Payload Sensitivities for Human Mars Exploration Transportation Systems

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I. Nomenclature

HPS	=	Hybrid Propulsion System
MCPS	=	Methane Cryogenic Propulsion Stage
NTP	=	Nuclear Thermal Propulsion
TMI	=	Trans Mars Injection
MOI	=	Mars Orbit Insertion
TEI	=	Trans Earth Injection
EOI	=	Earth Orbit Insertion

II. Introduction

NASA is continuing to investigate mission and transportation system alternatives to support human exploration of Mars. Several publications over the last few years have outlined, in detail, the baseline reference architectures under consideration. These alternatives include SEP-Chemical Hybrid Propulsion Systems, oxygen/methane propulsion stages, and nuclear thermal propulsion systems. Studies to date have focused on identifying mission architectures that leverage these different transportation options to best support a Mars mission within the context of overarching guidelines and constraints. The focus on identifying "closed" reference mission architectures for these transportation options is a key first step in comparing alternatives and supporting the development of technology investment strategies. Architecture closure implies that the architecture identified provides a viable solution which meets all constraints and closely aligns with guidelines. If a viable architecture cannot be identified for a given transportation option, there is no need to continue investigating that option. However, at this early stage of architecture development, metrics of comparison should look beyond how these architectures perform relative to the baseline reference mission. Architectural robustness, or an insensitivity to requirements drift, should also be considered in any comparison of architectures. At this early stage of design, mission requirements have the potential to change as more definition is provided and more analyses are completed. Particularly in relation to the mass of transported elements, including Mars landers and crew habitat, it is recognized that as designs for these elements mature there exists the potential for mass growth. Selection of an architecture alternative carries with it programmatic risks and relative sensitivity to mass growth can provide insight into a particular architecture option's risk of being unable to complete its mission without significant redesign as more element definition is provided. This paper outlines the current understanding of the sensitivity of various transportation architectures to payload mass growth for both crew and cargo delivery missions.

III. Vehicle & Mission Design

Several different transportation architecture options are currently being considered in NASA's human Mars exploration trade space. In all cases, reference mission and vehicle design points have been established. The element reference designs have been developed through bottoms-up conceptual design processes involving engineers from across the agency. Many of these efforts have been the subject of previous publications including the MCPS design

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(AIAA Space 2016), the Hybrid Spacecraft design (AIAA Space 2015, 2016, 2017), and the NTP vehicle (AIAA Space 2018). A brief overview of the designs and associated architectures is provided here for quick reference.

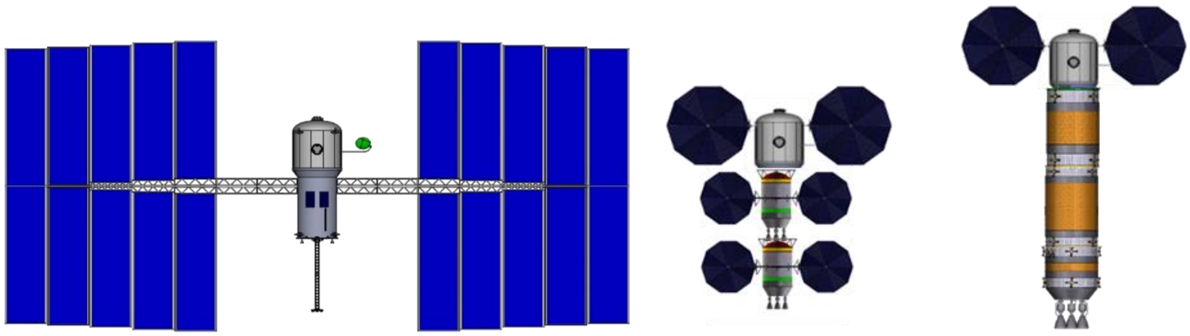

Fig. 1 Transportation Options under consideration for Human Mars exploration missions include SEP Hybrid Spacecraft, Lox/LCH4 Chemical Stages, and Nuclear Thermal Propulsion elements.

IV. Vehicle Payload Sensitivity

The vehicle concepts currently under investigation for Human Mars exploration missions vary greatly both in design and performance. Chemical propulsion options provide high thrust that supports impulsive trajectories but at lower specific impulse. Nuclear thermal options offer the same high thrust as chemical propulsion systems but at higher specific impulse. To achieve this higher specific impulse, nuclear engines are employed which increases vehicle inert mass when compared to comparable chemical systems. Hybrid spacecraft employ a novel combination of chemical and electric propulsion which opens up an entirely new set of interplanetary trajectories. Spacecraft employing only electric propulsion for cargo delivery follow more traditional low-thrust mission profiles. These differences in vehicle and trajectory design complicate the comparison of these options and make it difficult to hypothesize the relative sensitivity to payload growth among these various designs. Therefore, for each architecture within the context of the baseline mission design, a sensitivity analysis has been performed to identify sensitivity to mass growth of both the crew habitation module and the Mars lander designs currently under consideration.

A. Crew Habitat Mass Sensitivity

The crew habitation element for the Deep Space Transport system is currently envisioned to support a crew of 4 for 1200 days of operation. The habitat has a base mass of ~20t with another 20t – 22t of logistics and spares added for each trip. Logistics profiles, habitat outfitting, and subsystem design are all still open variables in the habitat design making sensitivity to habitat mass growth an important indicator of architectural robustness.

The sensitivity of the Hybrid Propulsion system to crew habitat mass was the subject of a paper at AIAA Space 2017 (Chai, et. al). With SEP-based propulsion systems, increases in payload mass can impact both the power required to operate the SEP system and the overall mass of the SEP spacecraft. This is reflected in the results for the SEP Hybrid spacecraft analysis where payload impacts are quantified both in terms of spacecraft power and spacecraft mass.

