Human Exploration Extensibility from Moon to Mars

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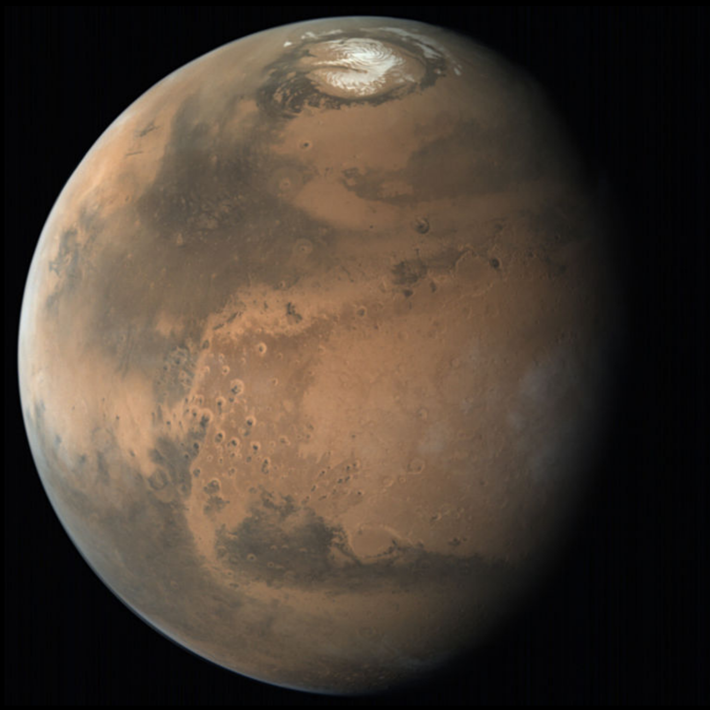
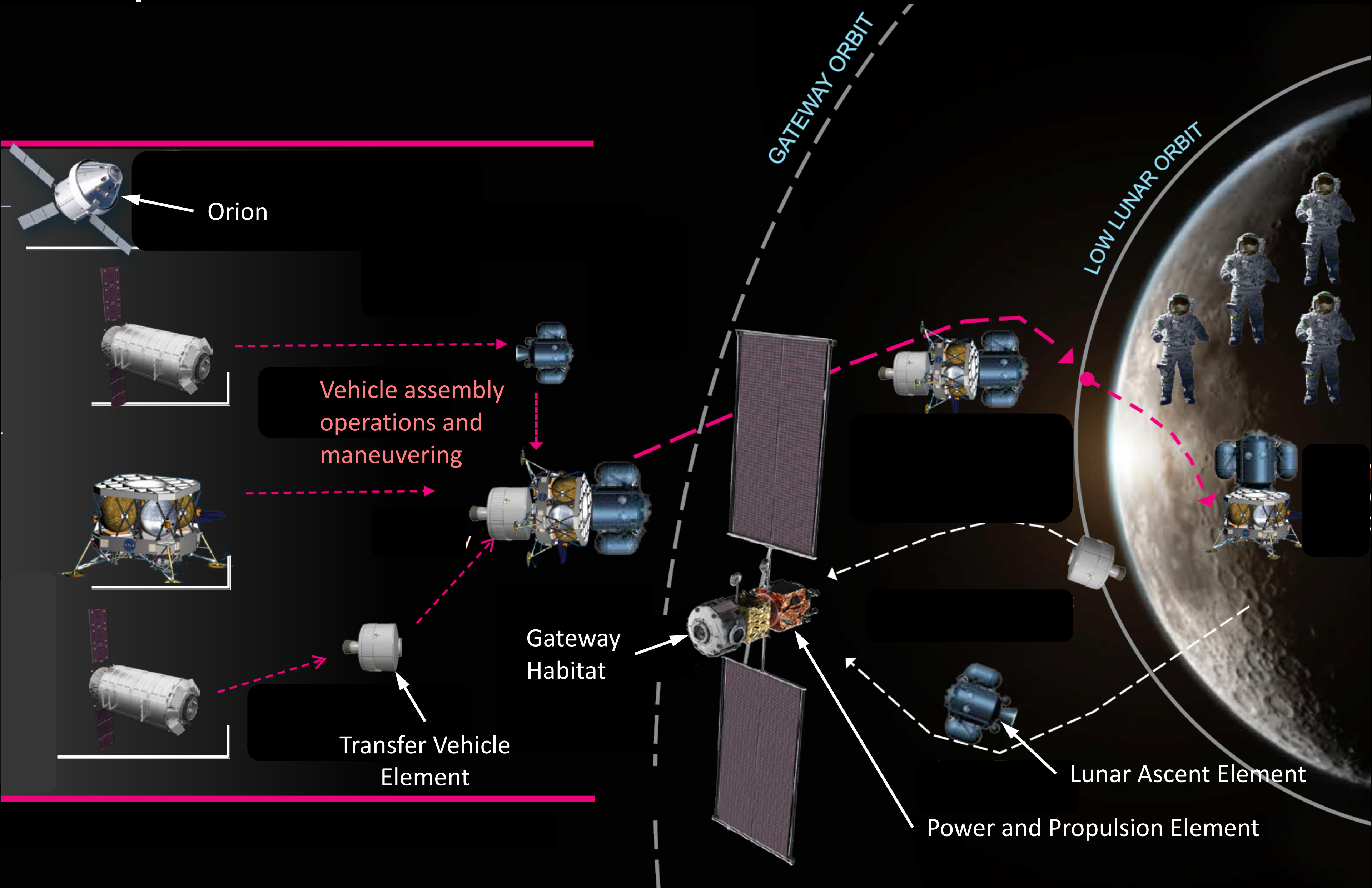


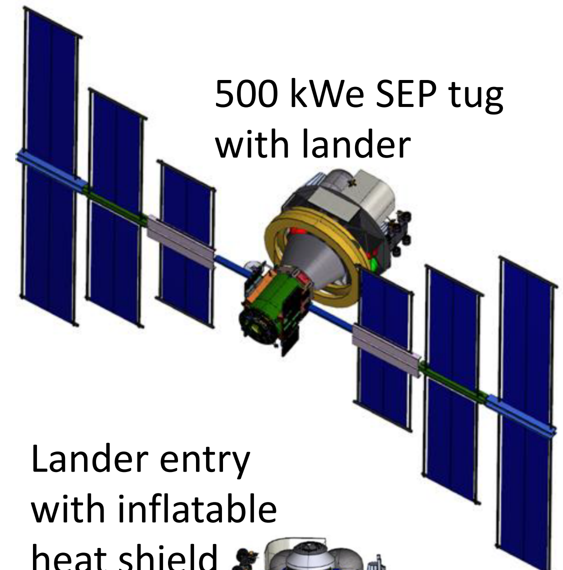
Humans to Mars Summit
Washington, D.C.
May 2019

Proposed NASA Lunar Architecture Elements

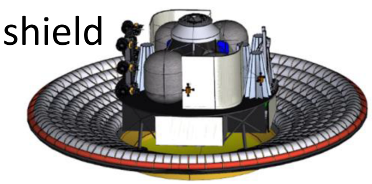


NASA Mars Architecture Concept

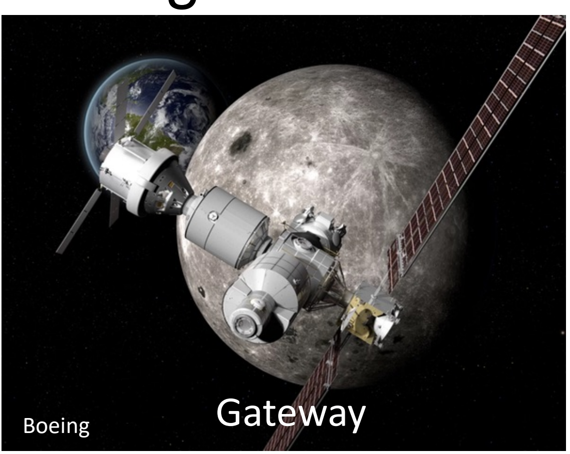
- Lunar orbiting Gateway would be used as an assembly point
- Reusable SEP/chemical Deep Space Transport (DST) would transfer crews between the Gateway and high Mars orbit
- Landers would be separately delivered to high Mars orbit by SEP tugs
- Crews would transfer from DST to lander in high Mars orbit

