Human Exploration Extensibility from Moon to Mars

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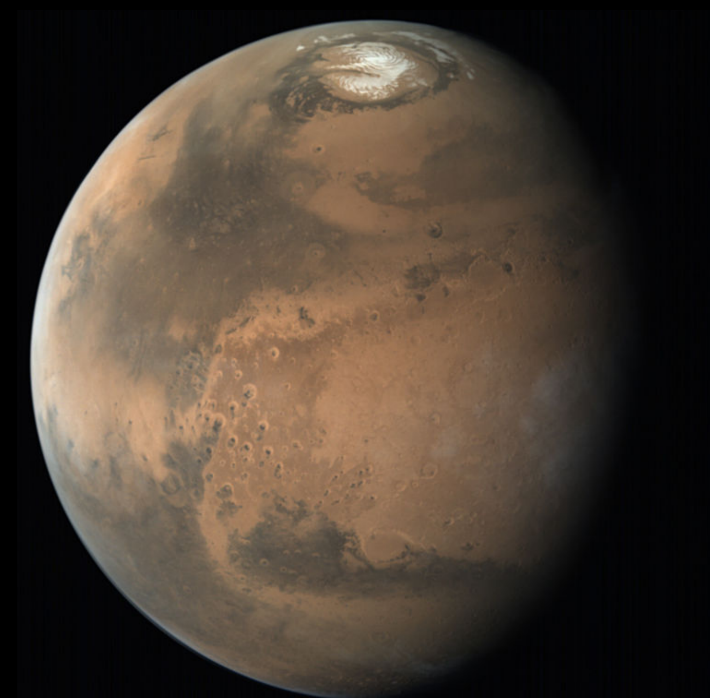
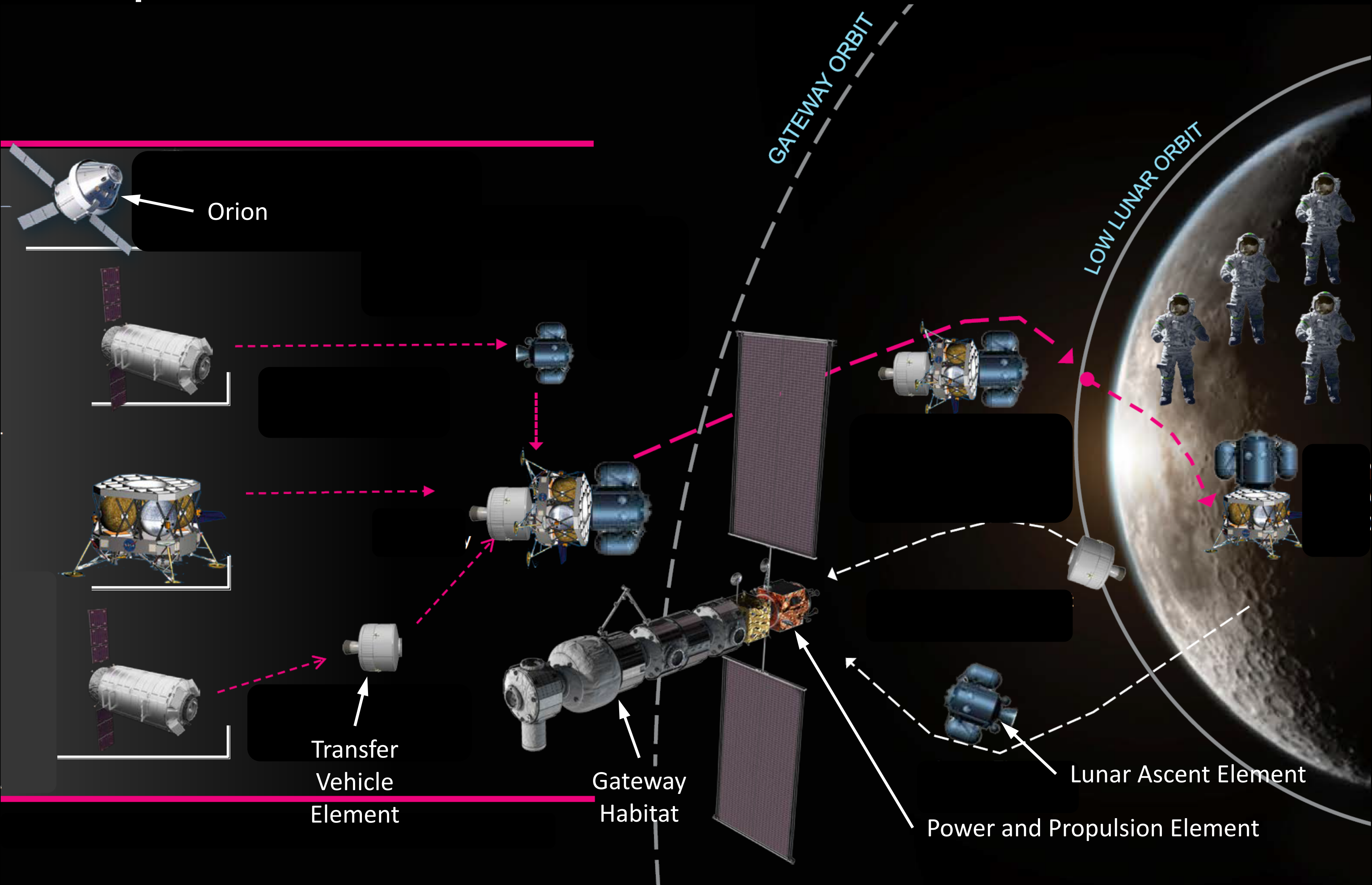


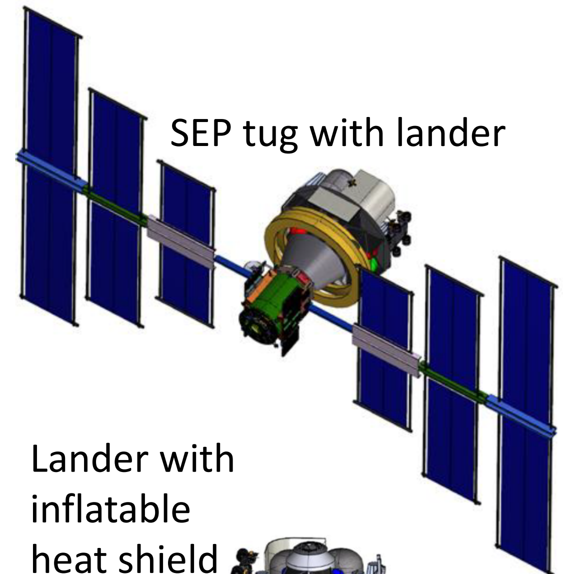
Humans to Mars Summit
Washington, D.C.
May 2019

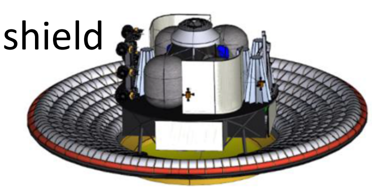
Proposed NASA Lunar Architecture Elements

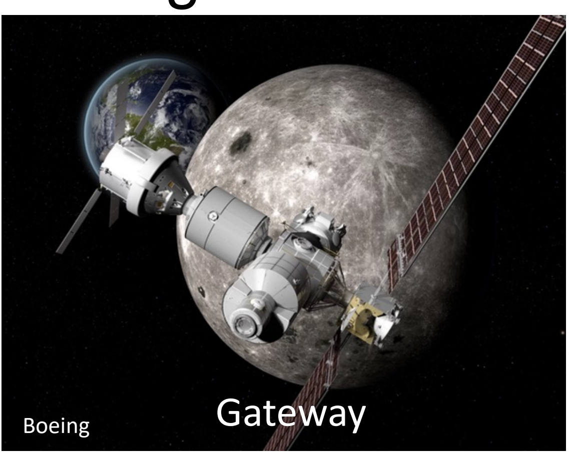


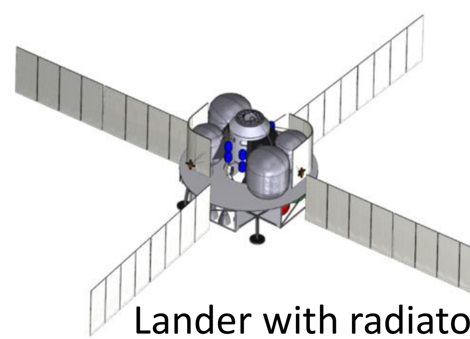
NASA Mars Architecture Concept

- Lunar orbiting Gateway would be used as an assembly point
- Reusable SEP/chemical Deep Space Transport (DST) would transfer crews between the Gateway and high Mars orbit
- Landers would be separately delivered to high Mars orbit by SEP tugs
- Crews would transfer from DST to lander in high Mars orbit



