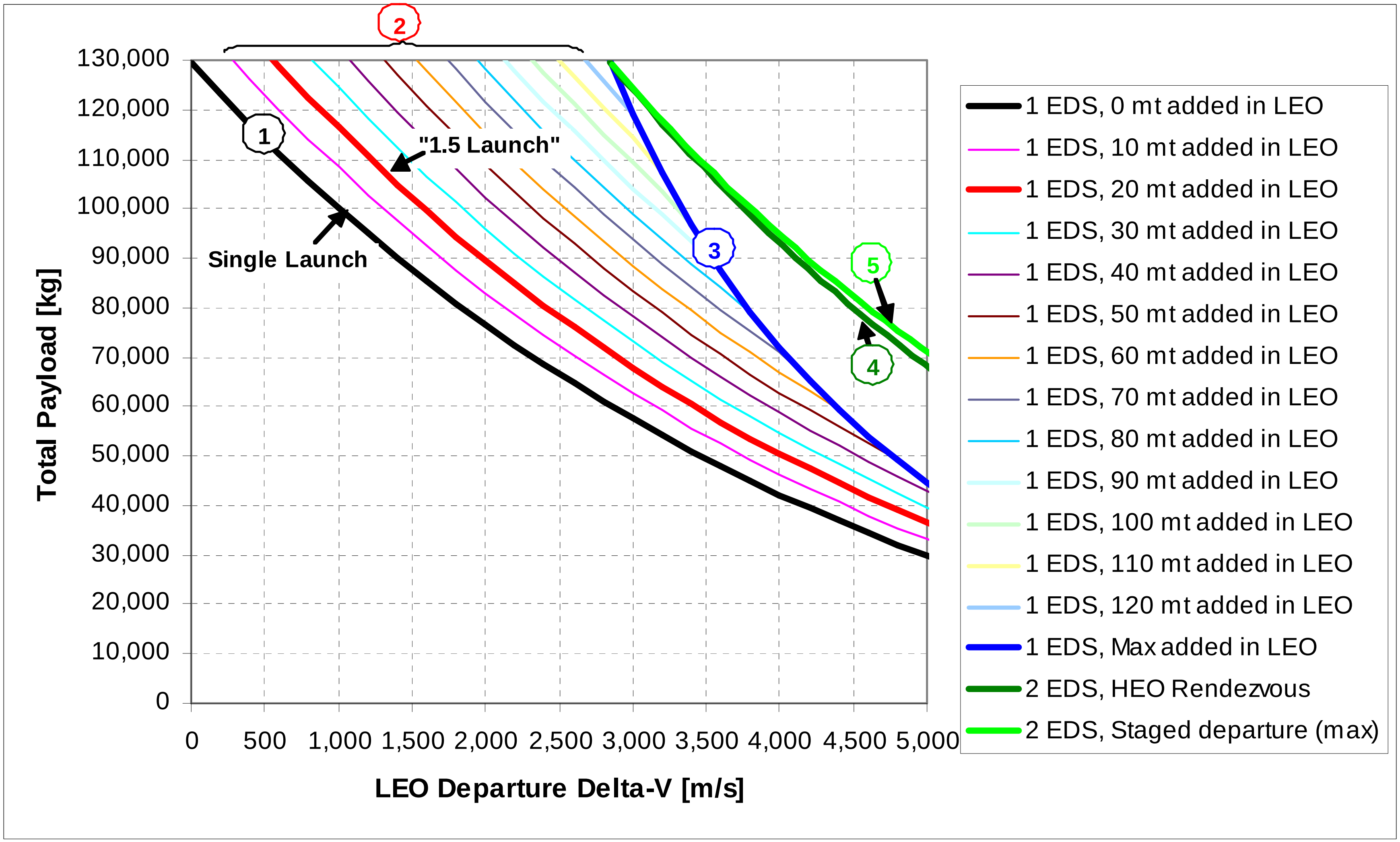


Abort Dependencies – MOR Architectures

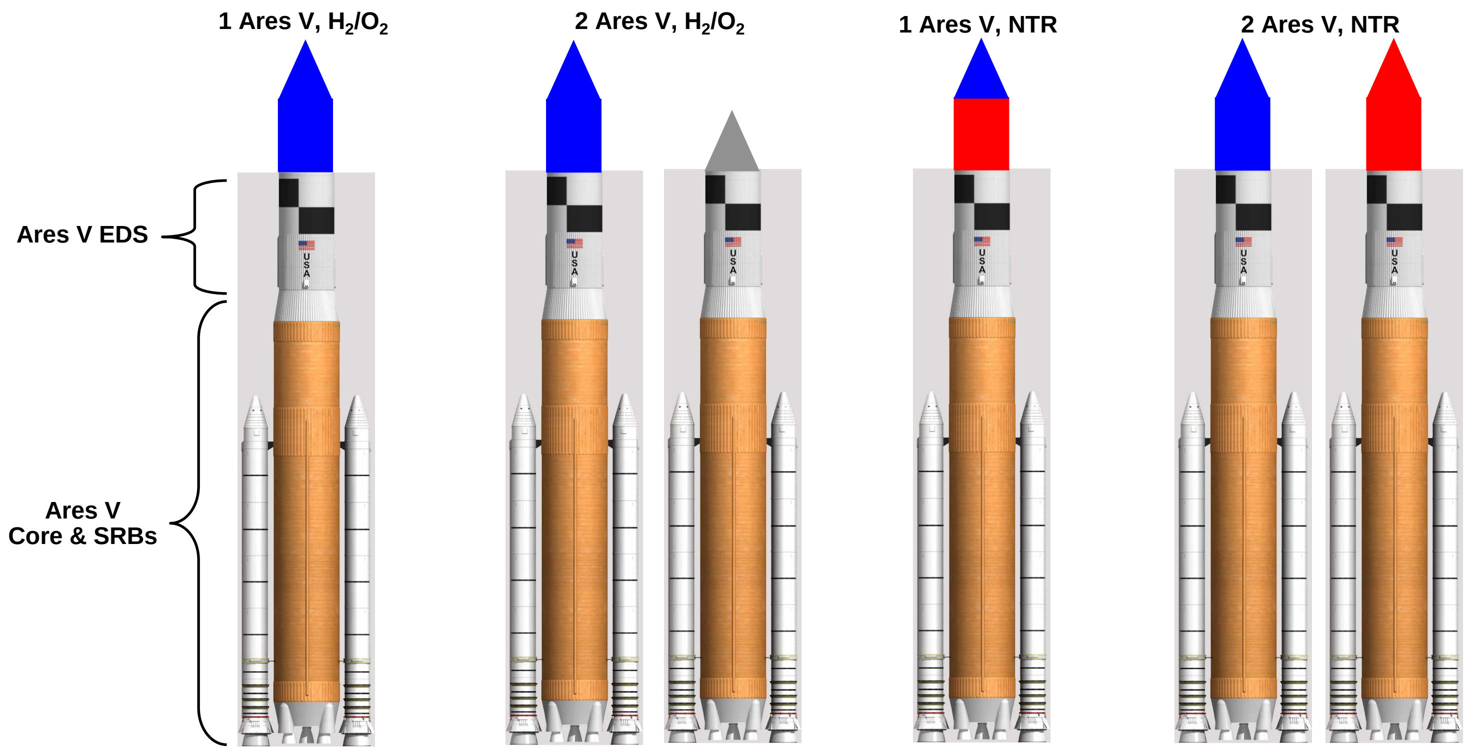


Outbound Abort?	Ascent Abort?	Outbound Config	# Ares I / COTS	# Ares V (Base)	# EDS (Base)	CEV (COTS)
Yes	Yes	MAV & ERV	0	3 (2)	3 (2)	1
Yes	Yes	TSH & ERV	0	3	3	1
Yes	Yes	TSH, Earth Aerocapture	1	3	3	2 (1)
Yes	No	TSH, Earth Aerocapture	0	3	3	1
Yes	Yes	TSH & Droppable CEV	0	4	3	2
No	Yes	TSH	1	3	3	2 (1)
No	No	TSH	0	3	3	1

