National Aeronautics and
Space Administration

Human Mars Ascent Vehicle Configuration and Performance Sensitivities

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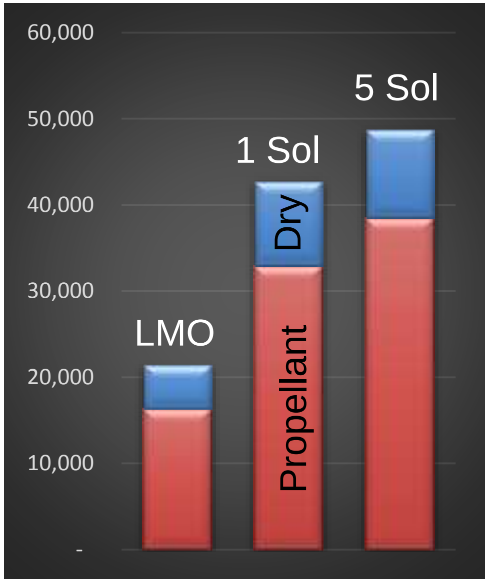
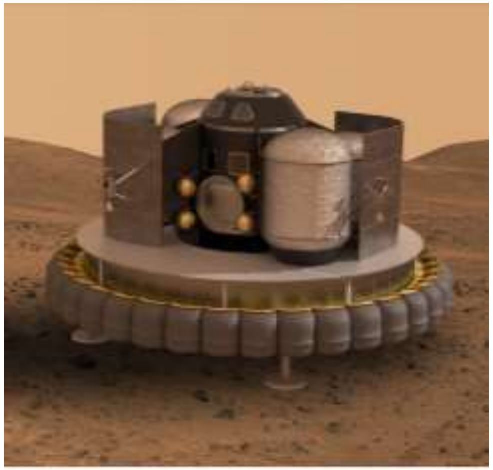
Introduction

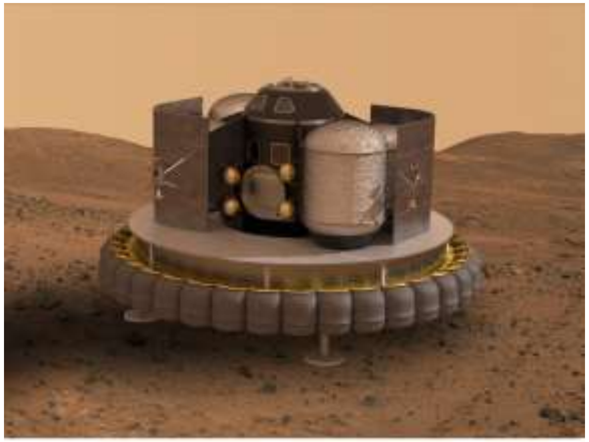
- **The MAV is the highest gear ratio element in human Mars mission architecture, growing by 5 to 9 kg for every 1 kg of added dry mass**
- **The MAV sets the cargo delivery requirement for the lander and the resulting lander mass, which in turn drives the Earth to Mars transportation system performance requirements.**
- **This paper explores MAV design sensitivities to trajectory, propulsion, crew cabin size and the benefits and impacts of using a common crew cabin design.**
- **Related papers at this conference**
  - "Mars Ascent Vehicle Sizing, Habitability, and Commonality in NASA's Evolvable Mars Campaign" – Mike Gernhardt

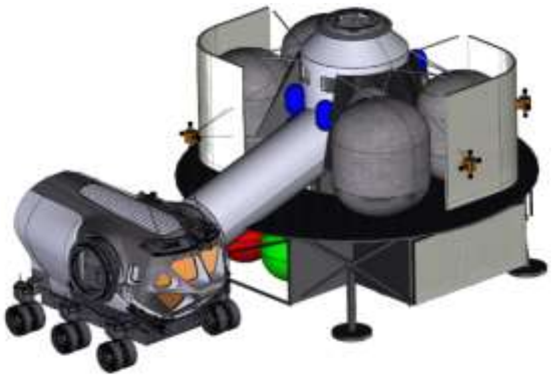
MAV Liftoff Mass





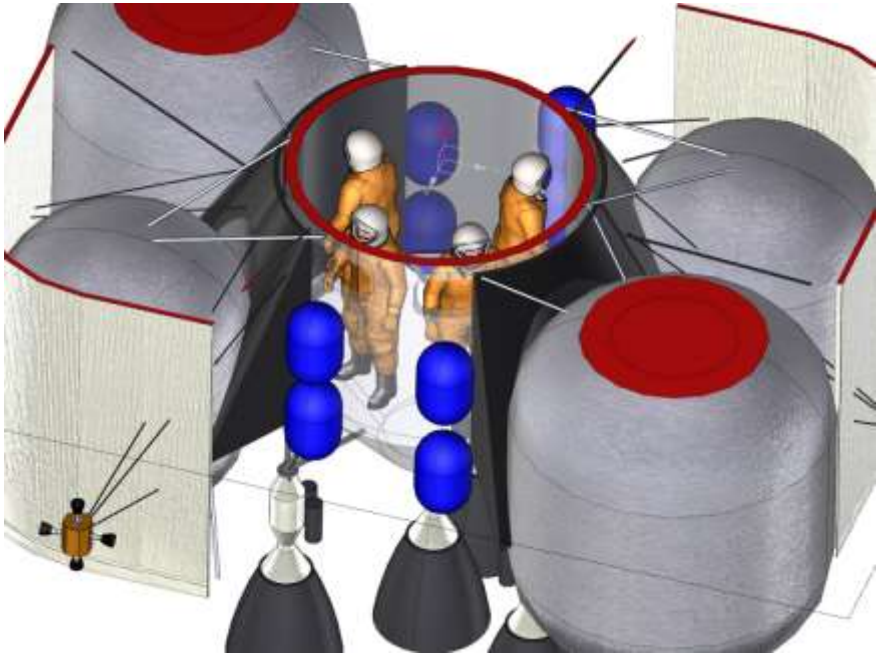
Human Mars Ascent Vehicle



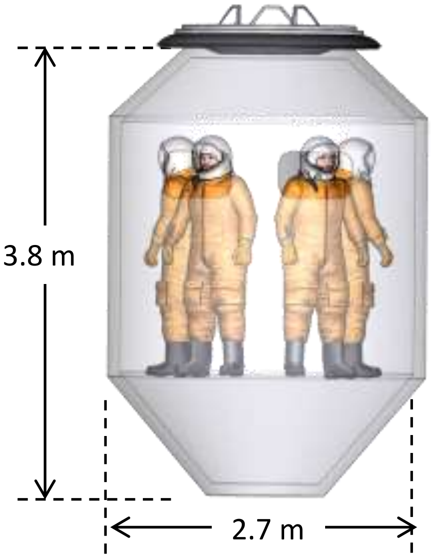


- **The MAV is delivered to the Mars surface before crew arrive.**
- **It carries 4 crew and 250kg of science cargo off the surface.**
- **Crew ingress through pressurized tunnel so that surface suits can be left behind. This minimizes cabin volume requirements and limits contamination with Martian regolith.**
- **MAV configurations that minimize CG height and total height improve lander performance**

