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# Lunar Innovation Park

## Site Plan & Bulk Regolith Feature Design


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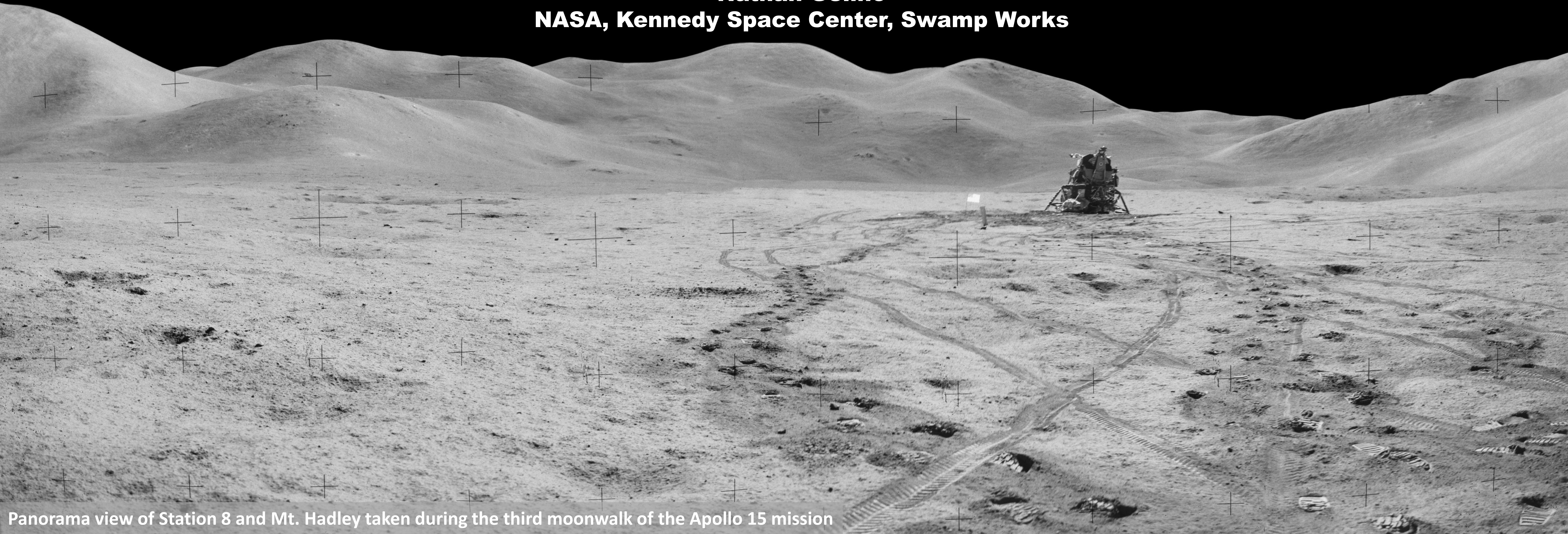
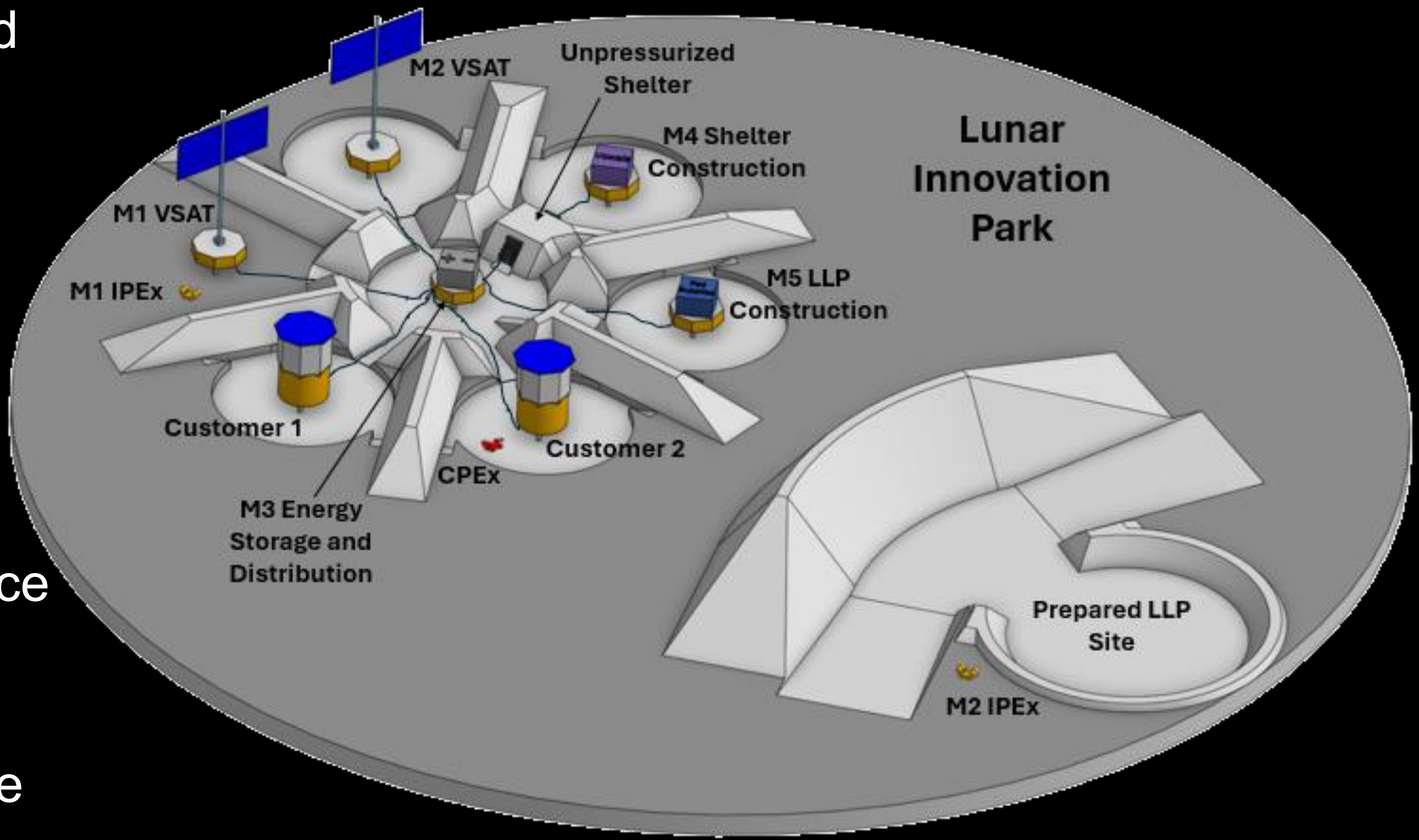


Panorama view of Station 8 and Mt. Hadley taken during the third moonwalk of the Apollo 15 mission