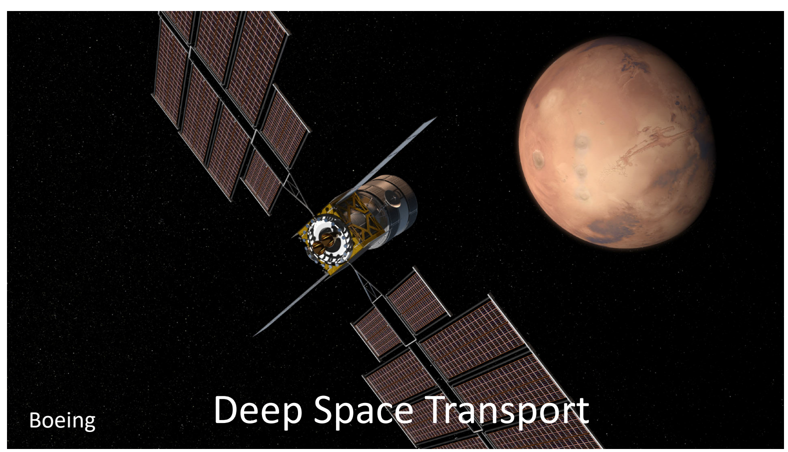


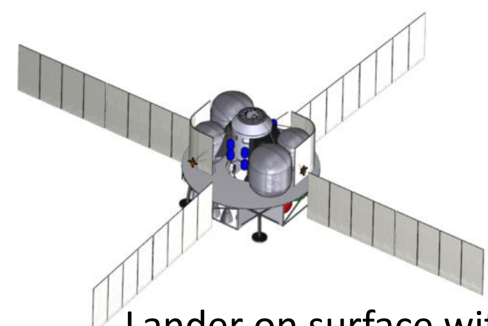
500 kWe SEP tug with lander



Lander entry with inflatable heat shield



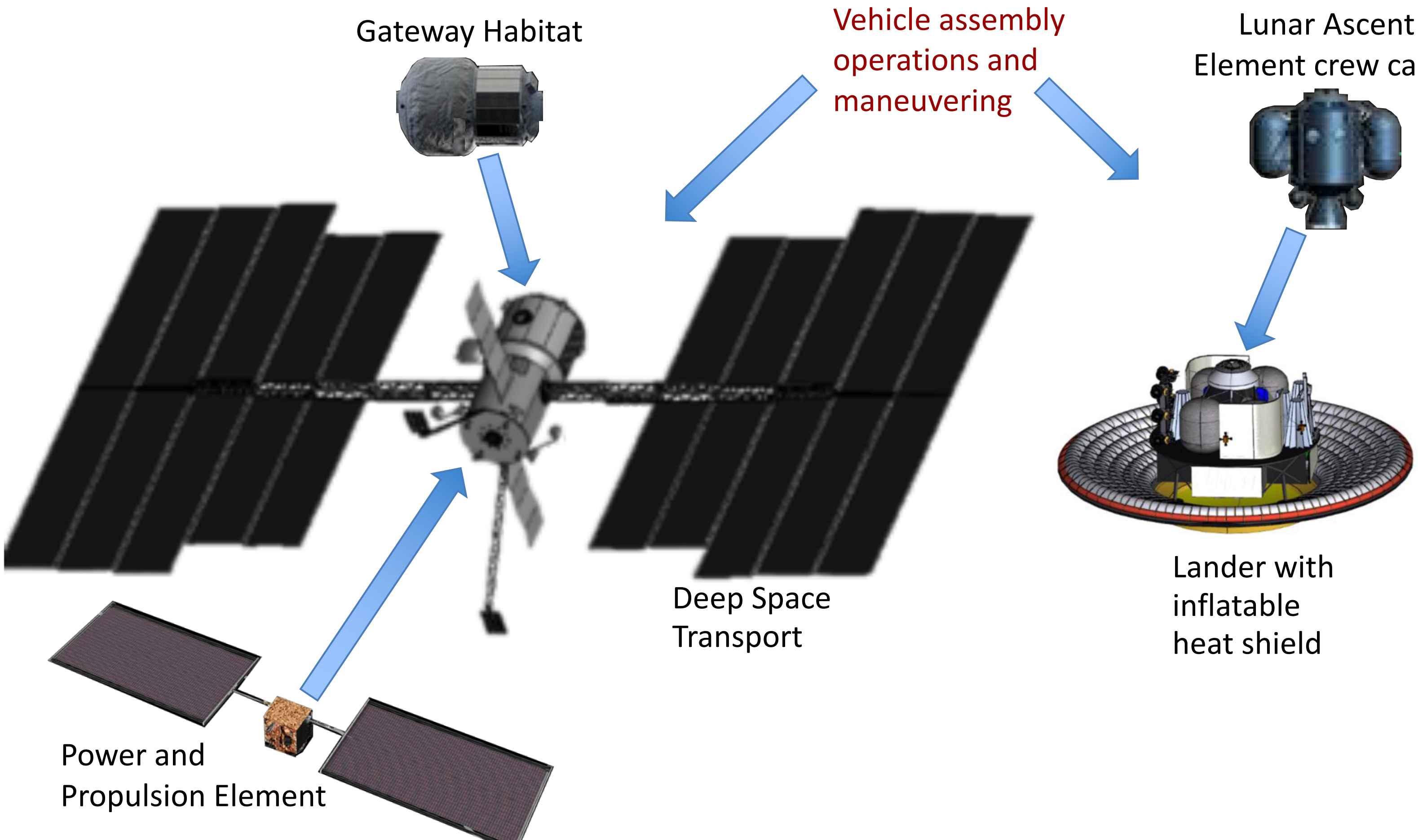




Lander on surface with radiators for cryogenic propellant production

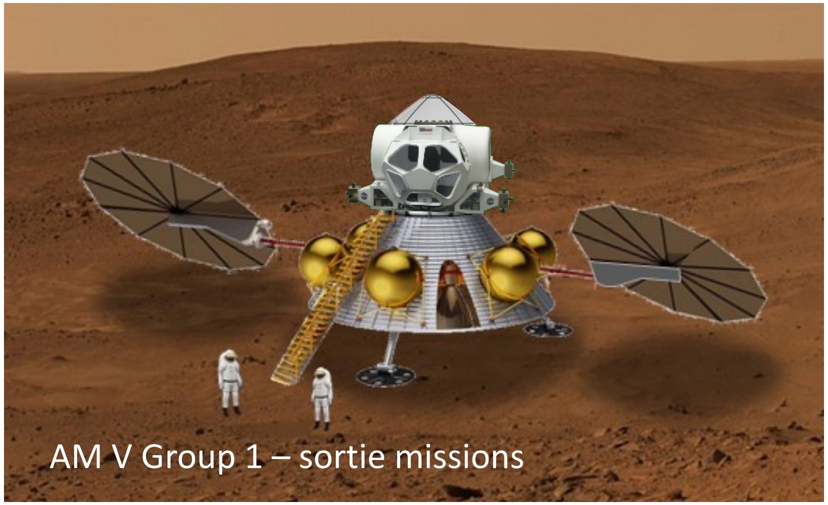
Feed Forward to NASA Mars Architecture Concept

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

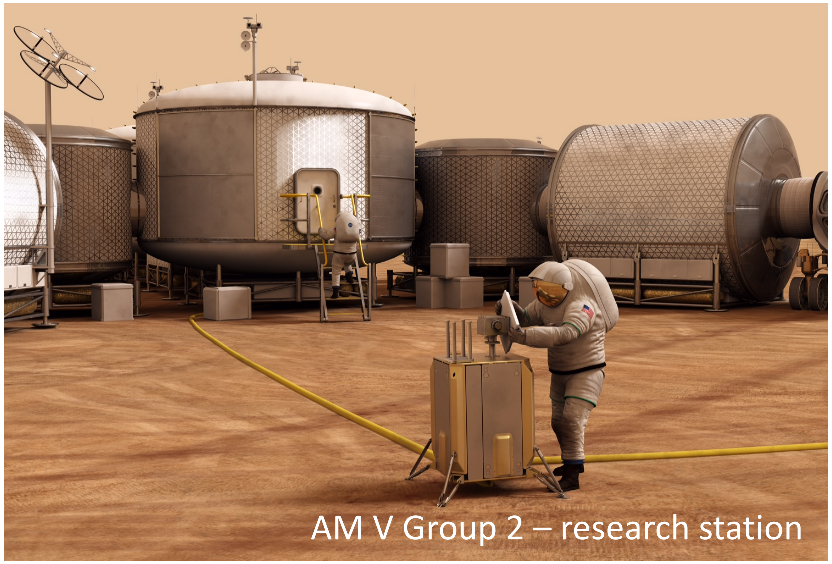


“Achieving Mars” Community Architectures
developed at December 2017 workshop

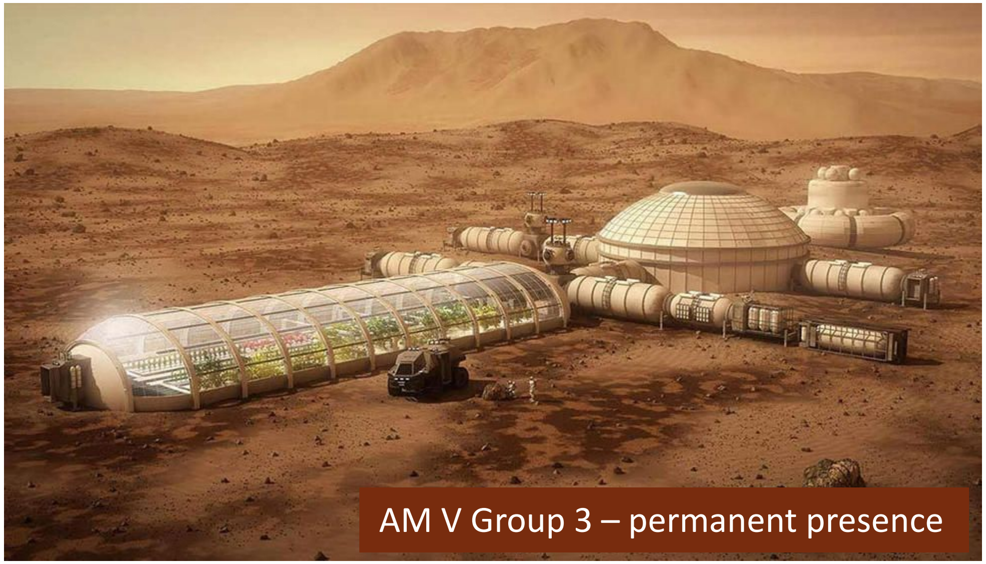
- Group 1 – sortie class missions
  - like Apollo plus, but evolvable
- Group 2 – research station
  - like Antarctic field camp
- Group 3 – permanent presence
  - like the South Pole Station



AM V Group 1 – sortie missions



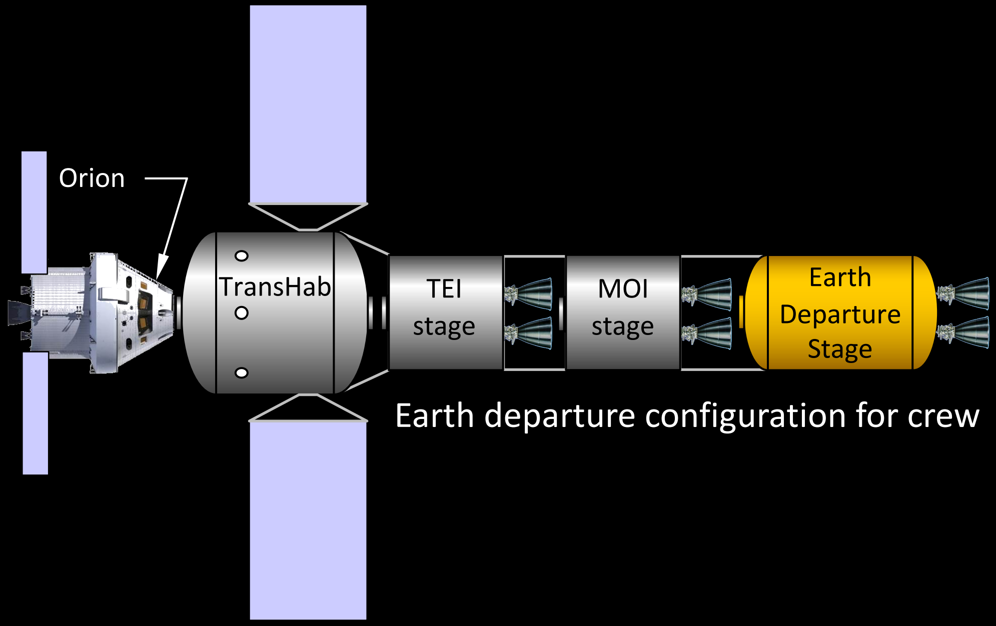
AM V Group 2 – research station



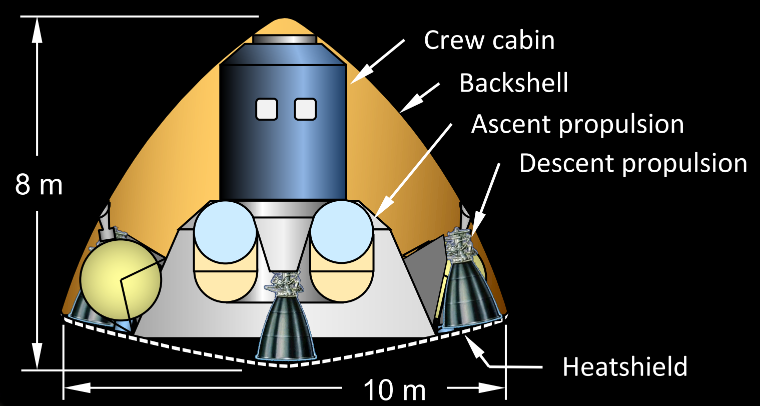
AM V Group 3 – permanent presence

Explore Mars AM V Group 1 Concept

- Would utilize near-term technology systems. Avoids risks cited in the STPI report*:
  - 500 kWe SEP
  - Cryogenic propellants
  - Refueling and reusability
  - ISRU propellant production
- 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 in 2033 (~570 day total mission duration)



