Lunar Innovation Park – Site Plan and Bulk Regolith Feature Design

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ABSTRACT

The Lunar Innovation Park (Park) is an infrastructure hub of co-located landers designed to stimulate space-resource-based economic activity through sustained robotic surface operations that enable the exchange of goods and services. The Park reduces risk for the Artemis Program by maturing transformative technologies in a risk tolerant environment. A human presence is not required. The Park is deployed via sequential Commercial Lunar Payload Service (CLPS) missions. A minimum viable kernel of services, including power distribution, communications, regolith manipulation, unpressurized shelter, limited logistics, and protective landing zones is established using mid to high Technology Readiness Level (TRL) systems. This paper details the Park's site plan and design of regolith features built using small robotic excavators. Construction of protective regolith berms enables extreme proximity landings which accelerates lunar economic development by reducing necessary payload mass and logistics complexity. The paper concludes with discussion of uncertainties and related work that must be completed to further define the Park.

INTRODUCTION

The Lunar Innovation Park is a set of co-located infrastructure elements deployed in the Moon's south polar region. The intent of the Park is to demonstrate critical technologies that reduce risk for the Artemis Program, and to provide the initial kernel of capability from which a space resource-based economy can grow on the Moon. The Park is designed to provide essential services - including power from Vertical Solar Array Technology (VSAT) (Belbin et al. 2024, Taylor et al. 2022), local and direct-to-Earth communications, robotic regolith manipulation, and payload transportation – to enable sustained lunar operations. By utilizing bulk regolith to construct landing zones and protective berms, the Park facilitates spacecraft landings in extreme proximity (~20 m) with landing accuracy improved by landing aids, local high resolution topographic mapping, and terrain relative navigation. Protective regolith berms mitigate risks to landed assets from Plume Surface Interaction (PSI) ejected regolith and provide some protection from lateral debris from any Rapid Unscheduled Disassembly (RUD) events. An unpressurized shelter protects surface assets from the lunar surface radiation, extreme temperatures, and meteoroid impact environments. A yet to be defined class II or III (Kennedy 2002) reusable Launch/Landing Pad (LLP) supports eventual repeated visits. The infrastructure utilizes mid to high TRL technologies to ensure near term feasibility; the first two missions could be completed in as soon as two years. A human presence is not required for Park construction or operations. Figure 1 shows the Park after five construction Missions (M#) and two customer (C#) missions.

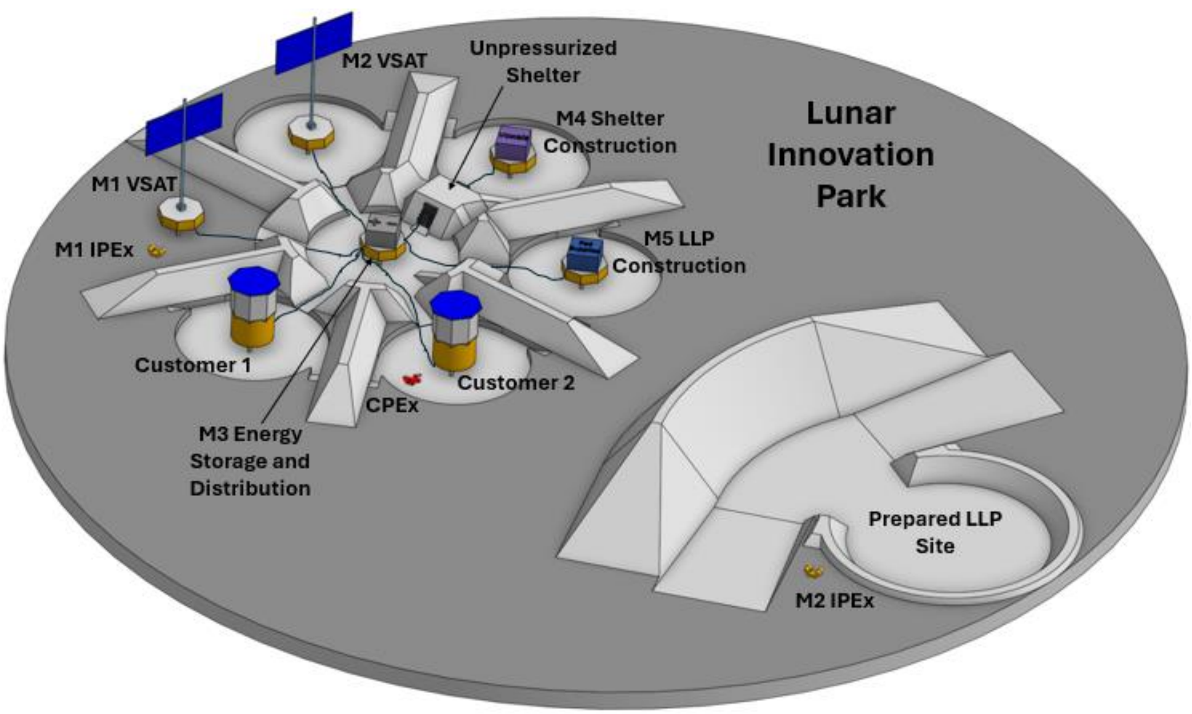


Figure 1. The Lunar Innovation Park after five construction missions and two customer missions. A reusable LLP is not shown because the construction method is not yet known.