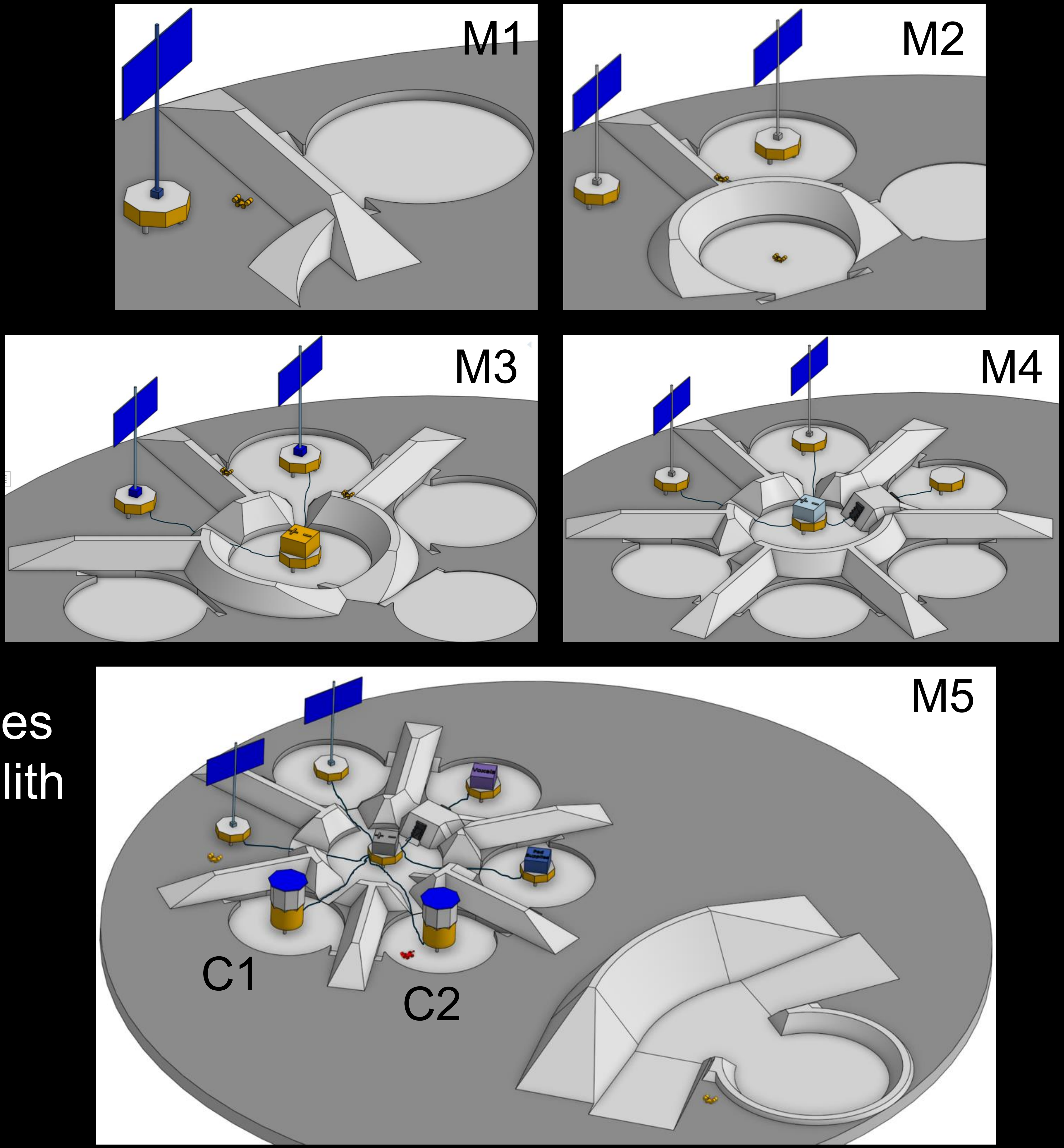
# Introduction

- Lunar Innovation Park is a set of collocated infrastructure elements deployed over a campaign of missions in the south polar region of the Moon
- Intention to define the fastest path to a sustained lunar presence
- Demonstrate critical technologies that reduce risk for Artemis
- Provide initial kernel of capability for a space resource-based economy on the Moon