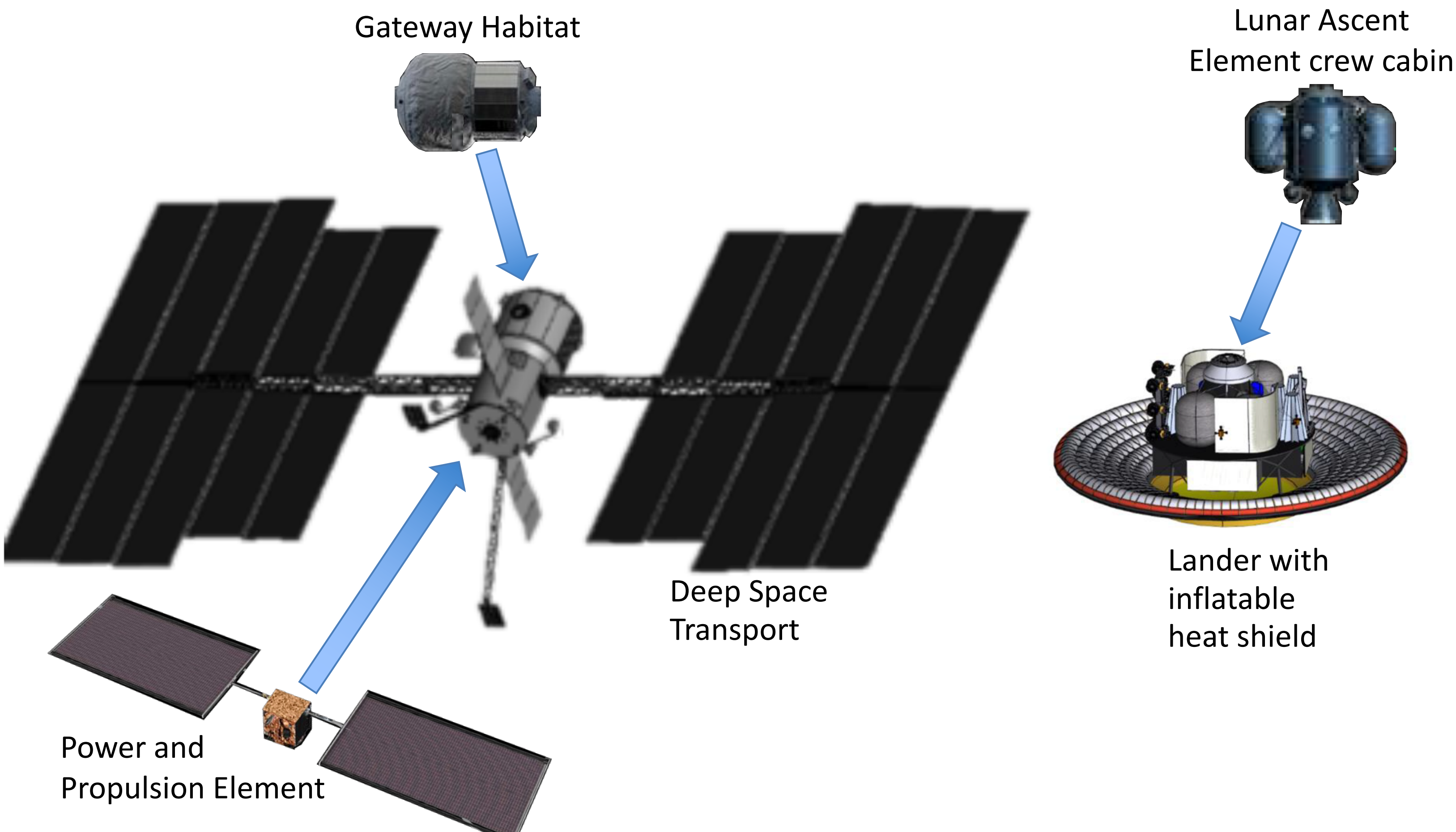






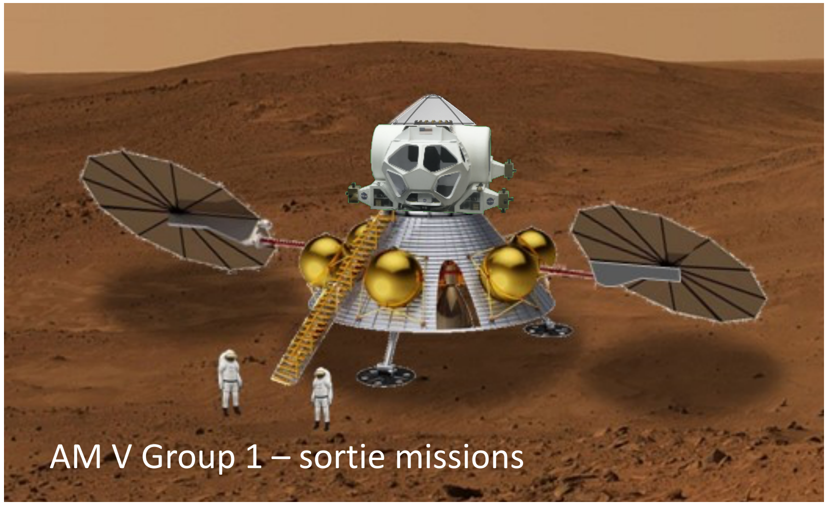
Feed Forward to NASA Mars Architecture Concept

- Lunar mission elements could be prototypes and pathfinders for Mars mission elements in the reference NASA Mars architecture

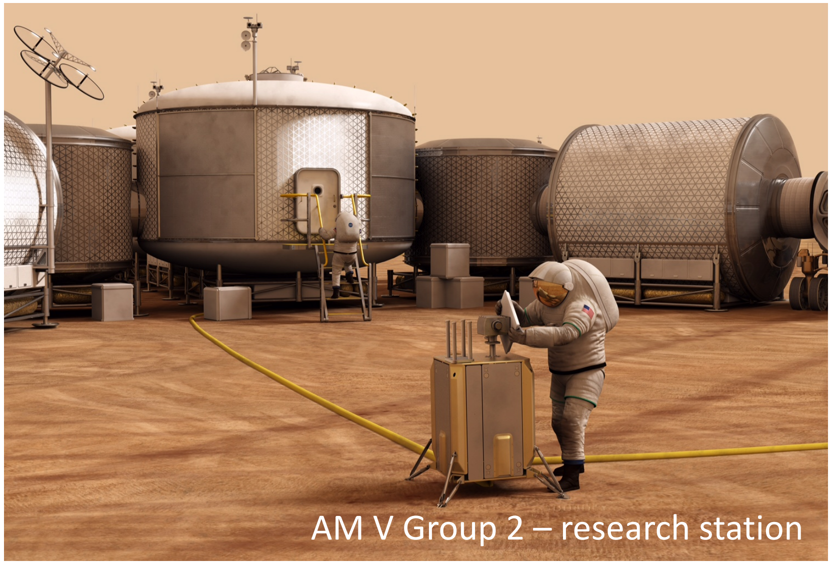


“Achieving Mars” Community Architectures
developed at December 2017 workshop

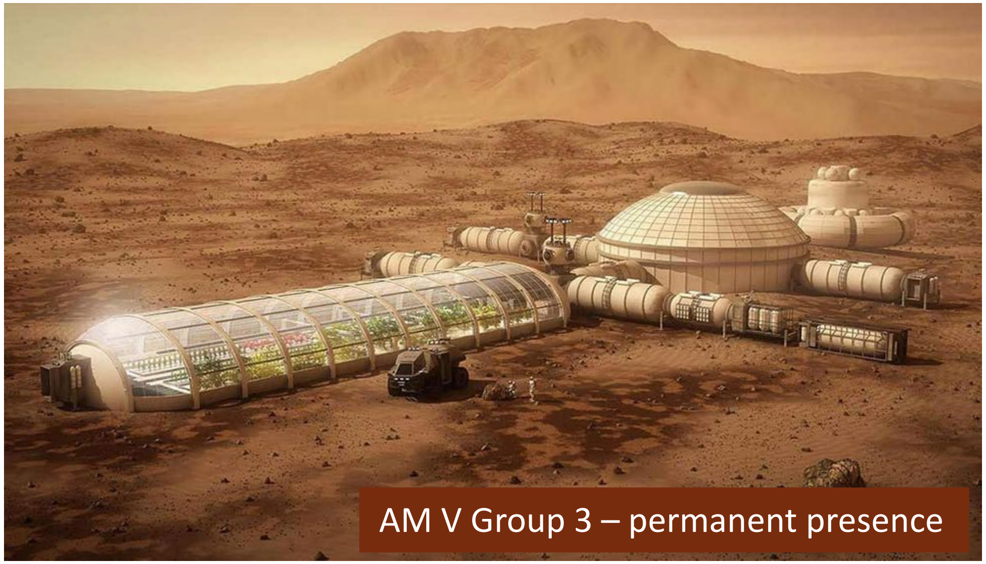
- Group 1 – sortie class missions
  - like Apollo plus, but evolvable
- Group 2 – research station
  - like Antarctic field camp
- Group 3 – permanent presence
  - like the South Pole Station



AM V Group 1 – sortie missions



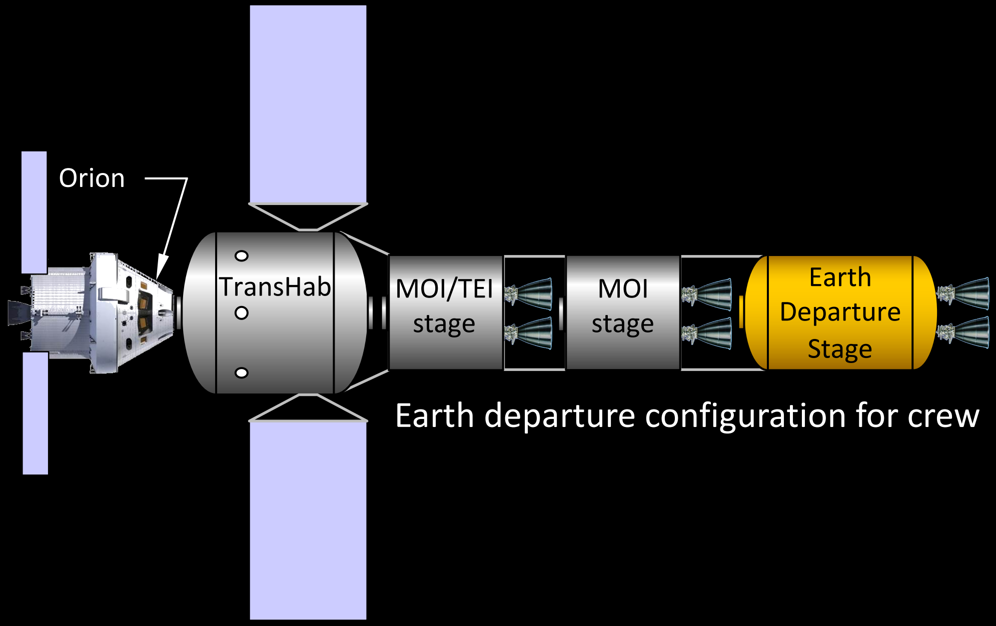
AM V Group 2 – research station



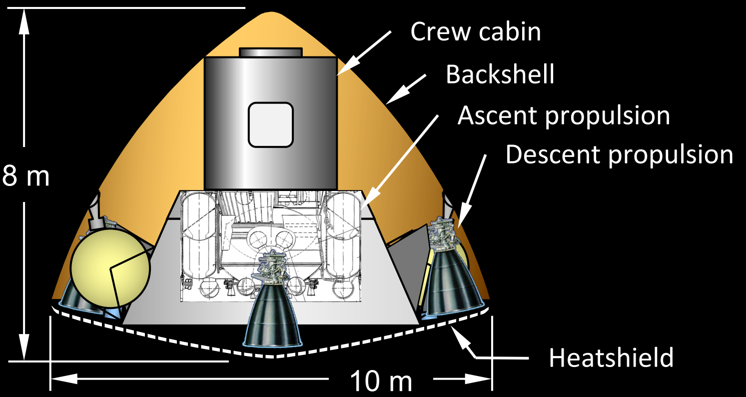
AM V Group 3 – permanent presence

Explore Mars AM V Group 1 Concept

- Would utilize near-term technology systems
- Would minimize the number of new vehicle developments
- Would minimize development and mission risk with less complex systems
- Would be evolvable to reusable systems and ISRU
- Could possibly support a short-stay landing mission in 2033 (~570 day total duration)