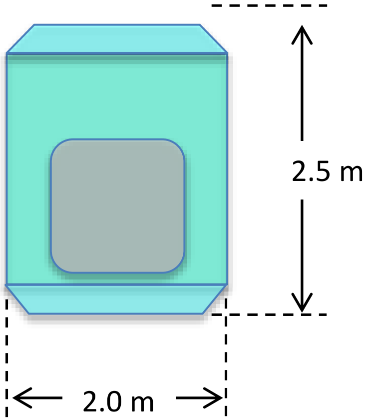
Configuration Overview: Vertical Cabin



High Mars Orbit
2-3 days



Low Mars Orbit
8-12 hours

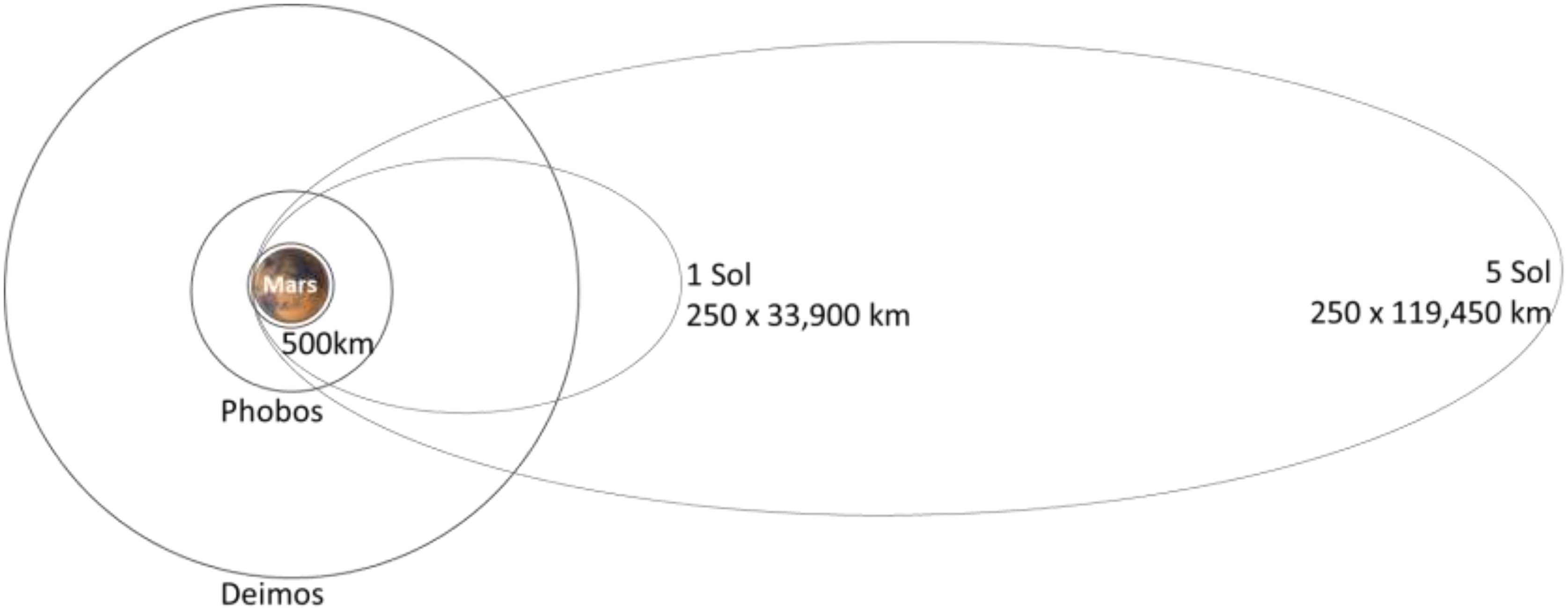


- **Ascent acceleration of 0.8-1.5 Earth g's, could be a problem for a deconditioned crew, recumbent seating desired but drives cabin size**
- **A minimal cabin size with standing restraints was also assessed**