Ares Launch Vehicle Capability

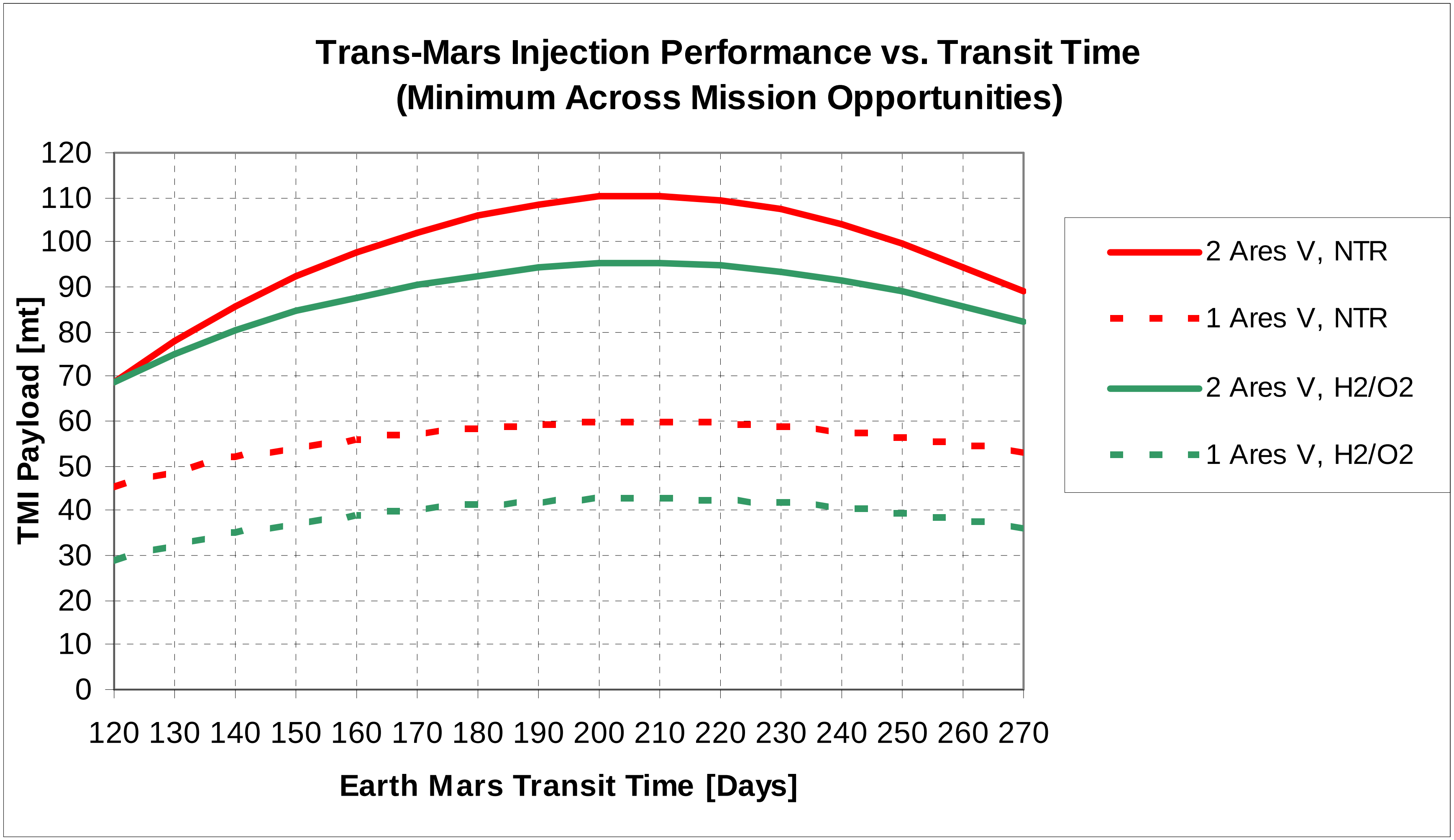


Selected Mars Launch and Earth Departure Configurations

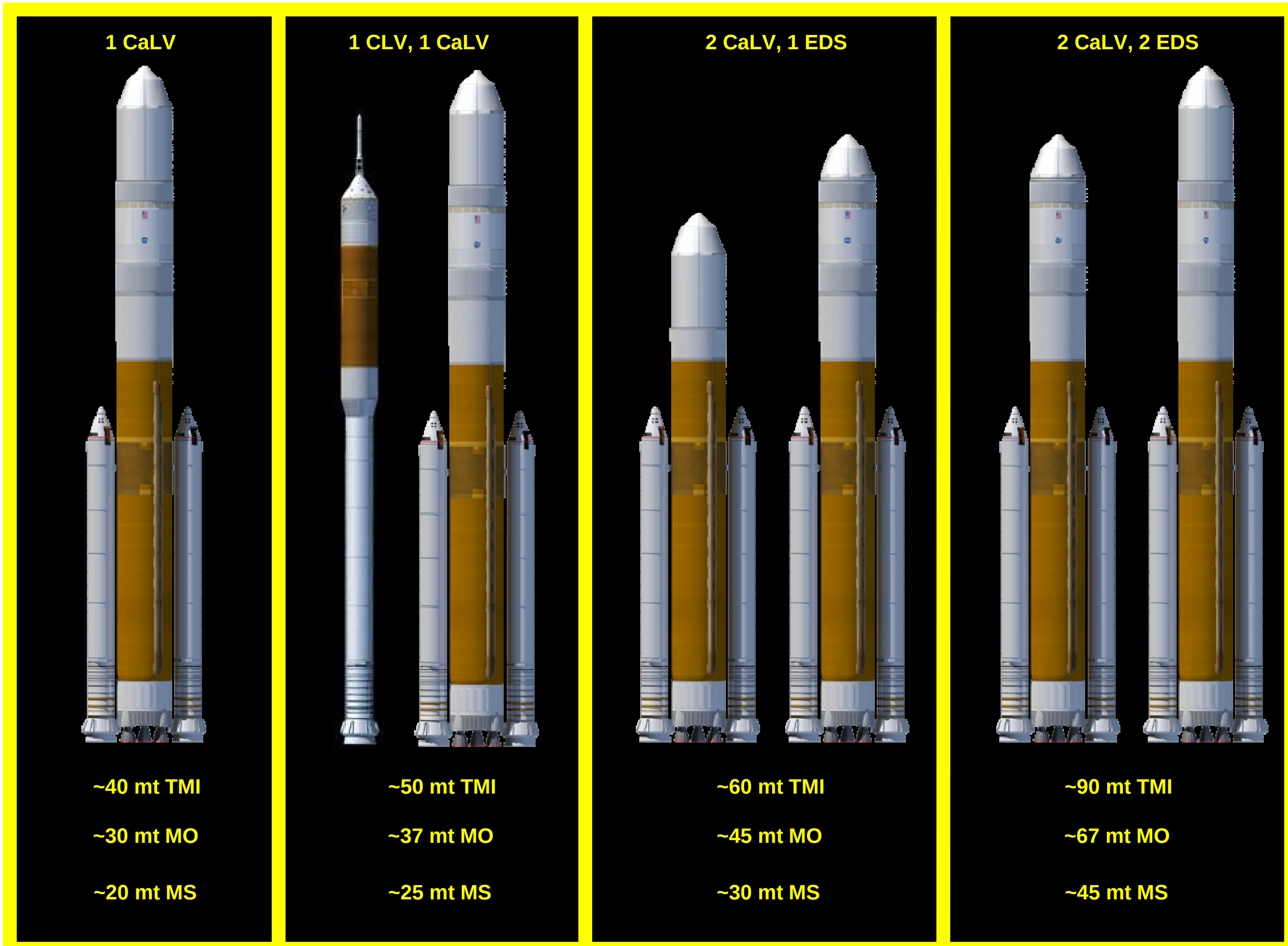


Blue = Payload; Gray = EDS Fairing; Red = Nuclear Thermal Stage

Launch and Earth Departure Performance



ESAS Launch Vehicle Mars Capability

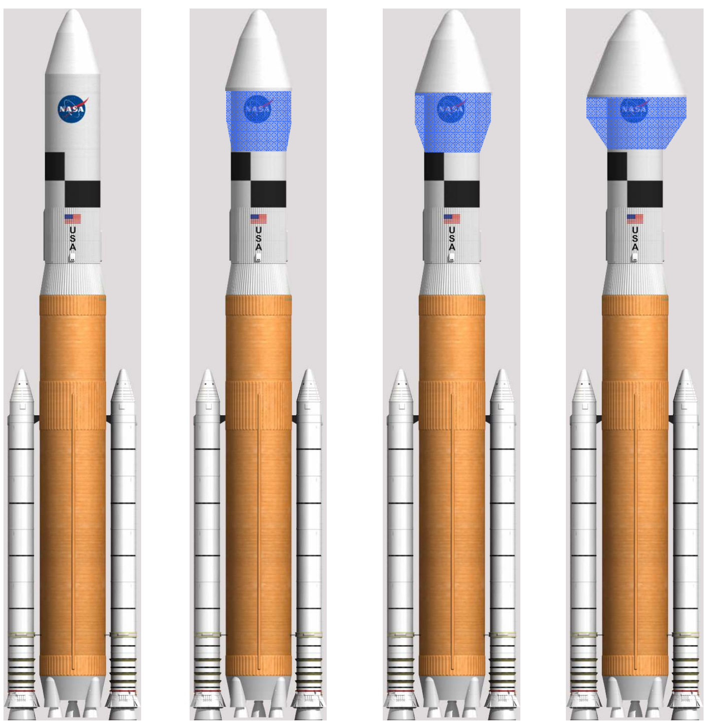


TMI – Trans-Mars Injection; MO – Mars Orbit; MS – Mars Surface

Aeroshell Sizing Impact on TMI Mass

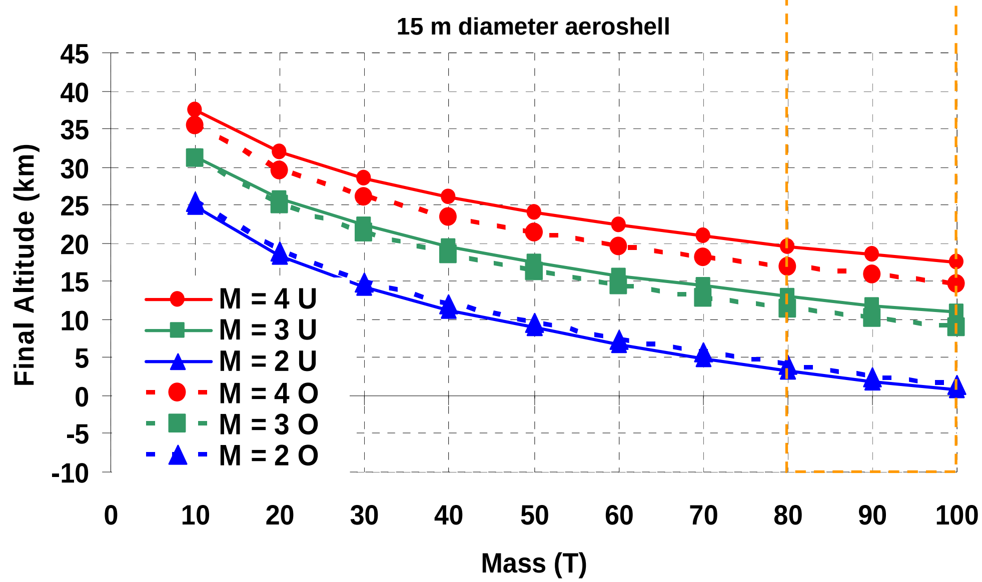
- CE&R aerocapture and aeroentry analysis indicated that aeroshell sizing (diameter) would have a major impact on maximum mass of Mars systems
- ESAS CaLV has a fairing diameter of 8.4 meters, although larger fairings for Mars systems would likely be possible
- For equal ballistic coefficient, the following entry mass limits likely apply for entry systems of the specified diameter:

8.4 m | 10 m | 12 m | 15 m



8.4^2 = 71 | 10^2 = 100 | 12^2 = 144 | 15^2 = 255

Diameter [m]	8.4	10	12	15
Entry Mass Range [mt]	25 to 31	35 to 44	51 to 64	80 to 100



Georgia Tech CE&R Aeroentry Analysis (Ventry = 4.63 km/s, L/D = 0.5)

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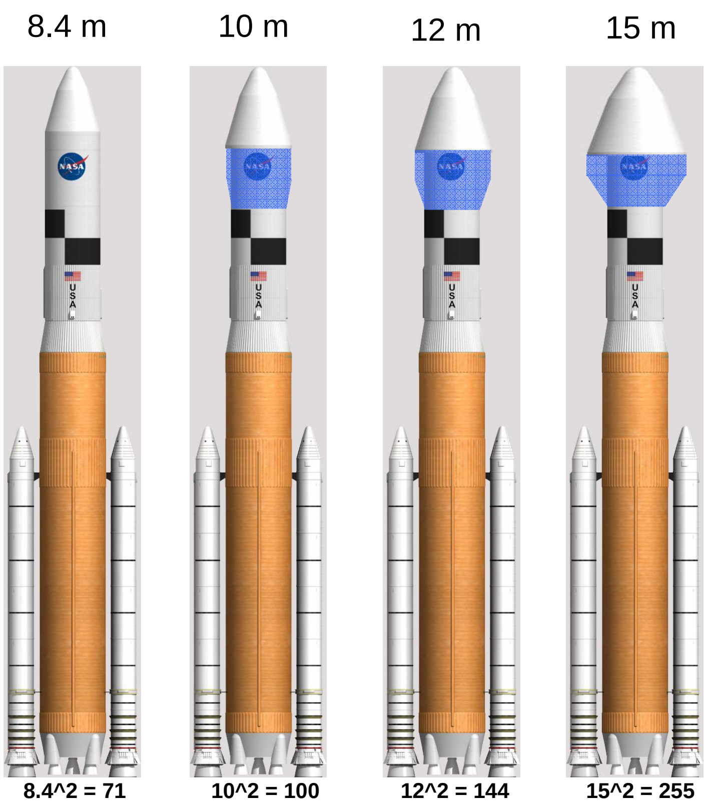