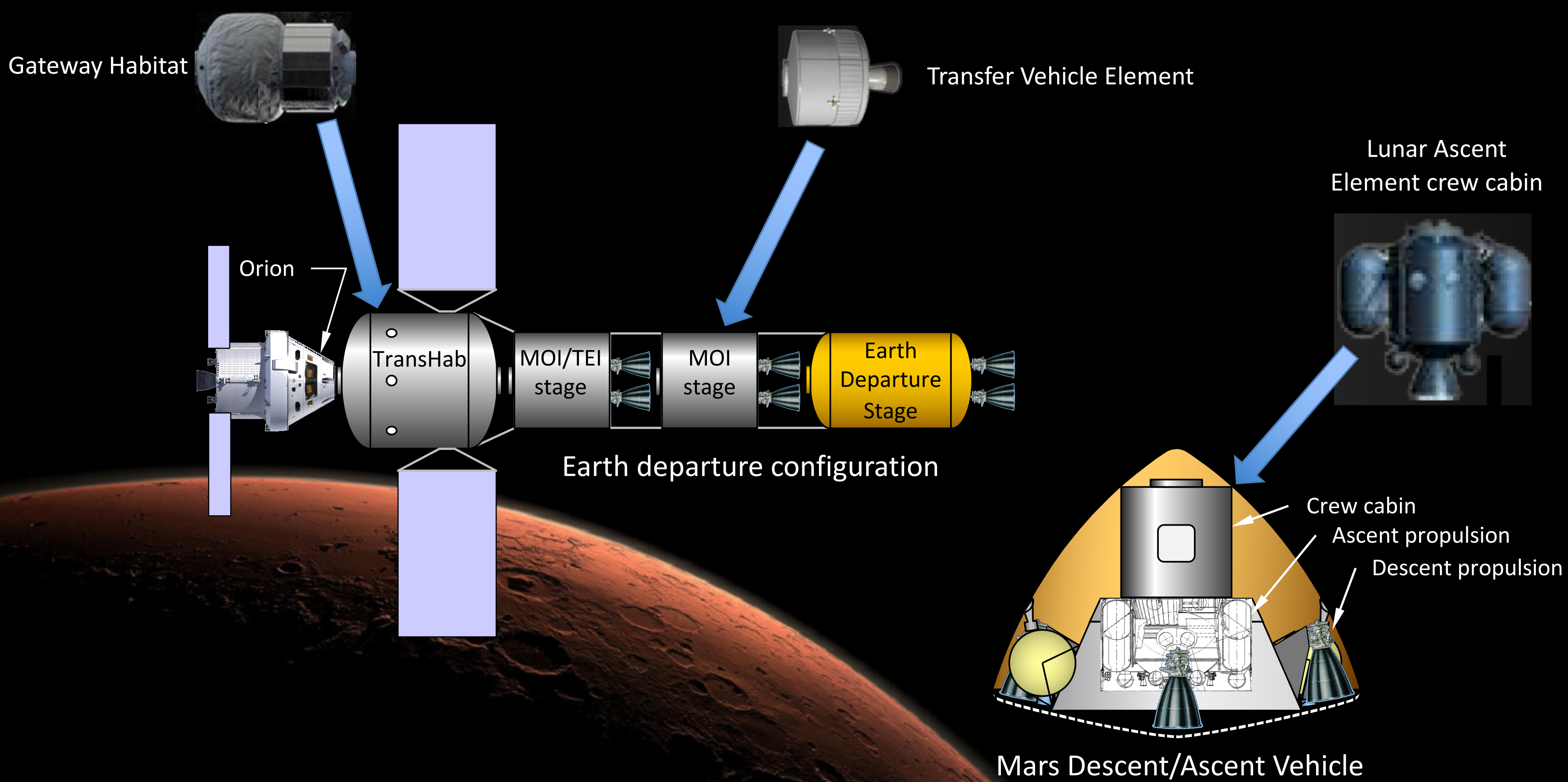
Earth departure configuration for crew



High heritage Descent/Ascent Vehicle

Lunar Feed Forward to AM V Group 1 Architecture

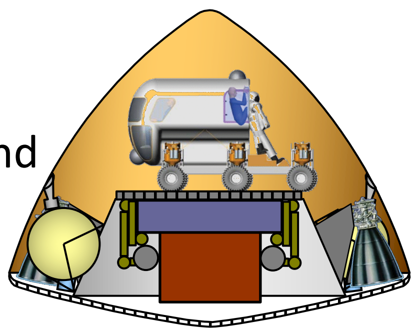
- Lunar mission elements could be prototypes and pathfinders for Mars mission elements in the AM V Group 1 architecture



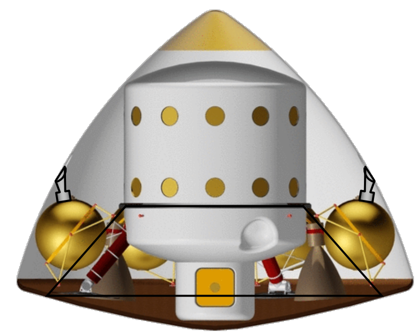
Cargo and Surface Elements Extensibility

- Lunar cargo and surface elements could have extensibility to Mars missions
  - Small Pressurized Rover (SPR)
  - Athlete mobility system
  - Cargo container systems
  - Surface power systems (solar, batteries, Kilopower, Stirling RTGs)
  - Surface habitat

