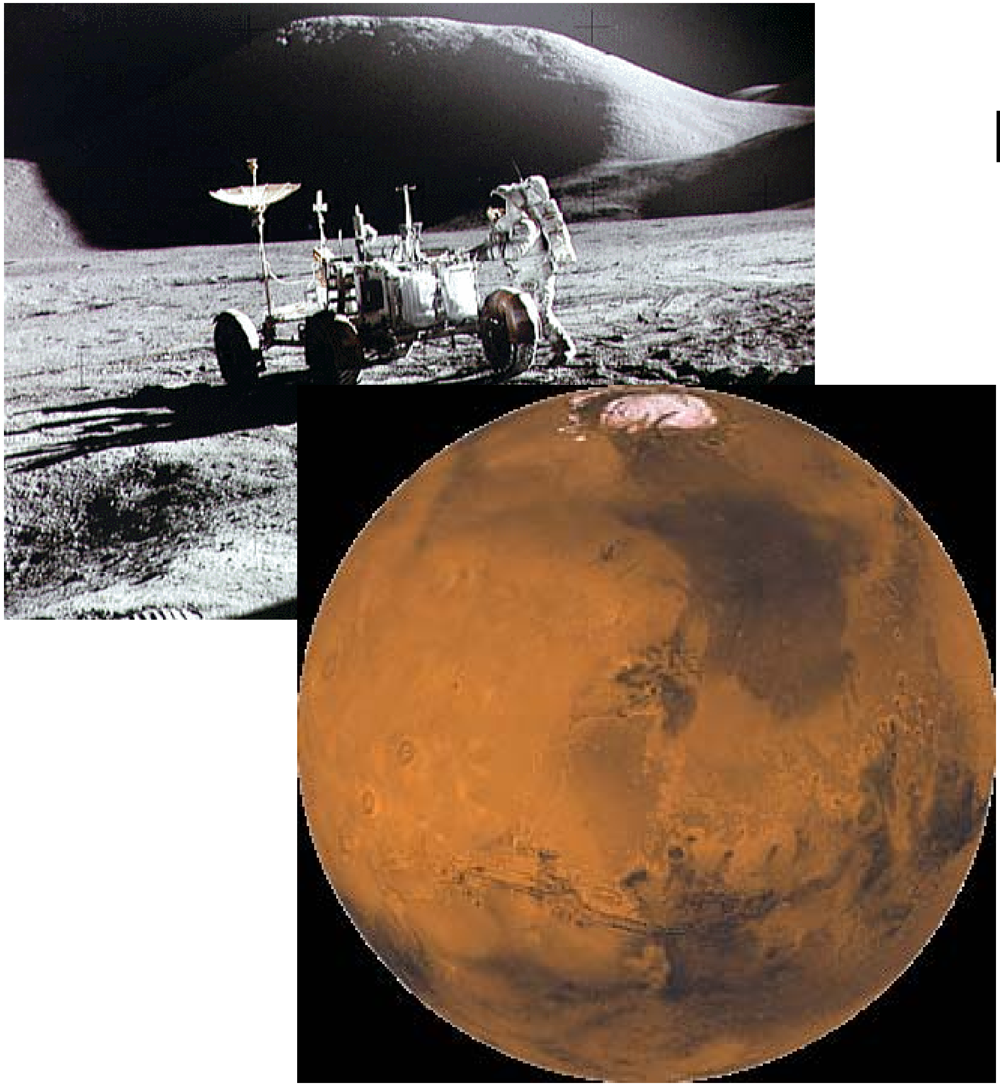


Mars-back Approach to Moon-Mars Exploration System Commonality

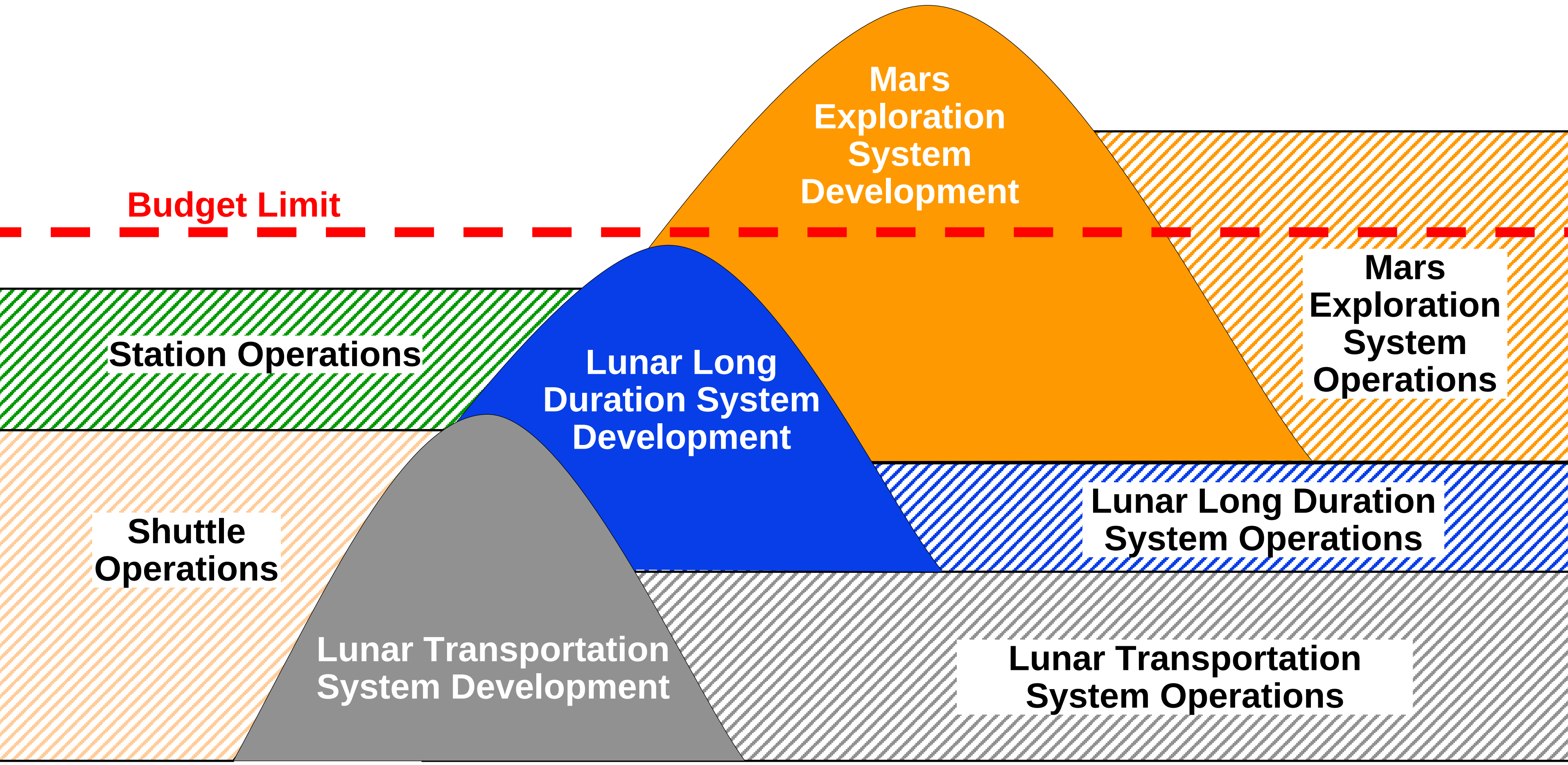
Authors:

Paul Wooster
Wilfried Hofstetter
Edward Crawley

Presentation Overview

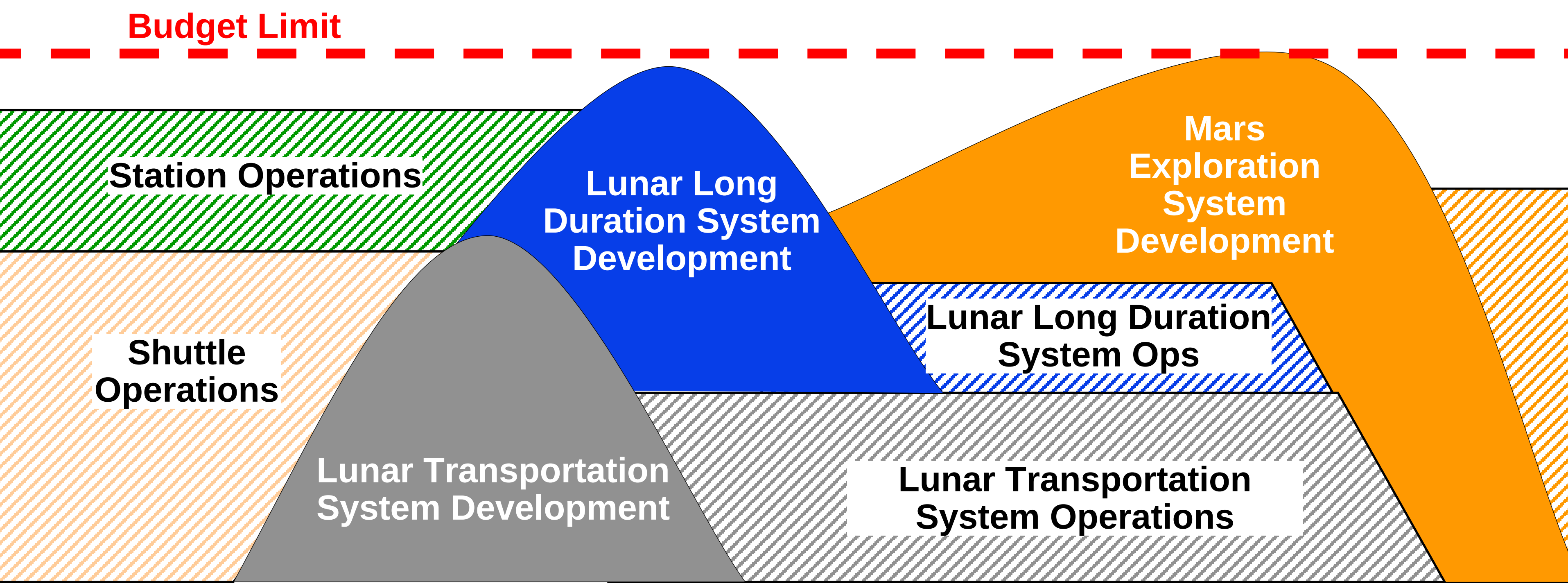
- **The Mars-Back Approach**
- **Baseline Moon-Mars Exploration System Concept**
- **Baseline Hardware Development Roadmap**
- **Conclusions**

Separate Moon and Mars Exploration Systems Notional Funding Profile, Breaking Budget Limit



