Lunar Landing and Launch Pad Construction: Concepts and Criteria

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INTRODUCTION

In 2017, Space Policy Directive–1 was issued to ensure that "the United States will lead the return of humans to the Moon for long-term exploration and utilization" and engage the National Aeronautics and Space Administration (NASA) in the national effort (The President, 2017). A long-term presence on the Moon will require numerous lunar landings and launches to build up surface assets, rotate crew, and deliver logistics supplies to/from the moon. Interactions between landing/launch rocket engine plumes and the unprepared lunar surface will lead to erosion and ejection of regolith particles at high velocities from beneath the vehicle. The associated ejecta elevates mission risks by: obscuring sensors and human vision during landing via lofted dust; cratering/modifying the surface that the vehicle will land upon; and subjecting the vehicle, surrounding assets, and potentially orbital assets to impacts and contamination from high velocity dust particles. The construction of a reusable landing/launch pad infrastructure is a method to mitigate such risks. A landing/launch pad system can provide a known, benign and reliable landing/launch surface, minimize regolith ejecta, and protect surrounding assets from liberated particles. Associated blast barriers can provide protection in case of a landing/launch catastrophic anomaly. This paper summarizes previous work towards construction of off-Earth landing/launch pad infrastructure and begins to identify key technology gaps. Additionally, this paper establishes metrics for comparison of pad construction technologies to guide future trade studies. The overall objective of this paper is to baseline the state of the art of off-Earth landing/launch pad construction technologies and serve as the starting point for further technical development.

There are four main objectives of this study: 1) To establish the state of the art in LLP construction methodologies. 2) To propose criteria for trade studies of LLP concepts. 3) To publicly share the authors' ideas for potential LLP solutions. 4) To serve as the starting point for future development of LLP technologies.

Establishing the state of the art in the area of off-Earth Launch & Landing Pad concepts will baseline the work that has been completed thus far and highlight the wide span between current Technology Readiness Levels (TRLs) and operational readiness. The authors aim to communicate the need for funding in this area in the near term by illustrating that there is much work to be completed before a truly viable option exists.

Setting forth criteria for trade studies of LLP concepts is important for several reasons. The first and most straightforward is to establish a framework for performing trade studies on LLP concepts. This will enable NASA to select the most promising concepts for continued development, and it will also help technology developers understand how their concepts compare with others and the priorities of development efforts.

Publicly sharing Swamp Work's ideas for LLP solutions serves two purposes. The first is providing insight into the concepts that are being considered internally at NASA. If concepts exist that are not under consideration, we would like to be informed of them. Secondly, presenting LLP concepts in this way will broaden researchers' perspectives on the topic, encourage public debate, trigger new ideas, and stimulate innovation.

TRADE STUDY CRITERIA

One of the primary objectives of this study is to establish key criteria for use in comparing Launch/Landing Pad (LLP) concepts and assessing suitability for specific surface architectures. Additionally, these criteria are intended to provide guidance to future LLP technology development efforts by identifying what concept attributes should be explored and quantified when possible. The vision is to eventually produce a trade matrix with data supporting the performance of each concept in each of the criterion. Trade matrix data gaps in high potential LLP concepts will be considered higher priority for future funding. It should be noted that specific architectures will weigh each criterion differently when comparing concepts. Lander size/configuration, number of required launches/landings, location and other factors could dramatically change the requirements for LLPs.

The construction process is divided into 3 phases: 1) Preparation and Staging, 2) Construction and 3) Operations and Maintenance. Table 1 displays each phase and its list of criteria. The Preparation and Staging Phase includes all preliminary work necessary to begin construction. Examples include mining/excavation, comminution, beneficiation, processing raw materials into construction feedstock, surface preparation, staging of materials and systems, and others. One of the most impactful trade is the origin of the materials (Earth based vs. Moon based), the associated up-mass, and the condition of the materials upon arrival at the construction site. The ratio of imported/lunar components will define the amount of power and the equipment necessary for placement into service. This includes sourcing the feedstock from lunar resources as well as the power to convert the feedstock into the end product.

Table 1. Key Trade Study Criteria for LLP Concepts

Preparation and Staging Phase	Construction Phase	Operations and Maintenance Phase
Up-Mass of Construction Materials and Systems	Constructability	Performance as a Landing/Launch Surface
Difficulty of Insitu Materials Collection, Handling, and Processing	Versatility	Expected Life
Effort of Site Preparation/Staging Time	Construction Time	Ease of Repairability
Reliance on other Surface Assets	Reliance on other Surface Assets	Reliance on Lunar, Gateway and Earth Crew Interaction
Reliance on Lunar, Gateway and Earth Crew Interaction	Reliance on Lunar, Gateway and Earth Crew Interaction	Robotics and Autonomy
Robotics and Autonomy	Robotics and Autonomy	Required Power
Robustness of process	Robustness of process	Lifecycle cost
Current Technology Readiness Level	Current Technology Readiness Level	
Required Power	Required Power	
	Ability to Verify As-Built Performance	

LANDING/LAUNCH PAD CONCEPTS

Proposed landing and launch pad concepts span a wide range of methods and components. For the purposes of this study LLP components include a central impenetrable zone for nominal landings and launches, an outer perimeter for off-nominal landings and dust mitigation, and barriers to mitigate blast ejecta and blast impingement. Subsystems like power, communications, fueling and other Surface Support Equipment (SSE) that are required for a full Launch & Landing Complex are out of scope for this paper. There are many concepts for construction of LLPs with a great deal of variation in maturity. This study attempts to establish a listing of all LLP construction concepts to date surveyed by the authors. Some concepts are simply ideas, others have undergone some development. Each LLP construction concept is briefly discussed below. The list represents concepts generated by the authors and prior art. Where prior art exists the authors are referenced. We envision that this list will grow over time as new LLP concepts are identified and explored. In a trade matrix, each concept below represents a row against which performance criteria are assessed in the columns of the matrix. In the future, another dimension in the trade matrix may be required to assess each construction concept for use in the LLP central zone, perimeter and barriers.

Table 2. Launch and Landing Pad Concepts

LLP Structure Concepts
Minimal Preparation
Existing Topography
Compacted Regolith Surface
Bedrock Surface
Ice Surface
Rock Piles
Surface Stabilization Applications
Regolith Bags
Ice Bladders
Pavers
Metallic Plates
Deployable Structures
Direct Emplacement of Sintered Structures
Direct Emplacement of Polymer Concretes
Direct Emplacement of a Concrete Pad

CONCLUSIONS

Launch/Landing Pad infrastructure will be necessary to reduce mission risks to acceptable levels and grow human lunar activities beyond "footprints and flags" into a vibrant scientific and economic endeavor. This is true for the same reasons why airplanes use runways and airports, ships use docks and seaports, cars and trucks use roads and service stations, trains use rails and stations, and Earth-based space operations use launching and landing complexes. Off-Earth spaceports will need Launch and Landing Pads (LLP) and eventually Launch and Landing Complexes to reduce mission risks and facilitate the exploration and utilization of off-Earth resources.

In order to prepare for the need of LLPs this study establishes a baseline of the current state of the art, provides a listing of known LLP concepts, and presents criteria to trade concepts and identify gaps for future technology development.

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