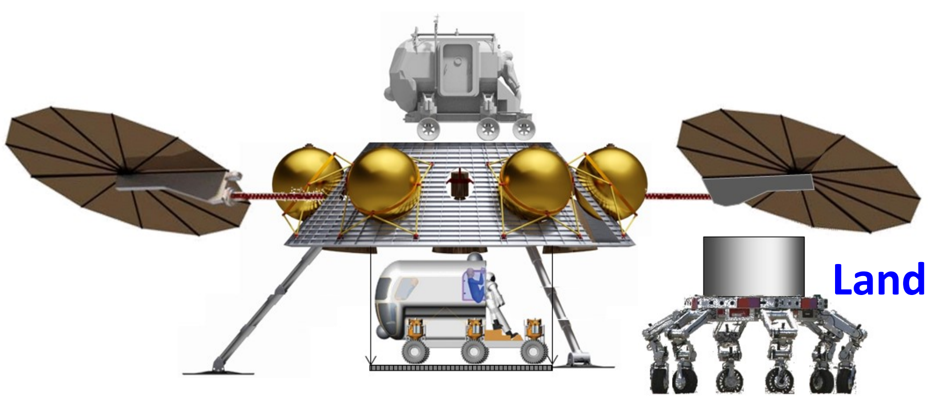
Cargo and logistics



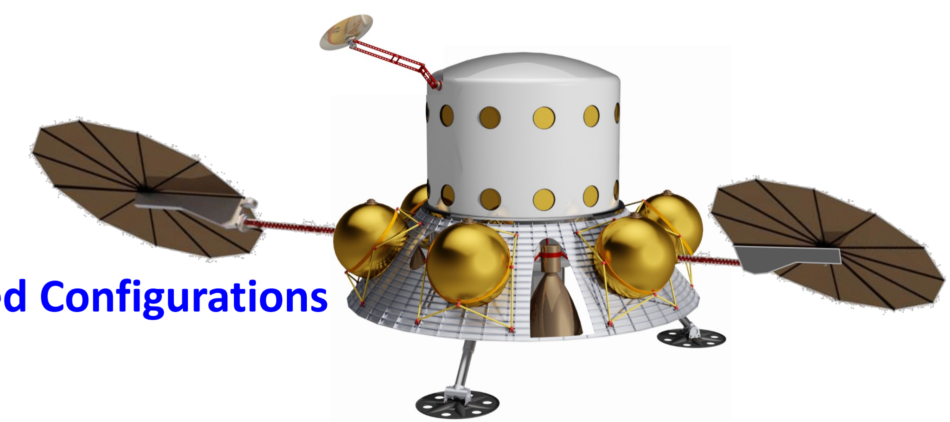
Entry Configurations



Surface habitat

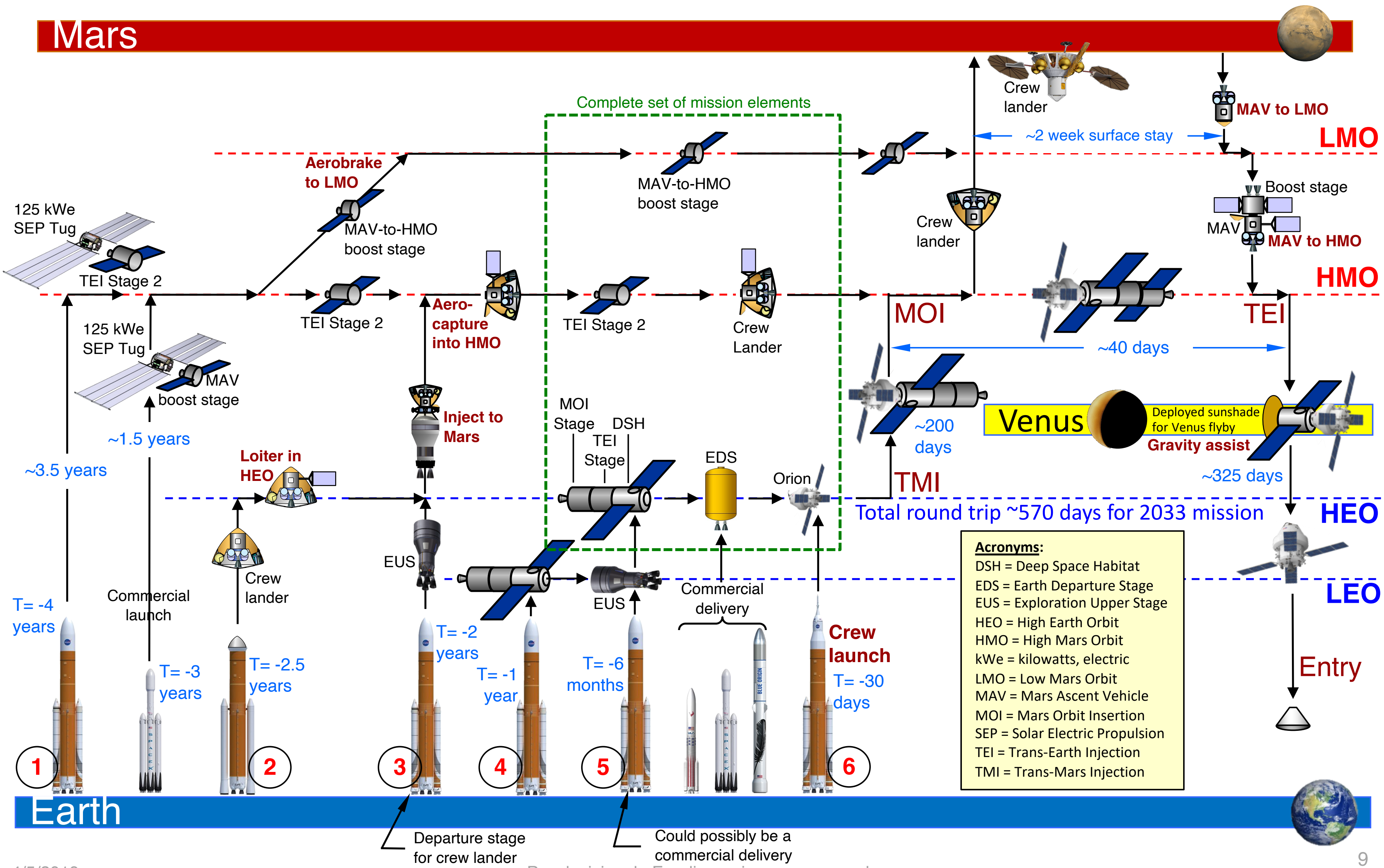


Landed Configurations



2033 Short-Stay Mars Landing Mission Concept

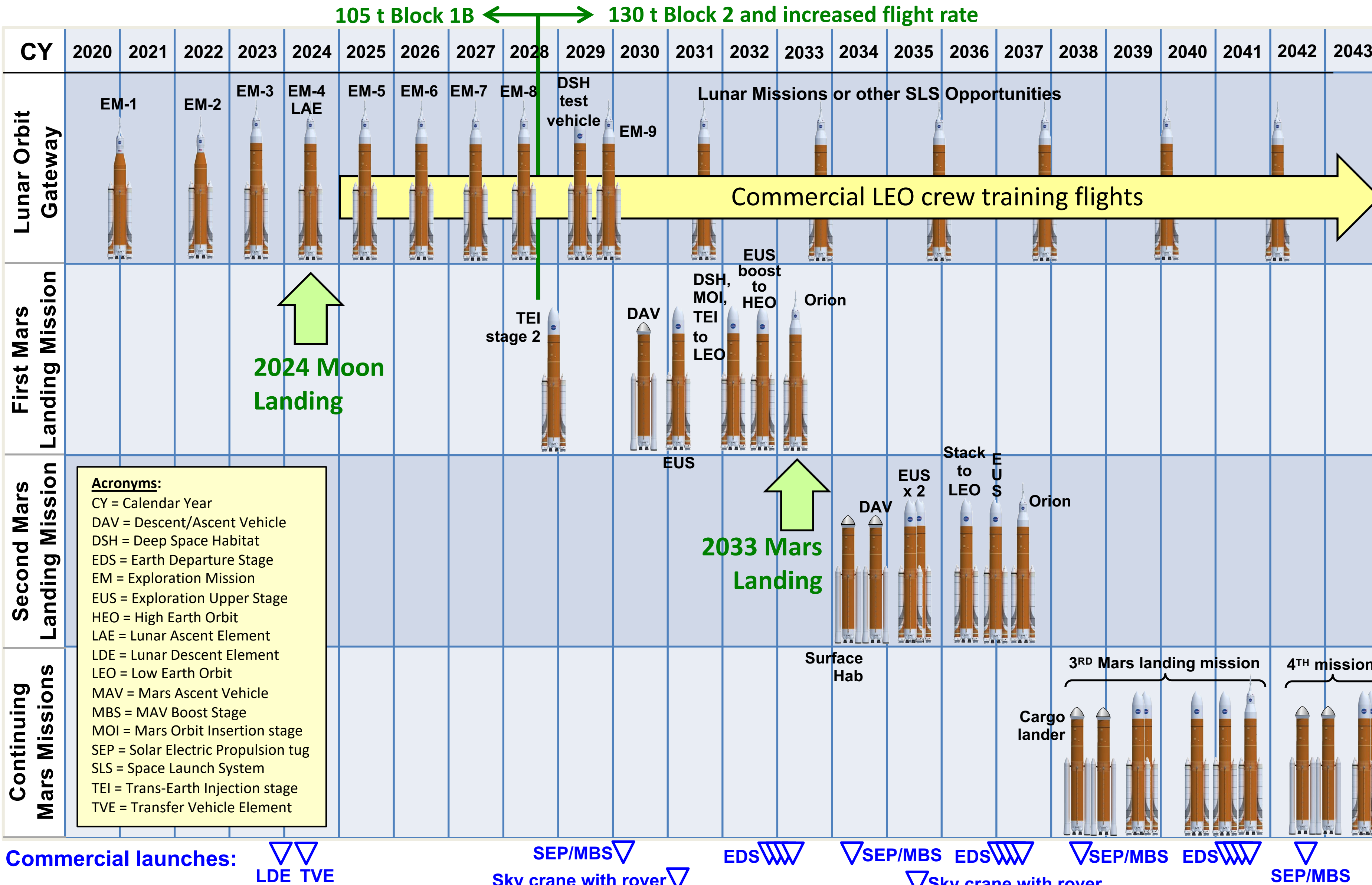
Crew of 4; 570 day round trip



Acronyms:
- DSH = Deep Space Habitat
- EDS = Earth Departure Stage
- EUS = Exploration Upper Stage
- HEO = High Earth Orbit
- HMO = High Mars Orbit
- kWe = kilowatts, electric
- LMO = Low Mars Orbit
- MAV = Mars Ascent Vehicle
- MOI = Mars Orbit Insertion
- SEP = Solar Electric Propulsion
- TEI = Trans-Earth Injection
- TMI = Trans-Mars Injection

Notional SLS Flight Scenario

for 2033 Short Stay Mars Landing and Follow-On Long Stay Landings



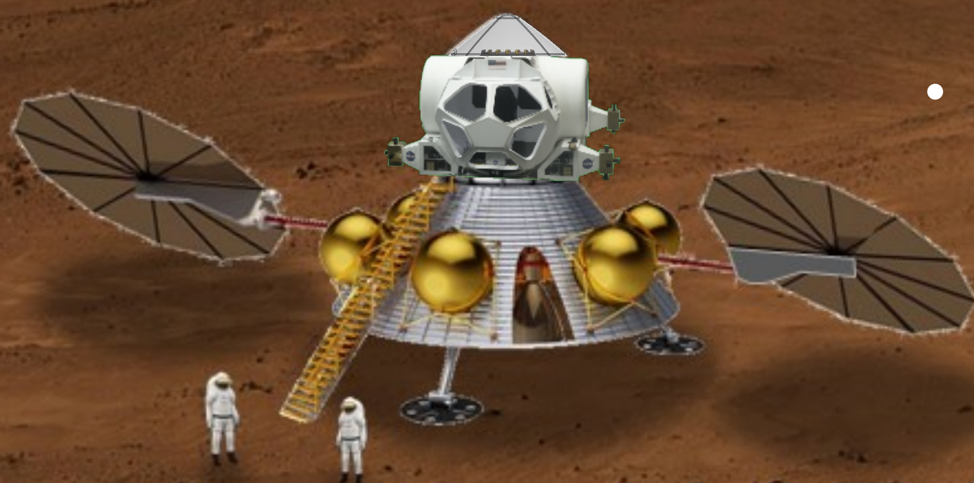
Maximizing Feed Forward to Mars

- Lunar elements could be designed to maximize feed forward to the Mars architecture elements to:
  - Prove out needed technologies, components, and system designs
  - Retire risk for the Mars missions
  - Reduce cost and schedule for developing Mars vehicles
- The initial Mars architecture vehicles could be designed to maximize heritage from the Lunar elements
  - Later missions to Mars would build on the higher heritage initial systems to on-ramp new technologies and capabilities

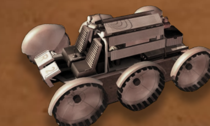
Supplementary Material

Mars Short Surface Stay Mission

First Crew on Mars



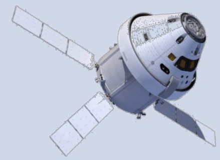
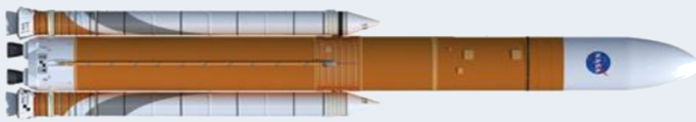
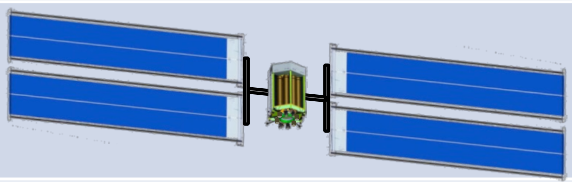
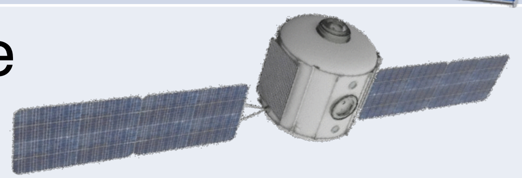
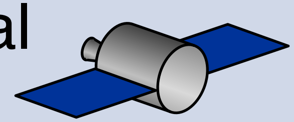
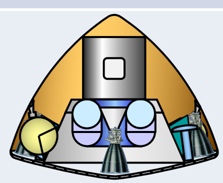
- Would be the pathfinder for a continuing series of longer crewed missions to Mars
- Would include a separate sky crane cargo lander with unpressurized rover and



science equipment that would provide for crew surface transportation and could also be teleoperated from orbit.