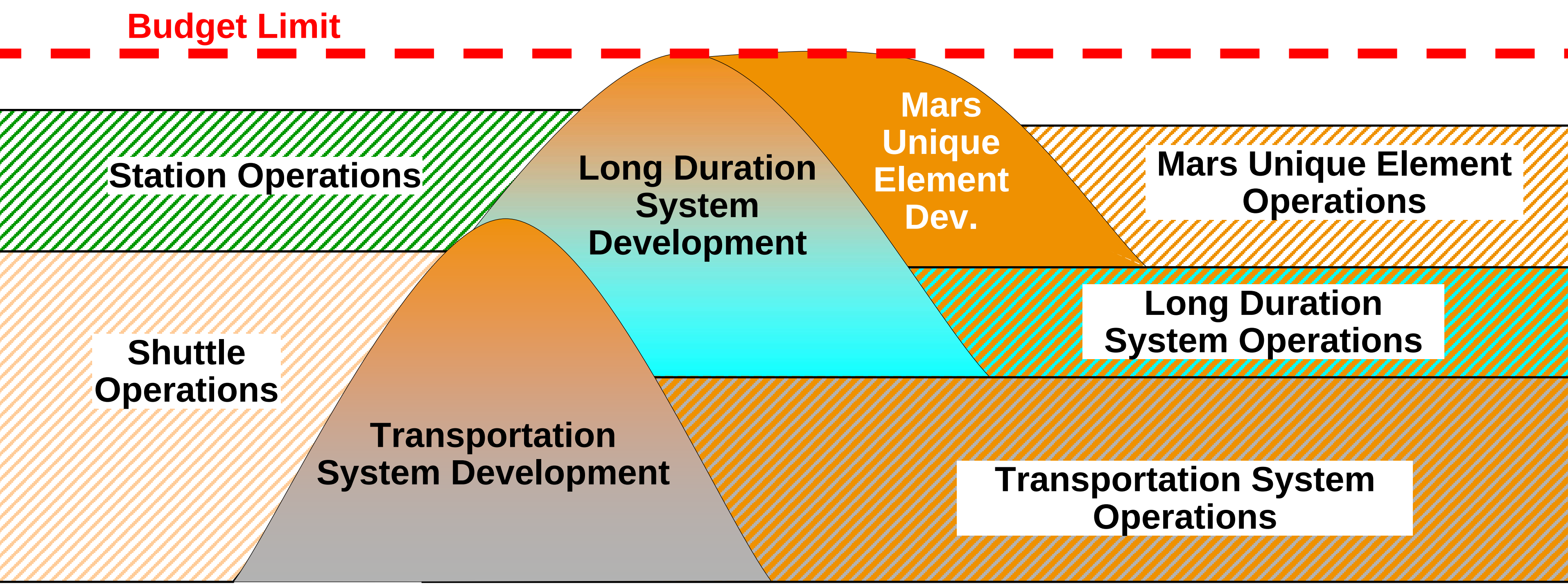
Paul Wooster
pwooster@mit.edu

Separate Moon and Mars Exploration Systems Notional Funding Profile, Meeting Budget Limit



Paul Wooster
pwooster@mit.edu

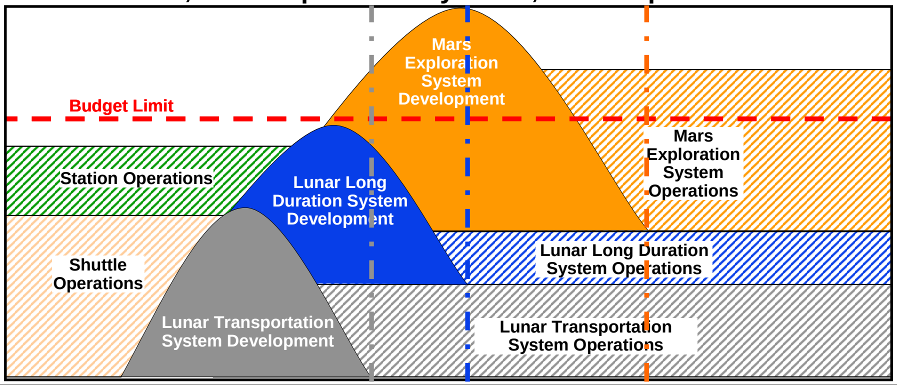
Common Moon and Mars Exploration System Notional Funding Profile, Meeting Budget Limit



Paul Wooster
pwooster@mit.edu

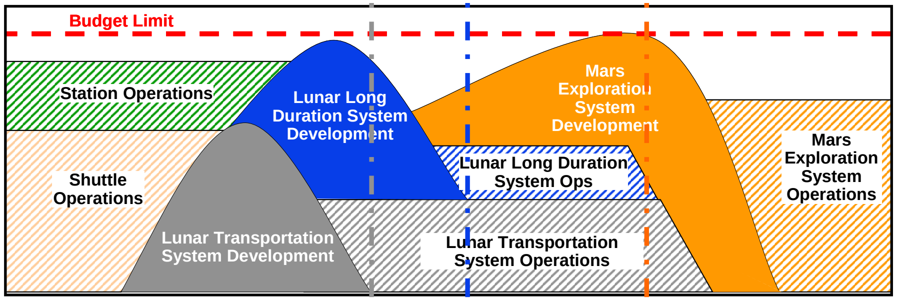
Remarks on Notional Funding Profiles

Distinct Moon, Mars Exploration Systems, Lunar Operations Maintained



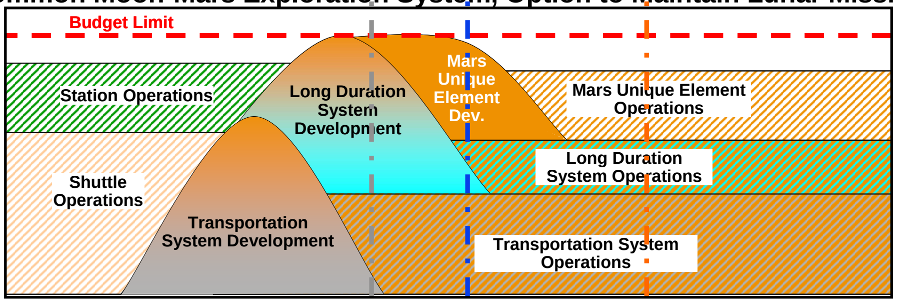
- Sequential development of unique systems for each of Moon and Mars exploration exceeds budget profile if lunar missions continue during Mars development
- Beyond the Mars development funding peak, the combined operation of both systems is likely unaffordable