Diameter [m]	8.4	10	12	15
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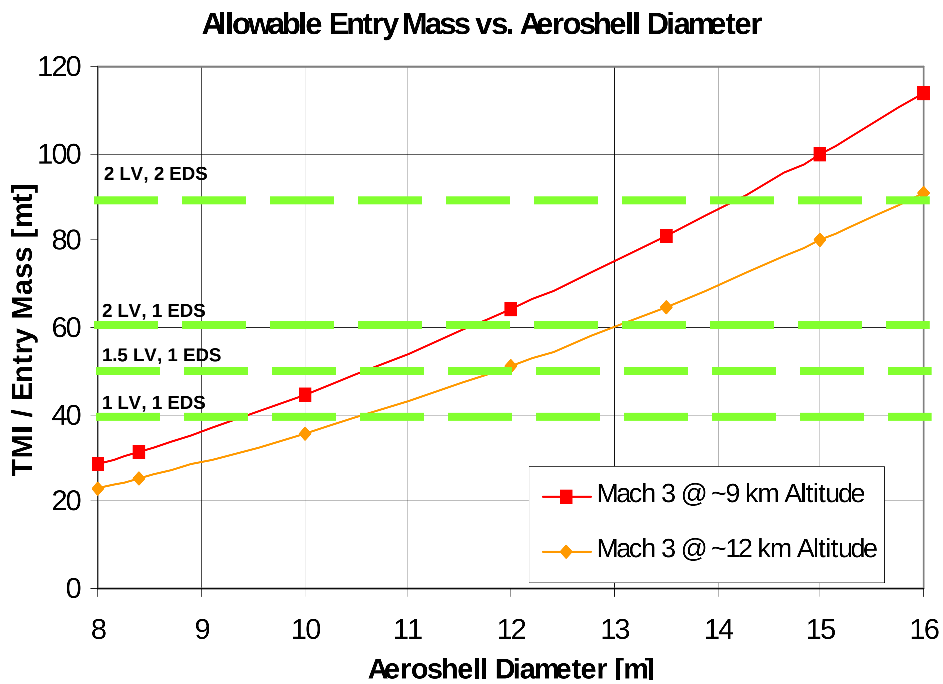
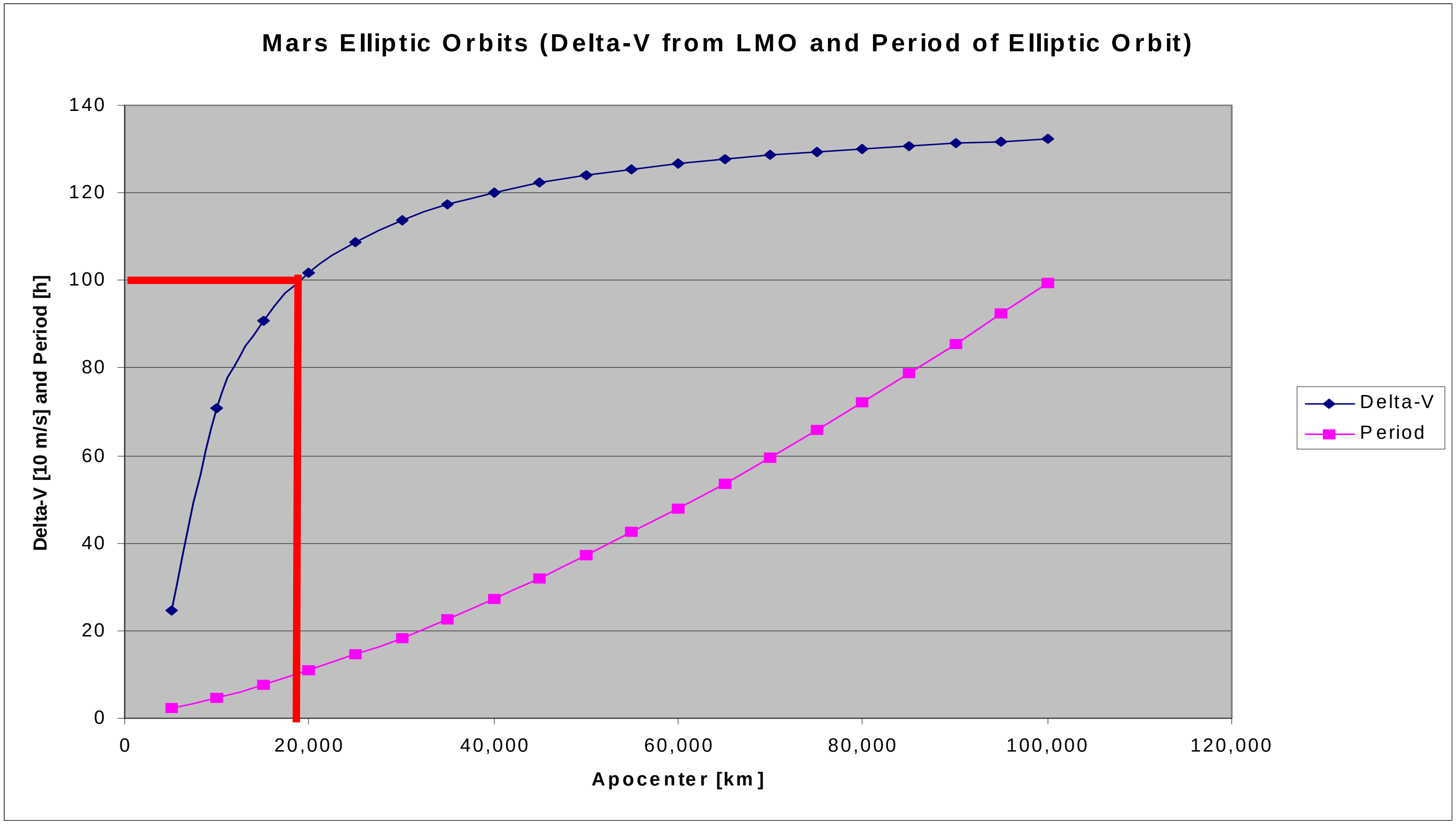


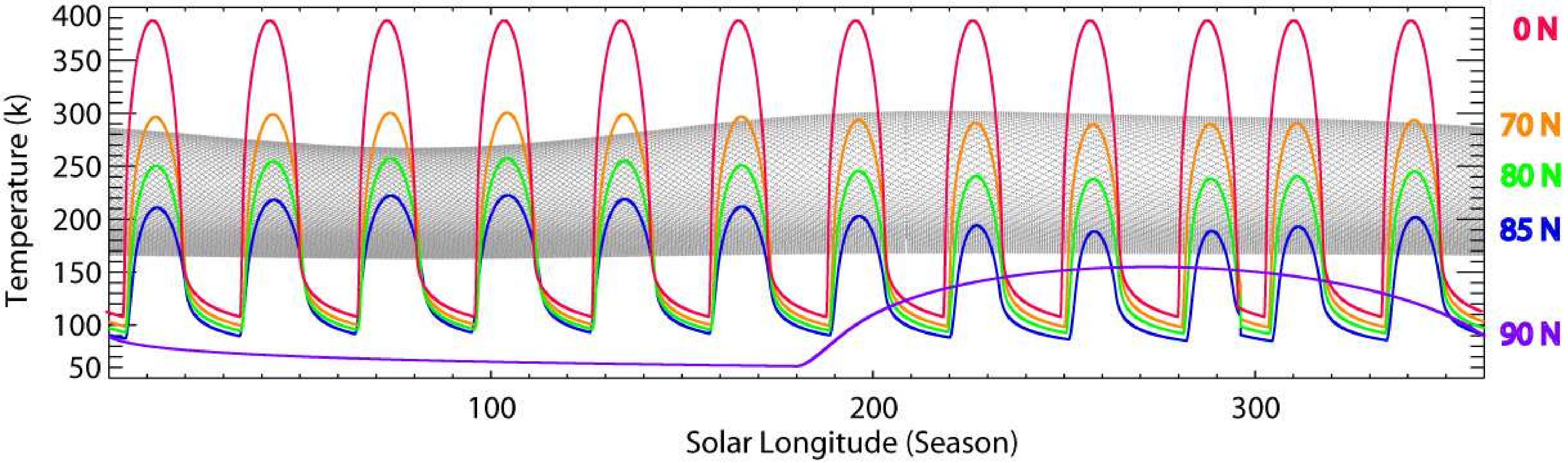
Highly Elliptic Mars Orbits



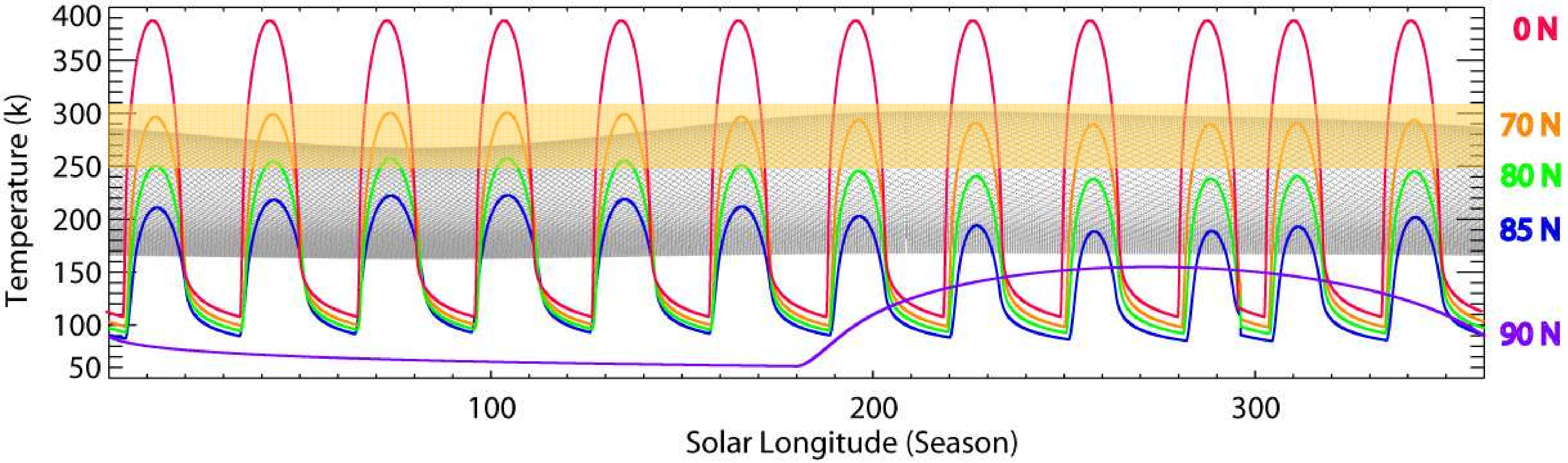
- Use of highly elliptic Mars orbits can decrease trans-Earth injection (TEI) delta-V relative to TEI from low Mars orbit
- In this analysis, a ~10 hour period highly elliptic orbit is assumed in elliptic orbit cases, which decreases TEI delta-V by 1,000 m/s (this delta-V is added to Mars ascent requirements)
- For the above chart, the pericenter is 3,700 km, equivalent to an altitude of ~300 km