The Park provides a unique opportunity to demonstrate, validate, and mature critical technologies for a sustained lunar presence. The Park is a feasible, near term, method to begin to realize the objectives presented in the recently published NASA Lunar Surface Innovation Initiative (LSII) Lunar Infrastructure Technology (LIT) report. Operating under a “go do” or “fail forward” philosophy, the Park concept promotes rapid innovation but necessitates a high degree of risk tolerance. These activities simultaneously reduce risk and expand options for the “Sustained

Lunar Evolution" phase of the Artemis Program while piloting commercial programs for the exchange of goods and services to stimulate space resource based economic activity. By demonstrating "the art of the possible," the Park exercises advanced technologies that can eventually be adopted to expand capabilities of human missions. It stimulates economic activity through public-private partnering that promotes commercial ownership of hardware, allowing goods and services to be offered for fee. Essentially, the Park provides an infrastructure backbone that reduces costs for future science and technology development missions by eliminating the need for every mission to be self-sufficient in terms of power generation, energy storage, communications, mobility/transportation, regolith manipulation, and others. The Park can accommodate NASA science, other government agency, commercial, or academic customers of initial Park services as soon as the first mission.

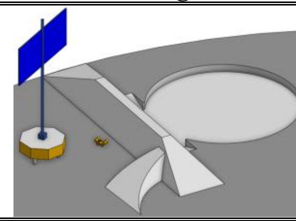
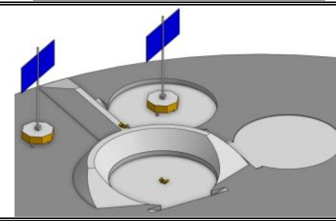
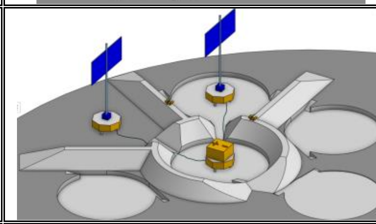
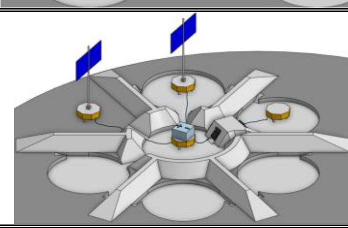
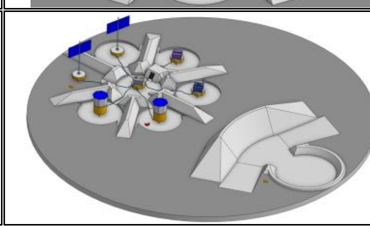
This paper presents the overall Park site plan and design of bulk regolith structures. This work is complementary to other publications on the Lunar Innovation Park (Hilburger et al. 2026). The mission design and quantitative feasibility analysis of four of the five Park construction missions was completed in collaboration with the Compass Lab multi-disciplinary concurrent engineering team at NASA's Glenn Research Center (NASA 2026). The fifth mission was excluded from this study due to schedule constraints and uncertainty about what reusable LLP construction technology would be used.

Excavation and site preparation are completed using the current robotic excavation capabilities of the In-Situ Resource Utilization Pilot Excavator (IPEx) (Schuler et al. 2022; Schuler et al. 2024; Gelino et al. 2026a) and a next generation construction and logistics mobile robot, notionally called Construction Pilot Excavator (CPEx). CPEx includes the capability to swap modular attachments such as a compactor, logistics arm, and geotechnical analysis tool suite. CPEx's functionality was derived from five core requirements: 1. Creating a lunar power grid by connecting power generation systems with energy storage and distribution systems; 2. Building regolith foundations for a shelter and reusable LLP; 3. Rock handling; 4. Providing Regolith manipulation, payload transportation, and logistics services for Park customers; and 5. Assisting the assembly and outfitting of an unpressurized protective shelter built with Automated Reconfigurable Mission Adaptive Digital Assembly System (ARMADAS) (Gregg et al. 2024).

Potential south polar sites for the Park were evaluated using LRO-derived data and a set of constraints including proximity to potential Artemis landing sites, illumination conditions, Earth visibility, slope, and distance to stable ice (Gelino et al. 2026b).

This study develops the Park concept assuming the use of medium scale (625-kg payload) CLPS landers. However, the Park architecture is lander-agnostic and could be built using any available cargo-delivery vehicle. Utilizing 625-kg CLPS landers, the Park can be constructed over a series of five missions. Each mission builds upon the prior one by preparing the next landing site and expanding capabilities for both Park construction and customer operations. Park construction missions are summarized in Table 1.

Table 1. A summary of Park construction mission objectives and achieved state.

Mission #	Objectives	Park Configuration
1	Land and deploy a Vertical Solar Array Tower (VSAT), local and Earth communication systems, and the IPEx excavator. Survey the site, build a protective bulk regolith berm, and prepare landing surface for Mission 2.	
2	Land and deploy redundant VSAT, comm systems, and IPEx. Build a bulk regolith protective berm and prepared landing surface for Mission 3.	
3	Land additional energy storage, power distribution and CPEx excavator. Connect power assets and commission a power grid. Build bulk regolith protective berms and prepare landing surfaces for Mission 4 and Customer 1.	
4	Land and provide power to ARMADAS. Prepare regolith foundation, assemble and bury the unpressurized shelter. Build a bulk regolith protective berm and prepare landing surface for Mission 5 and Customer 2.	
5	Land the construction systems for the reusable LLP. Prepare a regolith foundation and berms and build the class II or III reusable LLP.	