Distinct Moon, Mars Exploration Systems, Lunar Missions Curtailed



- Curtailing lunar operations can lead to affordable Mars program
- This however results in a significant mission gap between lunar and Mars operations and a significant delay in initial Mars operations
- Will be very difficult to maintain public support over such long time-scales without continued visible successes

Common Moon-Mars Exploration System, Option to Maintain Lunar Missions

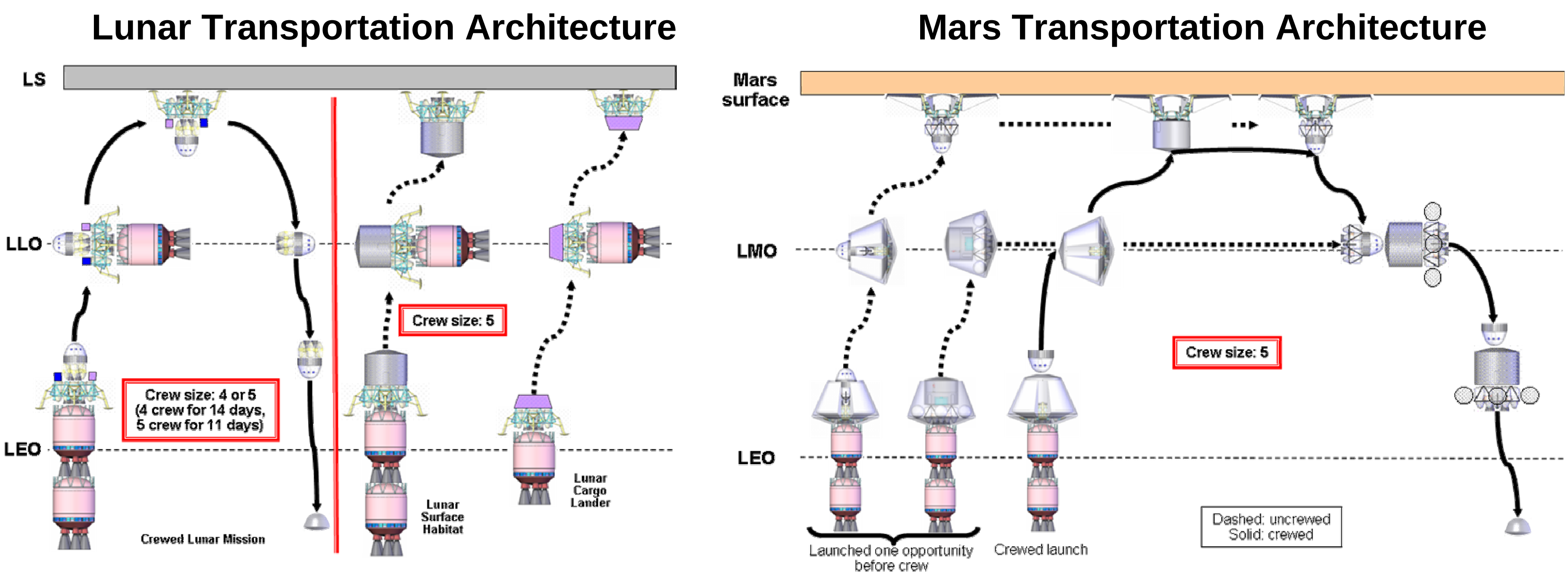


- Developing a common Moon-Mars exploration system, can meet budget, achieve Mars missions earlier than otherwise, and maintain continuous string of successes
- While not in Draper/MIT baseline campaign, option exists to continue lunar missions can continue once Mars starts as all of the assets required are still available

Mars-Back Approach Summary

- 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
  - Provide direct tie between Moon and Mars exploration in the eyes of the public and Congress

