Analysis of Alternative Architectures for Cargo Lunar Landers

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I. Abstract

NASA's Human Landing System (HLS) program has been working with commercial partners to develop human-class lunar landers to return the first American woman and next American man to the lunar surface in the mid 2020's. In an effort to expand human presence beyond low Earth orbit, NASA's Artemis program aims to facilitate a sustainable, long-term human presence in cis-lunar space. A component of this will require significant infrastructure to be delivered to the lunar surface. Delivering this infrastructure will require a significant lander capability that has yet to be developed. A thorough understanding of cargo lunar lander architectures is required such that select alternatives can be identified that best support the Artemis program's objective of sustainability. The goal of this study is to aid NASA and its partners in the understanding of the cargo lunar lander trades space, as well as identify potential robust alternatives. The results will support NASA as it moves forward with key activities such as requirements formulation, agency strategic planning, and potential cargo lunar lander procurements.

The study builds off of recent work performed by the Human Landing System program's Architecture and Systems Analysis group to encompass a broad trade space of cargo lunar lander architecture alternatives. The current trade space as depicted by the morphological matrix and mission graph in Fig. 1 and Fig. 2, respectively, includes key alternative options that have become highly relevant due to current HLS activities and include on-orbit refueling, active cryogenic fluid management, Earth orbit aggregation, and global lunar access. The authors believe that there is also a statistically relevant impact of lander-payload configuration on the primary structure of the vehicle that could greatly impact alternative selection. Because of this, several conceptual lander-payload configurations will be evaluated to determine the level of impact. The current set of conceptual configurations are shown in Fig. 3 and Fig. 4. To aid the conceptual evaluation of these configurations, a catalogue of notional payloads has been developed that represent a wide range of masses and volumes that are expected to be delivered in support of a sustained human lunar presence, including pressurized and unpressurized rovers, surface habitats, power systems, and other support infrastructure.

In order to execute this study in a timely fashion, a similar approach to that utilized in a similar 2019 study focused on 2024 human lunar sorties will be employed [1]. The team utilized a novel architecture synthesis framework currently being developed by NASA/MSFC to evaluate over 600,000 lunar lander architectures over a two month time frame [2]. From this large data set, varying ground rules and assumptions were applied as filters to explore the trade space to identify alternatives which exhibited robustness, as measured by launch vehicle payload margin, to absorb the natural growth that occurs during design maturation. The set of Earth-Moon system Delta-Vs assumed from the 2019 study, shown in Fig. 5, will be repurposed to accelerate model formulation for this effort. Additionally, current efforts in collaboration with the Georgia Institute of Technology's Aerospace System Design Lab will be integrated to provide probabilistic modeling of the cargo lunar lander architectures to aid in identifying robust design alternatives [3]. The approach will help minimize potential impacts due to large levels of uncertainty inherent to pre phase-A

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conceptual design. By leveraging these past and present studies and partnerships, a highly detailed set of data can be generated in a short time period to aid NASA in the coming years to support the goal of a sustained human lunar presence.

II. Optional Supporting Materials

A. Images, Figures, and Tables

Launch Vehicle	Launch Vehicle Termination	Initial Use Aggregation Node	Lander Elements	Lander Reusability	Propellant Supply	Recurring Reuse Aggregation Node	Propellant	Lander Payload Configuration	Cryogenic Fluid Management	Surface Location	Lunar Transfer Type
Vulcan Centaur	Sub-TLI	LV Termination	1	Expendable	No Refuel Capability	None (Expendable)	LO2/LH2 Pump-Fed	Deck	Active	South Pole	Fast Transit
Falcon 9	TLI	NRHO	2	Reusable	On-Orbit Refueling	NRHO	LO2/LCH4 Pump-Fed	Structural Tank	Passive	Global Access	Slow Transit (BLT)
Falcon Heavy		Low Lunar Orbit	3			Low Lunar Orbit	LO2/LCH4 Press-Fed	Top-Mounted Pallet			
New Glenn		Direct to the Surface				Earth Orbit	NTO/MMH Pump-Fed	Under-Slung Pallet			
Starship Cargo							NTO/MMH Press-Fed	Multi-Axis Internal Bay			
SLS Block 1 Cargo								Multi-Axis Under-Slung			
SLS Block 1B Cargo											

Fig. 1 Conceptual Trade Space.