Recumbent seating

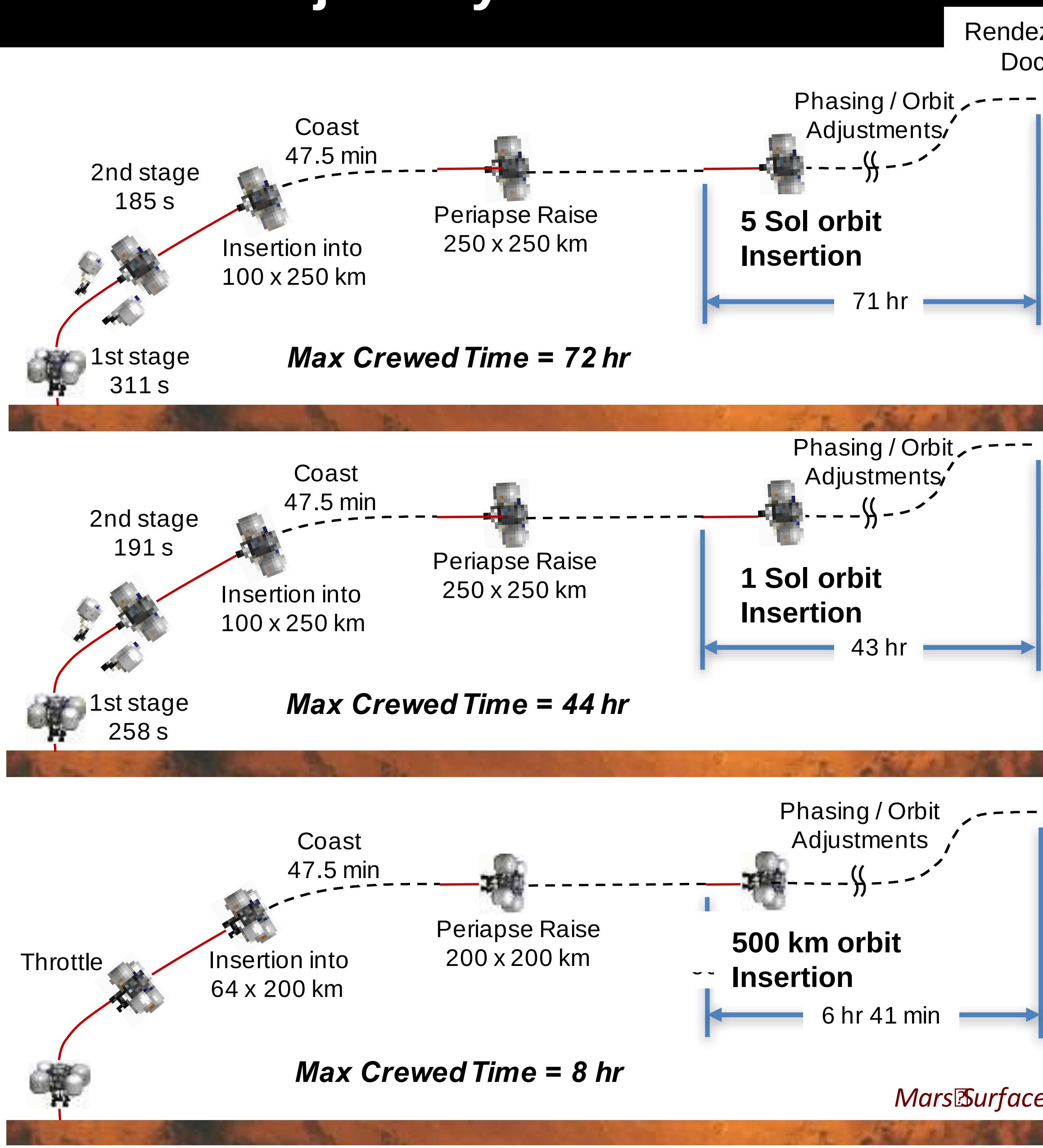
Apollo-style standing crew restraint

Ascent Trajectory



- **Ascent to 3 target orbits is assessed, 500km circ, 1 Sol, and 5 Sol**
- **Earth return vehicle will be in a high Mars orbit, 1 Sol – 5 Sol**
- **Ascent to low mars orbit minimizes MAV mass, but would require another vehicle to complete ascent and rendezvous with the Earth return vehicle.**