Base Moon-Mars Exploration System Commonality Concept

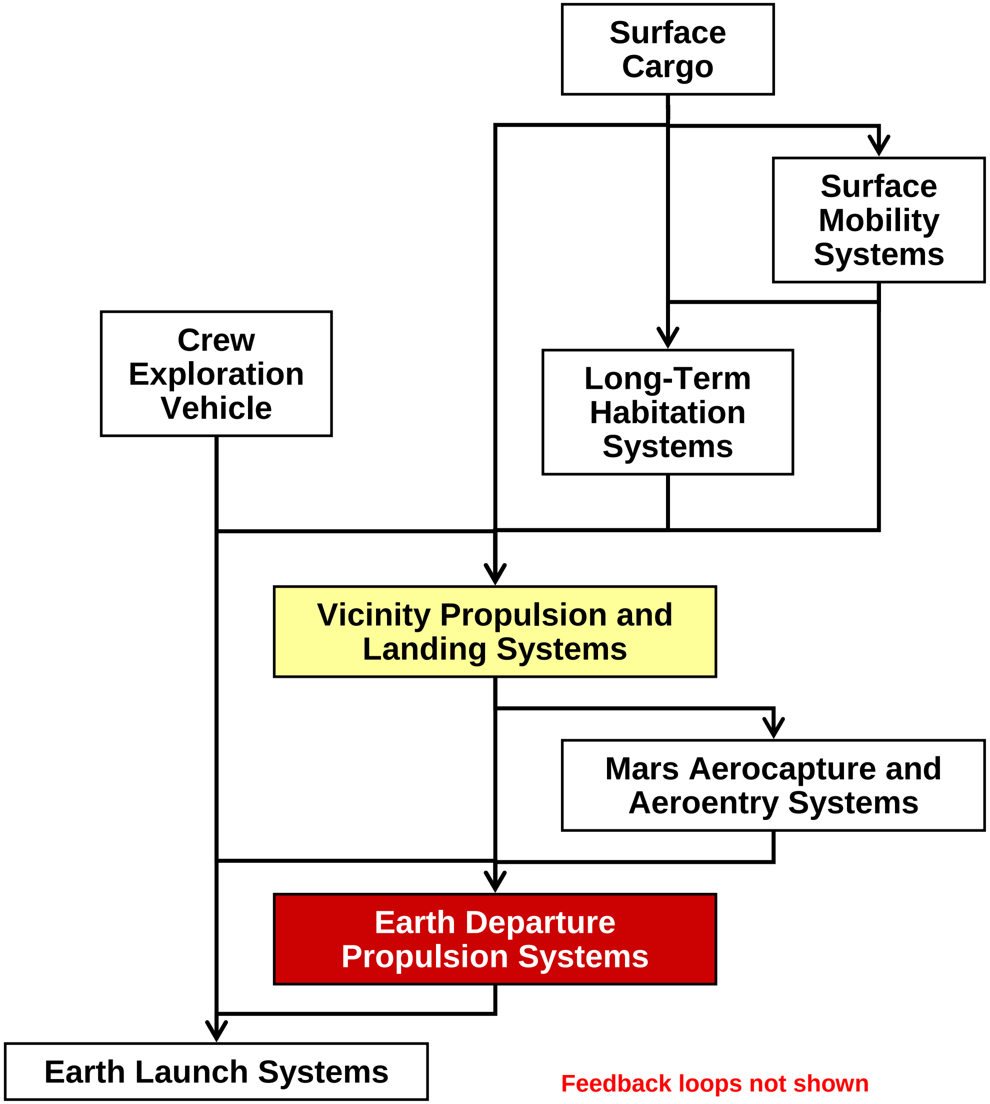


- **High-level commonality concept developed during Base Period using selected Moon and Mars architectures**
- **Commonality focused on design reuse of complete elements, with modularity in "Yellow Stage" and habitat design**
- **Develop high-level scheme to identify elements where commonality may be 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

Paul Wooster
pwooster@mit.edu

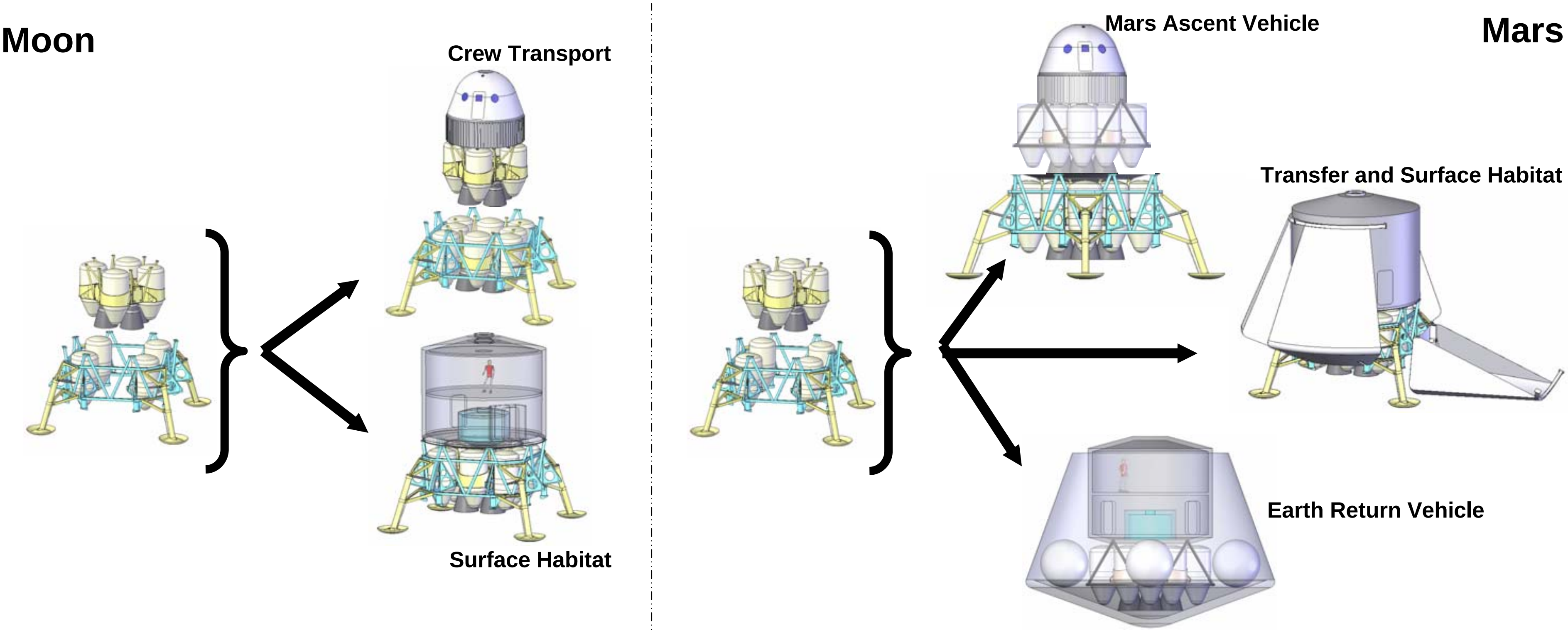
Common System Element Relationships



Feedback loops not shown

- Can decompose common Moon-Mars exploration system into elements with similar capabilities
  - Based primarily on driving requirements
- Each common element will have a series of use cases which it must support
  - e.g., CEV for ISS, Lunar Surface, Mars Crew Launch/Contingency Return, Mars Ascent/Nominal Return
  - e.g., Habitat for Lunar Surface, Mars Outbound Transfer and Surface, Mars Earth Return Vehicle
- Multiple options exist for meeting element requirements
  - Single design to fulfill all use cases
  - Modular/platform design with variants supporting one or more use cases
  - "Stretchable" design to more uniquely match particular use cases