Node	Description
1	Earth Launch Site
2	Low Earth Orbit (LEO)
3	Trans-Lunar Injection (TLI)
4	Near-Rectilinear Halo Orbit (NRHO)
5	Low Lunar Orbit (LLO)
6	Lunar Landing Site
7	Lunar Launch Site
8	Low Lunar Orbit (LLO)
9	Near-Rectilinear Halo Orbit (NRHO)
10	Trans-Earth Injection (TEI)
11	Low Earth Orbit (LEO)
12	Earth Landing Site

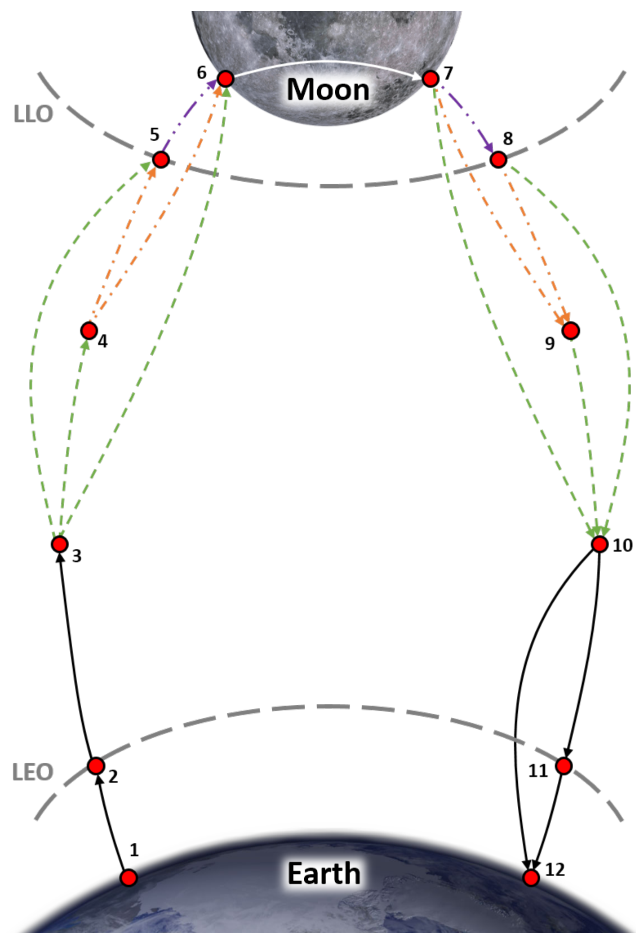

Fig. 2 Earth-Moon System Mission Graph.

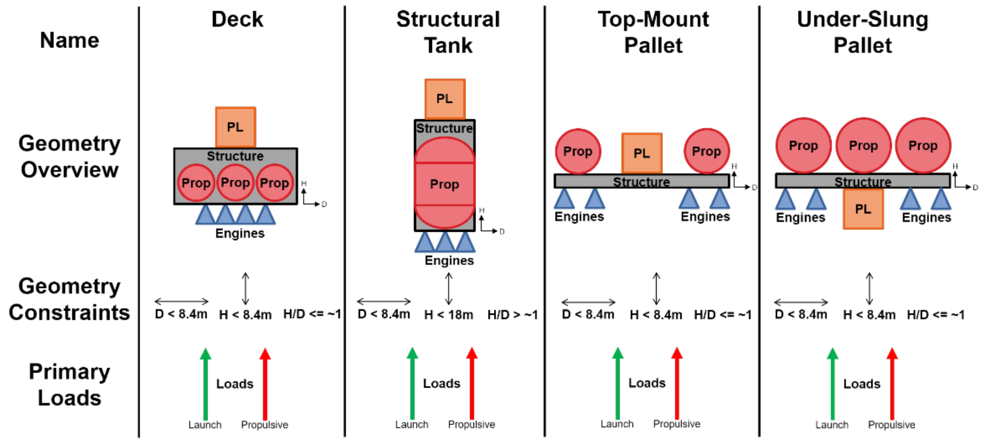

Fig. 3 Single-Axis Cargo Lander Configurations.