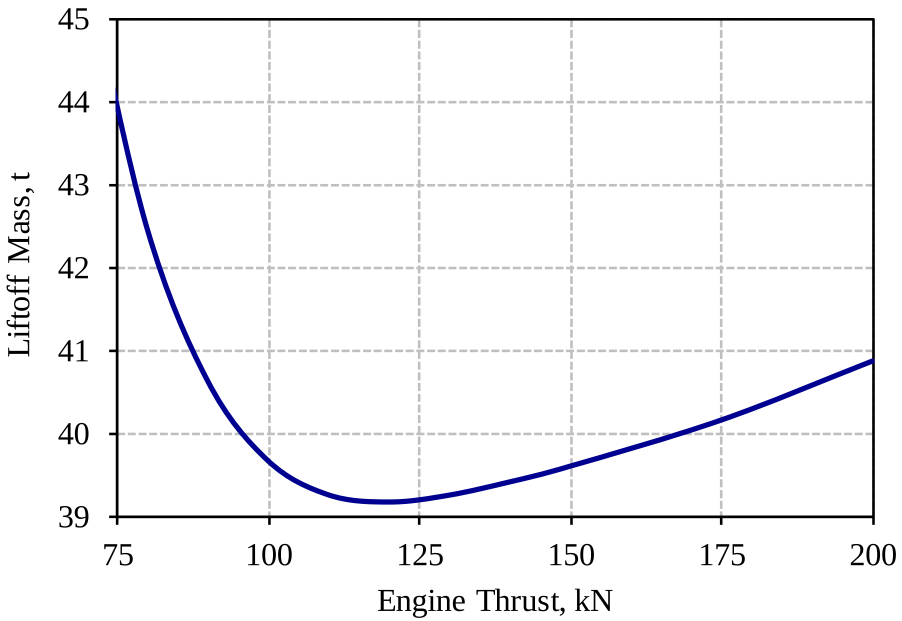
Ascent Trajectory



Configuration at Liftoff

Configuration After Staging

Ascent Performance Sensitivities: 1 Sol

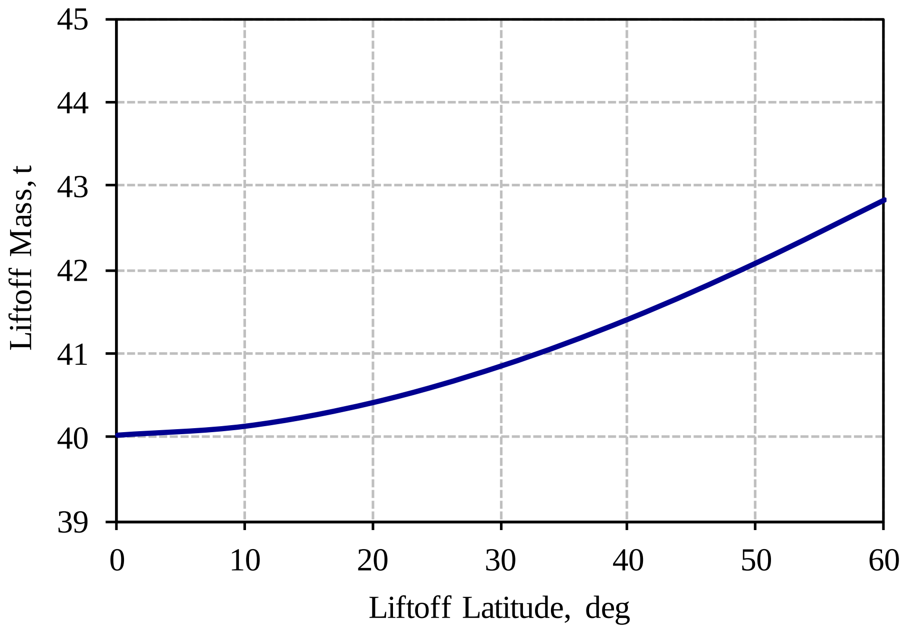


Liftoff Mass vs Engine Thrust

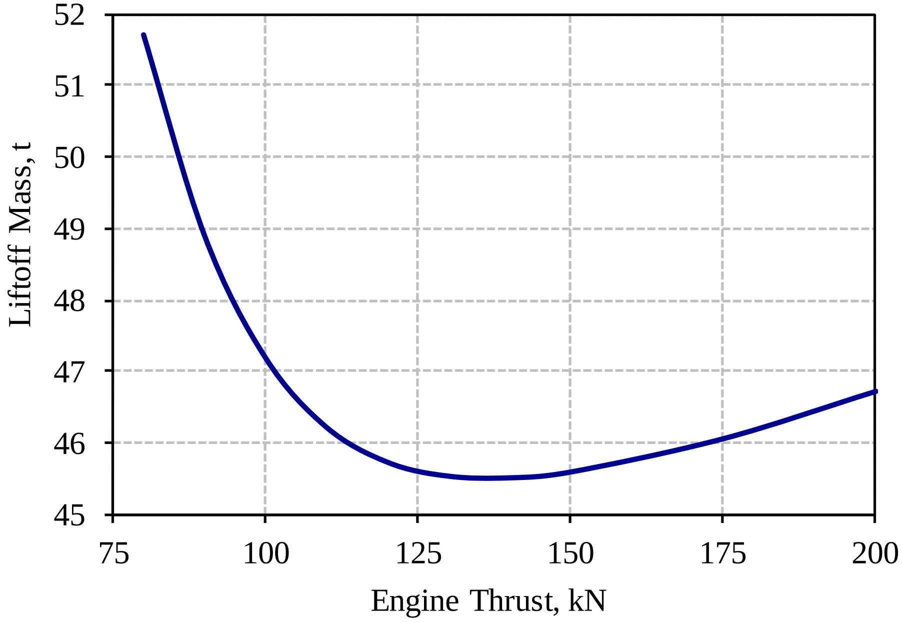
3 engine 1st stage

1 engine 2nd sage

Liftoff Mass vs Latitude



Ascent Performance Sensitivities: 5 Sol

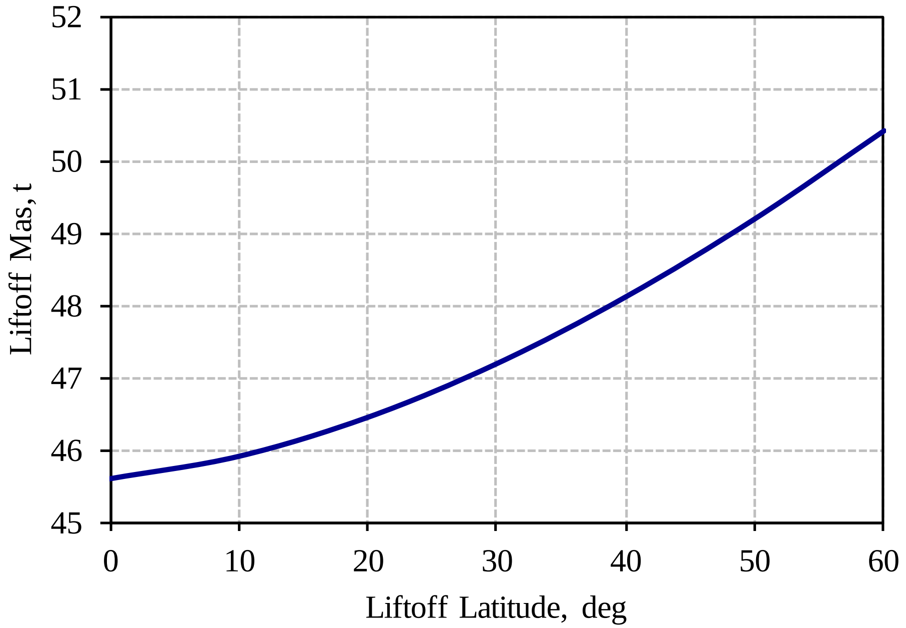


Liftoff Mass vs Engine Thrust