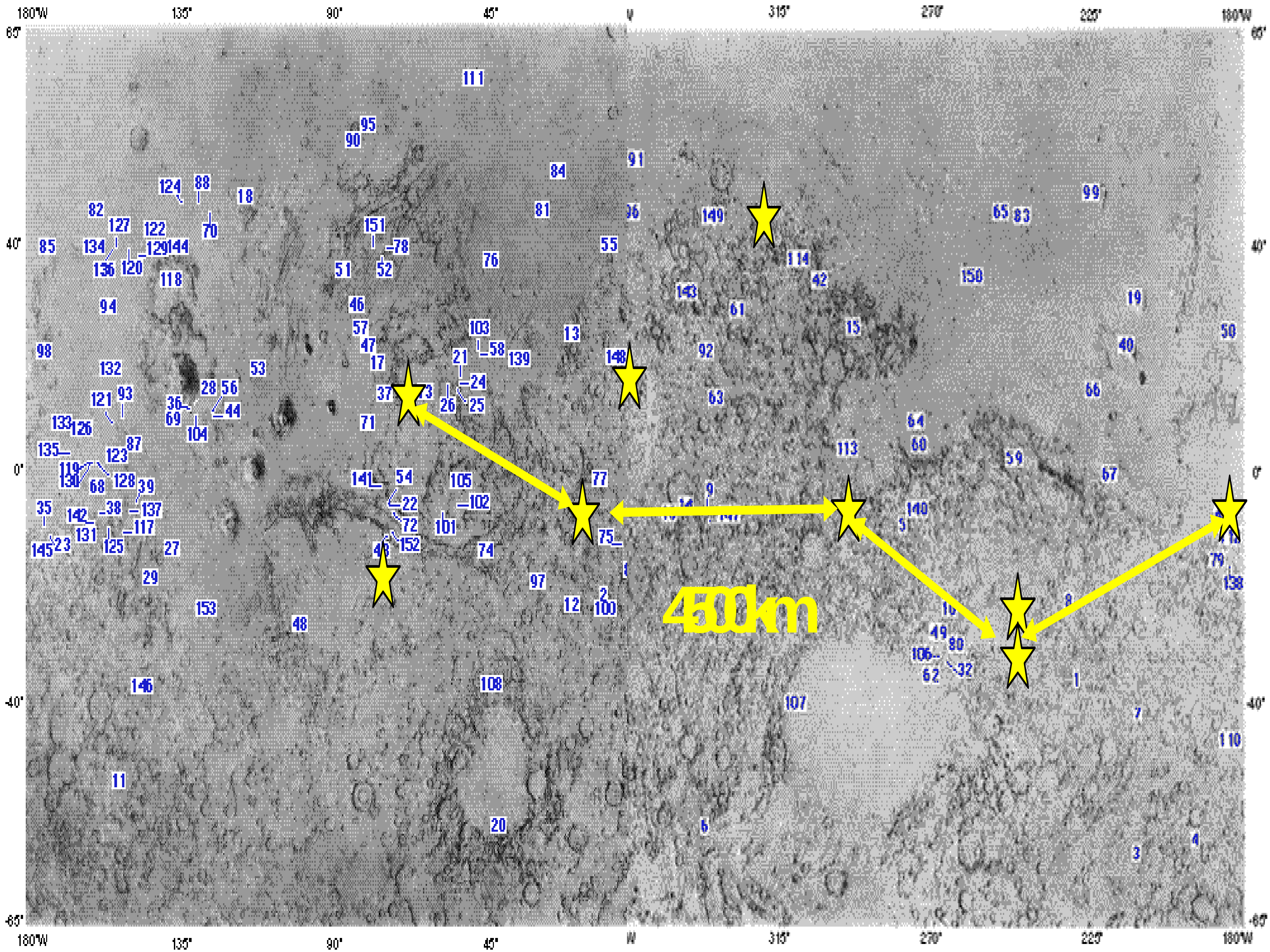
On Mars

Moon-Mars Thermal Comparison (Regolith Surface Temperature)

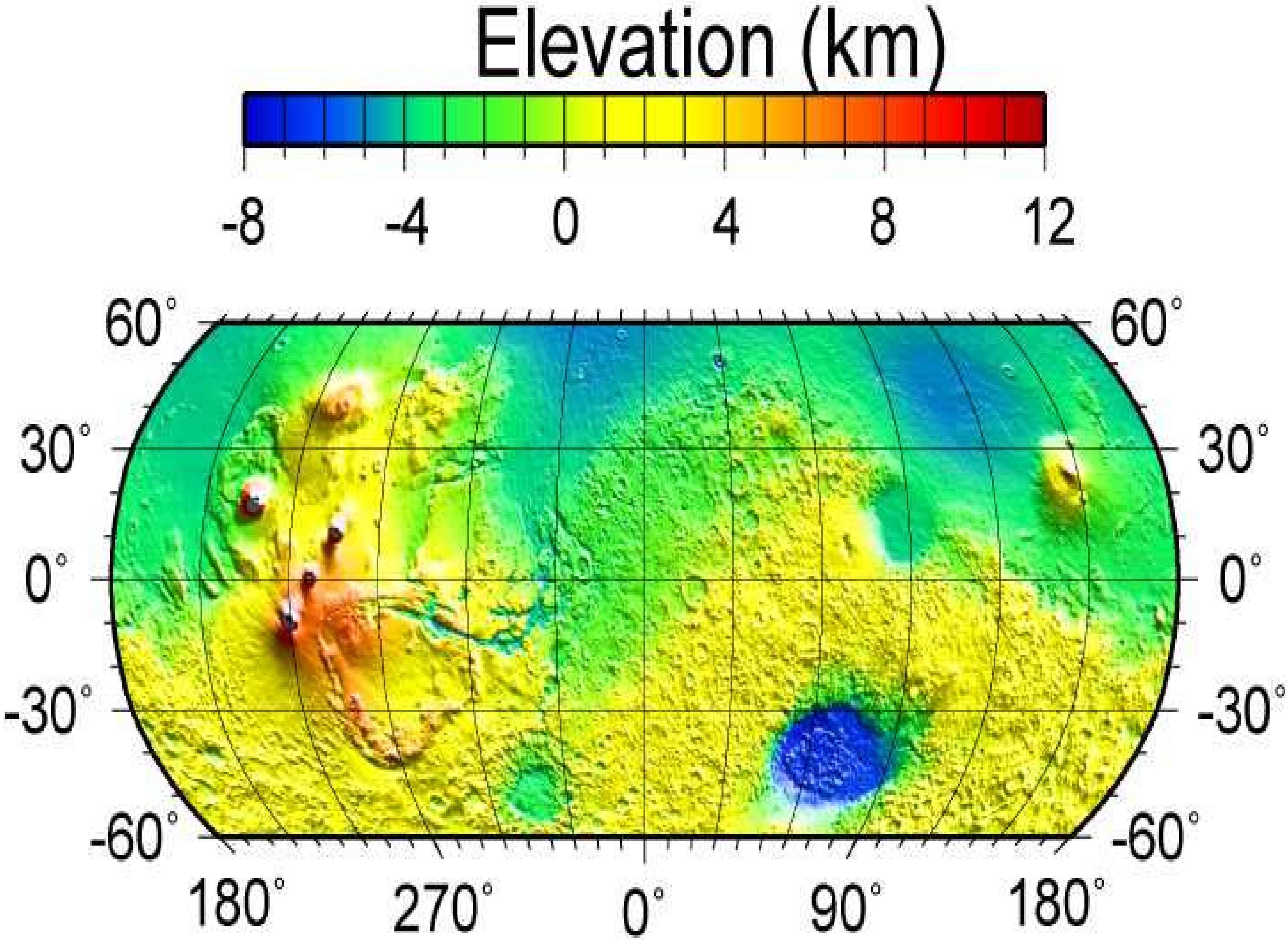


Moon-Mars-Boston Thermal Comparison (Regolith/Concrete Surface Temperature)