- Would be significantly greater in scope than Apollo 17

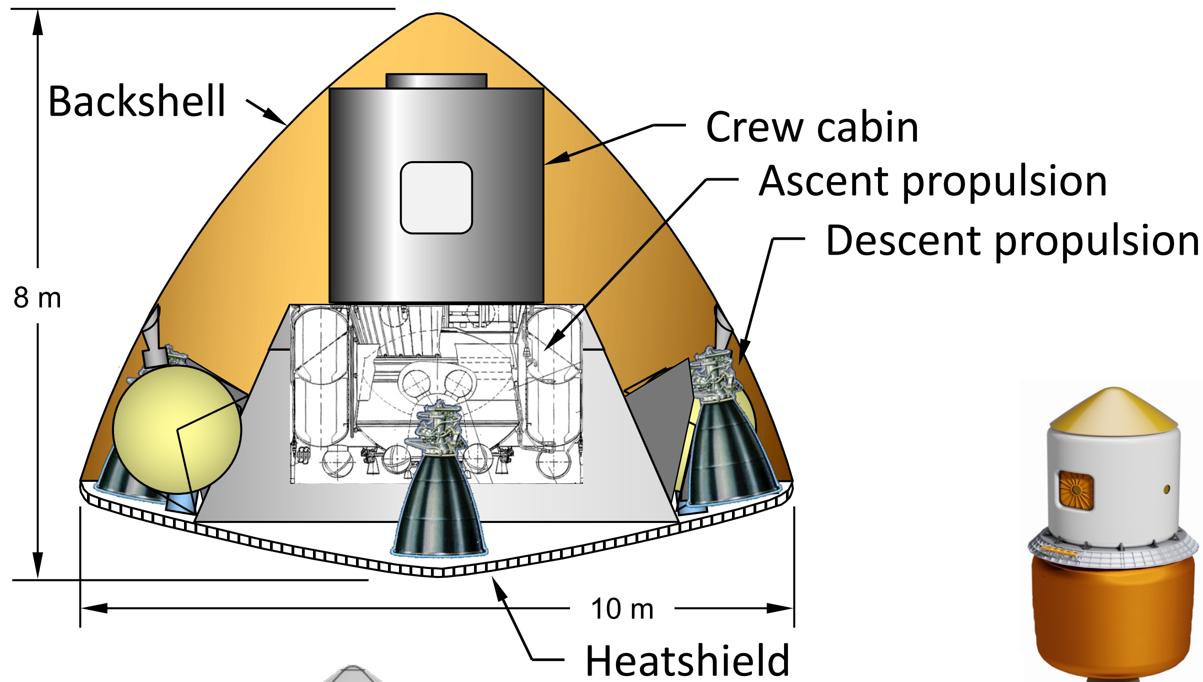
Six Vehicles to Enable Crewed Missions to Mars

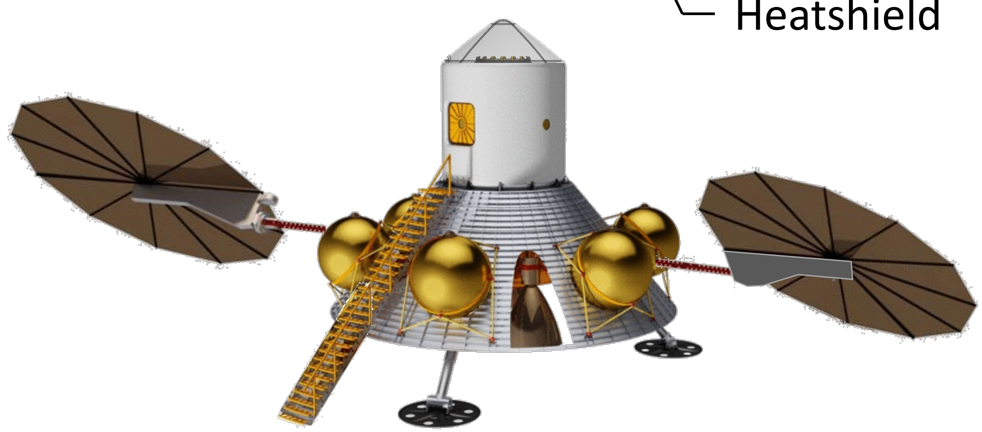
Vehicles	# Vehicles for Mission	
Orion 	1	In development
SLS 	6	In development
SEP Tug ~125 kWe 	2	Would have heritage to Gateway Power and Propulsion Element
Deep Space Habitat 	1	Would have heritage to Gateway Habitat
In-Space Chemical Propulsion Stage 	5	Would have heritage to Lunar Transfer Vehicle Element
Mars Lander 	1	MAV crew cabin would have heritage to Lunar Ascent Element

High Heritage Crew Lander Concept

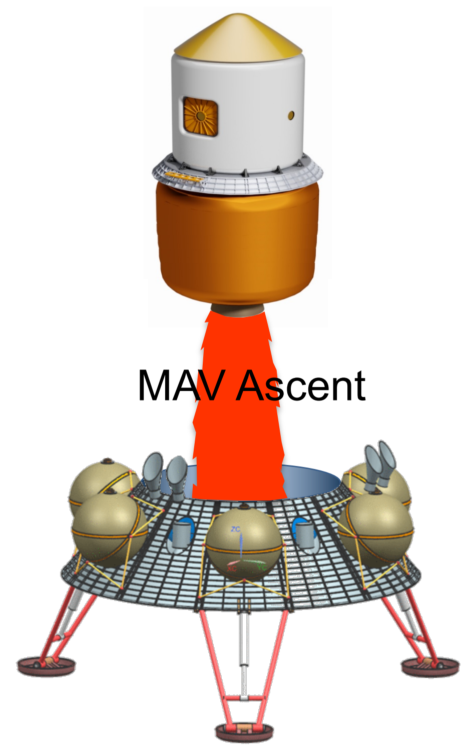
Could support crew of 4 for 2 weeks by itself, or longer with other surface assets

Launch



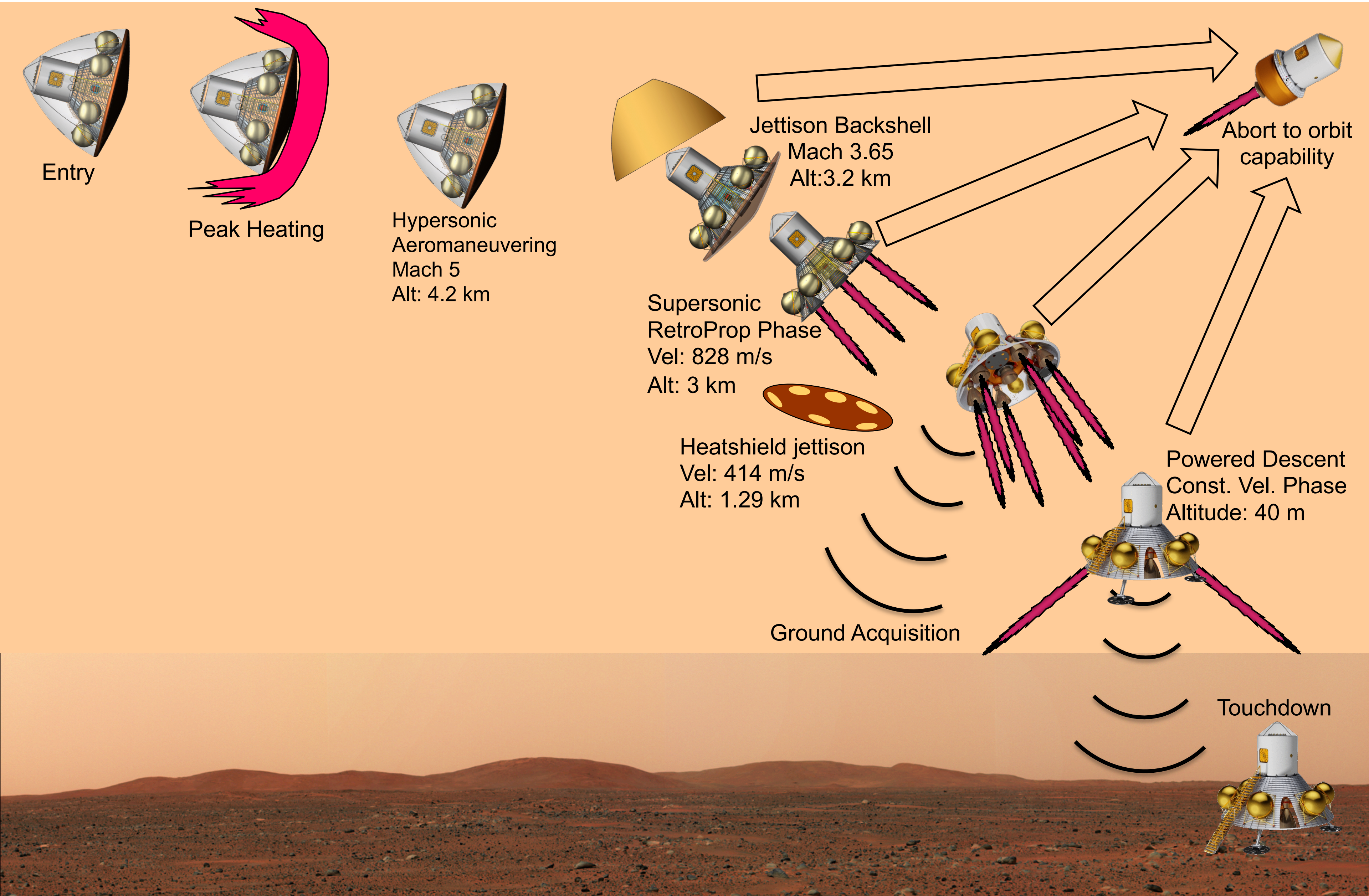


Landed Configuration

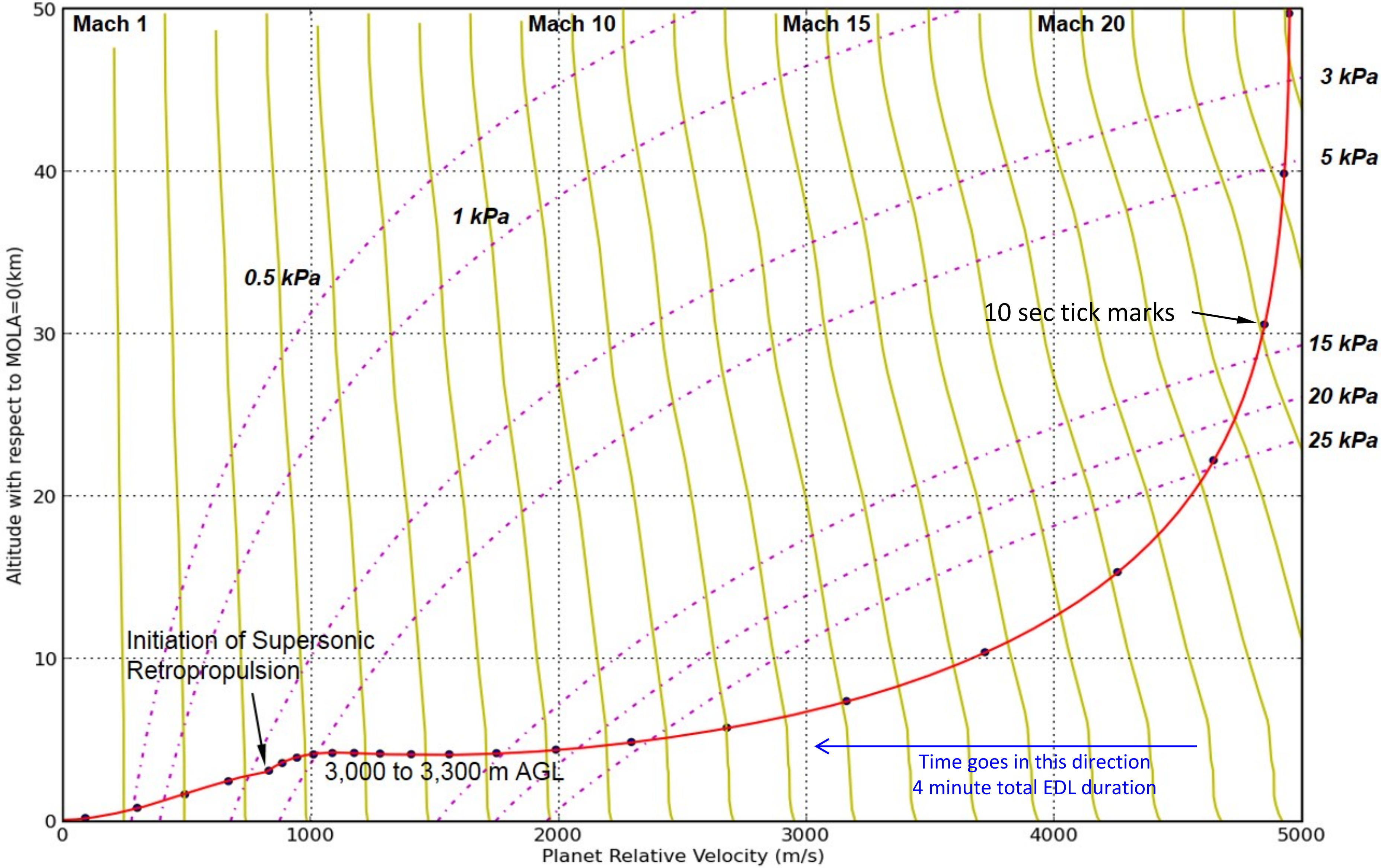


Pre-decisional. For discussion purposes only.