Earth departure configuration for crew

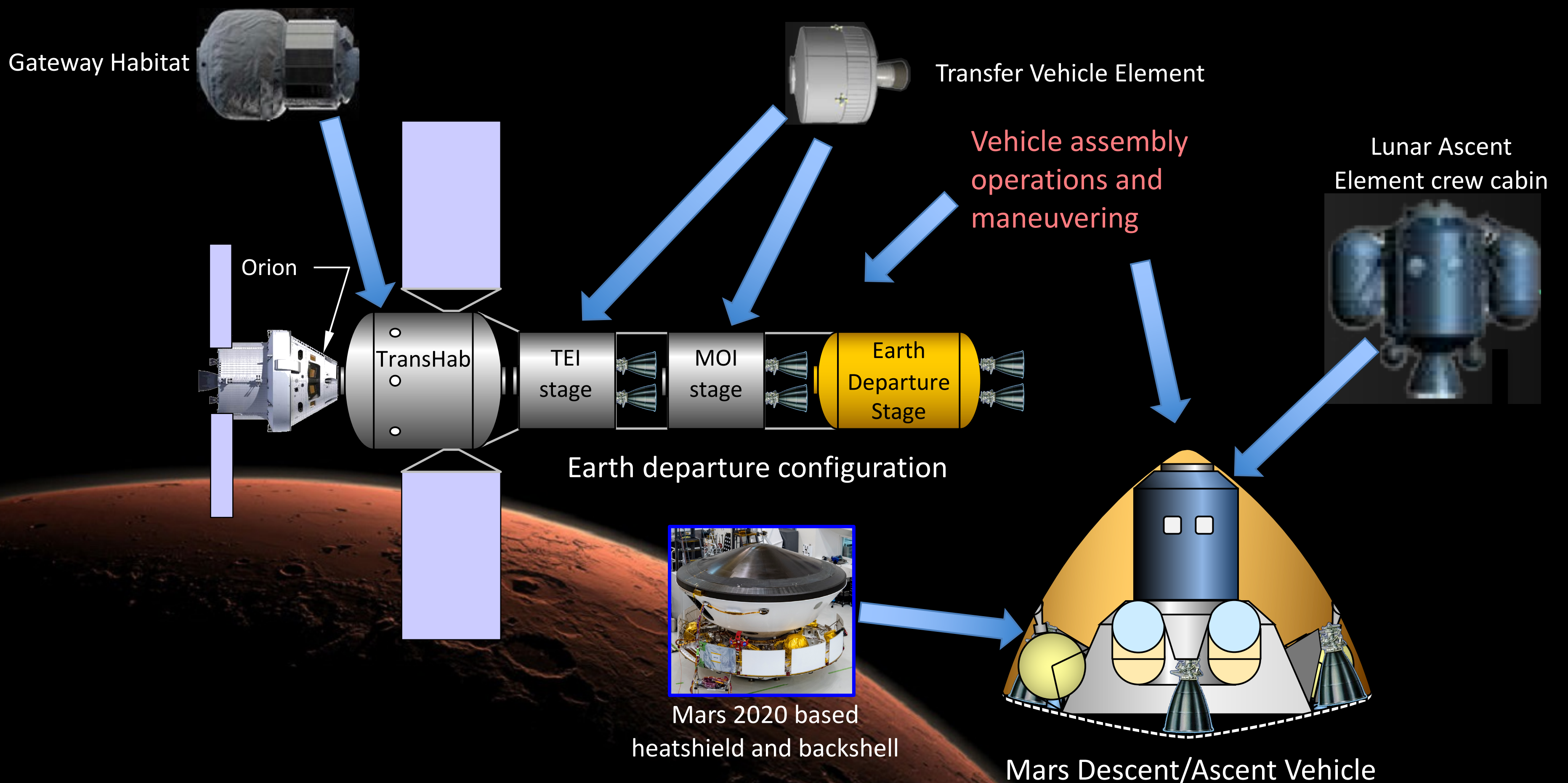


High heritage Descent/Ascent Vehicle

* Linck, E. et al, "Evaluation of a Human Mission to Mars by 2033", Science & Technology Policy Institute, IDA D-10510, Feb. 2019

Lunar Feed Forward to AM V Group 1 Architecture

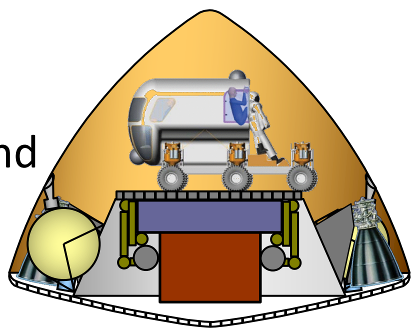
- Lunar mission elements could be prototypes and pathfinders for Mars mission elements in the AM V Group 1 architecture



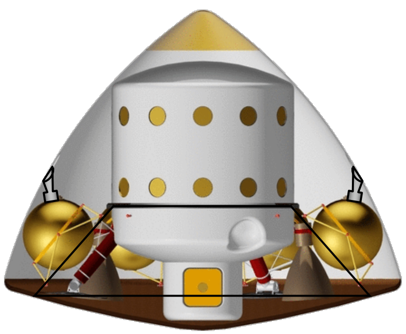
Cargo and Surface Elements Extensibility