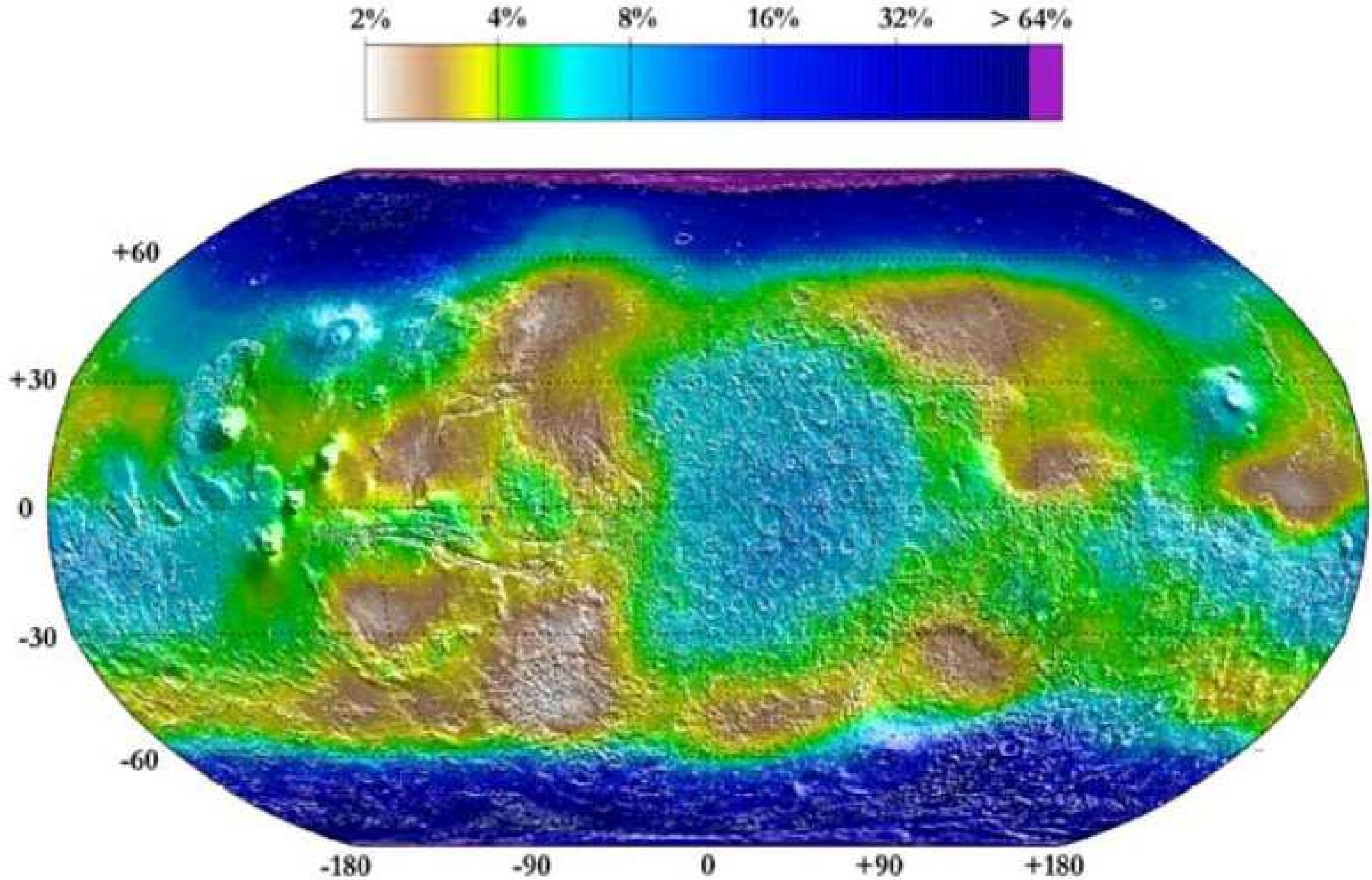


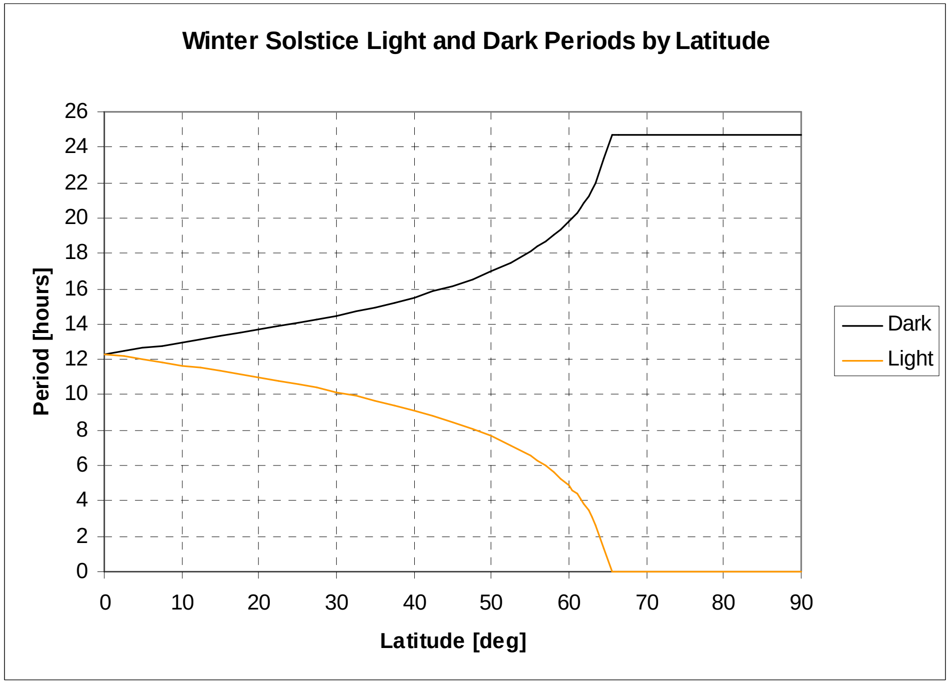


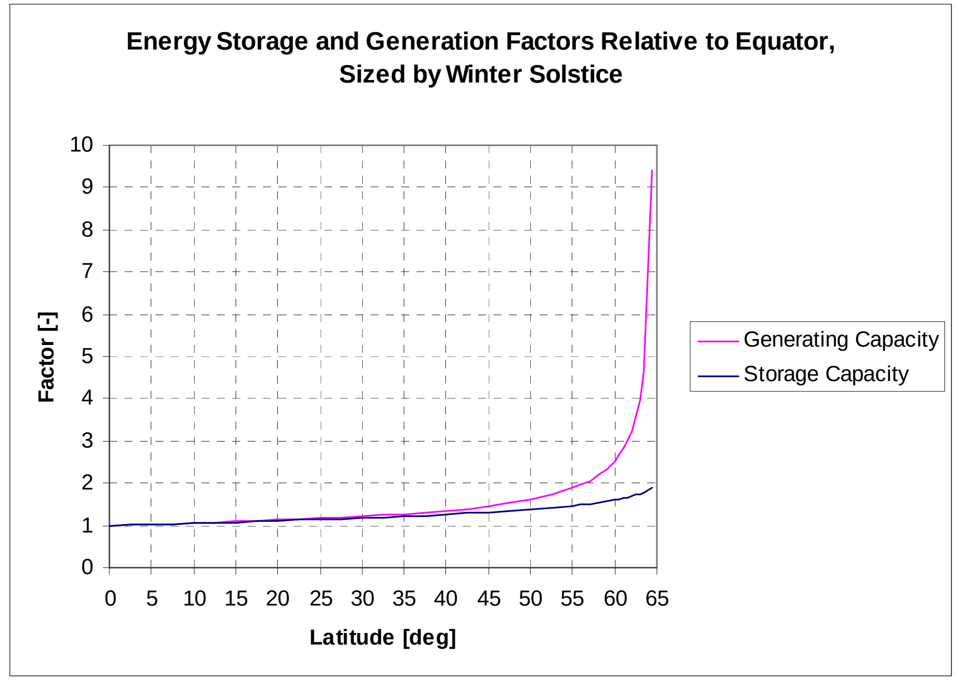
180°W
135°
90°
45°
0°
315°
270°
225°
180°W
65°
40°
0°
-40°
-65°

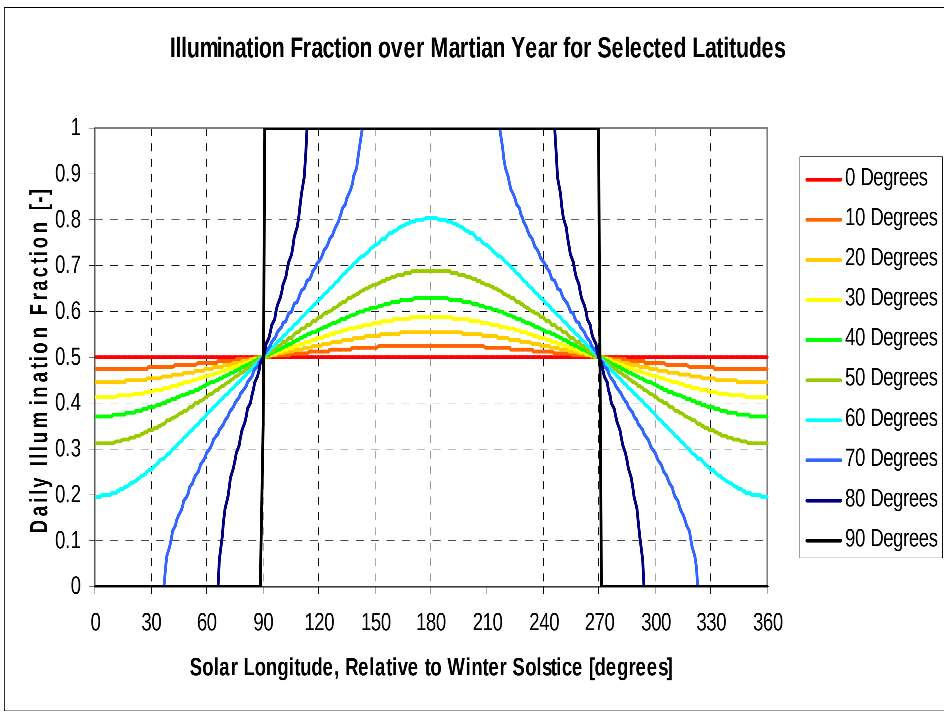

Elevation (km)
-8
-4
0
4
8
12
60°
30°
0°
-30°
-60°
60°
30°
0°
-30°
-60°
180°
270°
0°
90°
180°

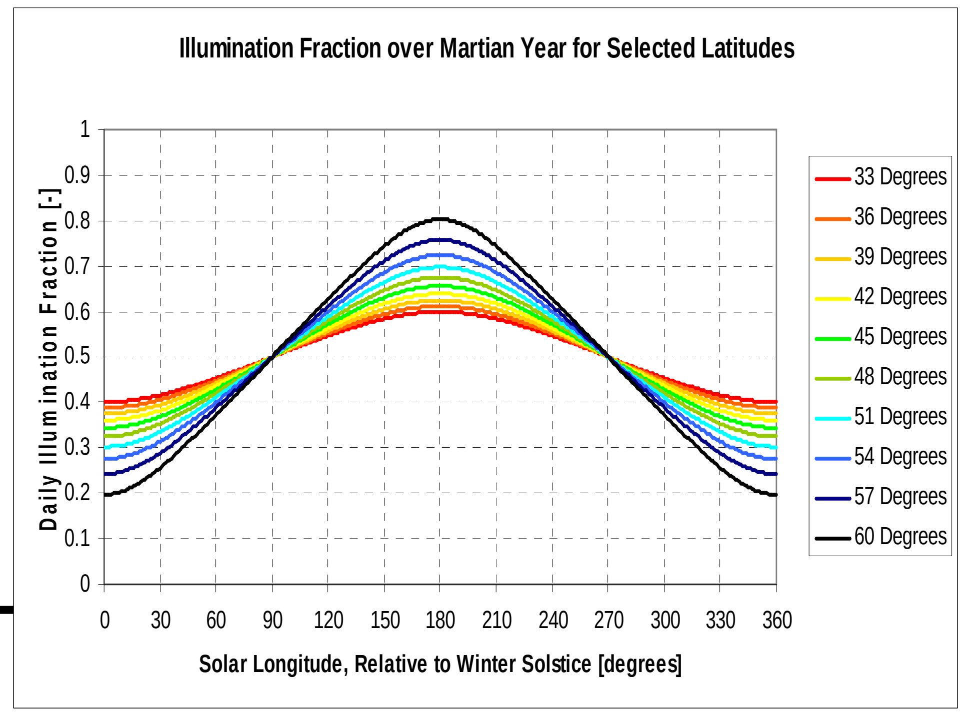
Mars Water



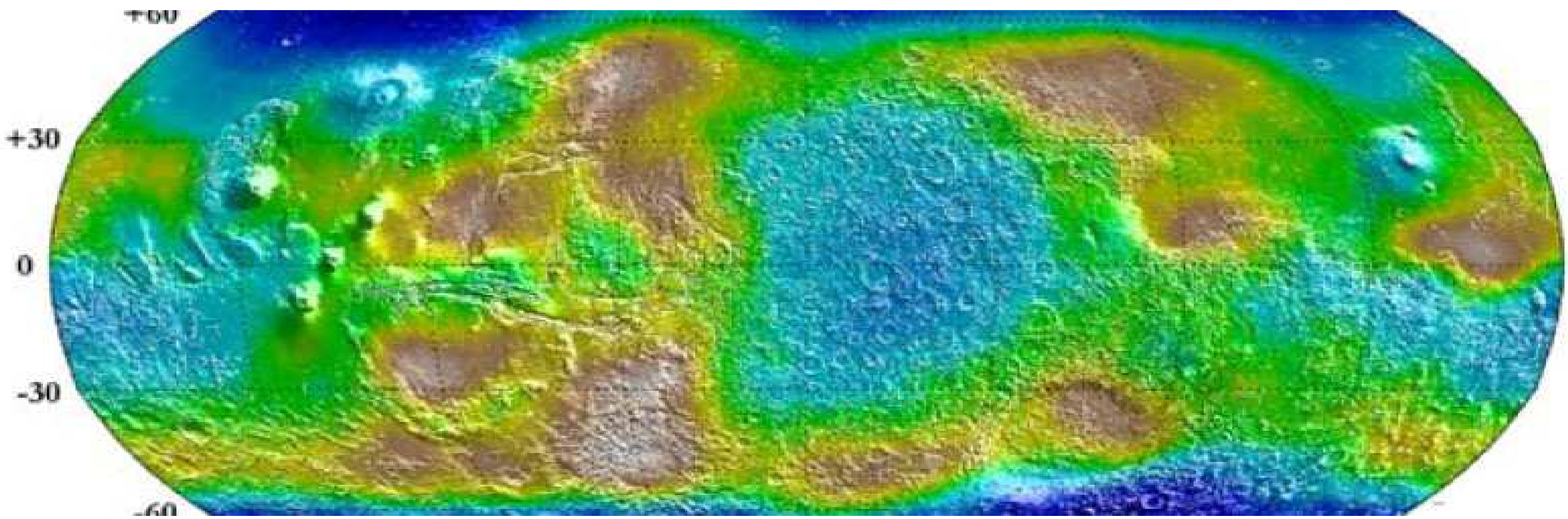

Winter Solstice Light and Dark Periods by Latitude
Period [hours]
Latitude [deg]
Dark
Light


Energy Storage and Generation Factors Relative to Equator, Sized by Winter Solstice
Factor [-]
Latitude [deg]
Generating Capacity
Storage Capacity