Entry, Descent, and Landing (EDL) Concept for Crewed Mars Lander

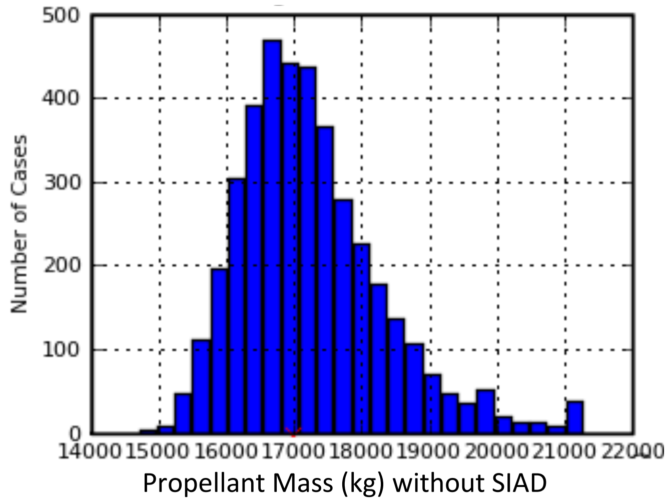


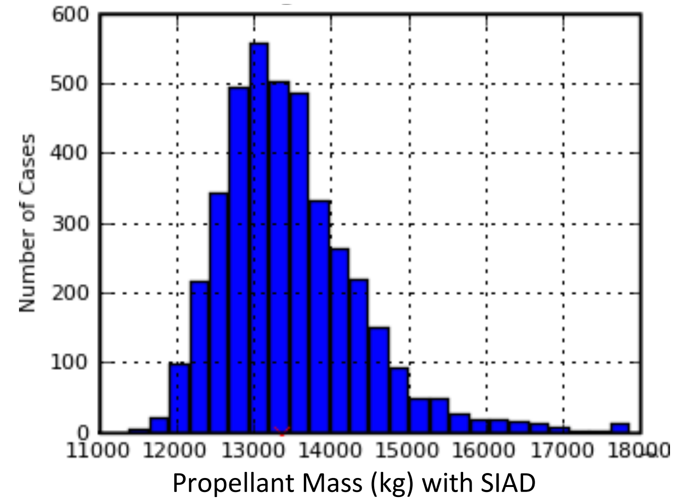
EDL Trajectory for Blunt-Body Lander Concept

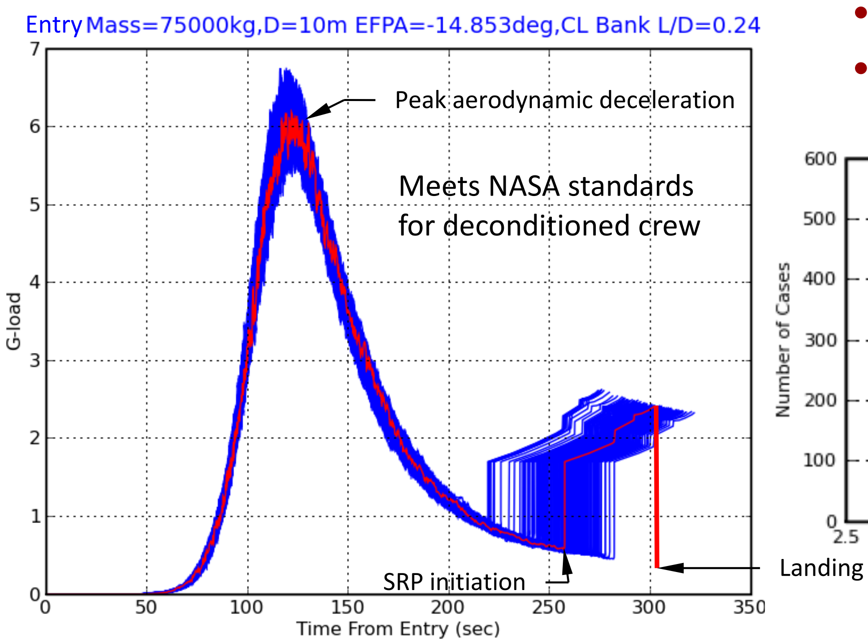


Selected EDL Monte Carlo Results

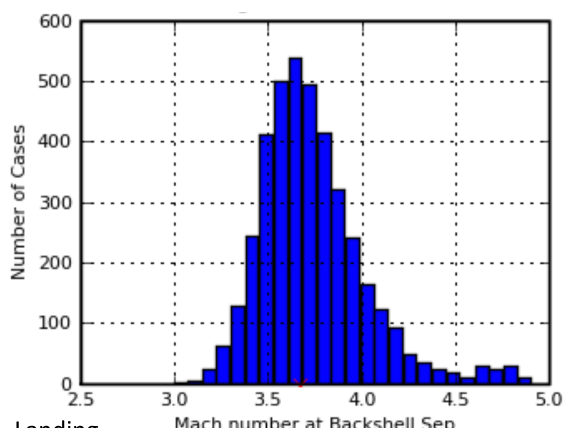
- ~20 t of propellant is used
- Crew experiences ~6.5 g for <30 s
- Backshell separation and SRP is at ~Mach 3.8 and 4 kPa

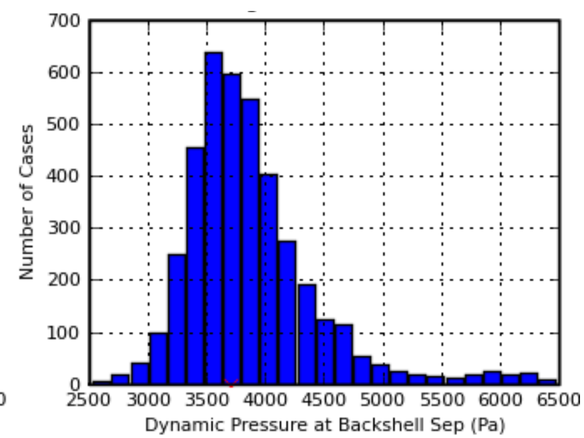




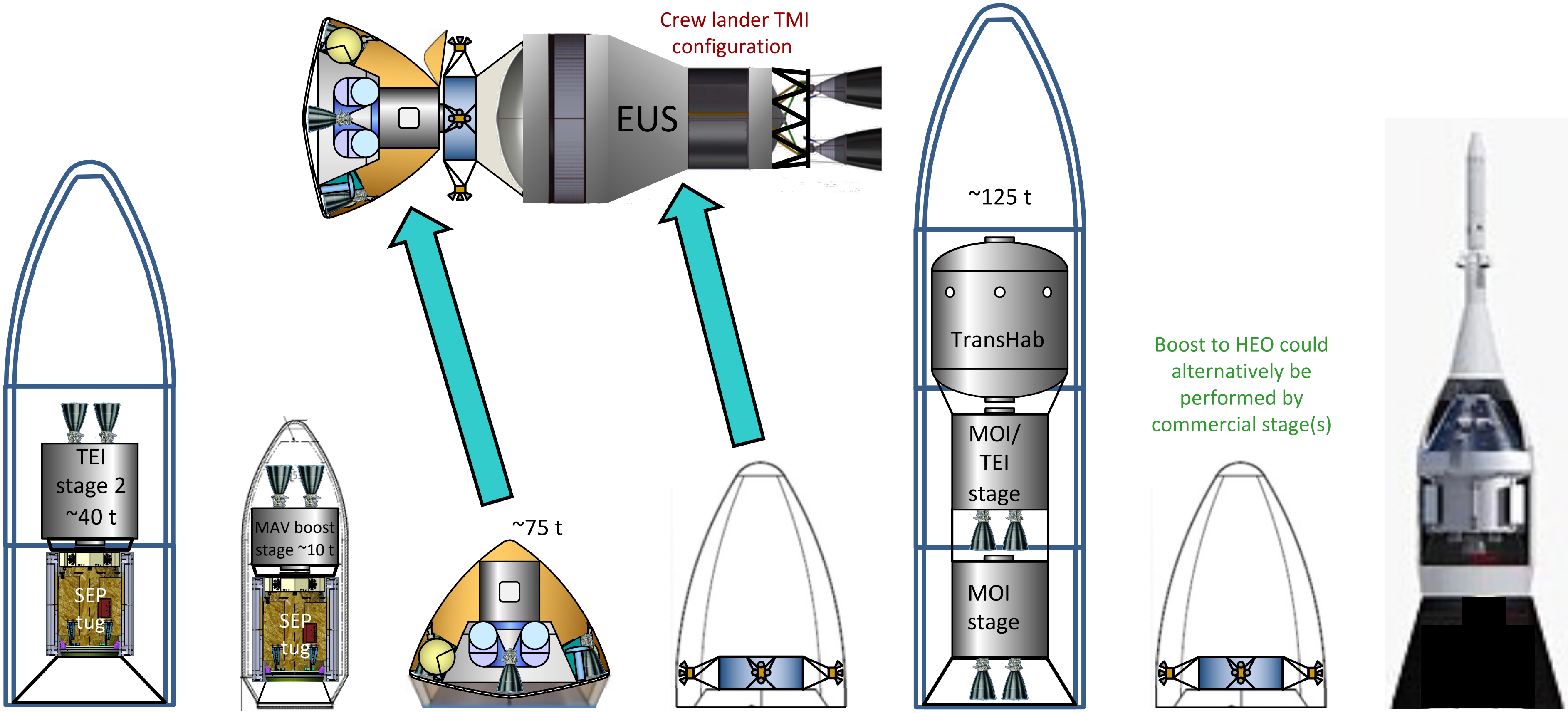


- LDSD derived SIAD could save ~4 t of propellant
- Could be an option for cargo vehicles





