Achieving a Human Mars Exploration Capability with Minimal Launch Site Ground Systems Architecture.
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Introduction: The mission architecture required for a Mars human exploration campaign needs to include a vision for launch site architecture. Multi-launch campaigns utilizing the Space Launch System (SLS) and launching from Kennedy Space Center (KSC) will provide a number of challenges for both ground and flight systems with respect to the infrastructure required for pre-flight launch processing. A high level summary of these considerations is provided below.

Launch manifest and the effects of launch spacing on ground systems:

Ground system architecture philosophy to support launch manifest: The current KSC ground system infrastructure is a "single string" architecture being designed to meet a steady state launch rate of two SLS vehicles per year and a 120 day launch-to-launch turnaround (with up to three launches in a given year)[1][2]. The ground architecture includes:

- One Mobile Launcher (ML) and crawler dedicated for SLS integration, pad delivery, and launch
- One Vehicle Assembly Building (VAB) test cell for vehicle integration and preparation
- A single LC-39 launch pad, tied to one Launch Control Center (LCC) firing room

While a particular Mars Design Reference Mission (DRM) can be analyzed to understand operational efficiencies and workforce approaches that could increase launch rate capabilities, the possibility of aligning a Mars human exploration campaign manifest with currently expected launch site capabilities may reduce new and recurrent launch site costs.

Previous analysis: Previous Mars campaign analyses performed for Constellation identified key single string assets which would likely require redundancy in order to ensure a launch site capability that could meet an acceptable predicted launch availability mark [3] (Note: Analysis based on NASA Design Reference Architecture 5.0, Nuclear Thermal Rocket (NTR) Reference). While portions of this analysis may be adaptable for use considering the current capability driven framework, an initial concept of the proposed manifest, along with the extent of its dependency on SLS vehicles versus possible commercial and international partner participation, would need to be understood in order to identify a new launch site concept of operations as well as possible impacts to the current ground architecture plan.

Launch rate and launch spacing effects on ground system architecture: Spacing between consecutive launches, as well as launch rate fluctuations, can have significant effects on the launch site concept of operations and associated ground systems architecture. Minimizing large workforce variations associated with launch rate spikes and gaps helps to maintain the launch team's ability to consistently meet launch spacing challenges. Mission planning, to the extent practical, needs to take into account early on the minimum launch-to-launch spacing of a human Mars exploration campaign in order to minimize the need for additional ground system/facility assets required to eliminate resource bottlenecks between two or more mission processing flows. For example, launch vehicle integration tasks that require a mobile launcher (ML) cannot occur until the ML is available and readied following the previous launch.

Launch availability considerations for launch spacing: A Mars human exploration launch campaign manifest may need to include consideration of historical, seasonal variations in launch availability when planning launch spacing in order to increase the likelihood of mission success.

Subsequent effects of constrained launch spacing:

Increased launch spacing effects on vehicle/spacecraft reliability: Increased launch spacing, whether due to ground system constraints or not, may increase flight hardware reliability demands due to longer loiter durations. However, as launch spacing decreases, in order to maintain acceptable launch availability, hardware reliability may need to increase to mitigate the likelihood of launch delays associated with hardware issue resolution. Further work may be required to trade this relationship.

Increased launch spacing effects on vehicle/spacecraft availability: Hardware availability for pre-launch multi-element integrated testing (MEIT), if required for interfacing elements that may not meet again until on orbit or at Mars, may be a challenge for element providers if on-dock dates for supporting elements occur earlier from their particular launch dates than might be normally expected for single launch missions. Anticipated MEIT element hardware/software fidelity needs to be considered for developing a comprehensive test strategy. The approach to hardware availability versus fidelity may depend on the extent of and method used to accomplish multi-element testing.

Other ground system considerations for vehicle/spacecraft design:

Ground system size and weight constraints: The dimensions of launch vehicles and spacecraft, as well as overall launch vehicle weight should be considered with respect to launch site ground system constraints. For example, the VAB has limitations on crane hook height for launch vehicle core segment handling, and has an overall height constraint that requires consideration of the vehicle and mobile launcher combined. Mobile launcher, crawler, and crawlerway designs need to support overall vehicle weight. Current payload fairing processing and encapsulation capabilities should be considered when determining fairing height and diameter to reduce the possibility of needing a new/modified facility due to current limitations on door sizes, floor space for fairing sector rotation, and crane hook maximum heights.

Transportation constraints: Physical constraints exist for transporting large payloads and other flight structures (on the order of 10m diameter) to the launch site. Currently, the only viable transportation method is via waterways. This increases transport timelines, delivery schedule risk, and launch site processing durations if any dis-assembly is required to ship. Portability/modularity or the possibility of on- or near-site manufacturing should be considered.

Commodity servicing constraints: Due to inherent constraints of existing/planned ground systems, serviceable commodity requirements need to be identified early in order to understand possible impacts to current storage and delivery capabilities (particularly for extensive cryogenic propellant servicing just prior to launch).

Sensitive material constraints: The inclusion of fissionable material handling at the launch site, whether for NTR stages or for a Mars surface power production payload, need to be identified in order to determine the need for a designated processing facility and/or additional safeguards.

Summary: To successfully minimize the launch site ground system architecture, mission planning and hardware designs for a Mars human exploration campaign should, when practical within mission and technical constraints, attempt to align requirements with planned launch site capabilities, constraints, and sensitivities. In particular, the early establishment of a minimum launch-to-launch spacing requirement will help identify key ground system development needs.

References:

[1] J. Madden and J. Graeber (2011) *21st Century Ground Systems Program Architectures and Concept of Operations Document (21CGS-ACO-1010)*, 36-40,48. [2] H. Grant (2011) *ESMD/SOMD Human Exploration Capabilities Requirements (ESMD-HEC.Reqt-6.2011)*, 9. [3] G. Cates (2010) *Mars Architecture Discrete Event Simulation (DES) Analysis*, 9-14.