ASSUMED SURFACE CONDITIONS

The most pertinent local environmental factors for Park layout and regolith feature design include solar exposure for power systems sizing; Earth line-of-sight availability for communications; and surface characteristics, such as slope, roughness, and rock distribution, for regolith excavation estimates, trafficability, and rock management. Sites were evaluated internally for suitability for the Park using a set of environmental constraints.

Data from the LOLA Slope 5M of the ACT QuickMap was used to assess slopes, roughness, and rock distribution. However, the data's resolution is limited to 5 m per pixel which is of limited value when designing a site that spans only 115 m in diameter with sub- meter features. Ideally, higher resolution DEM data would be used to design and optimize the site layout and regolith features. The actual site will have local high and low regions distributed across an overall average slope based on the site evaluation parameters. Lacking higher resolution topographic data, the Park layout was designed assuming a flat and level surface with a preliminary assessment of the effects of a sloped site with local high and low points.

A preliminary analysis comparing a level site with a 4° sloped site was completed and is shown in Figure 2. In this analysis, the first lander was assumed to land on the high side of the site to maximize solar exposure on the VSAT. To maintain shielding effectiveness, all berms were assumed to be built up to the height of the first lander. This constraint is likely overly conservative and drives a significant increase in regolith movement.

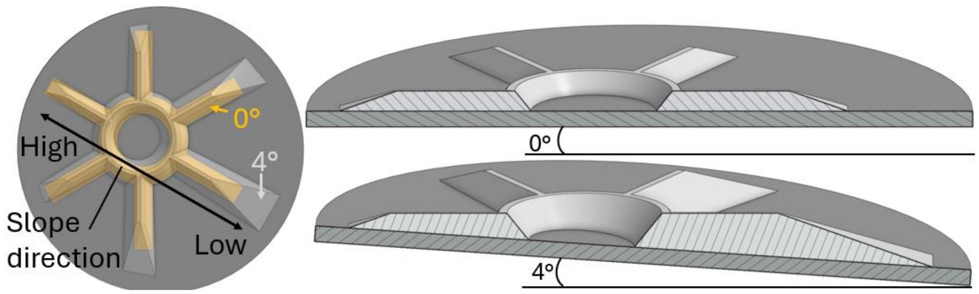


Figure 2. The enlarged regolith features of a sloped (4°) site are compared with a level site (0°).

Increased berm height expands the berm volume and footprint area due to the sloped sidewalls. This results in ~2.6 x increase in berm amount of regolith moved. A sloped site Park layout will require minor geometric modifications compared to a level site to provide additional space for wider berms. Future work will integrate slope, simulated terrain roughness, and stochastic rock distributions to refine excavation estimates.

PSI EJECTA EXTENT, RISKS, AND MITIGATION EXAMPLE

A low-fidelity PSI ejecta trajectory simulation was conducted using Lunar UNcrewed EXplorer Tool (LUNEXT) (an internal NASA tool) to evaluate the effectiveness of the Park's ejecta shielding. Figure 3 shows a simulated landing event at the Connecting Ridge (with ejecta velocity of 1 km/s and angle of 3°). The image illustrates the potential wide extent of ejecta across the Moon's south polar region. A simplified PSI ejecta barrier - representing Park's proposed berm geometry - effectively protects a large region behind the structure. A close-up view shows a hypothetical landed lander protected by the barrier, with site geometry like the Park at Mission 2 landing (excluding subgrade landing site).

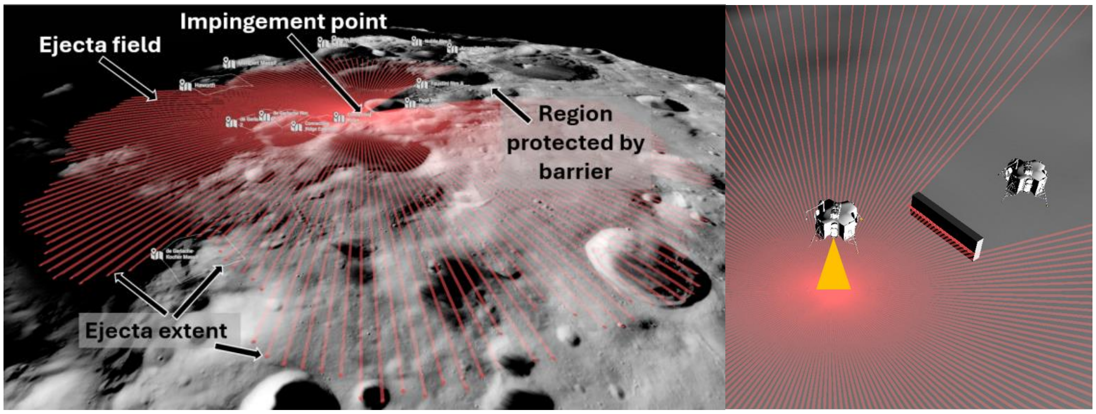


Figure 3. A low fidelity PSI simulation of plume ejecta from the Connecting Ridge shows the extent of ejecta across the south polar region of the Moon with protected region (left). A zoomed-in view of the simulation shows a hypothetical landed lander being protected from ejecta by a barrier (right).

Anthropogenic ejecta not only risks sandblasting damage to nearby and far afield landed assets (Immer et al. 2011a), it also alters the natural condition of the lunar surface which may jeopardize the scientific potential of affected sites. The risk of ejecta exposure reduces with distance since the flux of ejecta diminishes and larger particles drop out of the flow early. Accepted operational and scientific risk standoff distances to landing/launch events based on damage potential and science impacts have not yet been defined for various landers.