SLS Block 2 and Commercial Launch Concepts for Notional 2033 Mission



TEI stage 2 on 125 kWe SEP tug to C_3 = 0
SLS Launch #1

Commercial launch of 125 kWe SEP tug and MAV boost stage to C_3 = 0

Crew lander to HEO using back-shell as payload fairing
SLS Launch #2

Docking kit for EUS to use as departure stage
SLS Launch #3

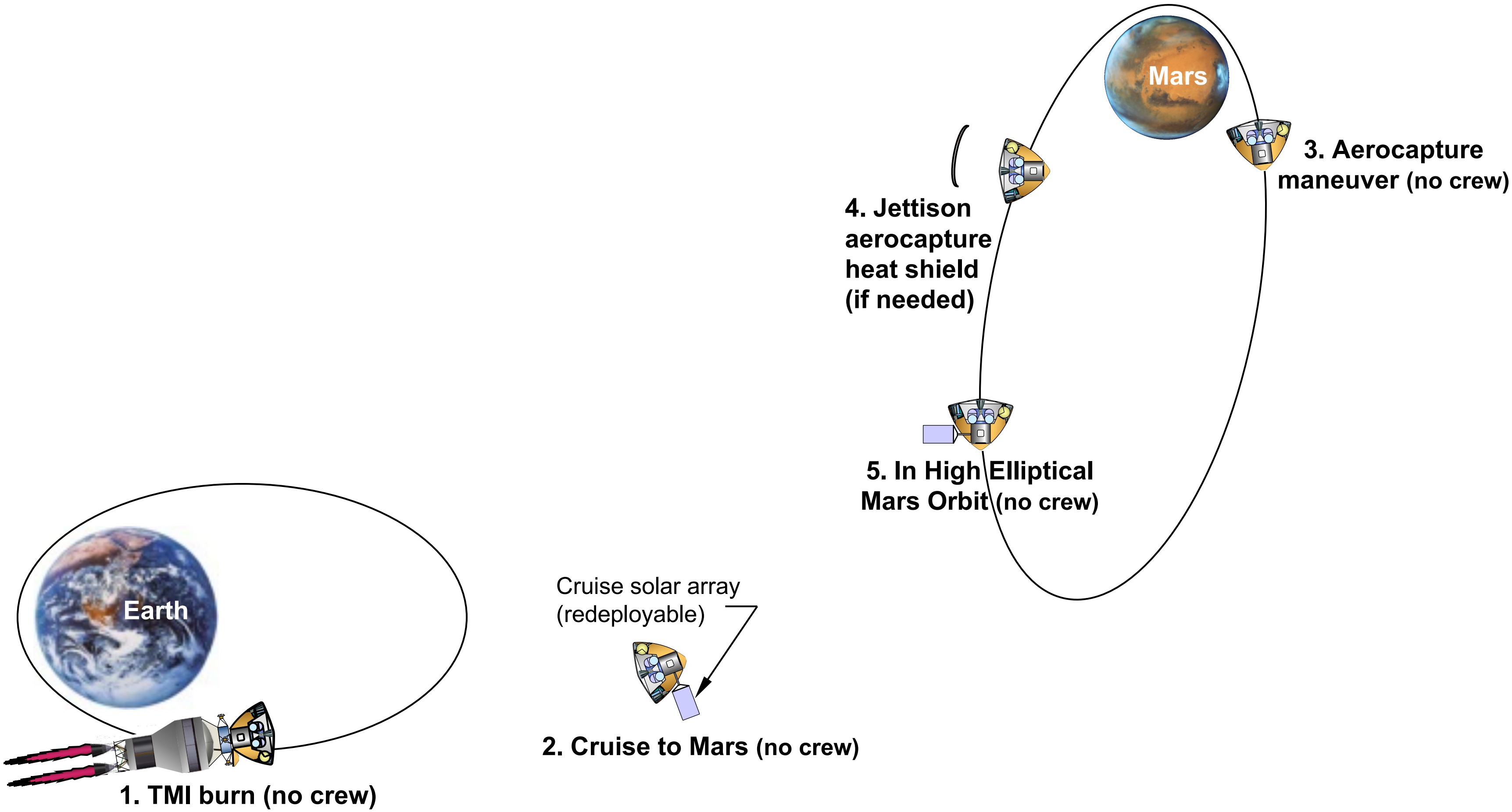
MOI & TEI stages and TransHab launch to LEO
SLS Launch #4

Docking kit for EUS to use for TransHab boost to HEO
SLS Launch #5

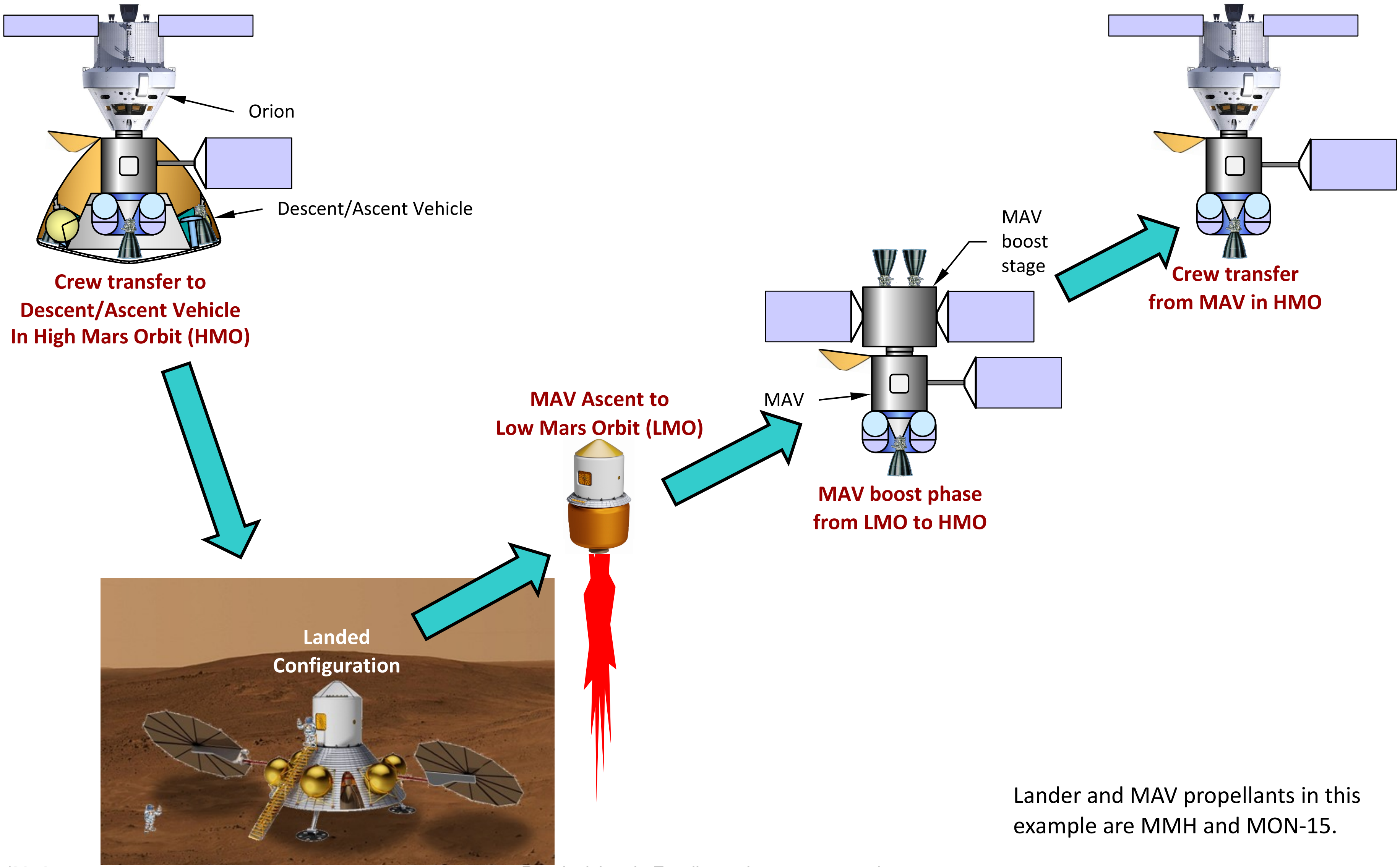
Orion with crew for docking with stack
SLS Launch #6

Launches #3 and #6 have limited launch periods. The other launches have flexible launch dates.