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

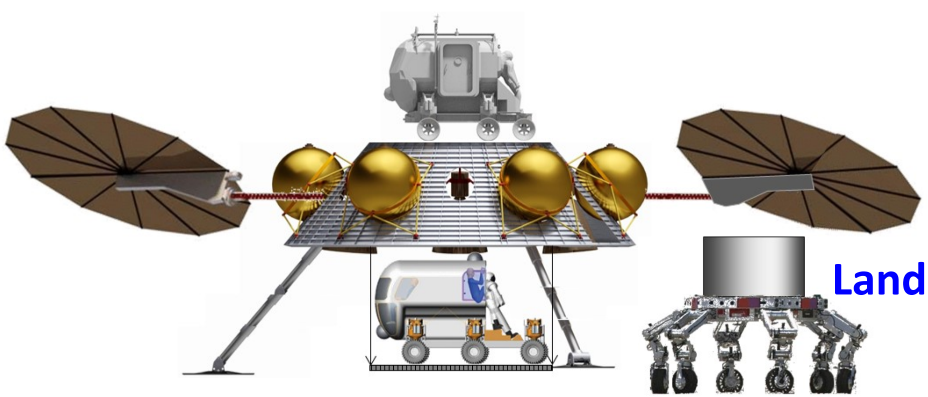
Cargo and logistics



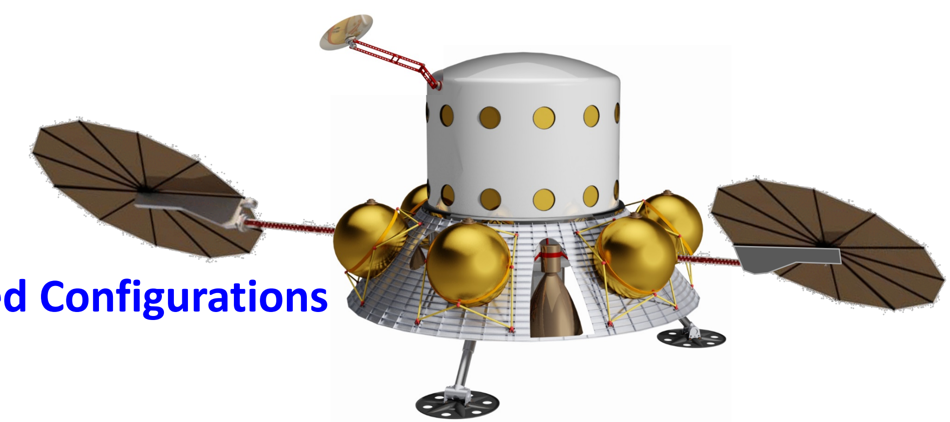
Entry Configurations



Surface habitat

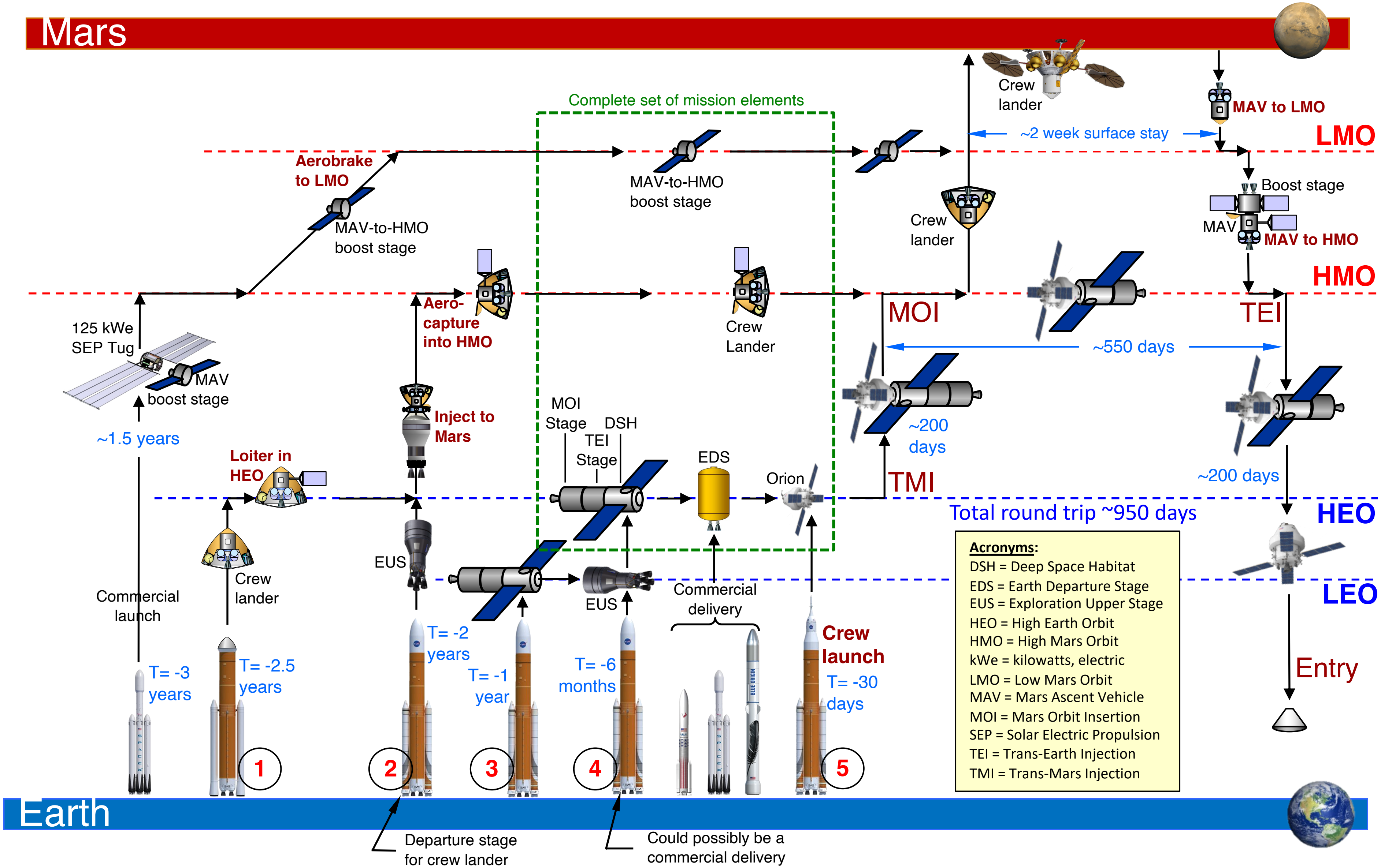


Landed Configurations



2033 Long-Stay Mars Landing Mission Concept

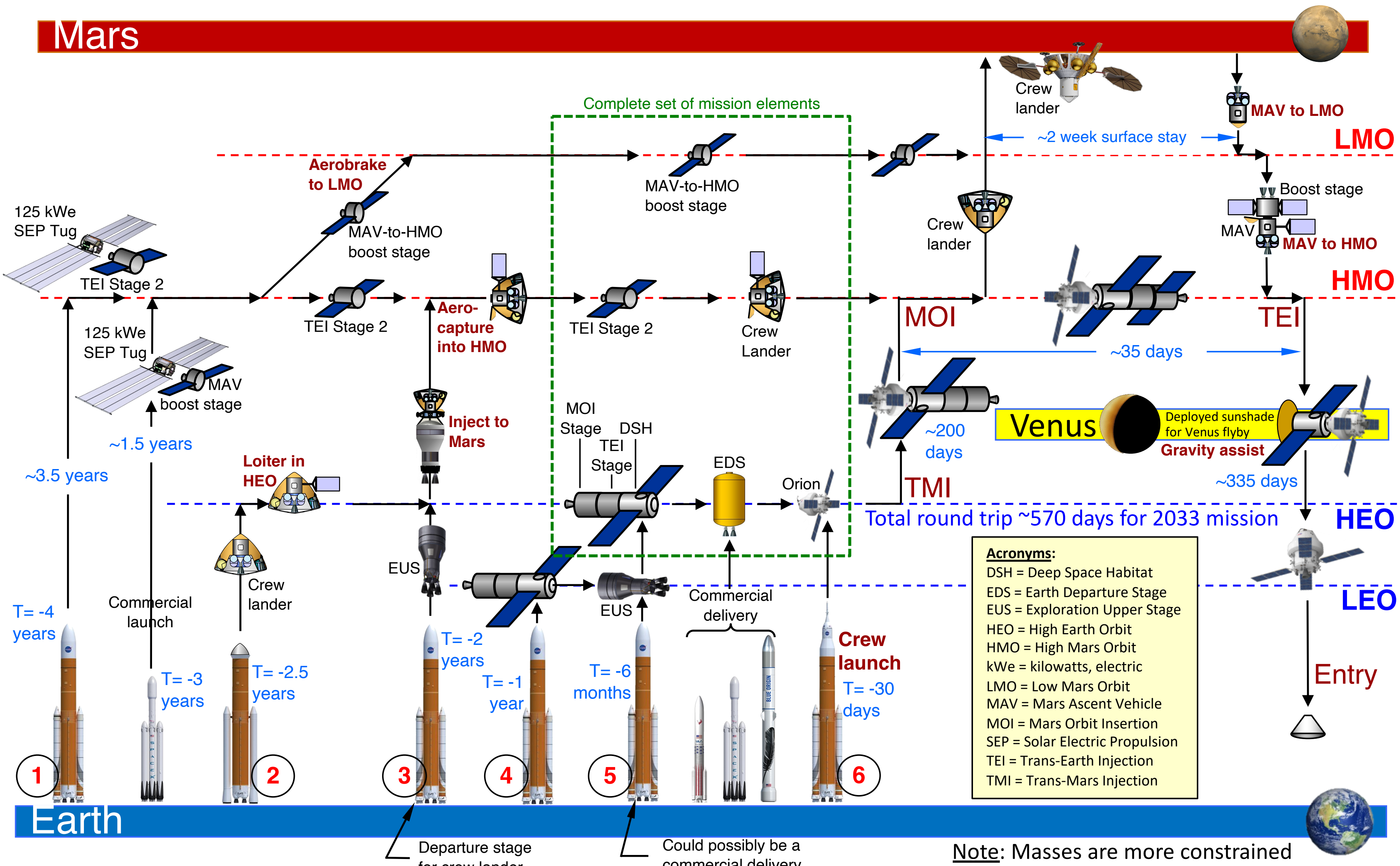
Crew of 4; 950 day round trip



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

2033 Short-Stay Mars Landing Mission Concept

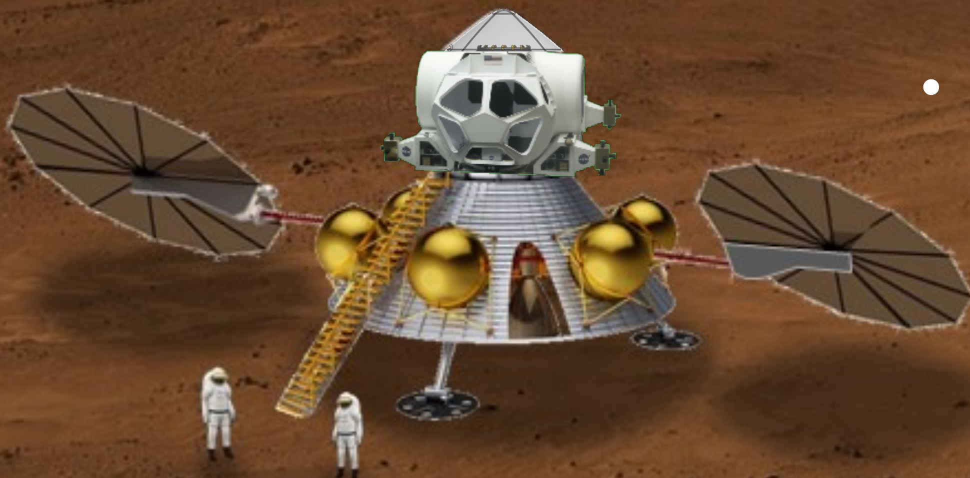
Crew of 4; 570 day round trip



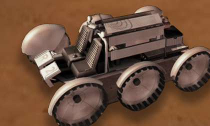
Note: Masses are more constrained for the 570 day trip option.

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

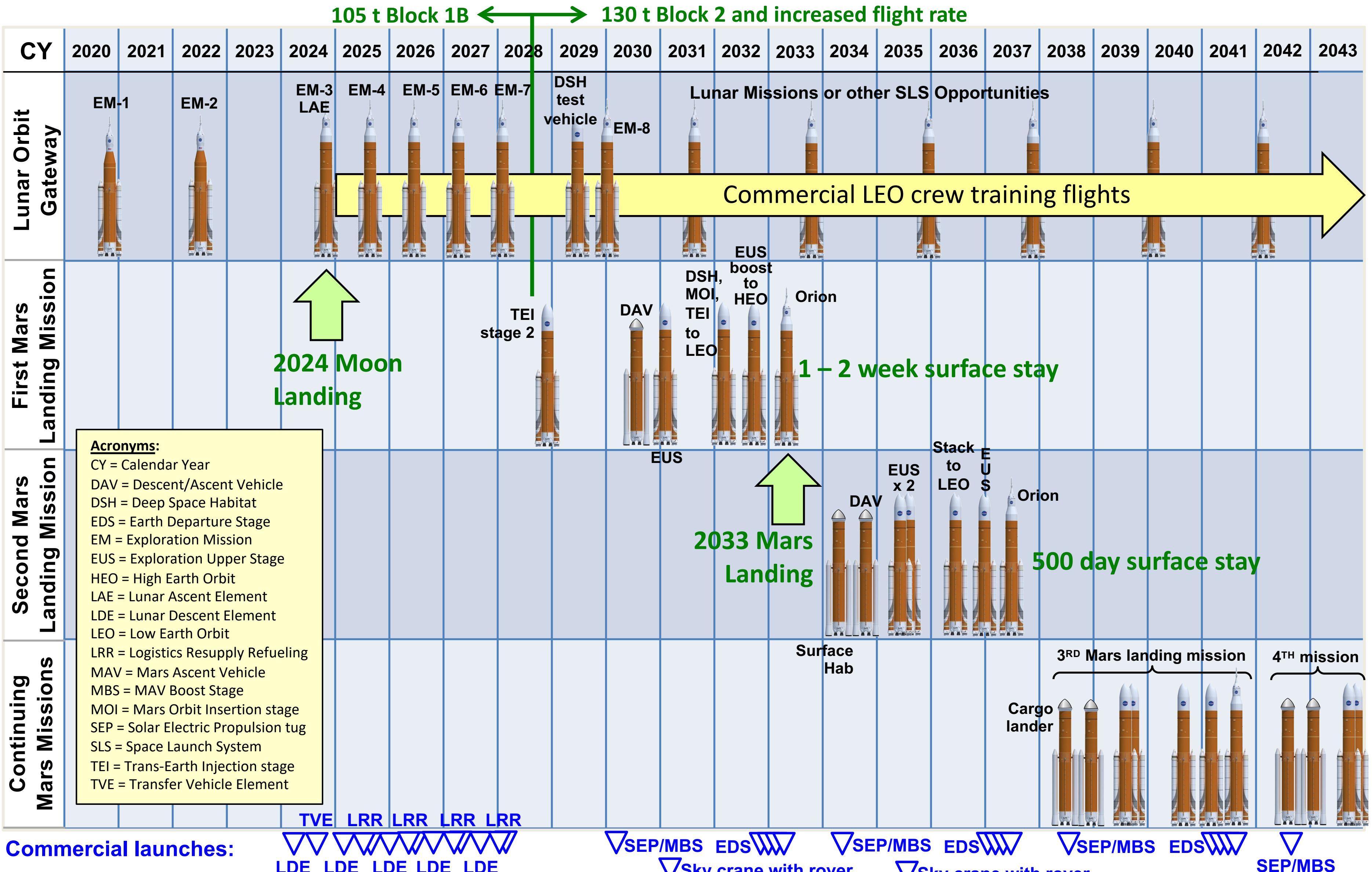


science equipment that would provide for crew surface transportation and could also be teleoperated from orbit.