- Bulk regolith infrastructure (e.g., berms, prepared surfaces) and landing aids enable extreme proximity landings (~20 m)



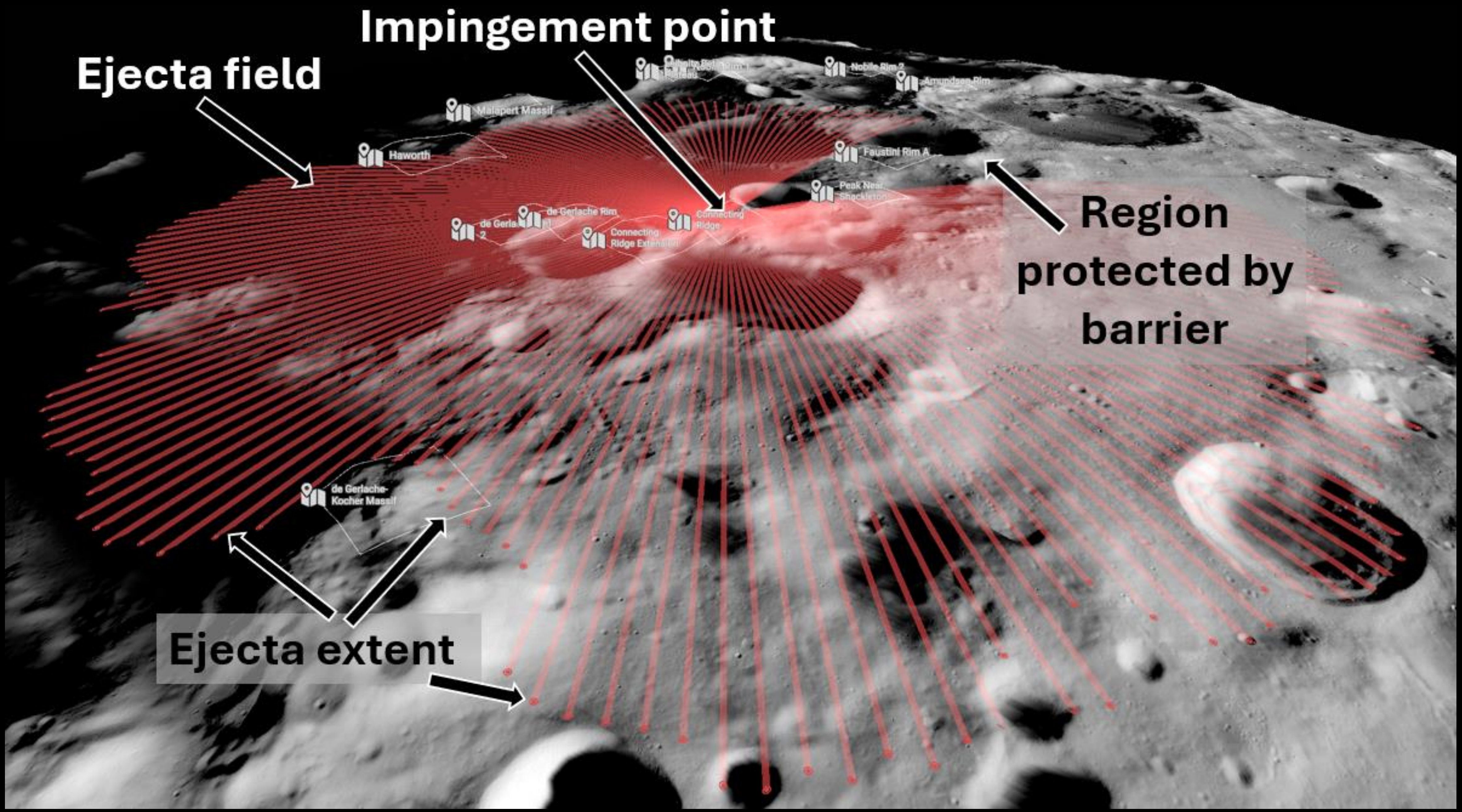

# Introduction

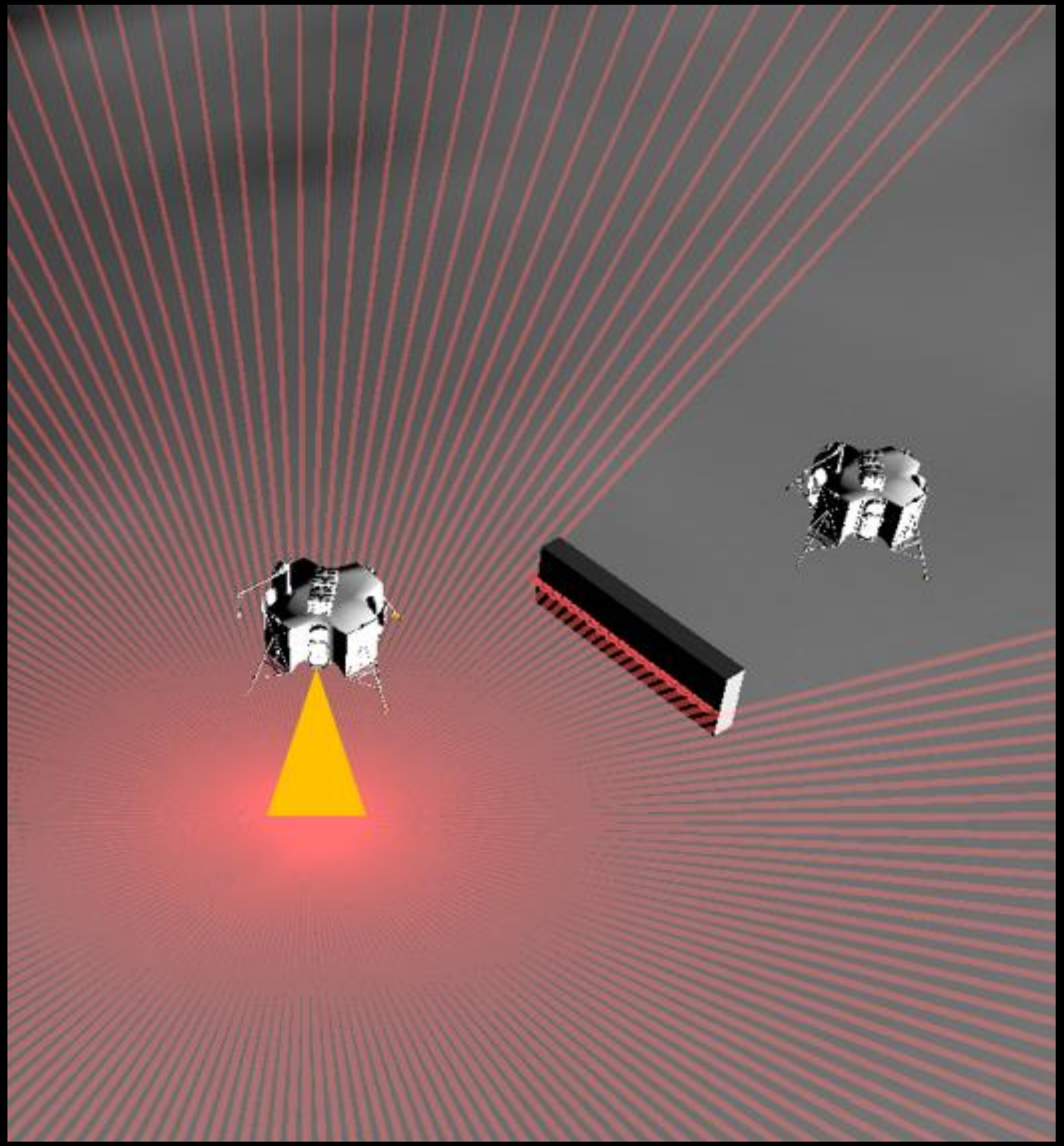
- Use of medium scale CLPS landers (~625 kg)
- Human presence not required
- Focus on site plan and regolith feature design