Concept for Descent/Ascent Vehicle (DAV) Transit to High Mars Orbit

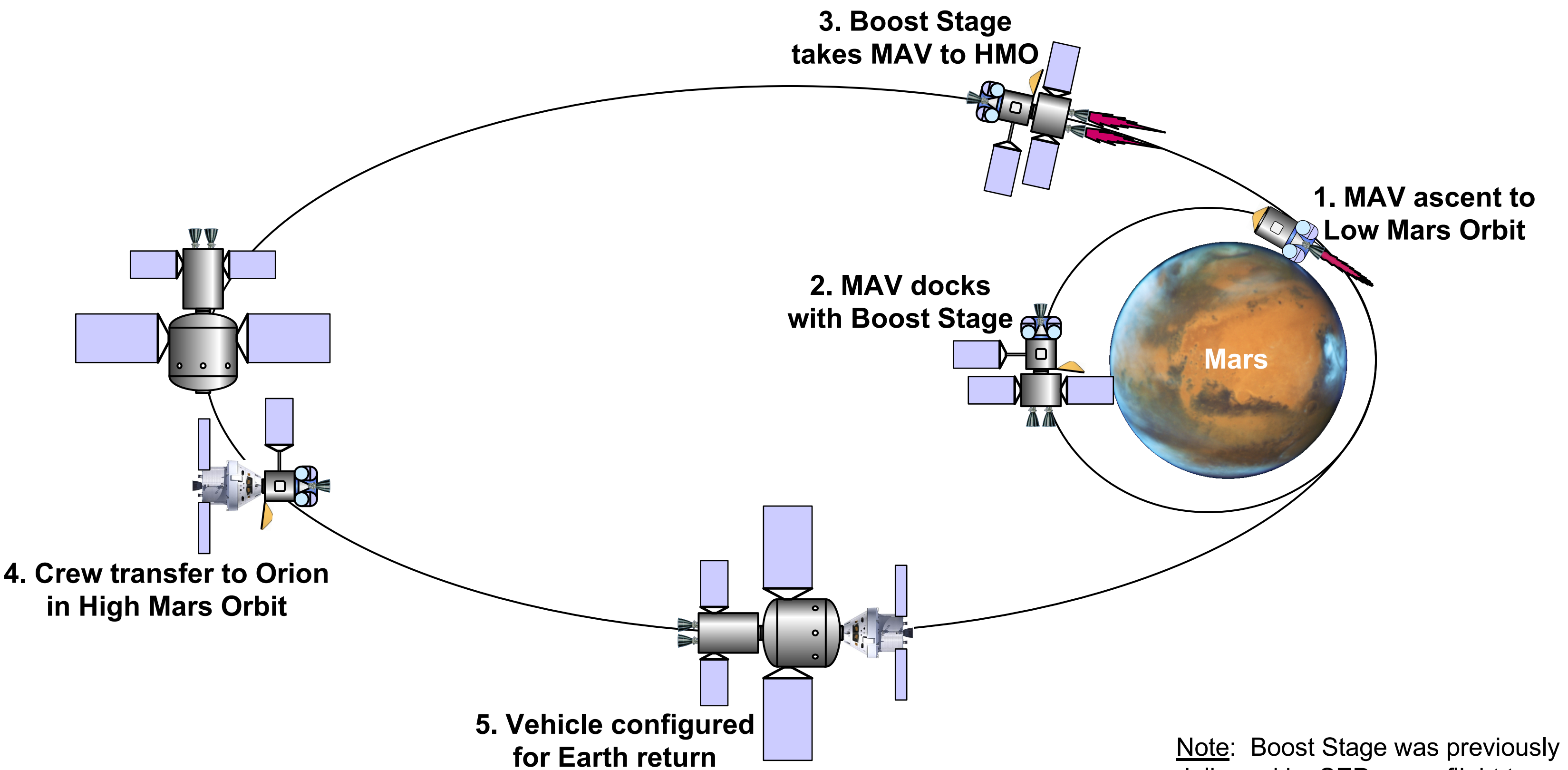


Crewed Mars Descent/Ascent Vehicle Concept



Lander and MAV propellants in this example are MMH and MON-15.

Concept for MAV Ascent, Transfer to Deep Space Hab, and Preparation for Trans-Earth Injection

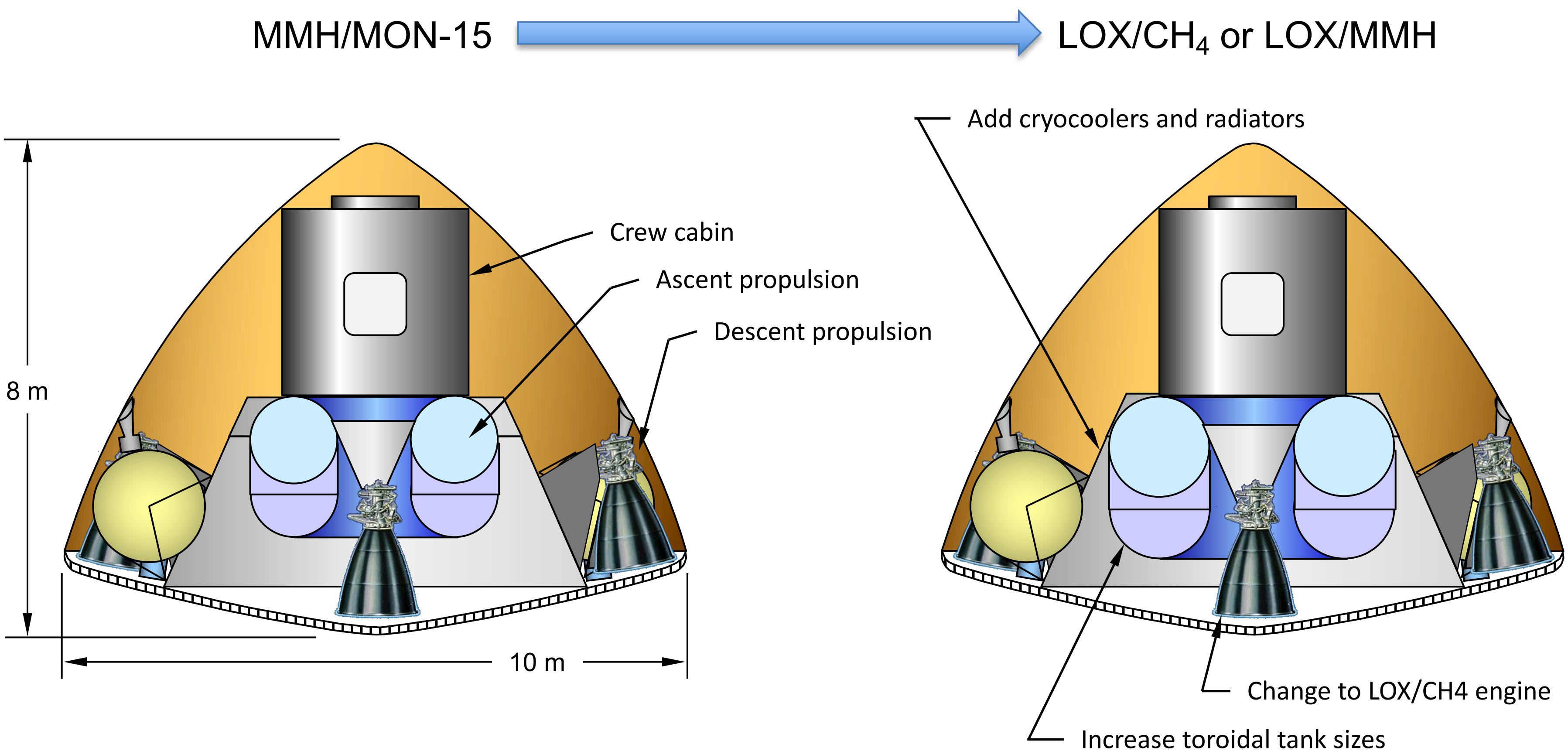


Note: Boost Stage was previously delivered by SEP cargo flight to HMO and aerobraked down to LMO.

Contingency and Abort Capabilities

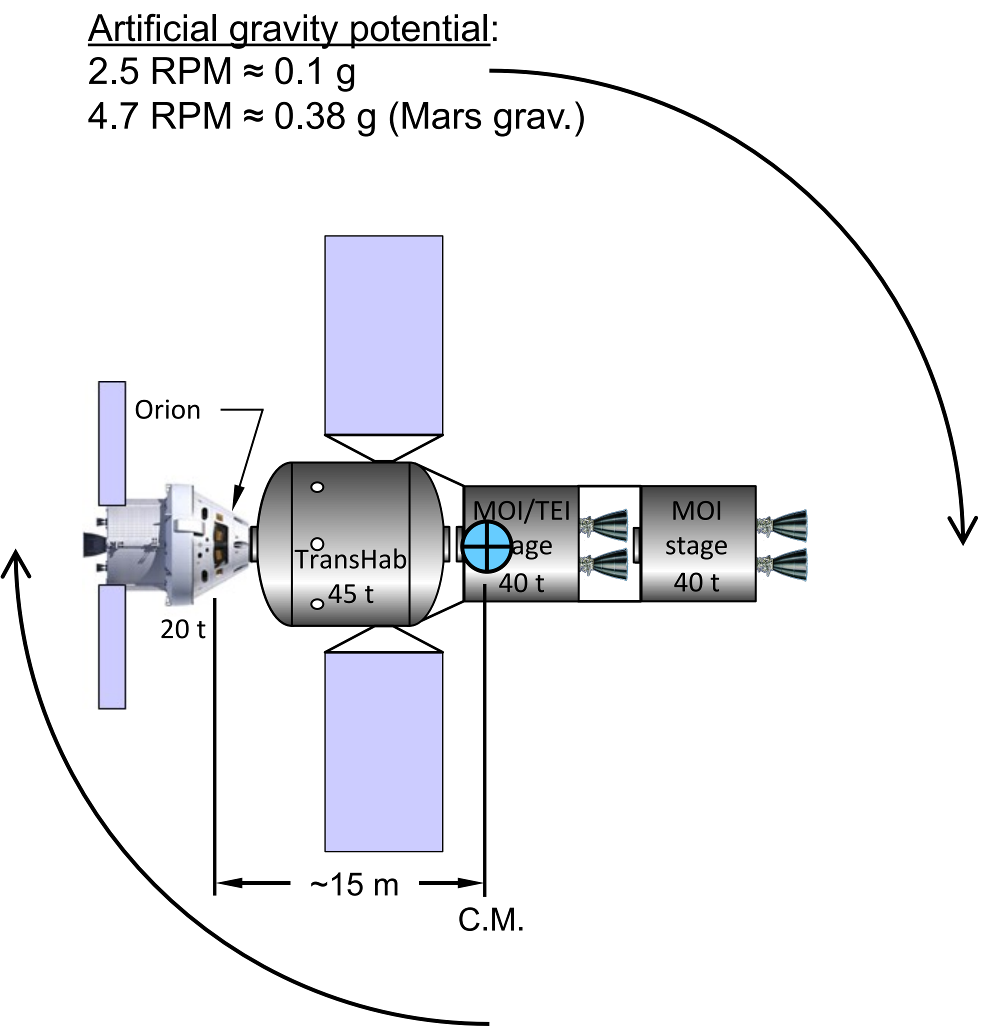
- The crew stack could abort back to Earth for a limited time after TMI, utilizing the MOI and TEI stages
- The crew stack could be on a free return trajectory to abort back to Earth if MOI was in jeopardy
- Orion could function as a temporary lifeboat in the event of other vehicle anomalies
- Orion could provide emergency EVA capability
- If MAV boost stage was not functional, then the landing would be cancelled
- Fully-fueled MAV concept would have abort-to-orbit capability during EDL and after landing
- If one of the two TEI stages was not usable, then the crew could wait an extra year in Mars orbit and return with just one stage on a long-stay mission. DSH would carry consumables to cover that contingency.

Going ISRU: Concept for Converting MAV from MMH/MON-15 to LOX/CH4



Note: Keep descent propulsion the same – MMH/MON-15

Potential Artificial Gravity Experiments During Transit to Mars



- A spin rate of 2.5 to 5 RPM could create a significant Artificial Gravity (AG) environment in Orion
- Boeing tests have suggested that most people could adapt to 5 rpm
- Orion could be reconfigured in-flight to move seats and support exercise equipment, food preparation, and other activities in the AG zone
- Vehicle stack would need to have spin axis toward sun and be on Low Gain Antenna communication
  - Would rotate about axis of greatest inertia with solar arrays facing sun
- This would be a capability-driven approach designed to have a minimal impact on vehicle design and cost
  - Would require strengthening of solar arrays if providing AG >~0.1 g