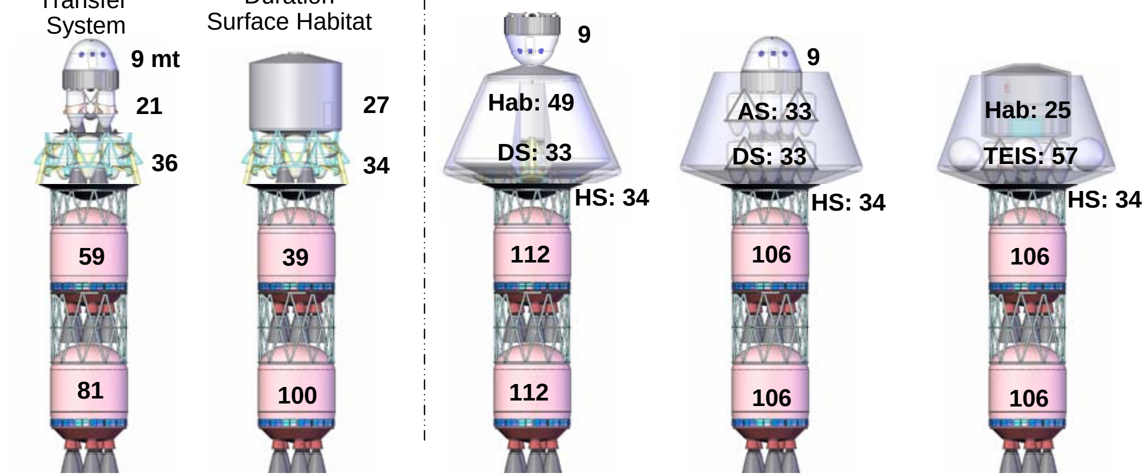
Common Destination Vicinity Propulsion System



- **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



- 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

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

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

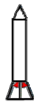
For modest mass increase, Mars-back commonality offers significant savings in development and production

Paul Wooster
pwooster@mit.edu

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:

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

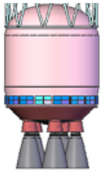
Short Lunar Mission Hardware

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

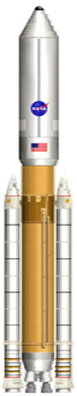
Lunar landing gear & exoskeleton:

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)

Long Lunar Mission Hardware

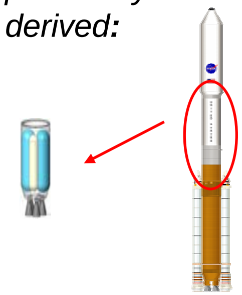
Habitat core and inflatable pressurized tent for planetary surfaces:

Mars Mission Hardware

Mars landing gear & exoskeleton:

Integrated aeroshell

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

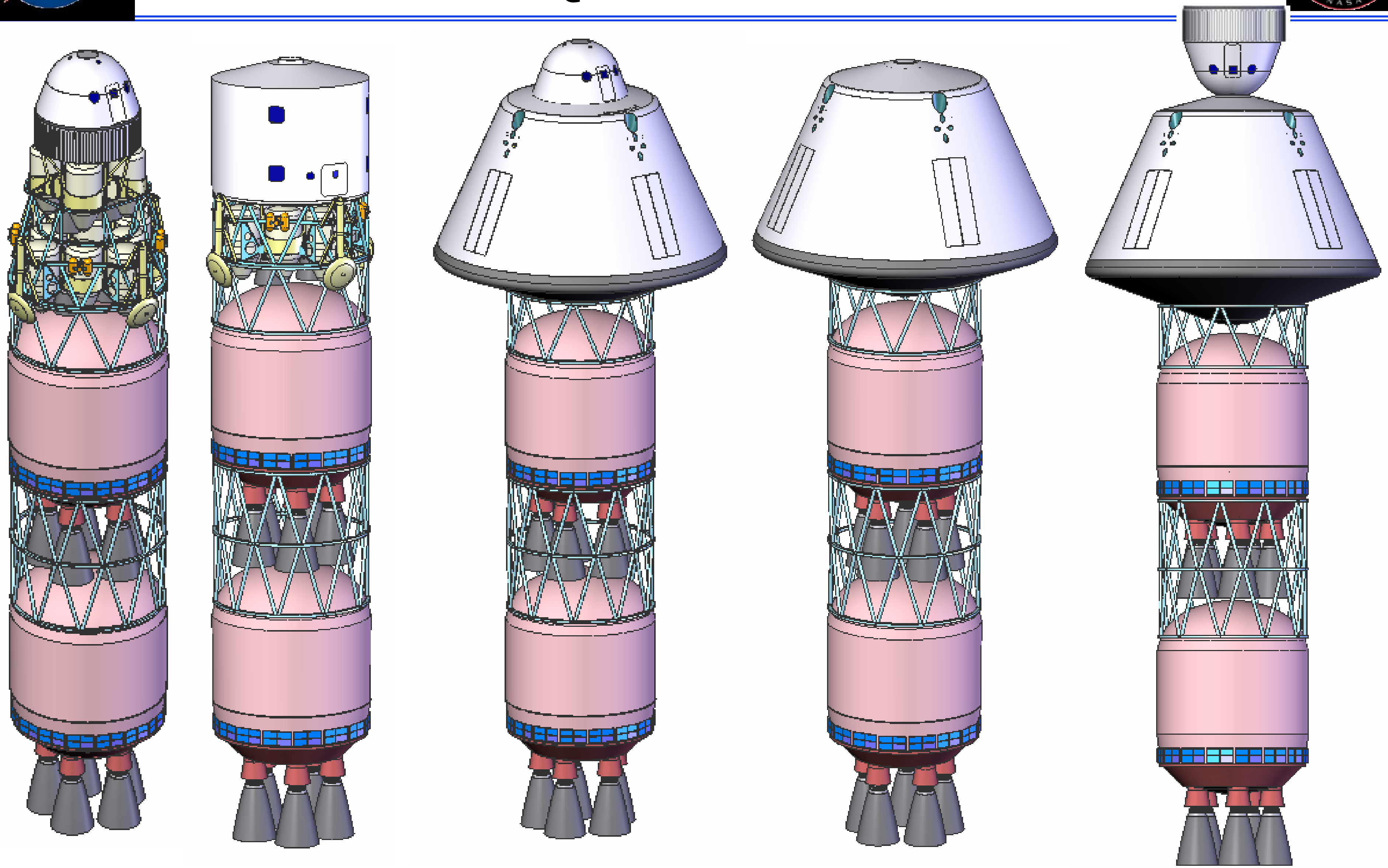


Note: Block upgrades across phases are not depicted

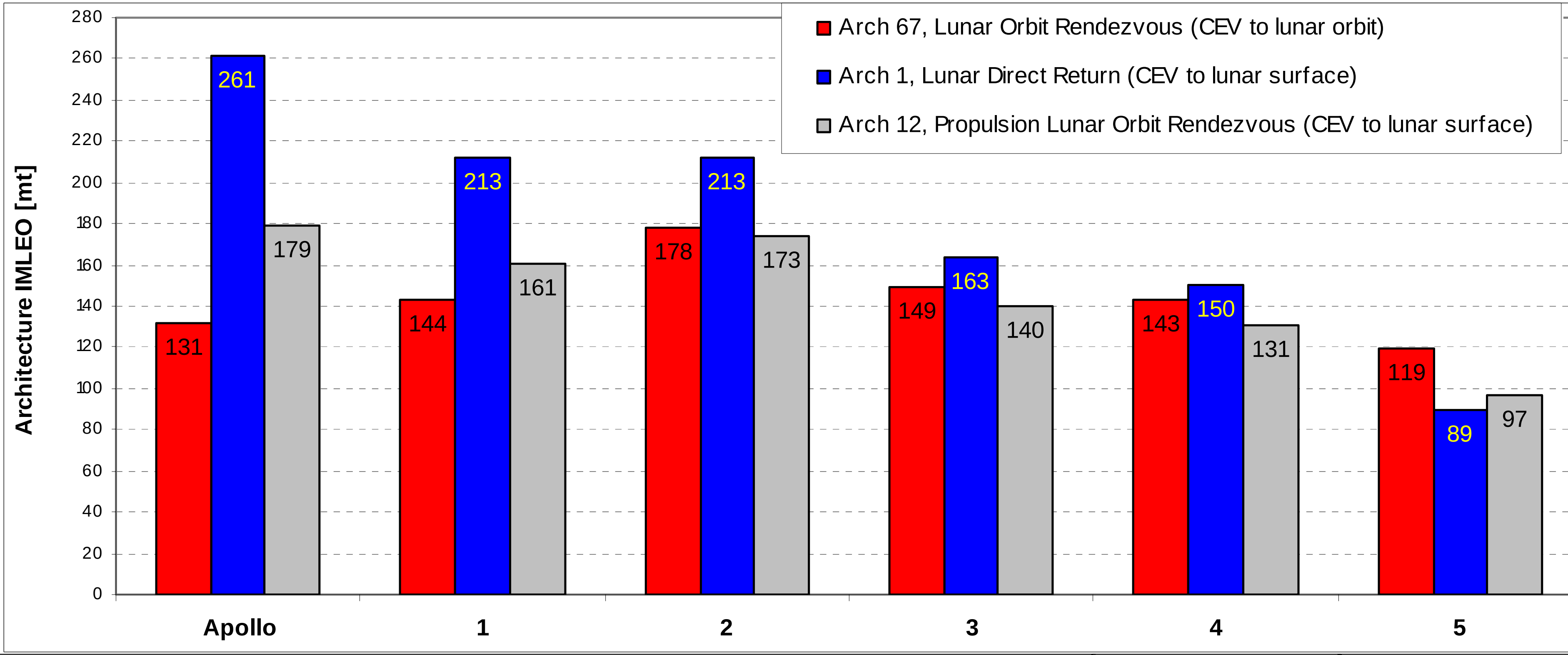
Conclusion

- Moon and Mars exploration system commonality is feasible
  - Proper selection of commonality concept and judicious application of modularity can keep performance at cost similar to point-designed systems
  - Note: While shown for one set of Moon and Mars architectures, similar approach is possible for a variety of architectural options
- Moon and Mars exploration system commonality offers significant benefits
  - Greatly accelerates onset of Mars exploration
  - Reduces or eliminates any development gap between Moon and Mars exploration
  - Allows Moon and Mars exploration to proceed simultaneously
  - Directly validates sub-set of Mars exploration elements during lunar missions
  - Significantly decreases overall lifecycle cost
  - Allows direct connection to be made between Moon and Mars exploration in the eyes of the public and Congress

Questions?