LUNAR INNOVATION PARK DESIGN

The design of the Lunar Innovation Park is driven by two competing requirements: the need for protective shielding from plume surface interaction (PSI) and the desire to minimize the distance between landing zones. By enabling extreme proximity landings, the Park reduces power distribution cable lengths, reduces logistics complexity, and minimizes the transportation distance for excavated regolith. These efficiencies directly translate to reduced power consumption, shorter construction timelines, and decreased mechanical wear on mobile systems.

Site layout and zoning. The Park has two functional regions: 1. The Industrial Area where the initial build-up of support infrastructure occurs. This area utilizes a "hub-and-spoke" geometry, where landing sites are protected by a combination of circular (hub) and linear (spoke) berms; and 2. A dedicated reusable Launch/Landing Pad (LLP) area that supports future sustained operations. The Park is a function of several factors including: 1. Existing site conditions; 2. Predicted landing accuracy; 3. Lander geometry; 4. VSAT geometry; 5. Plume geometry during descent; 6. Ejecta erosive effect on berms; and 7. Secondary ejecta trajectories from ejecta impacts with regolith berms and depressed landing zone sidewalls. Figure 4. Shows the layout of the park with each construction mission (e.g., M1) and customer mission (e.g., C1) landing zone identified along with basic dimensions. The Industrial Area is contained within a 61-m diameter circle and entire Park footprint, including reusable LLP, fits within a 115-m diameter circle. Bulk regolith landing zones in the Industrial Area are 15 m in diameter and separated by 20 m. The center of the Industrial Area is 71 m from the center of the LLP landing zone. The LLP has two 9-m ramped accessways with 5° slope.

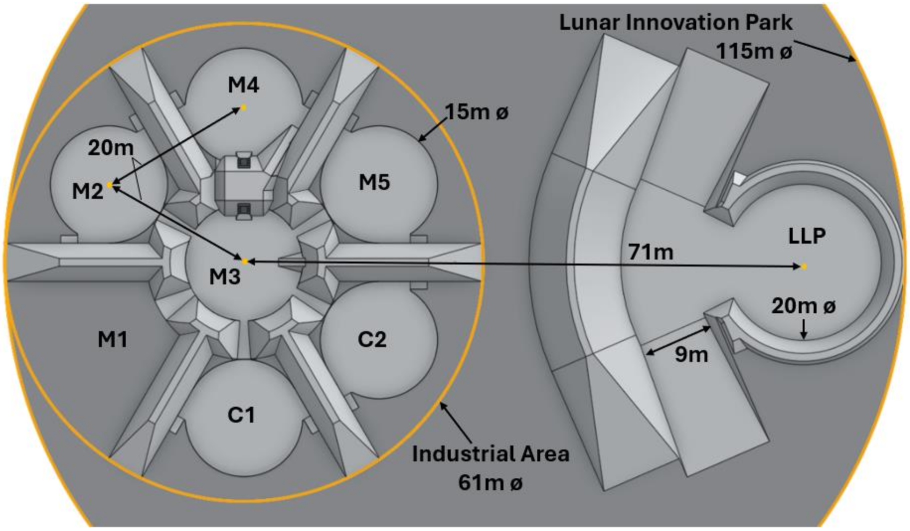


Figure 4. The Park consists of six construction mission landing zones, two customer mission landing zones, and a prepared regolith site for the construction of a class II or III reusable launch/landing pad. Regolith berms provide protection from PSI effects and RUDs between landing zones.

Construction sequence and logic. The landing location of each construction mission is selected to optimize Park capabilities and operations. The first VSAT lander (M1) lands on a natural surface at the ideal insolation location with the shortest maximum period of continuous darkness. The second VSAT is at site M2 which is positioned at the location with highest elevation at the required distance from M1. This configuration minimizes shadowing of the second VSAT and defines the rotational orientation of the Park. The energy storage lander is at site M3 in the center of the hub to minimize distances between energy storage, power generation, and power consuming systems. The shelter construction system lander is at site M4, and the shelter is constructed between it and the energy storage lander to minimize distance between each location. The LLP construction system lander is at site M5 which minimizes distance to the LLP site. The prepared LLP site is placed opposite of the VSATs to reduce berm height requirements for protecting the VSATs in an extended state. This configuration eliminates the need to retract the VSATs during landings at the LLP. Customer landers are in the remaining sites C1 and C2.

Regolith functional features. The Park includes six fundamental bulk regolith feature designs: 1. Berms – Constructed walls used to shield landed assets from ejecta; 2. Subgrade landing surfaces - Flat, level, excavated, rock free landing zones designed to reduce landing hazards; 3. Ramps – Sloped surfaces to provide trafficable transitions between elevations; 4. Berm cut-throughs – Passages designed to allow mobility platforms and cabling through berms rather than over or around; 5. Foundations – Flat, level, rock free, compacted locations for class II or III infrastructure; and 6. Regolith overburden – Protective burial layer of an unpressurized shelter to provide meteoroid, radiation, and thermal shielding.