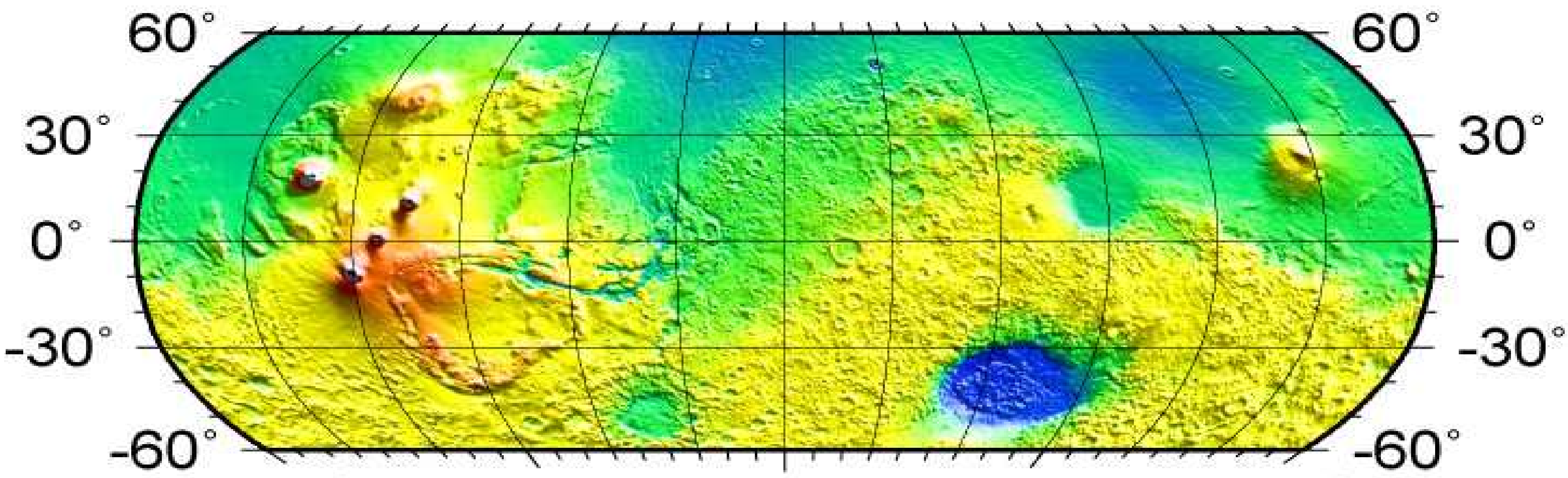

Illumination Fraction over Martian Year for Selected Latitudes
Daily Illumination Fraction [-]
Solar Longitude, Relative to Winter Solstice [degrees]
0 Degrees
10 Degrees
20 Degrees
30 Degrees
40 Degrees
50 Degrees
60 Degrees
70 Degrees
80 Degrees
90 Degrees


Illumination Fraction over Martian Year for Selected Latitudes
Daily Illumination Fraction [-]
Solar Longitude, Relative to Winter Solstice [degrees]
33 Degrees
36 Degrees
39 Degrees
42 Degrees
45 Degrees
48 Degrees
51 Degrees
54 Degrees
57 Degrees
60 Degrees

Mars Water



Mars Elevation



Moon and Mars

What to do on Moon to prepare for Mars

- Three main areas in which the Moon can offer aid in preparing for Mars, which could be considered objectives for lunar campaigns:
  1. Testing systems, technologies, and procedures for Mars exploration in an environment distinct from Earth.
  2. Increasing understanding of partial gravity (possibly coupled with radiation) impacts on crew health and performance.
  3. Providing an intermediate milestone for human space exploration efforts.

How to measure those things

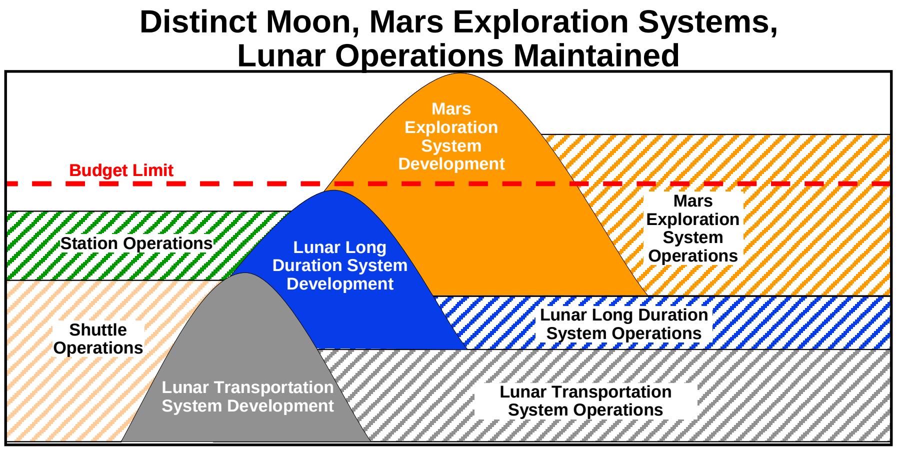
- **Metrics for each of the three areas of objectives for Mars preparation using the Moon are as follows:**
  1. **Degree to which lunar systems are similar to Mars systems and fraction of Mars systems validated during lunar activities**
  2. **Number of crew exposed to particular durations of lunar partial gravity (e.g., # at 1 month, # at 3 months, # at 6 months, etc.), with longer durations preferred**
  3. **Date of initial occurrence of high visibility events (e.g., lunar vicinity flight, human lunar landing, long-duration mission, total surface time of Mars mission)**

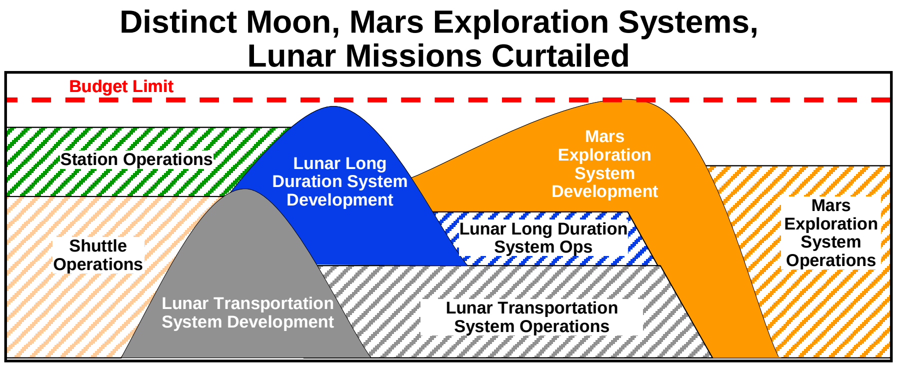
Mars Exploration Elements

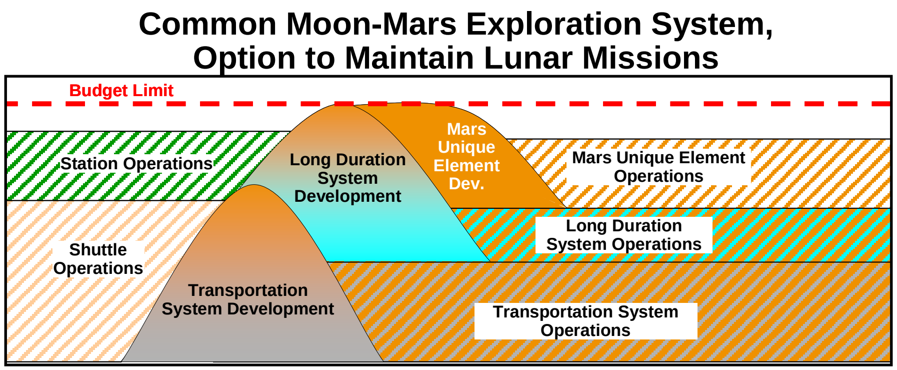
- Following list of elements required for Mars exploration
  - Earth Launch and Entry Crew Cabin(s)
  - Heavy Lift Launch Vehicle and Earth Departure Systems
  - Descent Stage
  - Heatshields
  - Long-term Surface Habitat
  - Mars Ascent Vehicle (Cabin and Propulsion)
  - Earth Return Vehicle (Habitat and Propulsion)
  - EVA and Mobility Systems
  - Surface Power Systems
- Following list of technologies beneficial for Mars missions
  - In-Situ Propellant Production/In-Situ Consumables Production
  - Mars ISRU Compatible Propulsion (e.g., CH_4/O_2, C_2H_4/O_2)

Items denoted in blue indicate high potential for Moon-Mars commonality

Moon-Mars Exploration System Commonality





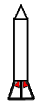


- **If distinct systems are developed for Moon and Mars, we may:**
  - **Significantly delay Mars operations**
  - **Need to curtail lunar operations to enable Mars (development, operations), resulting in a Moon-Mars mission gap**
  - **Never get to Mars at all, because the renewed major investment is not sustainable**
- **By developing a common Moon-Mars exploration system, we can overcome these obstacles and also:**
  - **Directly validate key Mars elements during lunar missions**
  - **Gain experience in routine production and system operation, decreasing cost and risk**
  - **Avoid workforce disruption during transition from Moon to Mars, and possibly continue lunar operations during Mars missions**
  - **Provide direct tie between Moon and Mars exploration in the eyes of the public and Congress**

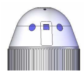
Commonality Strategy – Transportation Development Roadmap

LEO / ISS Mission Hardware

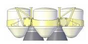
LAT for CEV capsule:



CEV + IPU (27 m³):



LEO propulsion stage:

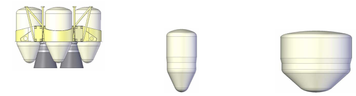


CEV power pack:

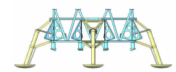
CEV launch vehicle:

Short Lunar Mission Hardware

Common in-space propulsion stage (LCH_4 / LOX):
Core propulsion stage
XL strap-on tanks
XXL strap-on tanks (ERV)

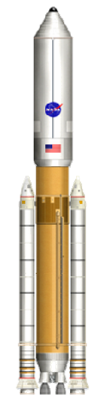


Lunar landing gear & exoskeleton:

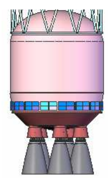


Engine 1 (LCH_4 / LOX)
Restartable, non-throttleable:

Engine 2 (LCH_4 / LOX)
Throttleable:



Common Earth departure stage (LH_2 / LOX)

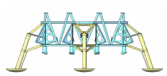


Heavy Lift Launch Vehicle:
("2 stages", 100 mt to LEO)

Design Philosophy: Maximize hardware commonality to minimize gap between lunar and Mars missions and overall development and production costs

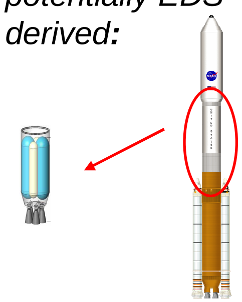
Mars Mission Hardware

Mars landing gear & exoskeleton:



Integrated aeroshell

SDLV upper stage (125 mt to LEO), *potentially EDS-derived:*



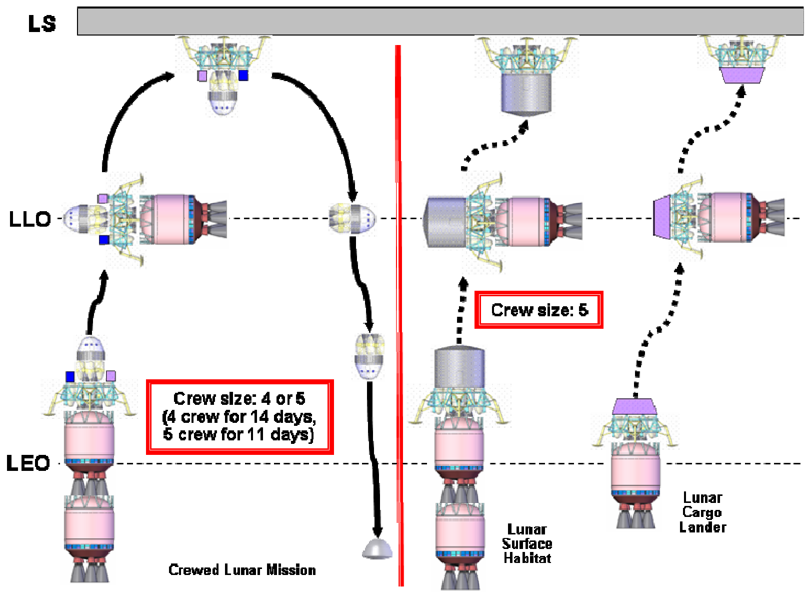
Long Lunar Mission Hardware

Habitat core and inflatable pressurized tent for planetary surfaces:

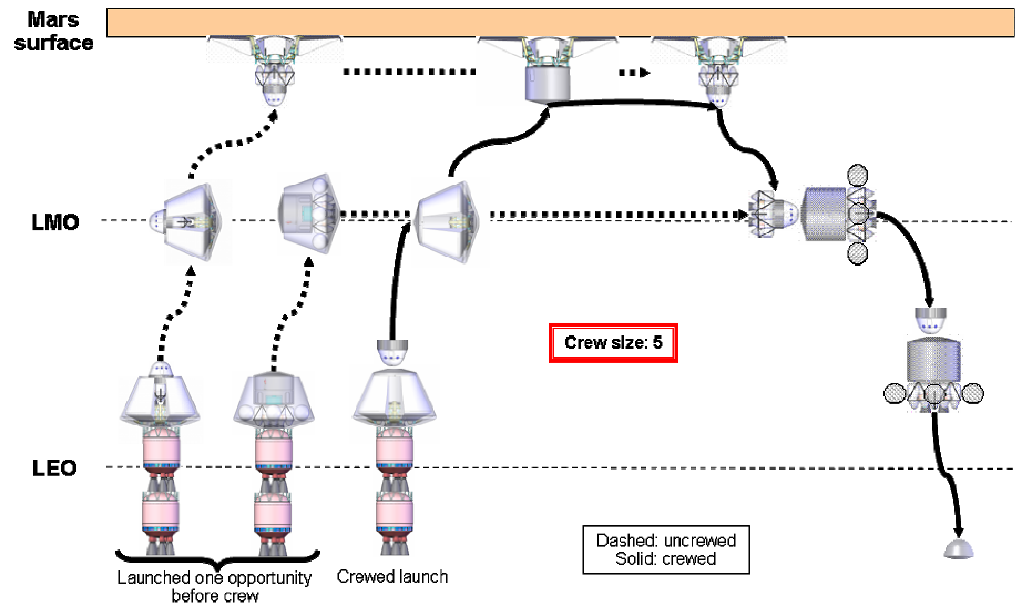
Note: Block upgrades across phases are not depicted

Base Moon-Mars Exploration System Commonality Concept

Lunar Transportation Architecture



Mars Transportation Architecture



- High-level commonality concept developed during Base Period using selected Moon and Mars architectures
- Commonality focused on design reuse of complete elements, with modularity in “Yellow Stage” and habitat design
- Develop high-level scheme to identify elements where commonality may be beneficial
  - Can be based upon elements with similar capabilities (or requirements)
  - Need to be careful which requirements are compared
    - e.g., for a propulsion stage, the combination of delta-v, payload, and thrust characterize the capability (to first order); taken in isolation they do not
- Develop commonality concept in further detail
  - Trades must be performed between modularity/platforming or “stretchable” options relative to a single design for many use cases

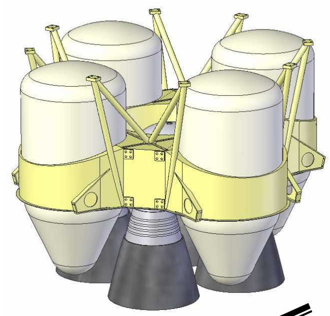
Note: While commonality shown for a particular pair of architectures, approach is not unique to those chosen

Extensible Destination Vicinity Propulsion System

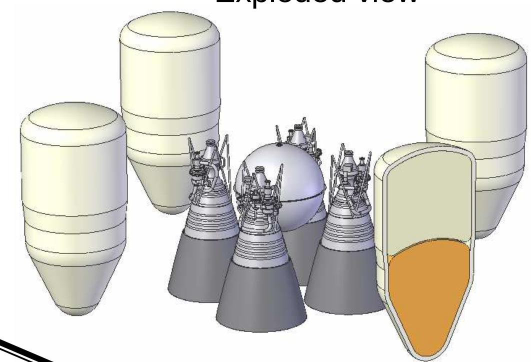
Core LCH4 / LOX propulsion stage

-4 non-throttleable LCH4/LOX engines
-4 common-bulkhead tanks (CBH)
-primary and secondary structure

Integrated view

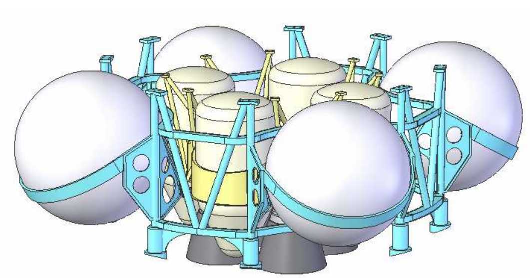


Exploded view



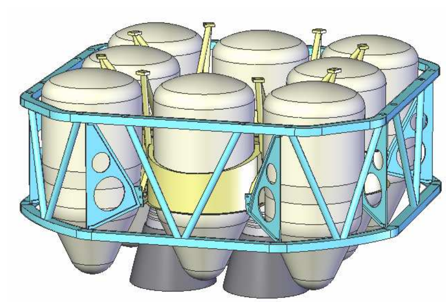
Derived LCH4 / LOX propulsion stages

Mars TEI



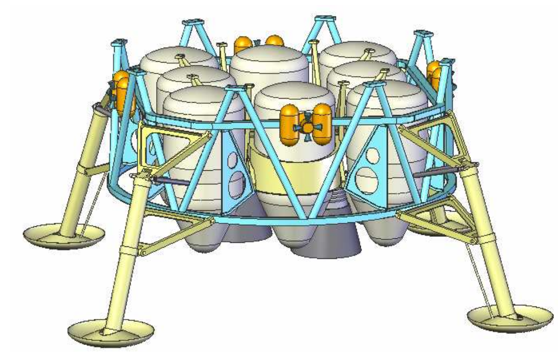
-4 non-throttleable LCH4/LOX engines
-4 common-bulkhead tanks
-4 spherical extension tanks (2 CH4, 2 O2)
-primary and secondary structure
-dedicated exoskeleton for Mars TEI

Mars ascent



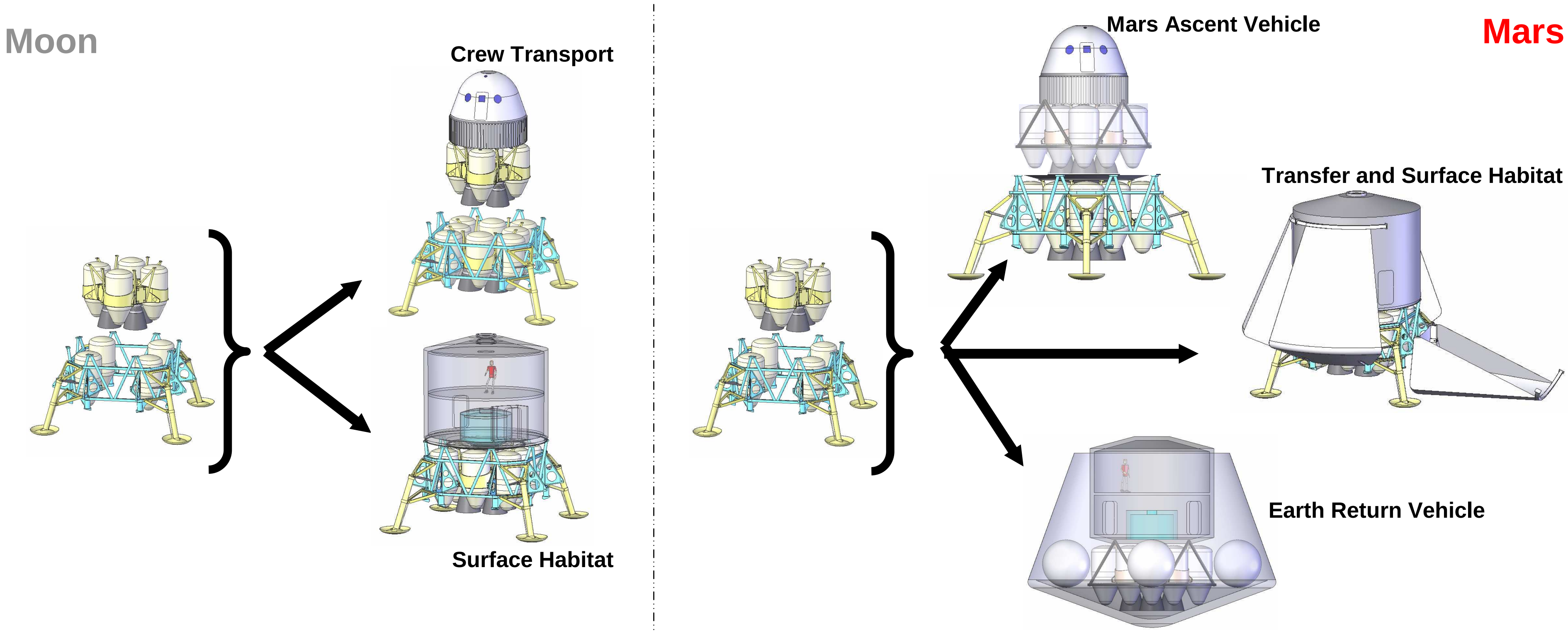
-4 non-throttleable LCH4/LOX engines
-8 common-bulkhead tanks
-primary and secondary structure
-additional primary structure

Lunar / Mars descent



-4 <u>throttleable</u> LCH4/LOX engines
-8 common-bulkhead tanks
-primary and secondary structure
-dedicated Moon and Mars landing gears and exoskeletons

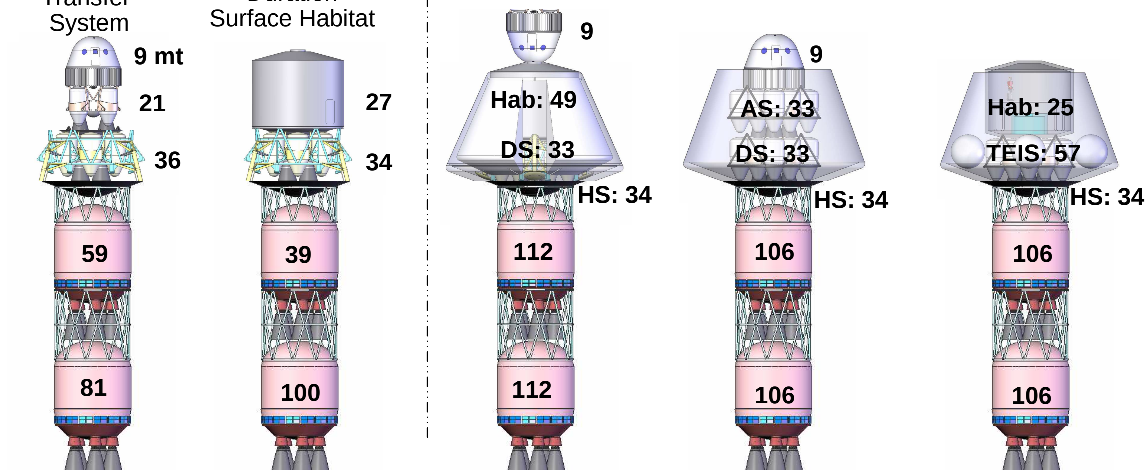
Common Destination Vicinity Propulsion System