- Would be significantly greater in scope than Apollo 17

Notional SLS Flight Scenario

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

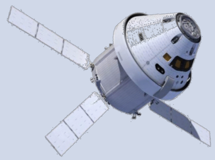
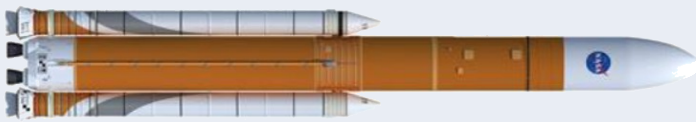
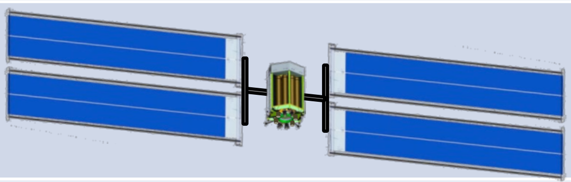
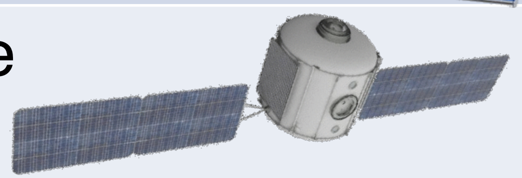
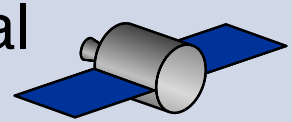
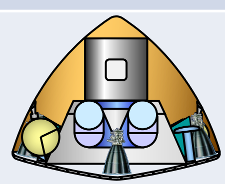


Maximizing Feed Forward to Mars

- Lunar elements could be designed to maximize feed forward to the Mars architecture elements to:
  - Prove out needed technologies, components, system designs, mission operations, and surface operations
  - Develop vehicle assembly and maneuvering capability at Gateway
  - 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
- An early crewed Moon landing in 2024 could serve to advance exploration vehicle development and could possibly lead to a Mars landing as early as 2033, if sufficient funding was available

Supplementary Material

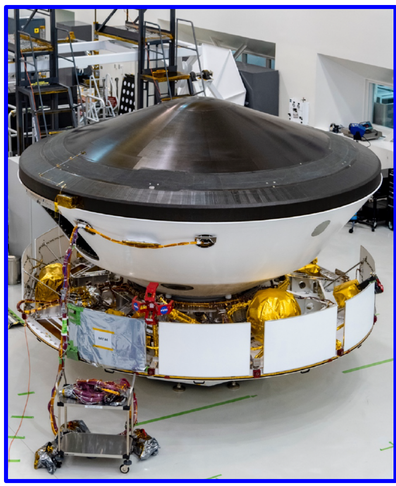
Six Vehicles to Enable Short Stay Mission to Mars

Vehicles	# Vehicles for Mission	
Orion 	1	In development
SLS 	6	In development
SEP Tug ~125 kWe 	2	Would have heritage to 50 kWe Gateway Power and Propulsion Element
Deep Space Habitat 	1	Would have heritage to smaller 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

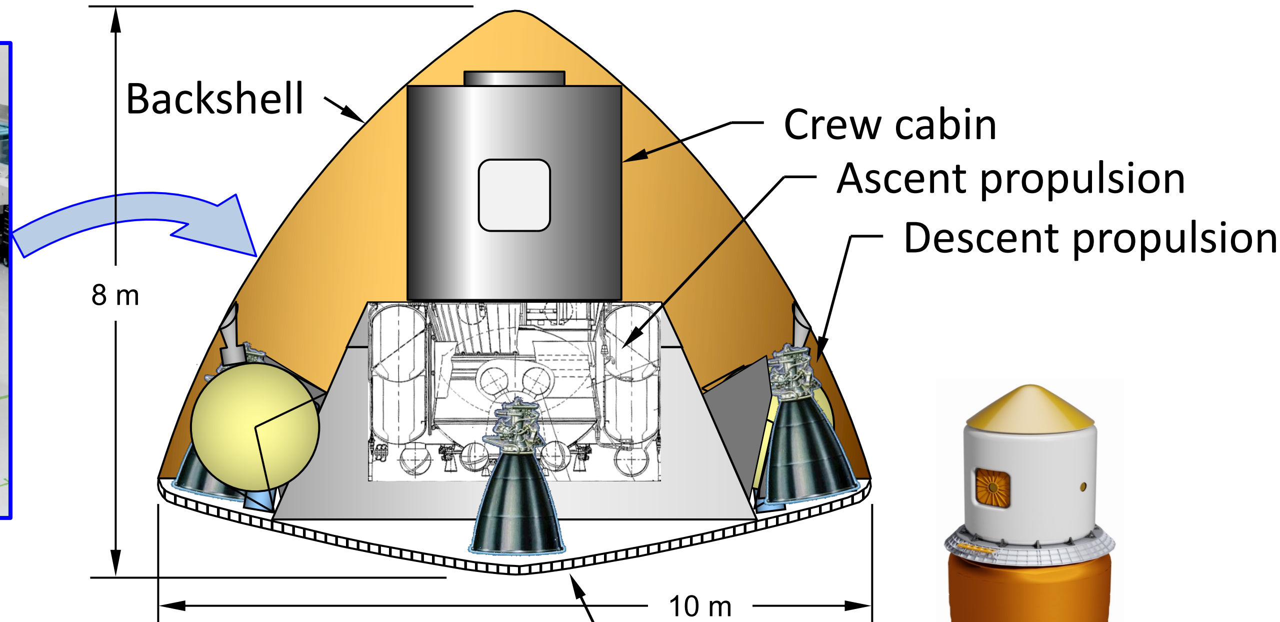
High Heritage Crew Lander Concept

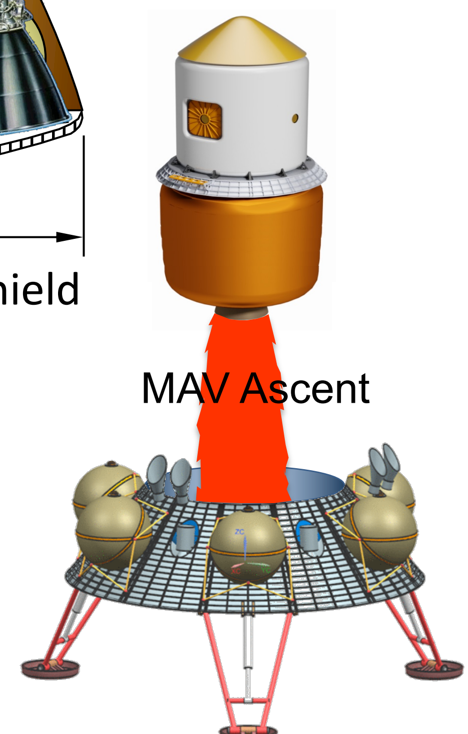
Could support crew of 4 for 2 weeks by itself, or longer with other surface assets

Launch



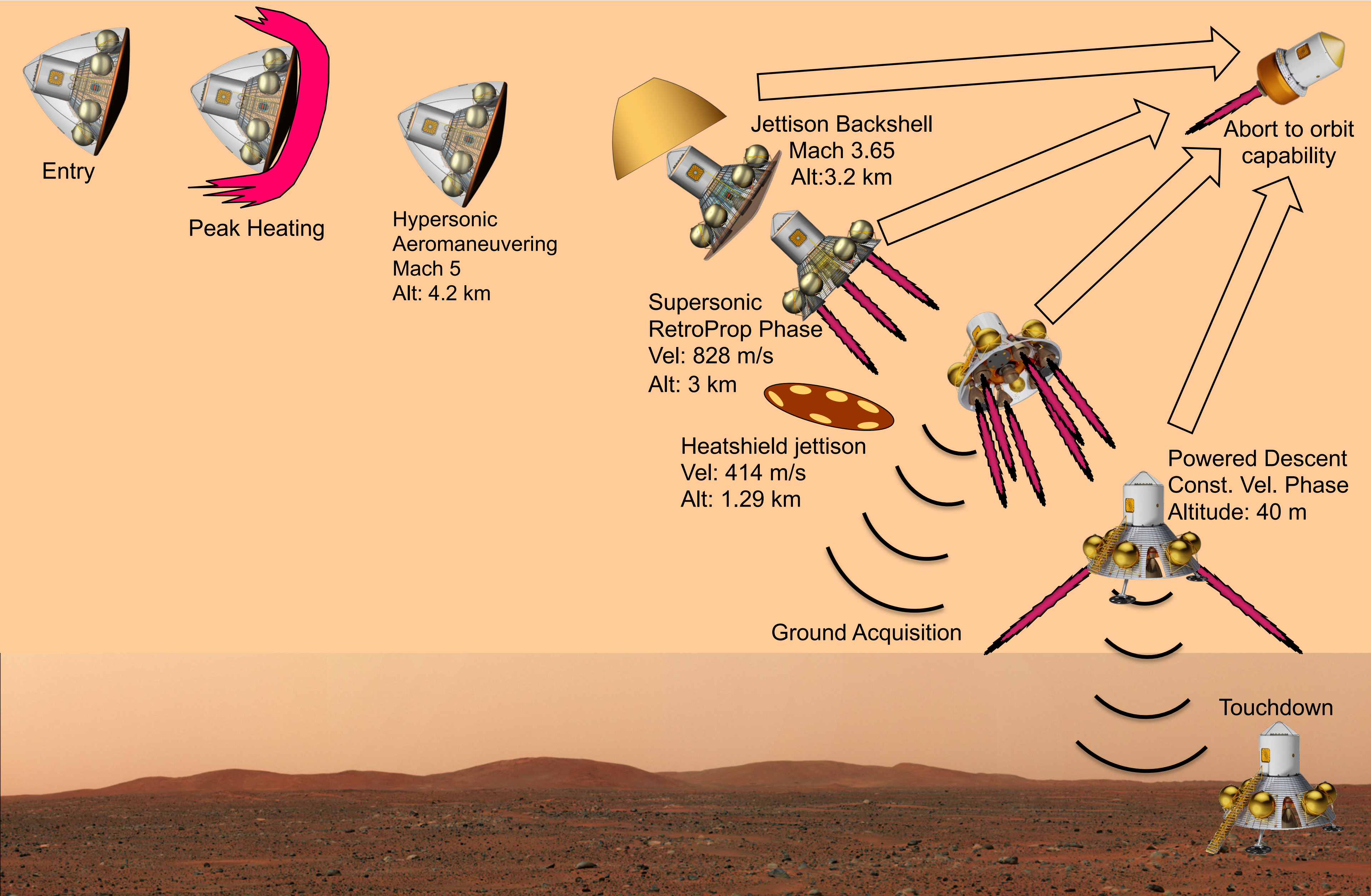
Mars 2020 heatshield and backshell (4.5 m)