Industrial area landing zone design. The six prepared bulk regolith landing zones are 15 m in diameter. This dimension is defined by assumptions of 5-m landing accuracy and 5 m lander diameter (7.5-m radius = 5-m landing accuracy + 2.5-m lander radius). This precision landing accuracy estimate was provided by Johnson Space Center Entry Descent and Landing (EDL) subject matter experts and assumes the use of landing aids (installed on previous landers) to provide range, range rate, and bearing data. Terrain-relative navigation can be enhanced by lander mounted laser altimeter, vision systems and high-resolution topographic maps/imagery generated by IPEx/CPEx during initial missions.

Bulk regolith landing zone center points are separated by 19.9 m. This spacing results from a safe standoff distance of 8.0 m between the nearest edge of a protected lander and the top of the berm sidewall facing the landing event (i.e., the distance between the top of the berm face that ejecta hits and the protected lander). This spacing ensures that landed landers remain clear of secondary ejecta resulting from initial impacts with the berm. Preliminary PSI modeling results by Outward Technologies/Blueshift indicates that a standoff distance of ≥ 8 m between the impacted berm face and lander is adequate to minimize secondary ejecta impact risk for medium scale CLPS landers (Goudarzi 2026). It is expected that understanding of secondary ejecta trajectories will be refined as analyses progress. Further assessment is required to determine the extent of plume exhaust gases and whether they create contamination hazards beyond the berms during descent.

Each bulk regolith landing zone is excavated to a depth of 0.8 m. Figure 5 illustrates section views for both nominal (centered) and off-nominal (5-m offset) landings with ejecta angles of 3° and 6°. This depth was selected for two reasons: 1. Mass balance - It balances the excavated regolith mass from landing zone cuts with mass required for berm fills for each mission; 2. Ejecta shielding- For nominal landings at the center of the landing zone, the walls of the subgrade landing surface have the potential to protect the surrounding region from PSI ejecta angles up to 6° which is approximately a 2x factor of safety on the expected ejecta angle of 3° (Immer et al. 2011b). For off-nominal landings 5 m from the center of the landing zone, the subgrade walls still have the potential to protect the surrounding region from PSI ejecta of angles up to 3° at the furthest point. In other words, a 0.8-m deep landing surface would provide some protection for regions within the extent of an unmitigated ejecta field. This has the potential to reduce sandblasting/contamination risks for far afield landed assets as well as reduce risks of contaminating/altering pristine natural surfaces.

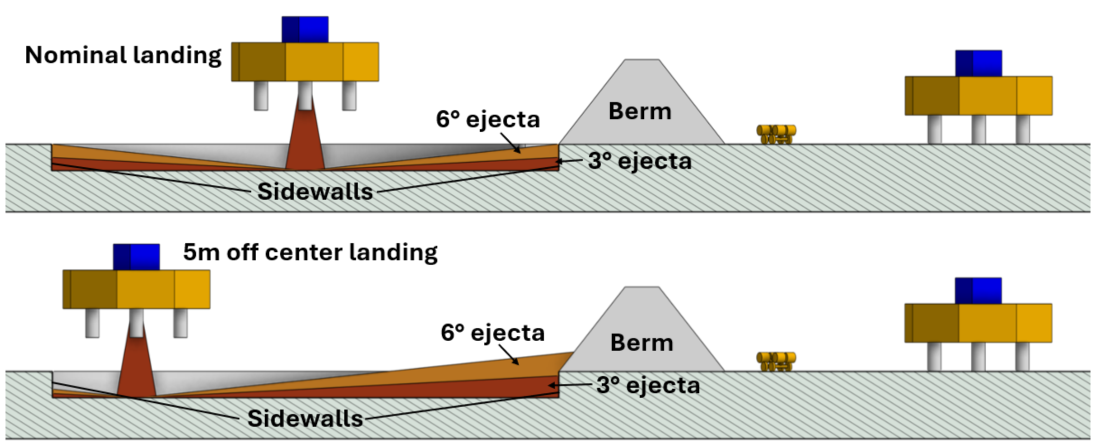


Figure 5. Plume geometry for nominal centered landings (top) and off nominal 5 m landing accuracy edge case landings (bottom) with 3° and 6° ejecta angles.

The sidewalls of the sub-grade bulk regolith landing zones are assumed to be vertical. Figure 7 shows a plot of artificial slopes from the Lunar Sourcebook, the plot shows that excavated regolith can maintain a vertical slope up to ~2.5 m with a factor of safety of 1.5 (Heiken et al. 1991). The Outward Technologies/Blueshift analysis shows that penetration of ejecta through a berm is not expected unless significant erosion of the berm from plume gases takes place first. It is expected that understanding of ejecta penetration/erosion of berms will evolve as analyses are refined. It is likely that wider landing zones will be required for off center landings without significant erosion of berms and sidewalls.

Industrial area berm design. Berm heights were designed to be 2.5 m which matches the assumed height of the first lander with VSAT in stowed condition. This geometry protects landed assets from ejecta angles up to 12.0° and provides a barrier against lateral debris field caused by a RUD of a subsequent lander. The berm crest is 1 m wide to allow for the entire width to be compacted by wheel or drum traversals (e.g., wheel tracks can overlap across the entire width). This trafficking increases consistency of berm bulk density and prevents ruts from forming.

As shown in Figure 6, the length, or arclength, of the full berm height spans the distance between tangent lines drawn from a 10-m diameter landing zone (i.e., 5-m landing accuracy) to a 15-m diameter potential position of protected landers (i.e., 7.5-m landing zone radius = 5-m landing accuracy + 2.5-m lander radius). In other words, the full width of landed landers is shielded from ejecta regardless of the position of the landed or landing lander within the 5-m landing accuracy. This assumes that ejecta originates from a lander's vertical centerline.