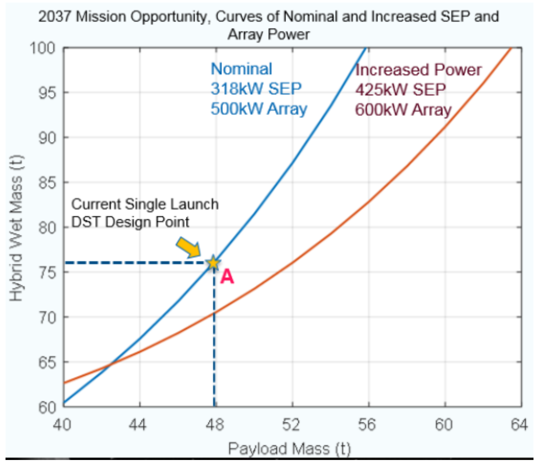

Fig. 2 Habitat mass sensitivity for the Hybrid Spacecraft.

B. Cargo Mass Sensitivity

Several Mars lander concepts are currently under consideration. Several factors impact the mass of these elements however the most distinguishing feature of the landers is the choice of aero-decelerator. Several options employ deployable structures while others take on the more traditional capsule or lifting body shapes. The baseline lander concepts range in mass from 50t - 70t. Payload sensitivity analysis takes on two rolls when considering delivery of these lander concepts to Mars. For any one concept, mass growth as the design matures is likely. Additionally, by evaluating the various architecture concepts across a wide range of potential payload values, robustness to lander concept selection can also be evaluated.

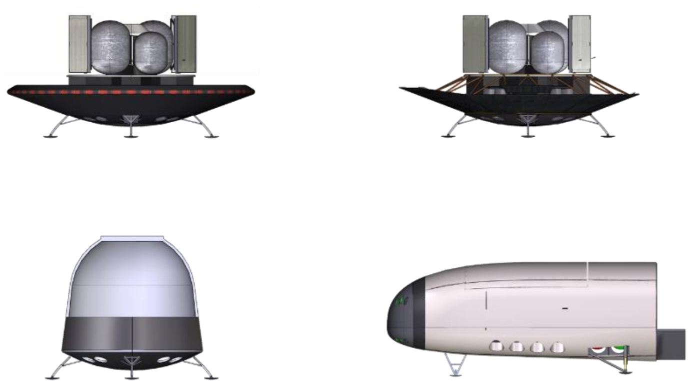

Fig. 3 Lander concepts for Mars exploration including the HIAD and ADEPT deployable concepts, the capsule concept, and the Mid L/D concept.

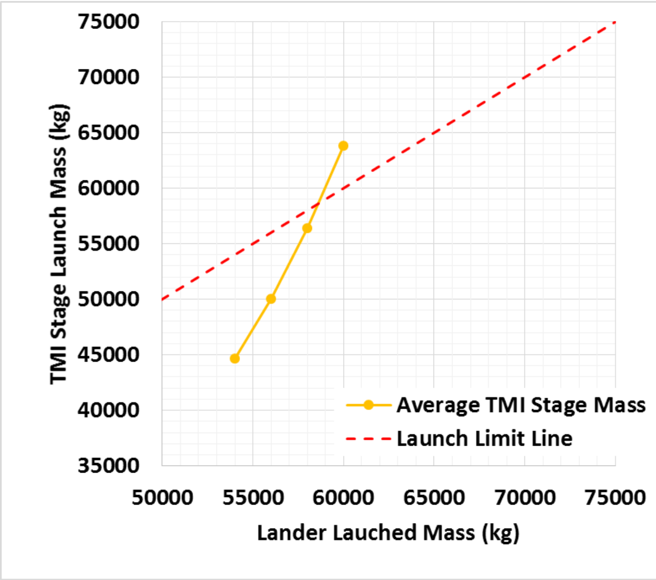

Fig. 4 Sensitivity of MCPS TMI stage mass to Lander Mass Growth.

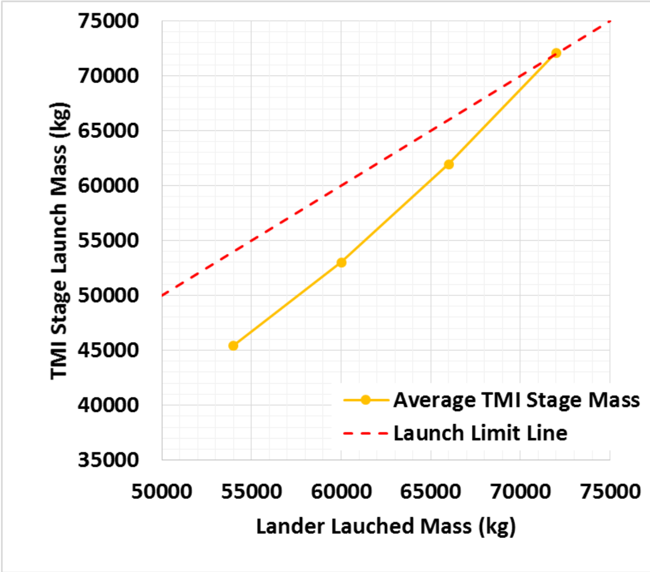

Fig. 5 Sensitivity of NTP Core Stage mass to Lander Mass Growth.

V. Conclusion

VI. Appendix

VII. Acknowledgments

VIII. References

[ref_hdt_1] Battin, R. H., *An Introduction to the Mathematics and Methods of Astrodynamics*, AIAA, Inc., New York, NY, 1987.
[ref_hdt_2] ??? MAnE reference ??? .