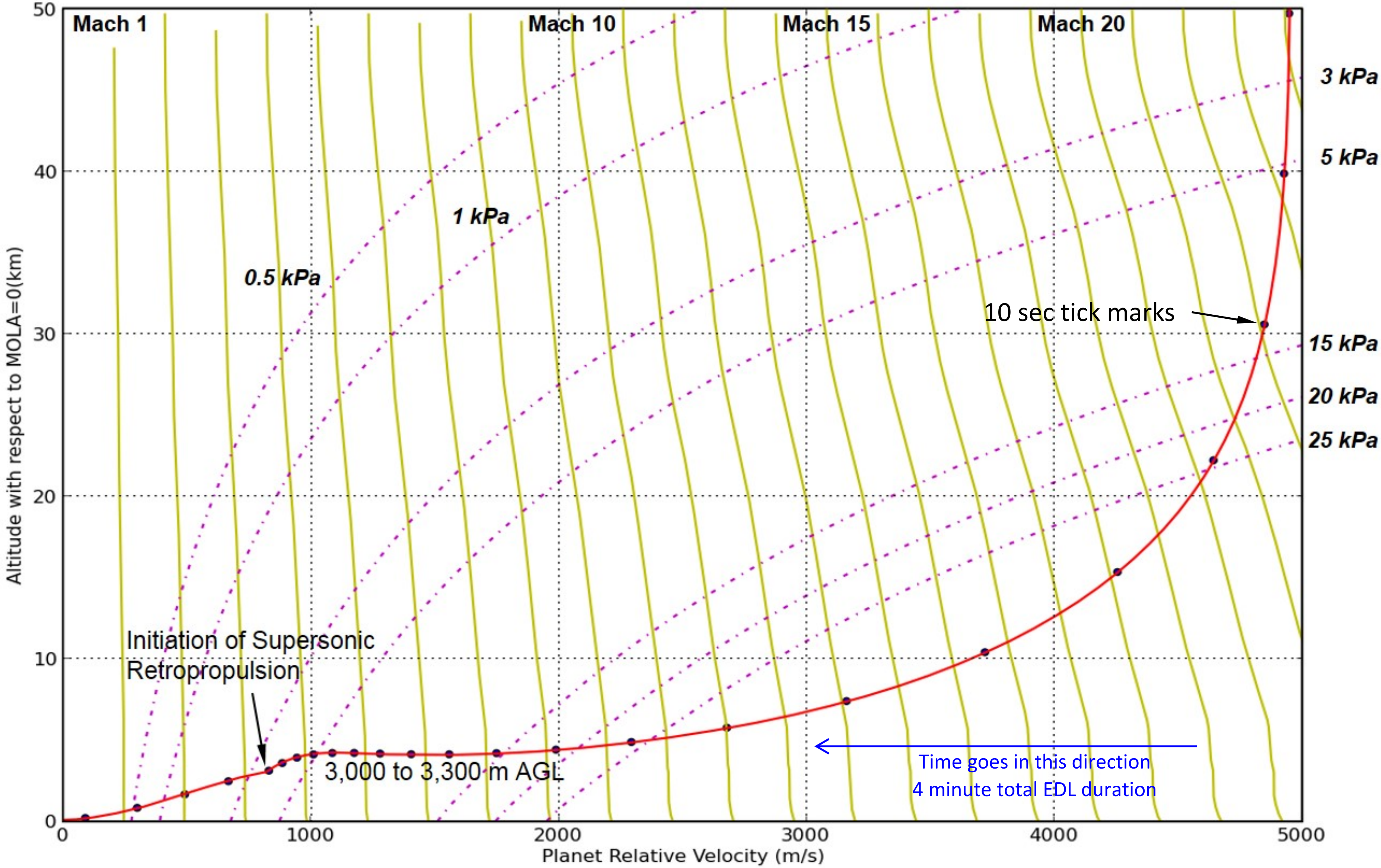


Landed Configuration

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

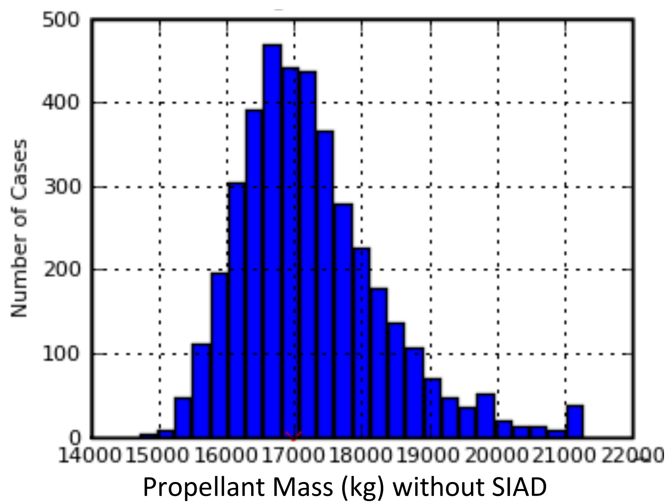


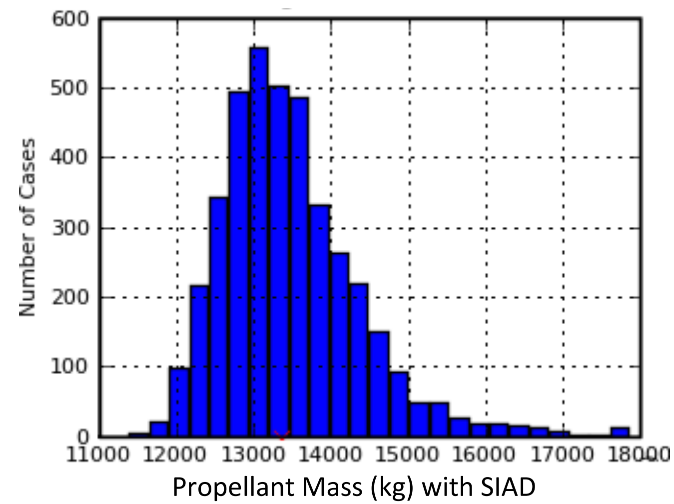
EDL Trajectory for Blunt-Body Lander Concept

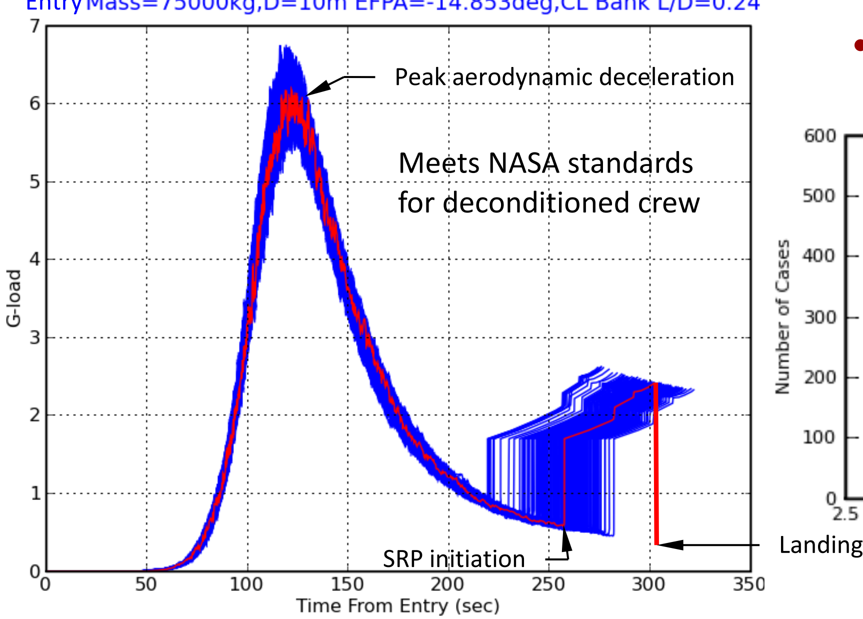


Selected EDL Monte Carlo Simulation Results

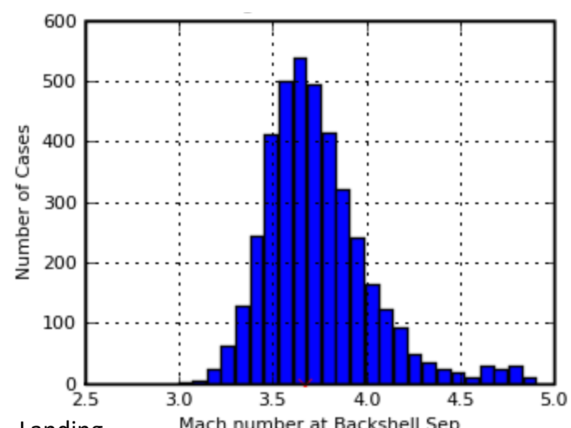
- ~20 t of propellant is used
- Crew experiences ~6.5 g for <30 s
- Backshell separation and SRP are at ~Mach 3.8 and 4 kPa

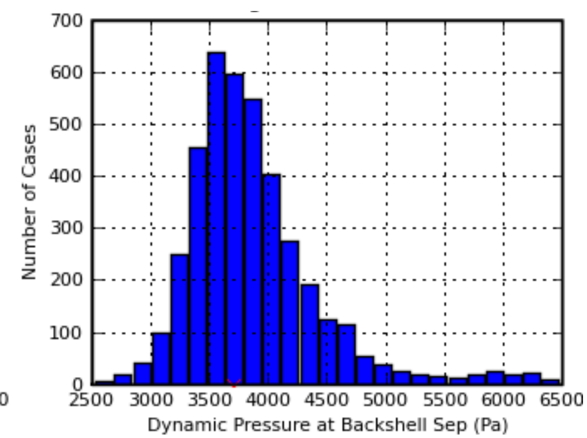




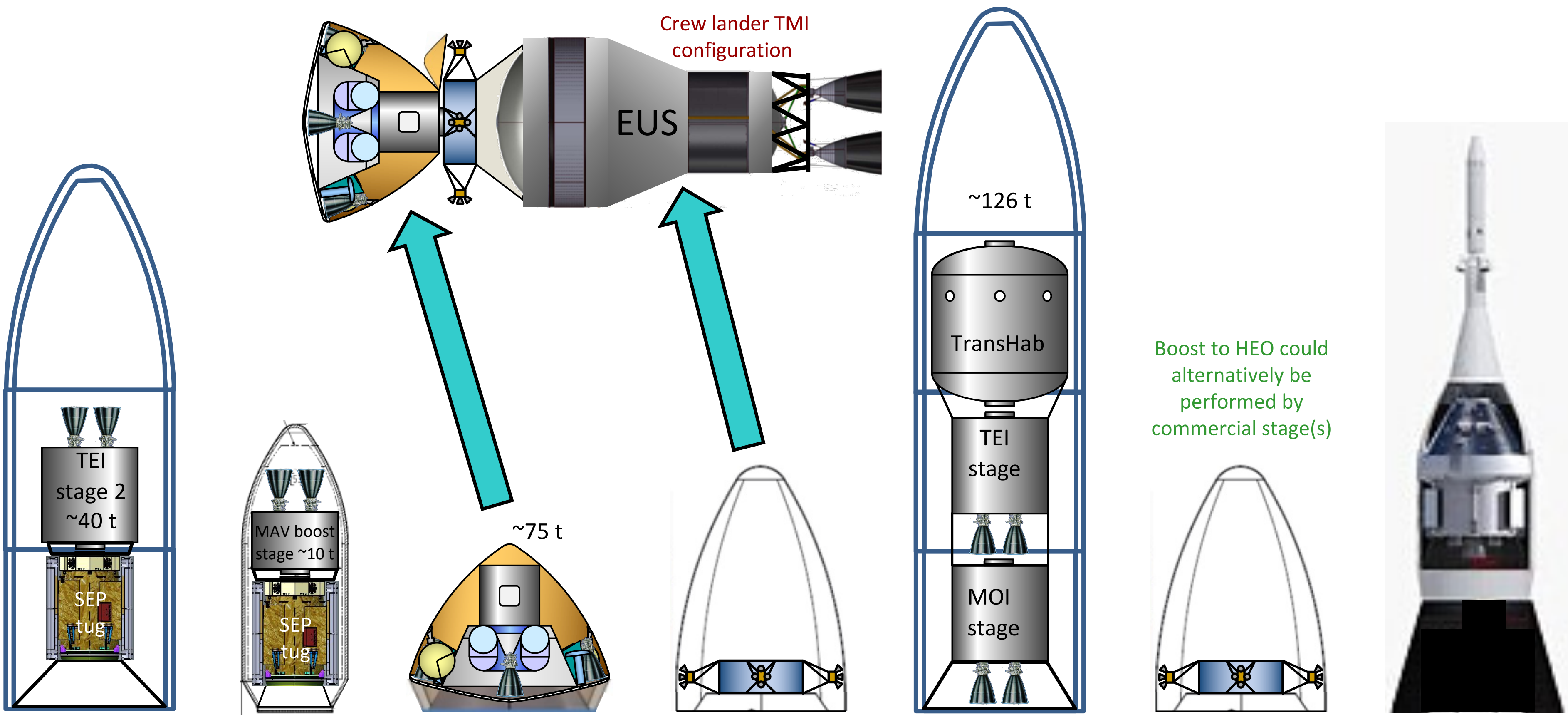


- LDSD derived SIAD could save ~4 t of propellant
- Could be an option for cargo vehicles