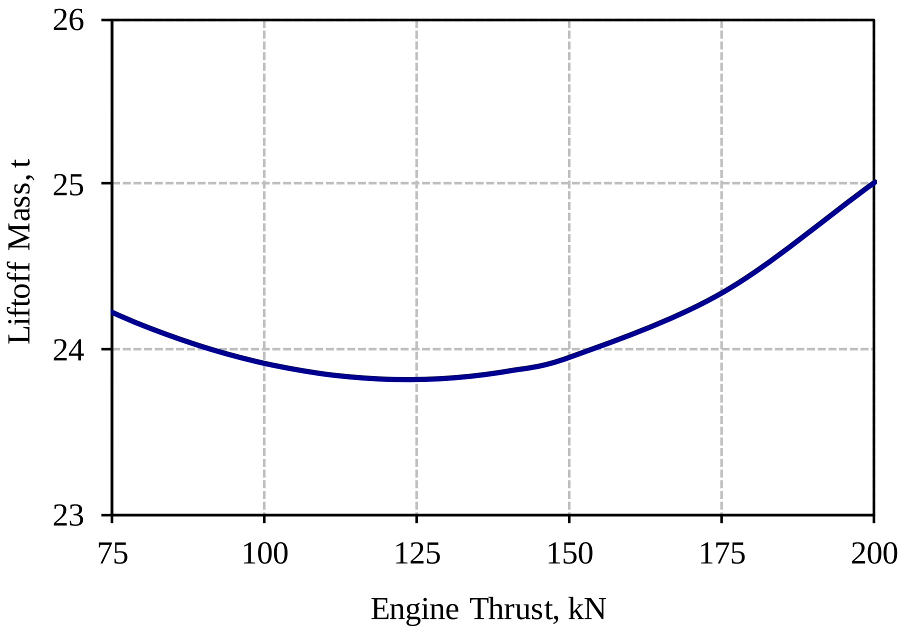
3 engine 1st stage

1 engine 2nd sage

Liftoff Mass vs Latitude



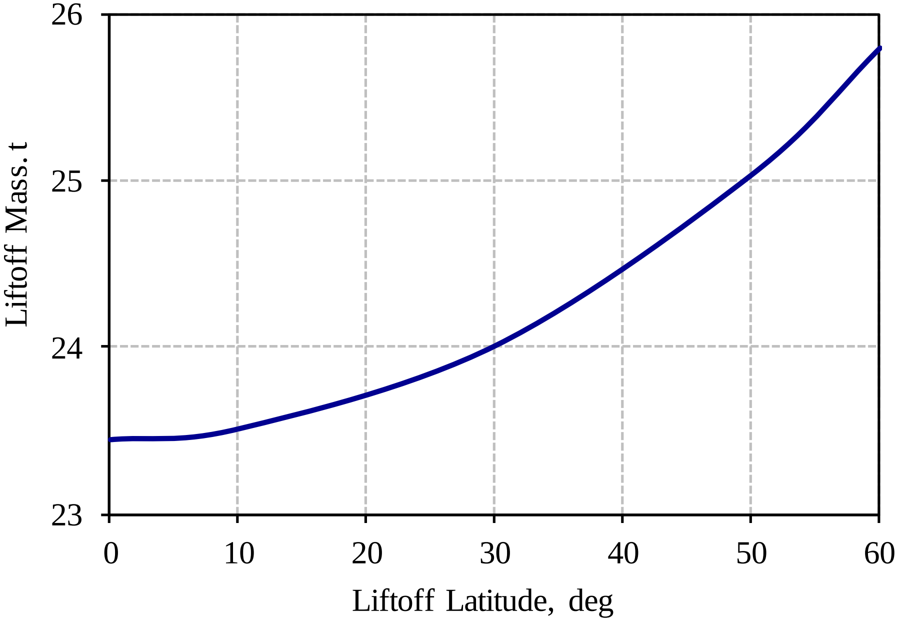
Ascent Performance Sensitivities: 500 km



Liftoff Mass vs Engine Thrust

3 engine single stage

Liftoff Mass vs Latitude

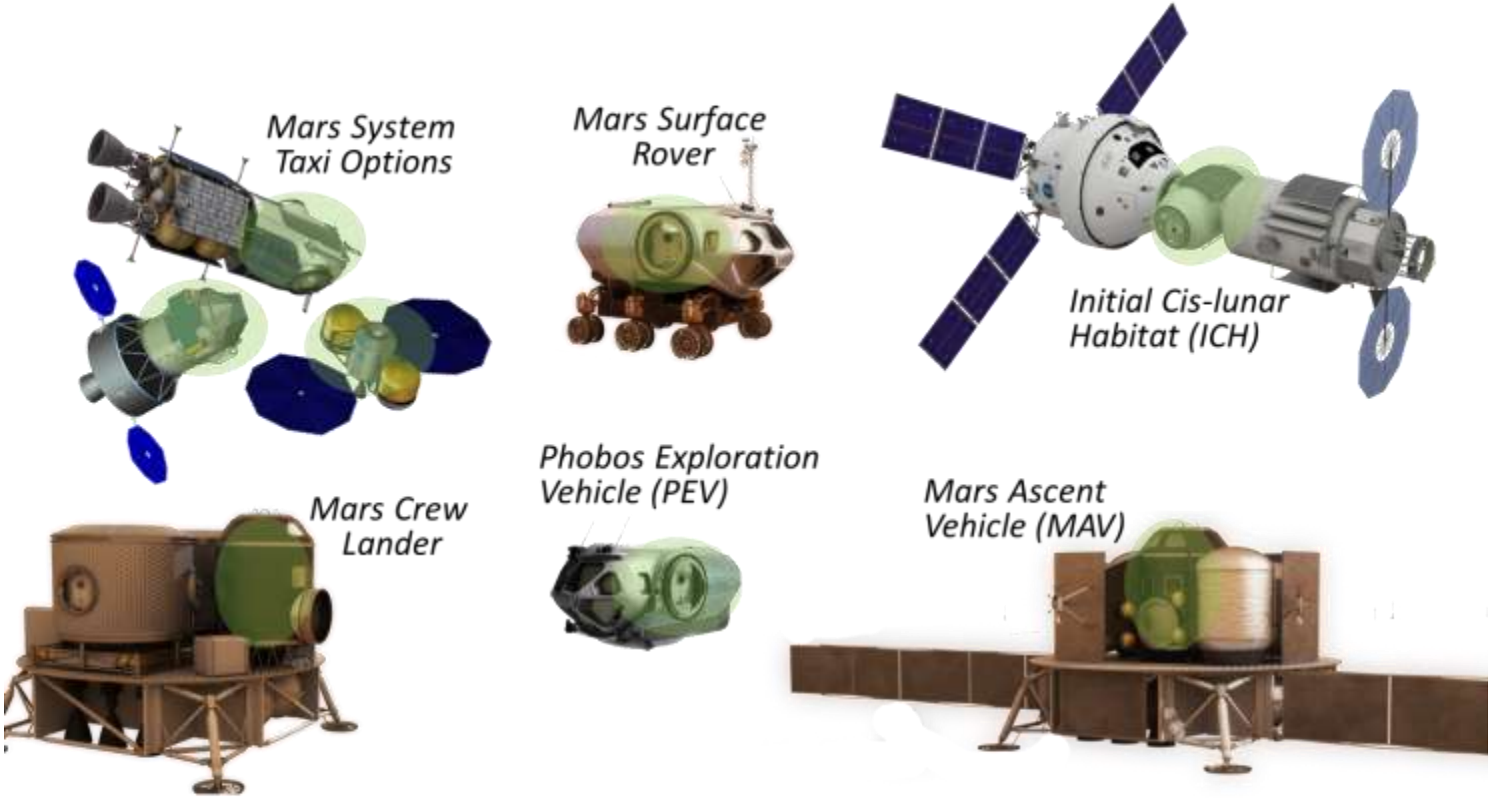


MAV Performance Summary

- Multidisciplinary team developed designs for 3 MAV options
- Protecting for +/- 30 deg latitude launch sites