- **Modular solution for Destination Vicinity Propulsion System**
  - **Common propulsion stage core employed in all use-cases (sized by Lunar Ascent & TEI)**
  - **Duplicate set of tanks (relative to core) provides additional propellant for Lunar/Mars Descent and Mars Ascent**
  - **Extra-large set of strap-on tanks used for TEI from Mars on Earth Return Vehicle**
  - **Descent stage structural ring and landing gear specific to destination due to distinct loading conditions**
  - **Common ascent engines, common descent engines for Moon [2 engines] and Mars [4 engines]**

Moon-Mars Common System Vehicle Stacks

Lunar Direct Return (Arch 1)		Mars Orbit Rendezvous: Combined Trans. and Surf. Habs (Arch. 969)		
Short Mission Lunar Crew Transfer System	Long Mission Lunar Long-Duration Surface Habitat	Outbound Transfer & Surface Habitat	Mars Ascent Vehicle & Return CEV	Earth Return Habitat & Propulsion



Post-Earth departure commonality mass overhead relative to customized systems:

1%	**2%**	**4%**	**3%**	**2%**

IMLEO commonality overhead relative to customized systems:

13%	**20%**	**4%**	**4%**	**3%**

Number launches (HLLV+CEVLS):

2+1	**2+0**	**3+1**	**3+0**	**3+0**

- **Elements combine together to form vehicle stacks for variety of missions**
- **Numbers at left represent wet mass in metric tonnes of elements in LEO**
  - **Earth Departure Stages have the same dry mass (11 mt) and maximum wet mass (112 mt)**
  - **CEVLV capacity 30 mt**
  - **Lunar HLLV capacity 100 mt**
  - **Mars HLLV upgraded to 125 mt**
- **Low commonality overhead due to appropriate use of modularity to support variants**

63% savings in unique element dry mass for common vs. custom system design

For modest mass increase, Mars-back commonality offers significant savings in development and production

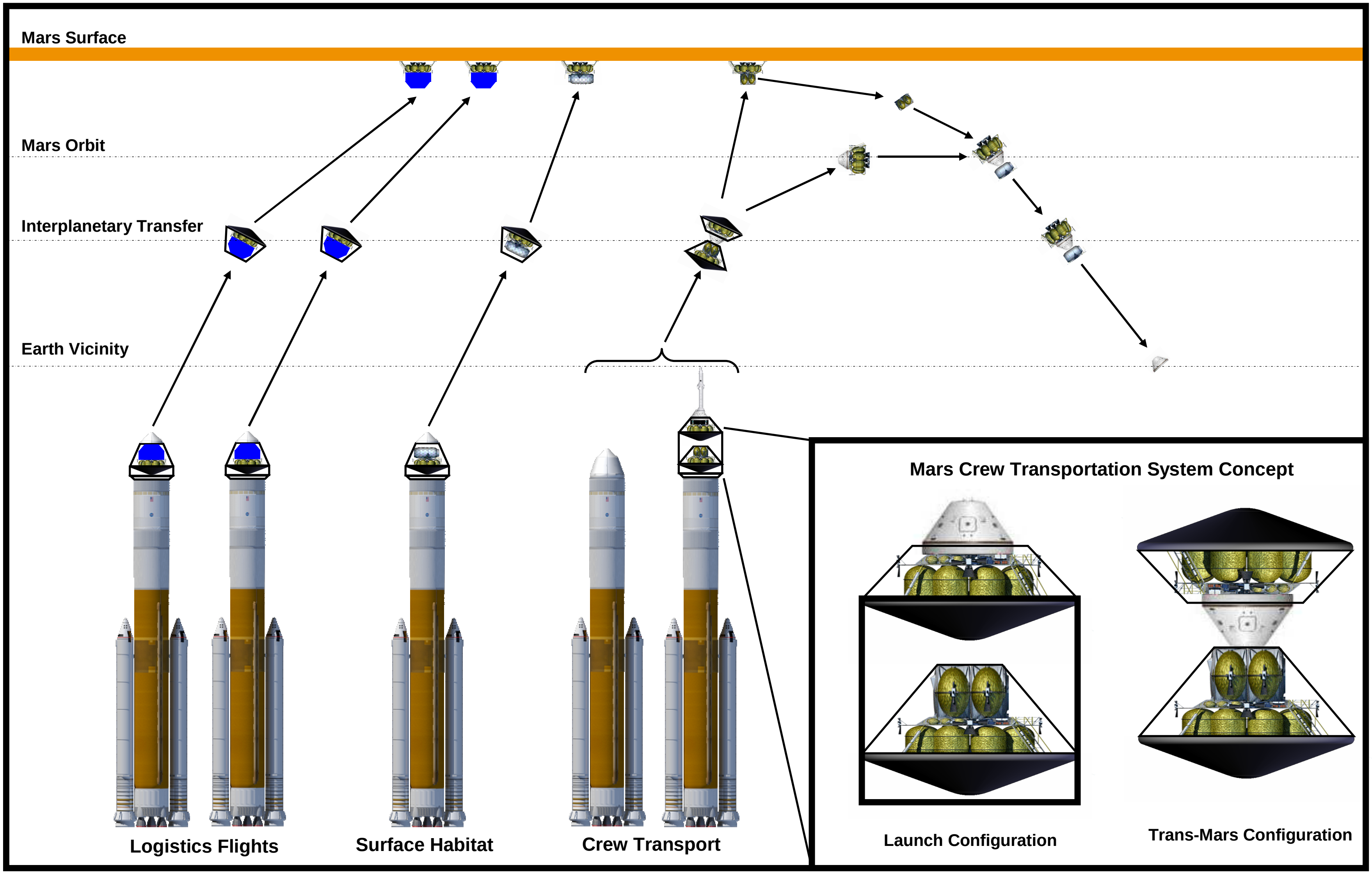
Extending ESAS Elements to Mars Missions

- Based upon the significant capability of ESAS launch vehicles to deliver payloads to Mars, options to extend the remaining elements were assessed

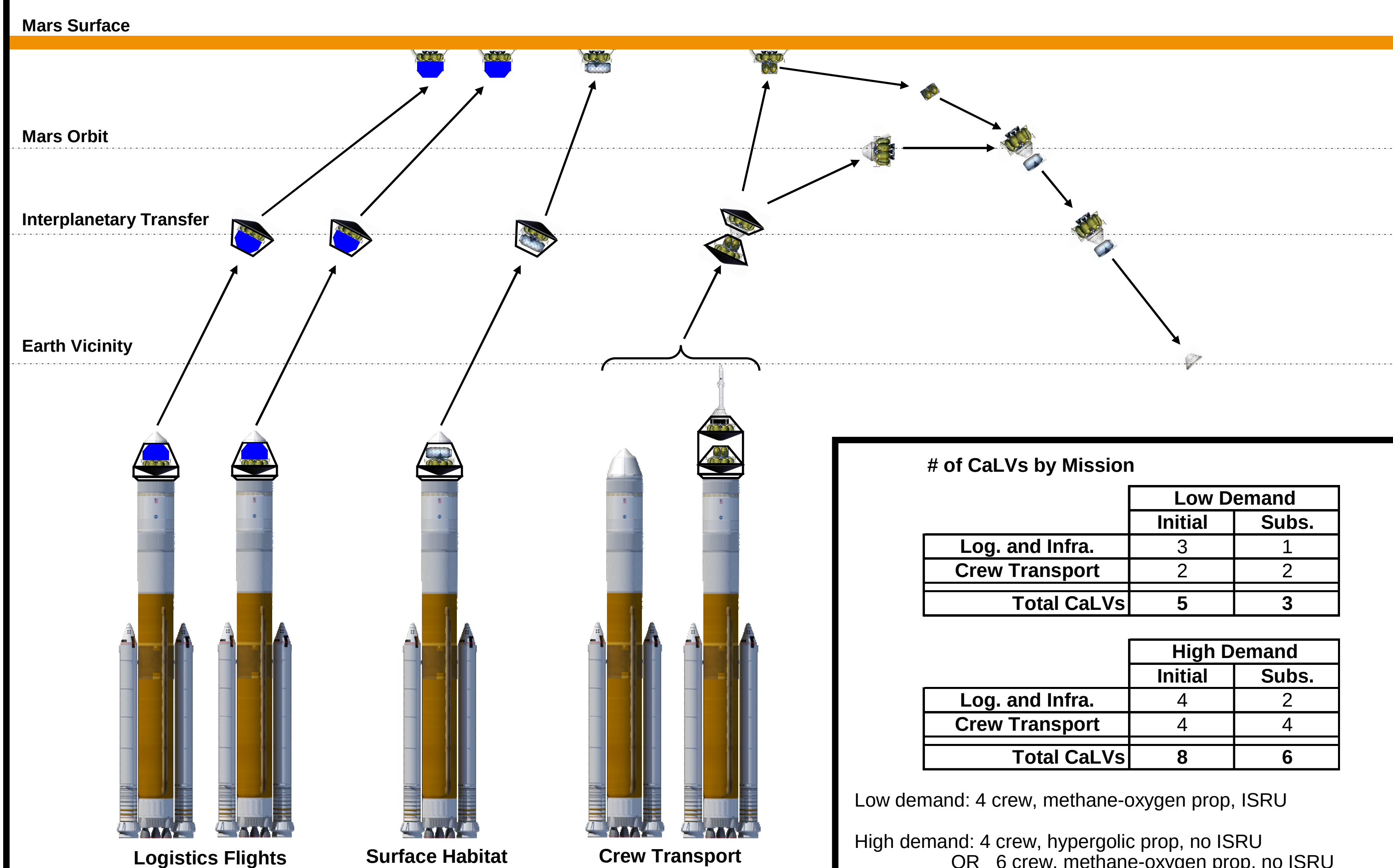
- In the baseline architecture presented:
  - Mars-dedicated aeroentry and propulsion systems are developed for aerocapture/descent, landing, ascent, and trans-Earth injection
  - The CEV is extended to provide habitation during Earth launch and entry, and during Earth-Mars and Mars-Earth transit in combination with the LSAM-derived Mars Landing and Ascent Vehicle crew compartment, as part of a dual-launch, dual-heatshield crew transportation system
  - A large surface habitat capable of supporting up to 6 crew members is positioned to the Martian surface prior to the arrival of the crew in a single launch
  - Single launch logistics flights pre-position consumables, surface exploration equipment, and power infrastructure for initial mission, resupply consumables and spares for subsequent missions

- Total number of CaLV launches required (no CLV launches are needed) is presented for a low launch demand and a high launch demand scenario
  - "Low demand" could be achieved with 4 crew (in one crew transportation system), methane-oxygen propulsion for maneuvers near Mars, and ISRU for both consumables production and propellant production
  - "High demand" could be achieved either with 4 crew (in two crew transportation systems), hypergolic propulsion, and no ISRU, or with 6 crew (in two crew transportation systems), methane-oxygen propulsion, and no ISRU
  - While not presented, intermediate launch demand options also exist with other crew size and technology combinations

Conceptual Mars Exploration Architecture Based on Lunar Elements



Conceptual Mars Exploration Architecture Based on Lunar Elements



# of CaLVs by Mission

	Low Demand	
	Initial	Subs.
Log. and Infra.	3	1
Crew Transport	2	2
Total CaLVs	**5**	**3**

	High Demand	
	Initial	Subs.
Log. and Infra.	4	2
Crew Transport	4	4
Total CaLVs	**8**	**6**

Low demand: 4 crew, methane-oxygen prop, ISRU

High demand: 4 crew, hypergolic prop, no ISRU
OR 6 crew, methane-oxygen prop, no ISRU