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

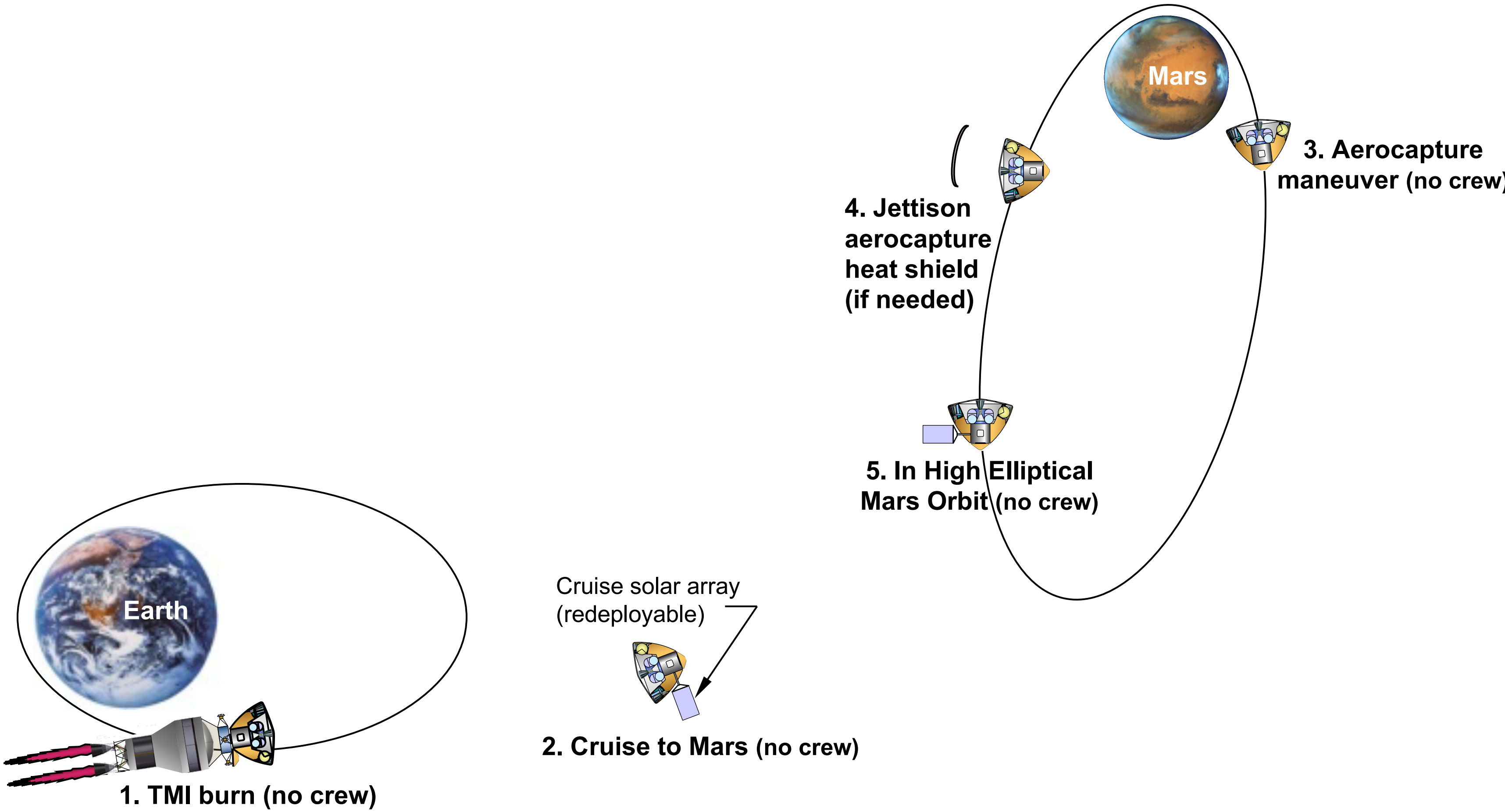
MOI & TEI stages and TransHab launch to LEO
SLS Launch #4

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

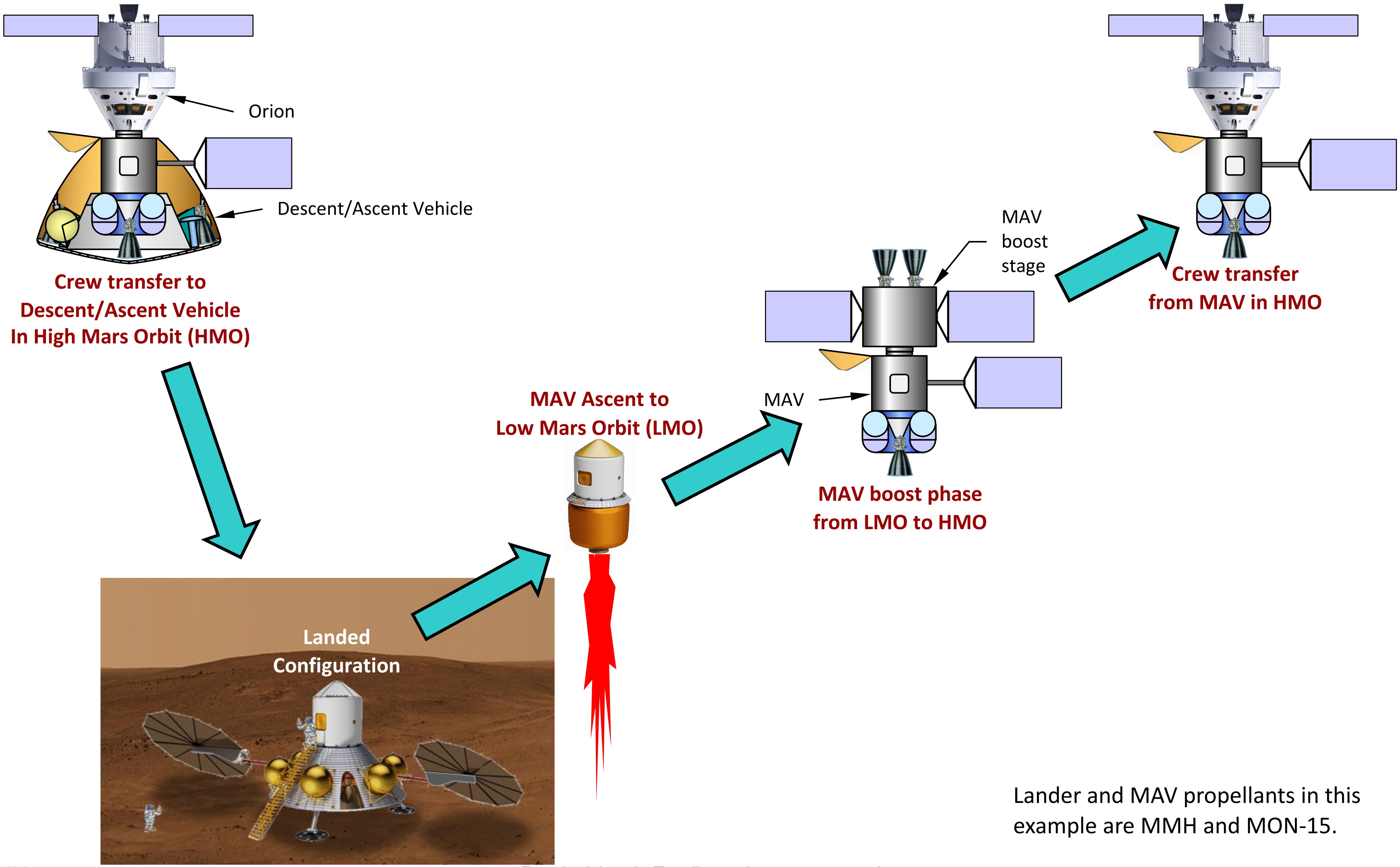
Orion with crew for docking with stack
SLS Launch #6