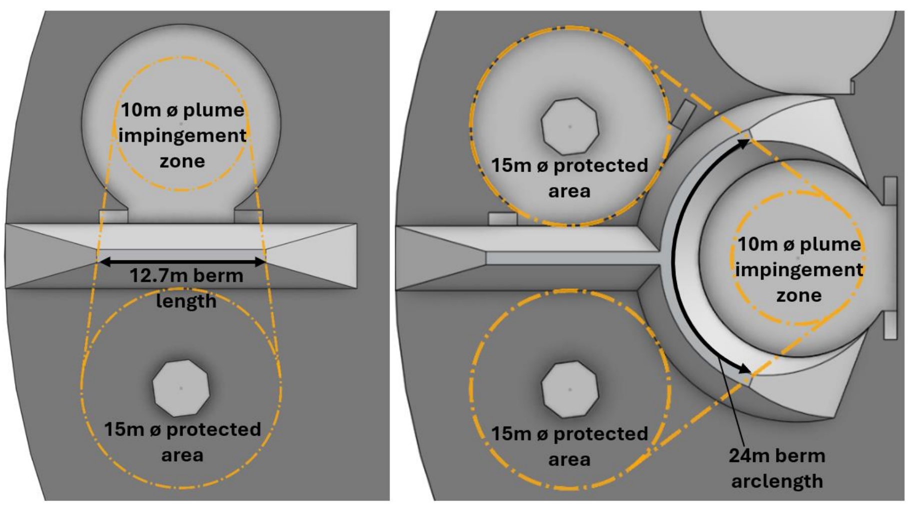


Figure 6. Full height berm lengths (left) and arclengths (right) are designed so landers on the surface are protected from subsequent landing ejecta everywhere within a 5-m landing accuracy.

The berm sidewall slope is 52°, based on a plot from the Lunar Sourcebook that describes stability of constructed and excavated slopes shown in Figure 7 (left) (Heiken et al. 1991). An angle of 52° was assumed for constructed berms because it approximates the maximum angle of "dumped" regolith for a 2.5-m berm height with a factor of safety of 1.0. This is considered conservative since the regolith will be compacted by repeated traversals of the excavators.

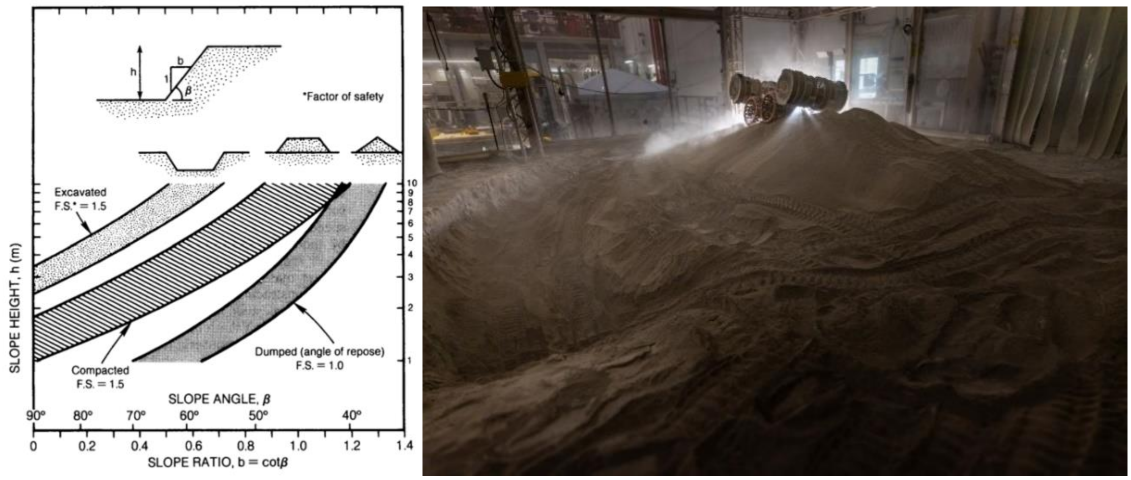


Figure 7. A berm sidewall slope of 52° was used based on "dumped" regolith with some compaction via repeated traversals and a maximum height of 2.5 m. Depressed landing zone sidewall slopes used 90° based on the "Excavated" regolith region of the plot with a maximum depth of 0.8 m (left). A robotically built berm in BP-1 regolith simulant (right).

The 1-m crest and 52° sidewall slope result in a 4.9-m bottom width. The design density of berms is 50% relative density (R.D.) (1.4 g/cm^3 for lunar regolith) based an assumed dumped regolith density of 30-40% (Heiken et al. 1991) with an additional 10-20% densification R.D due to repeated trafficking. A berm building demonstration completed with the RASSOR 2.0 (Mueller et al. 2016) excavation platform in Earth gravity with Black Point-1(BP-1) simulant had an average R.D. of 61% achieved by repeated trafficking shown in Figure 7 (right). The berms have a ramped surface of 20° on both ends to allow the excavators to transition between grade and the top of the berms. This angle balances trafficability with overall berm volume. The RASSOR 2.0 excavator prototype has a maximum traversable slope angle of 35° in BP-1 in Earth gravity. Excavator tractive capabilities, reduced gravity, regolith density or other factors on the Moon may necessitate a shallower slope to improve operational efficiency.