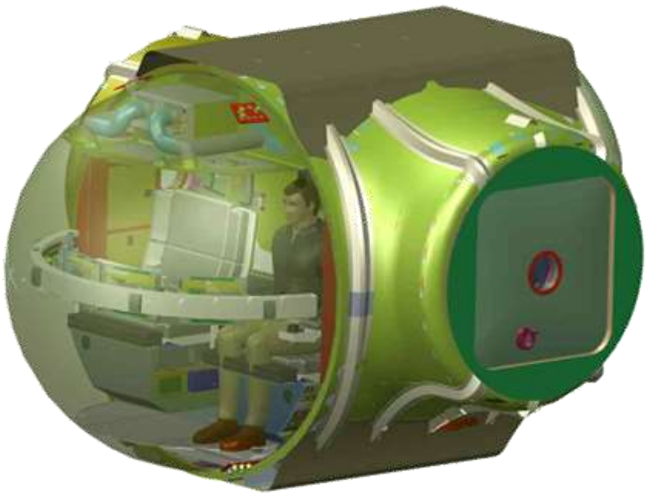
Target Orbit	1 Sol	5 Sol	500 km
Habitable Duration (hrs)	44	72	8
Number of Crew	4	4	4
Ascent Cargo (kg)	250	250	250
MAV cabin mass (mt)	4.2	4.3	3.9
Propellant			
Oxygen (mt)	25.0	29.2	NTO: 12.2
Methane (mt)	7.9	9.2	MMH: 6.2
Thrust (kN)	300 / 100	300 / 100	300
Minimum Throttle	20%	20%	20%
Liftoff Mass (mt)	42.9	48.9	24.4
MAV mass delivered to Mars Surface assuming ISRU LOX production (mt)	17.2	19.0	23.7

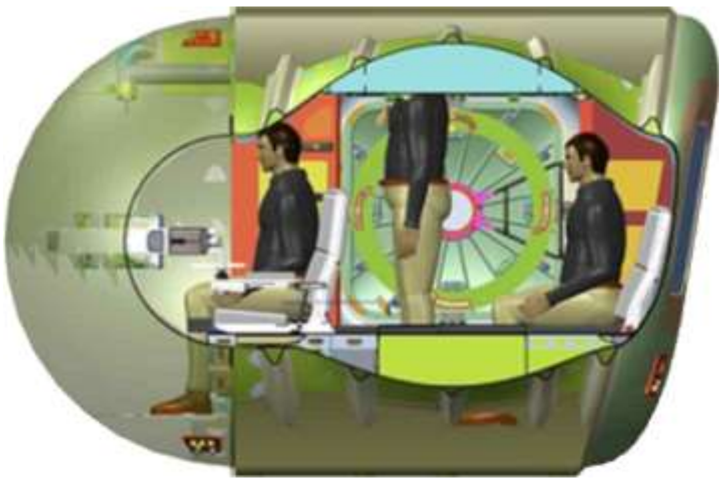
Common Crew Cabin



- There are many possible uses for a small crew cabin for cislunar and Mars missions
- A common crew cabin used in multiple applications may reduce overall development costs