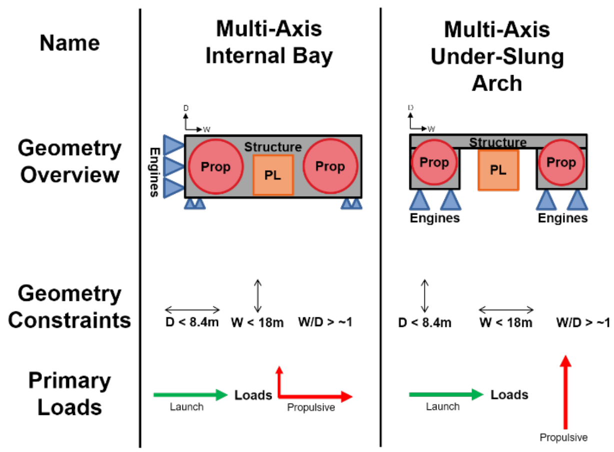

Fig. 4 Multi-Axis Cargo Lander Configurations.

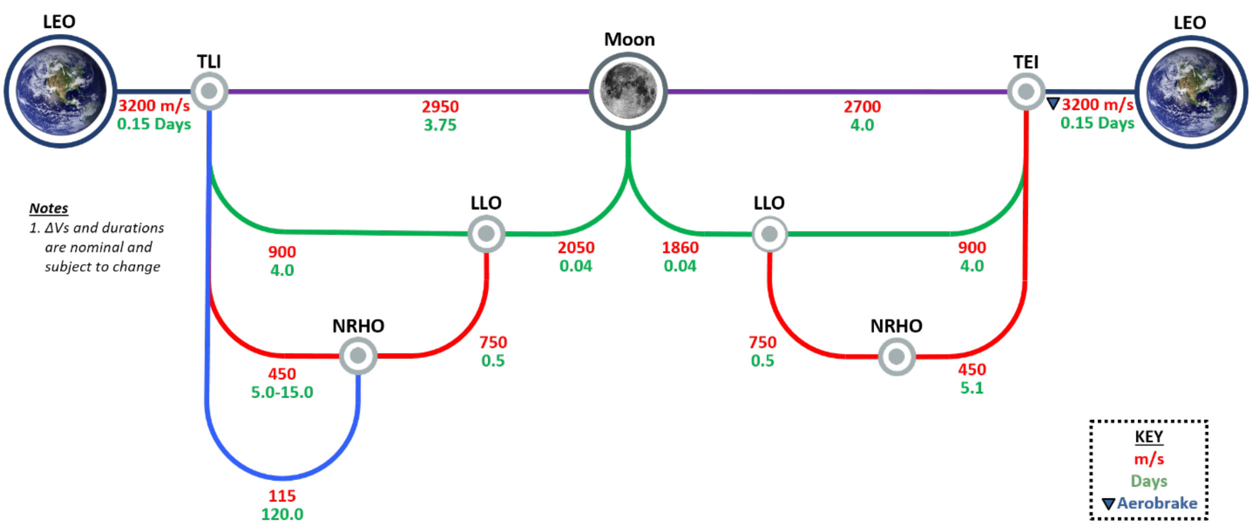

Fig. 5 Earth-Moon System Delta-V Map.

B. References

[1] Trent, D. J. and Edwards, S.J., “Analysis of Alternative Architectures for a 2024 Lunar Sortie,” AIAA ASCEND Conference, 2020. doi: 10.2514/6.2020-4087
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