Industrial area accessway design. The Industrial Area includes ramped surfaces to allow access between the sub-grade landing zones and the surrounding surface grade. Each landing zone has two 1-m wide ramped accessways to enable efficient, looped dig – haul – dump cycles during construction. The position of some of the ramps change across mission phases to provide optimal travel routes. A unique ramp is located within the M3 landing area which provides temporary access from the partially built circular berm to the energy lander for recharging during M4. All ramps are 1 m wide and have slopes ≤ 20°.

As Park construction missions progress, it becomes necessary to excavate berm cut throughs between landing zones to provide efficient access and minimize cable lengths between landers. The accessways are ≥1 m wide and maintain the standard 52° berm sidewall slope.

Industrial area shelter foundation and overburden design. The structural design of the shelter is currently notional. The shelter is intended to mitigate risks associated with radiation, meteoroid impacts, thermal cycling, and limited RUD debris ejecta impacts, while surviving anticipated moonquake loads. The shelter is sized to accommodate IPEx, CPEx and several other customers such as Power Management and Distribution (PMAD) systems, batteries, and local computing hardware, to improve reliability and longevity. The shelter is assumed to be assembled with ARMADAS robotic construction technology using 550 0.3-m voxels. Figure 8 provides a cross-section and close view of the shelter.

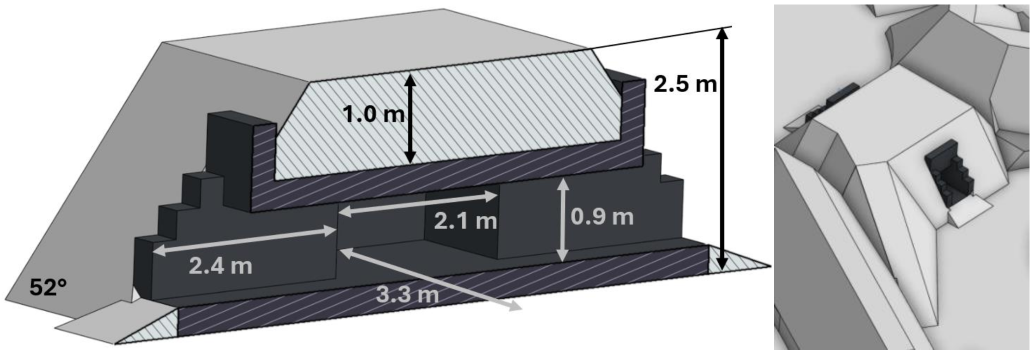


Figure 7. A cross-section view of the notionally designed protective shelter with dimensions (left) and a close-up view of the shelter in the Park (right).

The interior volume is notionally 2.1 m x 3.3 m x 0.9 m (l x w x h) with 2.4-m long access tunnels on either side. The structure footprint is 17.4 m^2 and fits within a rectangular area of 7 m x 4 m. The prepared regolith foundation is assumed to extend 1 m beyond the rectangle on each side. The foundation is prepared by leveling the surface and compacting to 80% R.D. (Gudino et al. 2025). The shelter is covered with 1 m of regolith overburden which is assumed to provide an acceptable level of protection against cold/thermal cycling, meteoroid impacts and radiation. A ramp ≥ 1 m in width with 20° slope is used to build up the regolith overburden and allow access to the top of the shelter.

Reusable LLP prepared regolith foundation design. The reusable LLP consists of a 20-m diameter prepared regolith surface. This area provides a 2.5-m wide pad apron of prepared regolith around a yet to be defined durable class II or III circular pad of 15 m diameter. The LLP foundation is prepared by removing rocks, leveling the surface and compacting to 80% R.D. To optimize mass balance between excavation (cut) and berm construction (fill), the LLP pad is located 1.6 m below the surrounding grade. This subgrade configuration also reduces total berm height requirements. The design of the LLP prepared surface will be refined as construction technologies mature.

Reusable LLP berm design. The reusable LLP is protected by a dual-berm system designed to mitigate PSI ejecta hazards. One large berm provides protection for the Park Industrial Area and a smaller circular berm around the circumference of the landing zone provides protection for the surrounding area (Figure 9). Both berms utilize the standard design parameters established for the Industrial Area: 1-m wide crests, 52° sidewall slopes, and 20° access ramps. The large berm is 6.1 m tall which provides ejecta protection up to 2 m beyond the height of extended VSATs regardless of the landed position within the 15-m landing zones. This eliminates the need to retract the VSATs for each launch/landing event.