Common Crew Cabin

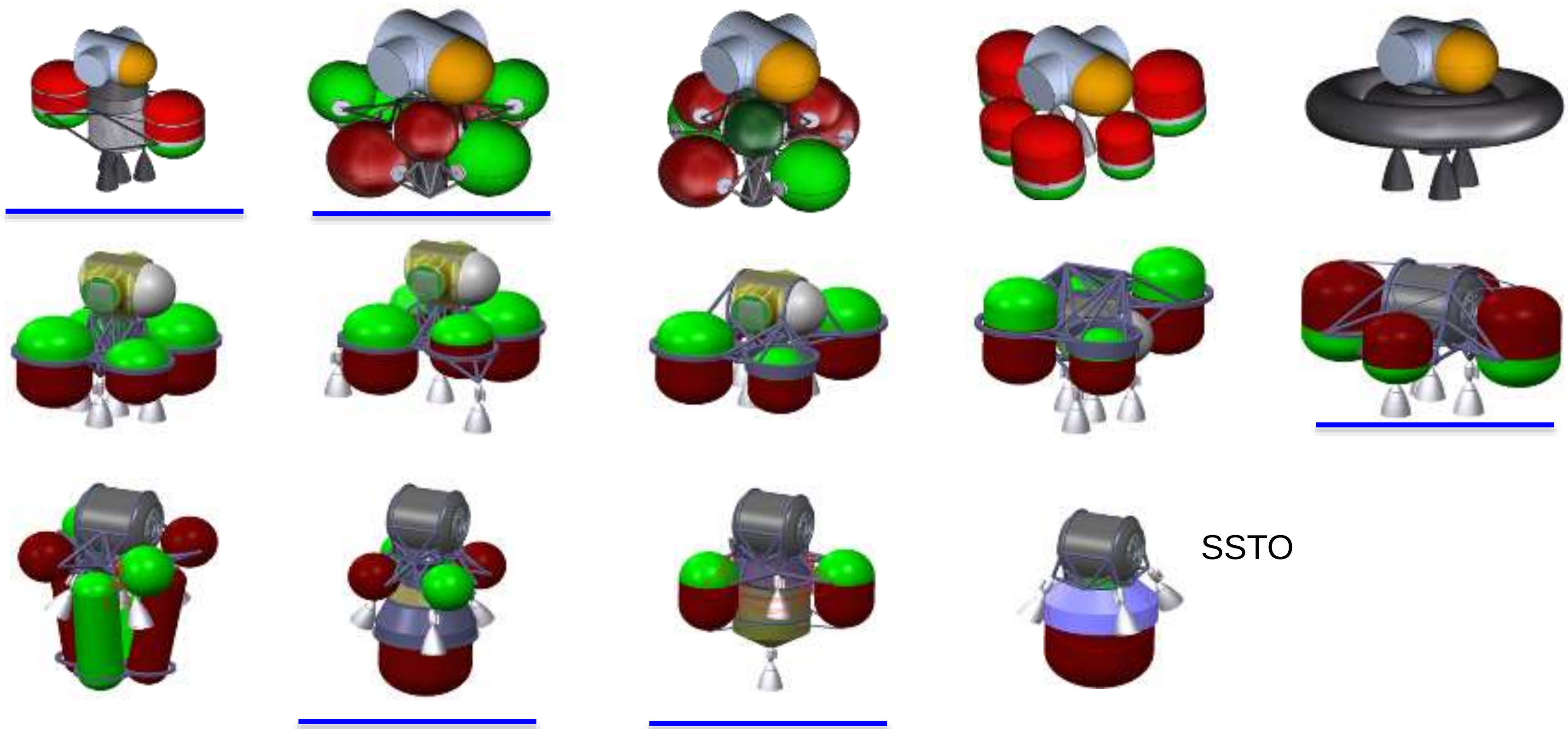




- **A horizontal orientation was chosen for the common crew cabin study because it is better suited to the pressurized rover application and recent mock up evaluations show that it can function well as an ascent cabin.**

Common Crew Cabin Configuration Trade Study

- Several propellant tank packaging options were considered. Each constrained to fit within a 10m diameter SLS fairing.
- 5 options were selected for further evaluation

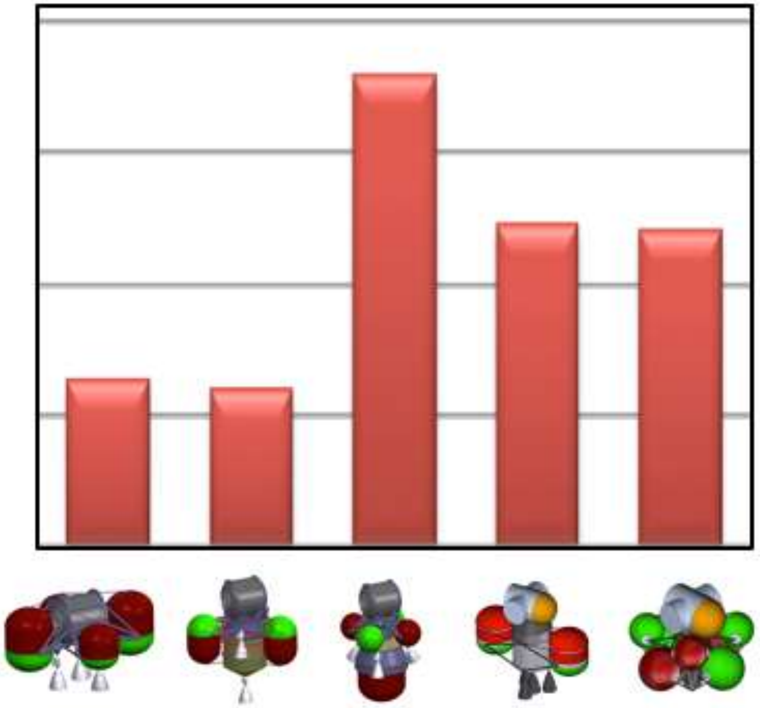


Radiators not shown

Common Crew Cabin Configuration Trade Study

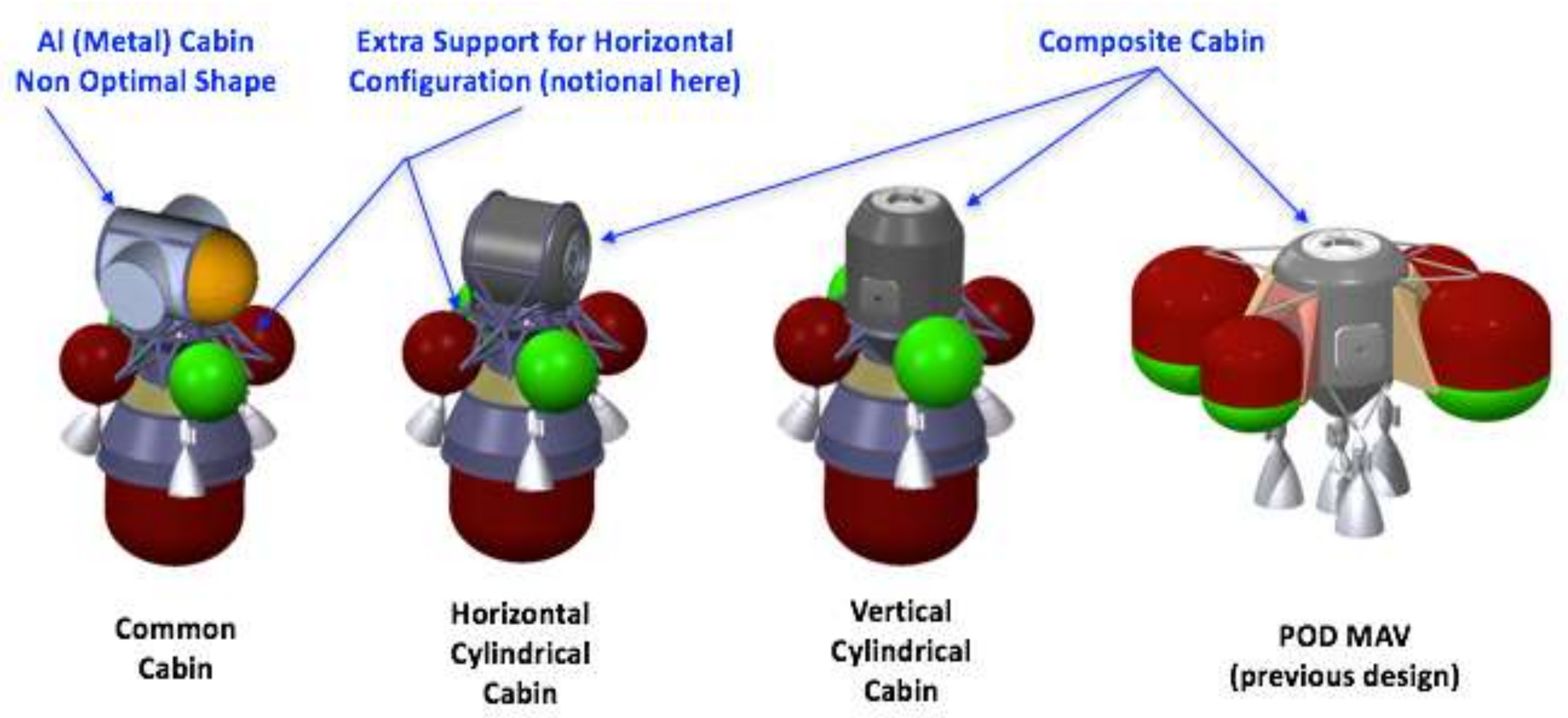
- **Concepts were ranked using the pair-wise comparison techniques of the Analytical Hierarchy Process (AHP) with equal weighting on all FOMs**