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

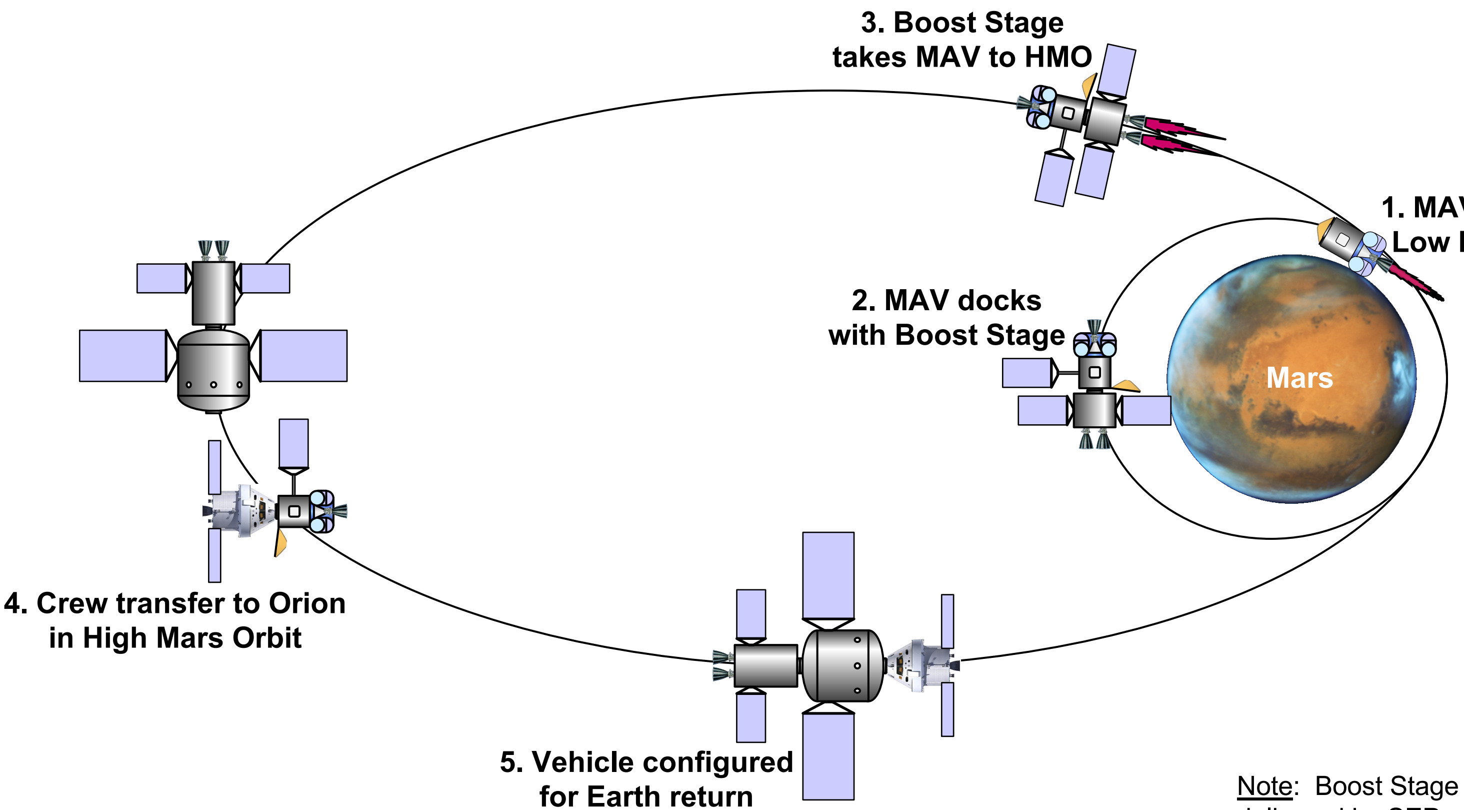


Crewed Mars Descent/Ascent Vehicle Concept



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 for 2033

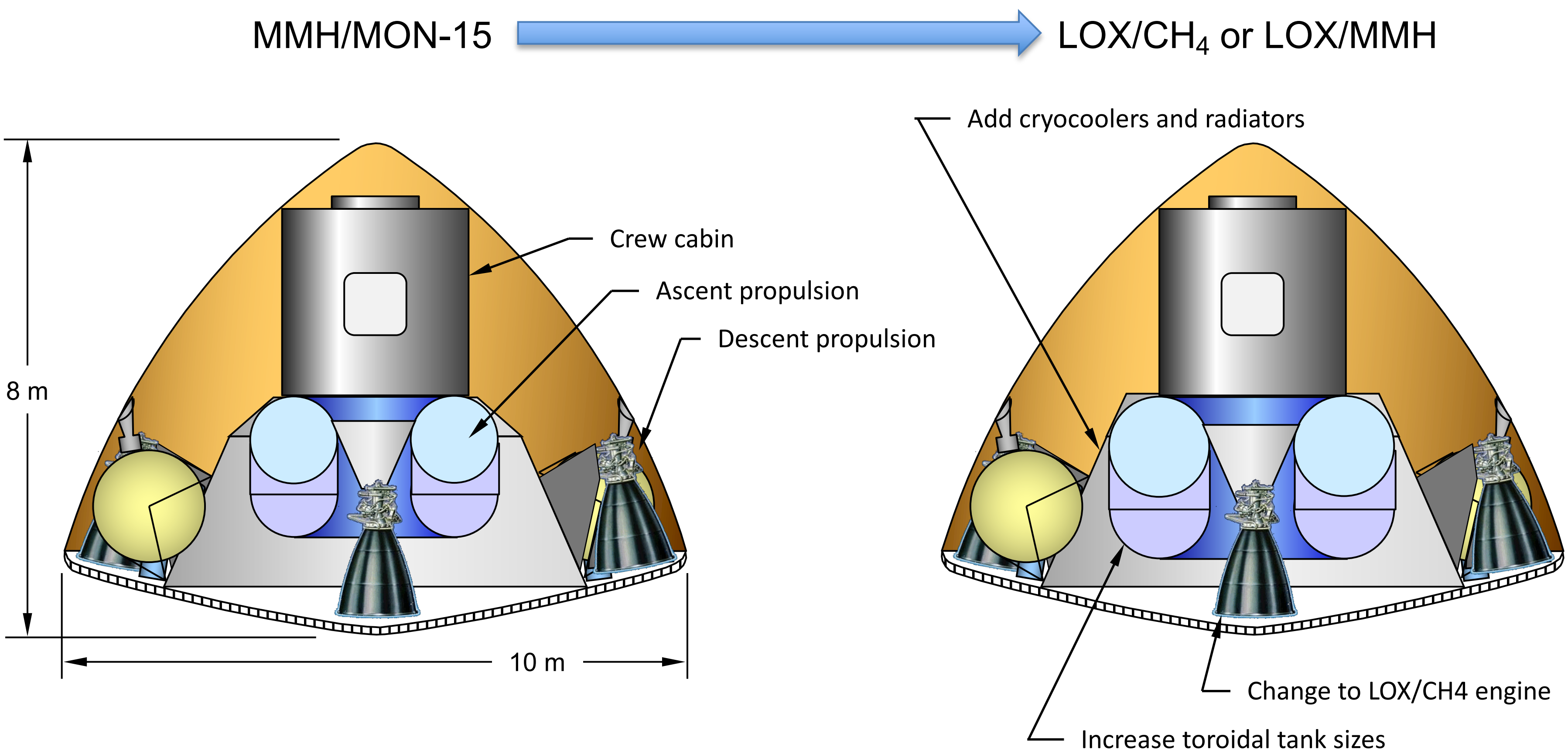
- The crew transit vehicle stack could abort back to Earth for a limited time after TMI, utilizing the MOI and TEI stages
- The crew transit vehicle stack could be on a free return trajectory to abort back to Earth if MOI was in jeopardy
- Orion could function as a temporary lifeboat in the event of other vehicle anomalies
- Orion could provide emergency EVA capability
- Orion and the MOI/TEI stages could each perform attitude control and TCMs for the crew transit vehicle stack in the event of a failure of one of them
- If the MAV boost stage was not functional, then the Mars 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.

2033 Short vs. Long Stay Mission

- Long-Stay Conjunction-class and Short-Stay Opposition-class mission architectures are options for the 2033 opportunity
  - Short-Stay mission is 570 days vs. 950 days, but requires much larger Mars departure ΔV
    - Greater mass constraints on Deep Space Hab and chemical stages
  - Both missions share type I transfer to Mars in April 2033
  - Long-Stay spends 550 days at Mars, whereas Short-Stay spends 31 days at Mars and performs a Venus fly-by on the return leg (at a cost of 3.3 vs. 1.1 km/s for TEI)

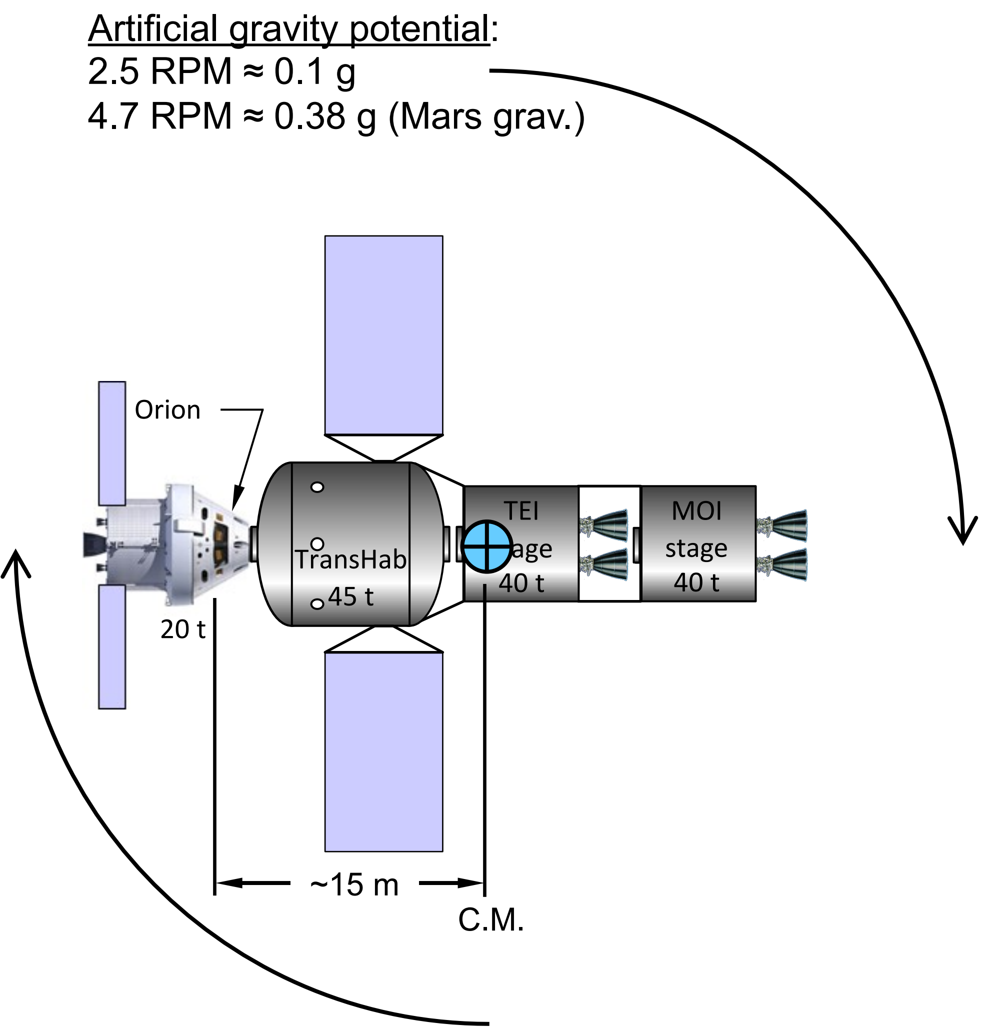
	Long Stay	**Short Stay**	
Launch C3	9.07	9.07	km^2/s^2
Mars VHP	3.32	3.32	km/s
Departure VHP	2.96	5.91	km/s
Earth VHP	3.03	4.59	km/s
E Launch Date	4/17/2033	4/17/2033	
M Arrival Date	11/2/2033	11/2/2033	
M Launch Date	5/7/2035	12/3/2033	
E Arrival Date	11/23/2035	11/8/2034	
Mission	950	570	days
Stay	551	31	days
Out	199	199	days
Back	200	340	days

Going ISRU: Concept for Converting MAV from MMH/MON-15 to LOX/CH_4 or LOX/MMH



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 useful experimental 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 minimal impact on vehicle design and cost
  - Would require strengthening of solar arrays if providing AG >~0.1 g