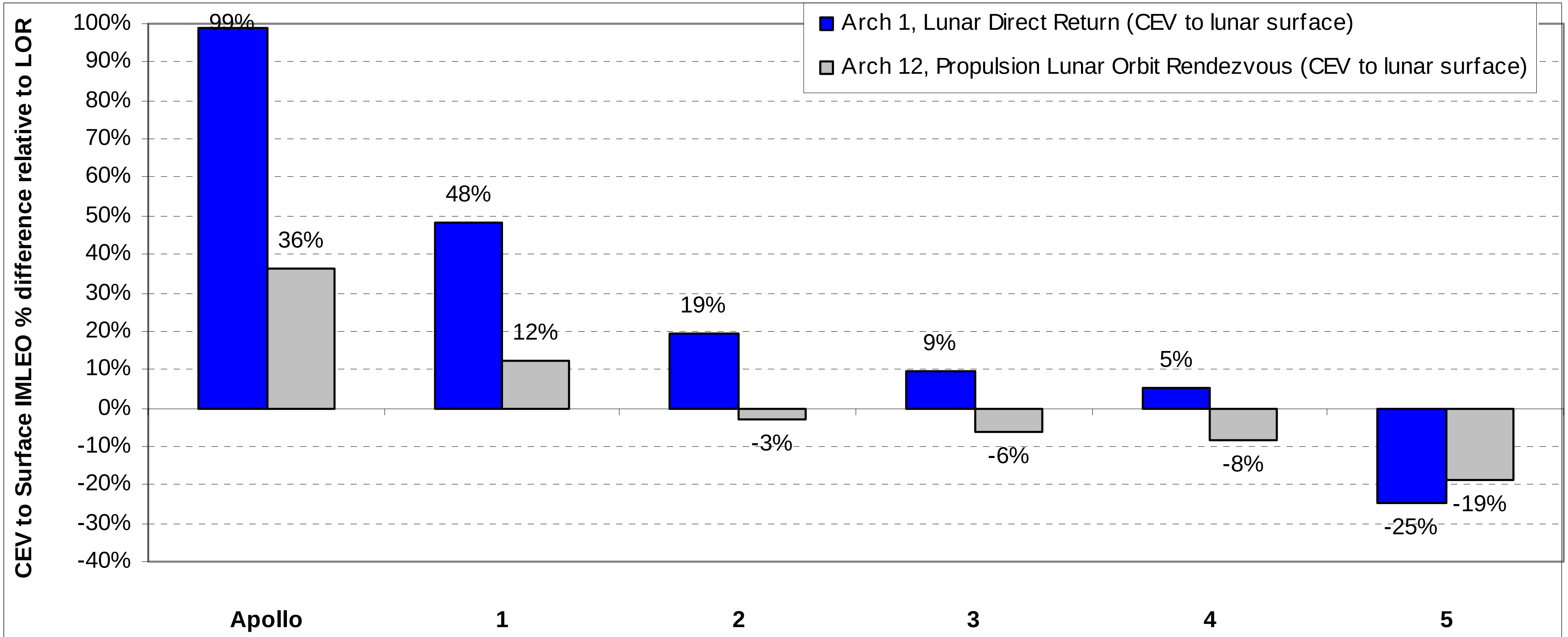


Absolute IMLEO by Lunar Architecture
O CEV 9,150 kg; LS CEV 10,050 kg; LSAM 6800 kg (all without crew)



	Apollo	1	2	3	4	5
Crew size	**3 crew, 2 to surface**	**4 crew, 4 to surface**	**4 crew, 4 to surface**	**4 crew, 4 to surface**	**4 crew, 4 to surface**	**4 crew, 4 to surface**
Propellant Type	**H_2/O_2 430 s for EDS;** **Hypergolics 311s for Asc/Dsc, 314 s elsewhere**	**H_2/O_2 460 s for EDS;** **Hypergolics 316 s elsewhere**	**H_2/O_2 460 s for EDS;** **Hypergolics 316 s elsewhere**	**H_2/O_2 460 s for EDS;** **CH_4/O_2 362 s elsewhere**	**H_2/O_2 460 s for EDS;** **H_2/O_2 430 s for Descent;** **CH_4/O_2 362 s elsewhere**	**H_2/O_2 460 s for EDS;** **H_2/O_2 430 s for Descent;** **CH_4/O_2 362 s elsewhere**
Operation Sequence	**LOI with SM / descent stage**	**LOI with EDS**	**LOI with EDS**	**LOI with EDS**	**LOI with EDS**	**LOI with EDS, ISRU oxygen for ascent**
Location	**'Near equatorial'**	**'Near equatorial'**	**Global access**	**Global access**	**Global access**	**Global access**

IMLEO % Difference relative to LOR
O CEV 9,150 kg; LS CEV 10,050 kg; LSAM 6800 kg (all without crew)



	Apollo	1	2	3	4	5
Crew size	3 crew, 2 to surface	4 crew, 4 to surface	4 crew, 4 to surface	4 crew, 4 to surface	4 crew, 4 to surface	4 crew, 4 to surface
Propellant Type	H2/O2 430 s for EDS; Hypergolics 311s for Asc/Dsc, 314 s elsewhere	H2/O2 460 s for EDS; Hypergolics 316 s elsewhere	H2/O2 460 s for EDS; Hypergolics 316 s elsewhere	H2/O2 460 s for EDS; CH4/O2 362 s elsewhere	H2/O2 460 s for EDS; H2/O2 430 s for Descent; CH4/O2 362 s elsewhere	H2/O2 460 s for EDS; H2/O2 430 s for Descent; CH4/O2 362 s elsewhere
Operation Sequence	LOI with SM / descent stage	LOI with EDS	LOI with EDS	LOI with EDS	LOI with EDS	LOI with EDS, ISRU oxygen for ascent
Location	'Near equatorial'	'Near equatorial'	Global access	Global access	Global access	Global access

Paul Wooster
pwooster@mit.edu

Enabling Alternate Missions

- Using the same commonality analysis methods utilized in design the system for human lunar and Mars exploration can allow the analysis of the applicability of the same elements to other missions
- Using our common exploration system design, we can also undertake mission to Earth-Moon and Earth-Sun Libration points and to Near-Earth Asteroids