FOM	Associated Considerations
1-Structural System	mass, load path, simplicity, HMAV support structure
2-Propulsion System	mass, tank geometry and complexity, number of tanks
3-Center of Gravity	c.g. height at launch and during entry, descent, and landing
4-Deck Space	space for non MAV cargo, radiators, solar arrays, other subsystems
5-Access	crew access, accommodation of ingress/egress tunnel
6-Design Flexibility	sensitivity to future changes in requirements, ability to evolve



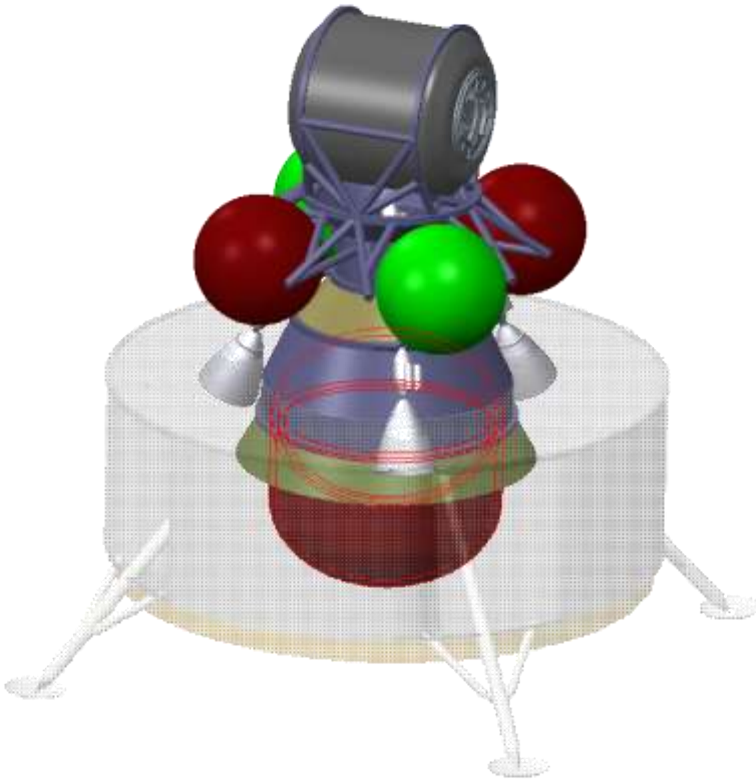
Common Crew Cabin

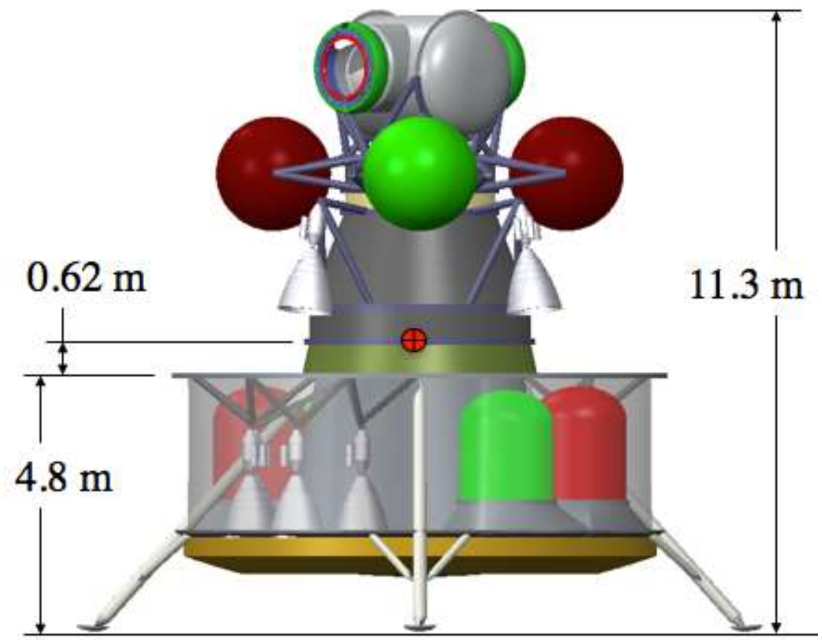
- **To fairly evaluate the effects of using a common rover-derived cabin for the MAV, several cabin geometries were assessed with the same propulsion system configuration**



Common Crew Cabin Lander Integration

- The leading MAV configuration with the common crew cabin is taller than the previous vertical cabin design.
- Crew must ascend a greater distance to ingress the vehicle.
- It appears the taller configuration allows for greater packaging volume for additional equipment around the MAV





Common Crew Cabin Structural Analysis




Structure	Common Cabin (Horizontal)	Cylindrical Cabin (Horizontal)	Cylindrical Cabin (Vertical)	Previous POD MAV
Cabin	896	*Results fall between the Common Cabin and Verical Cabin Cases (not analyzed)*	648	760
1st Stage	304		366	232
2nd Stage	313		251	127
Total (Primary)	1,513	~1,390 (estimate)	1,265	1,119
MAV Adapter	85	85	85	174

- **Comparison of MAV primary structure shows vertical crew cabin MAV to be more structurally efficient by 200-300 kg. Additional refinements of the common cabin structural design may reduce this difference.**

- **While it appears that the common cabin will result in higher MAV vehicle mass, the benefit of a common cabin development across the entire architecture may outweigh the cost in MAV performance.**

Conclusions

- **Mars ascent vehicle mass varies significantly with the target orbit, propulsion, and cabin design choices.**

- **Decisions about MAV design and performance must be considered in the context of the end to end mission architecture**
  – Choices that minimize MAV mass may result in additional mission complexity
  – Choices that result in a heavier MAV may minimize development cost across the architecture.

Questions?