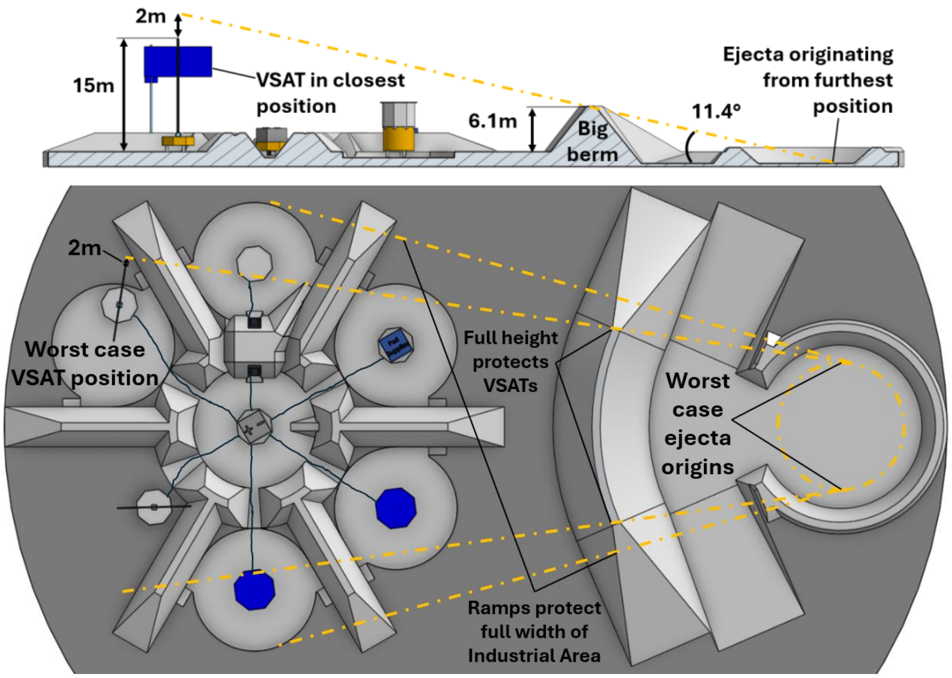


Figure 9. The reusable LLP site geometry and shielding design. The profile view (top) highlights the vertical clearance provided for deployed VSATs, while the plan view (bottom) depicts the dual-berm layout and landing zone.

The arc length of the full height of the large berm is sized so that the width of the solar panels on both VSATs are protected with 2 m of margin irrespective of the actual landed location within the 15-m diameter landing zones. The ramps of the large berm provide protection for the remainder of the width of the Industrial Area on either side of the shelter lander and C1 mission.

The shorter circular berm is sized so that the surrounding region is protected from a 6° ejecta angle for all landing positions within the 15-m landing zone diameter which is 2x the expected average angle (Immer et al. 2011b). It is possible that other class II or III PSI mitigation technologies will be preferred over bulk regolith berms for the LLP. These technologies include spray on surface stabilizers, matting, assembled barriers, or sintered/melted regolith bricks/surfaces. The design of the LLP prepared surface/berms will evolve as these technologies mature and trades are completed.

Reusable LLP accessway design. The LLP is designed with two access ramps, each is 9 m wide and have a slope of 5°. Repeated use of an LLP requires that landers be removed from the pad. The method for lander removal has not yet been defined but options exist such as powered or unpowered wheeled platforms/attachments, cable winching, cranes, and even relaunching and landing in a lander "bone yard". The accessways are designed wide enough to accommodate a 5-m diameter lander with 2-m margin on either side. The accessway size can also accommodate larger mobile systems in anticipation of hardware scale up. LLP accessway design will evolve as operational requirements mature, it is likely that the ramps will be augmented with assembled structures, mats, surface binders, or regolith bricks/pavement to facilitate operations.

CONCLUSIONS

Preparing a site with bulk regolith features is a viable strategy for enabling extreme proximity landings and co-locating minimum viable surface infrastructure. By using a series of medium scale CLPS lander missions, the Park establishes a hub of basic services and robotic capabilities. The Park can kickstart a lunar resource-based economy by developing the technologies that are necessary to produce and exchange goods and services. The current layout provides a robust framework for shielding critical assets from PSI ejecta while establishing a clear operational path toward the construction of a reusable LLP. It is desirable that at least one of the customer missions be used for a smaller scale demonstration of LLP construction technologies leading to the full scale construction of an LLP. Follow on work is required to further define the Park and validate assumptions related to layout, operations, and regolith feature design:

1. Site fidelity and geotechnical stability - Higher resolution analysis of lunar surface conditions such as slope, roughness, and rock distribution must be incorporated. Beyond initial construction, the long-term stability of bulk regolith features must be assessed against seismic activity (moonquakes) and "thermal pumping" from extreme day-night temperature cycles that may cause slumping. Risks associated with differential settling under high-center-of-gravity assets, such as VSATs, caused by non-uniform compaction must be understood and mitigated.

2. Ejecta dynamics - Analysis of primary ejecta effects on bulk regolith features and secondary ejecta trajectories must continue to be refined with risk definition for surrounding assets. This includes modeling ejecta penetration and erosive effects on berms. Additionally, the risk of "plume channelization" must be studied, where high-relief berms may funnel exhaust gases, potentially accelerating erosion or aiming plumes toward unprotected areas.

3. Lander trajectory and contamination - Development and analysis of lander trajectories that are compatible with the Park layout to define the risk associated with the plume during flyover and ascent/descent. For example, the volume of the plume may span beyond the region protected by berms and pose risks of damage or contamination from plume gases. Furthermore, vehicle attitude changes during flight may aim plumes out of the protected area.

4. Robotic site preparation operations - Further analysis and optimization of regolith features and construction operations are needed. For example, berm design may change as plume and ejecta dynamics are defined.

5. Technology maturation - Technologies such as power systems, comm systems, and LLP construction methods will evolve, the Park design must reflect the continued development.

6. Rocks – Little is known about the subsurface rock distribution especially in the south polar region. Rocks may pose a risk to excavation and site preparation operations. Methods for managing rocks must be developed to reduce risks associated with subsurface rocks.

8. Automation – Site preparation automation must continue to be developed to enable long-duration, multi-robot coordination and construction operations in the lunar environment.

With continued progress the Nation’s goals of a sustained lunar presence and space resource-based economy can begin to be accomplished by the Lunar Innovation Park.

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