- Related publications focus on:
  - Motivations for the Park
  - Lunar site evaluation methodology
  - Site preparation operations analysis
  - Mission analysis and design
- Incremental build up of surface infrastructure in Mission 1 (M1) through M5
- Initiate economic development by providing Park services commercially for fee (e.g., power, comm, logistics, regolith delivery and manipulation, shelter)
- Customer missions (C1 & C2) for science or tech development
- Lower cost science and tech development because customer missions do not need to be self sufficient



# PSI Ejecta Example

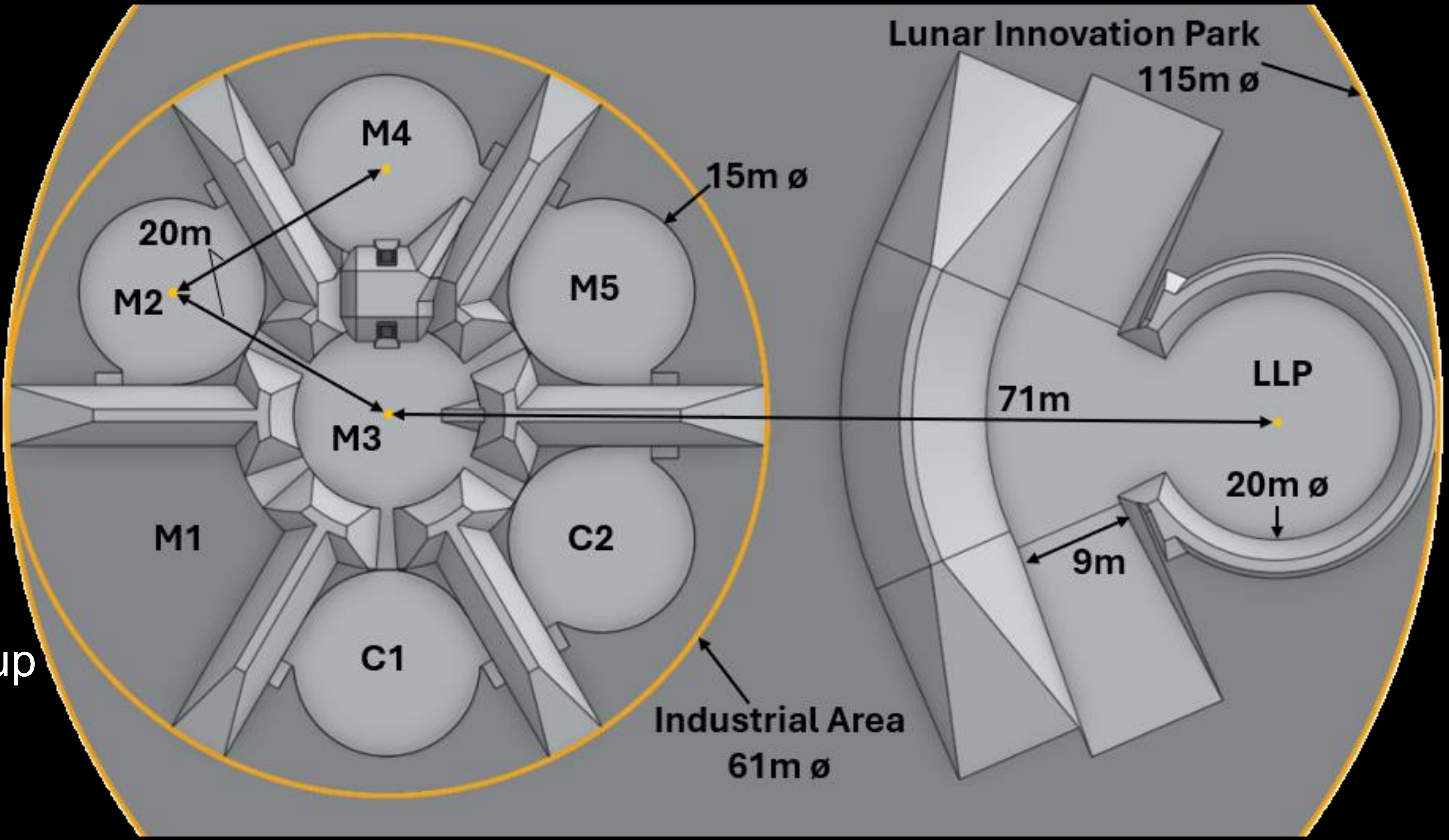
- Lunar Uncrewed Explorer Tool (LUNEXT) shows a low fidelity simulation of the extent of PSI ejecta and effects of mitigation features (ejecta velocity of 1 km/s and angle of 3° )
- Ejecta risks sandblasting landed assets and jeopardizes surface science potential via contamination
- Distance reduces risks due to diminished ejecta flux and early drop out of larger particles
- No safe scientific or operational standoff distances have been defined for various landers



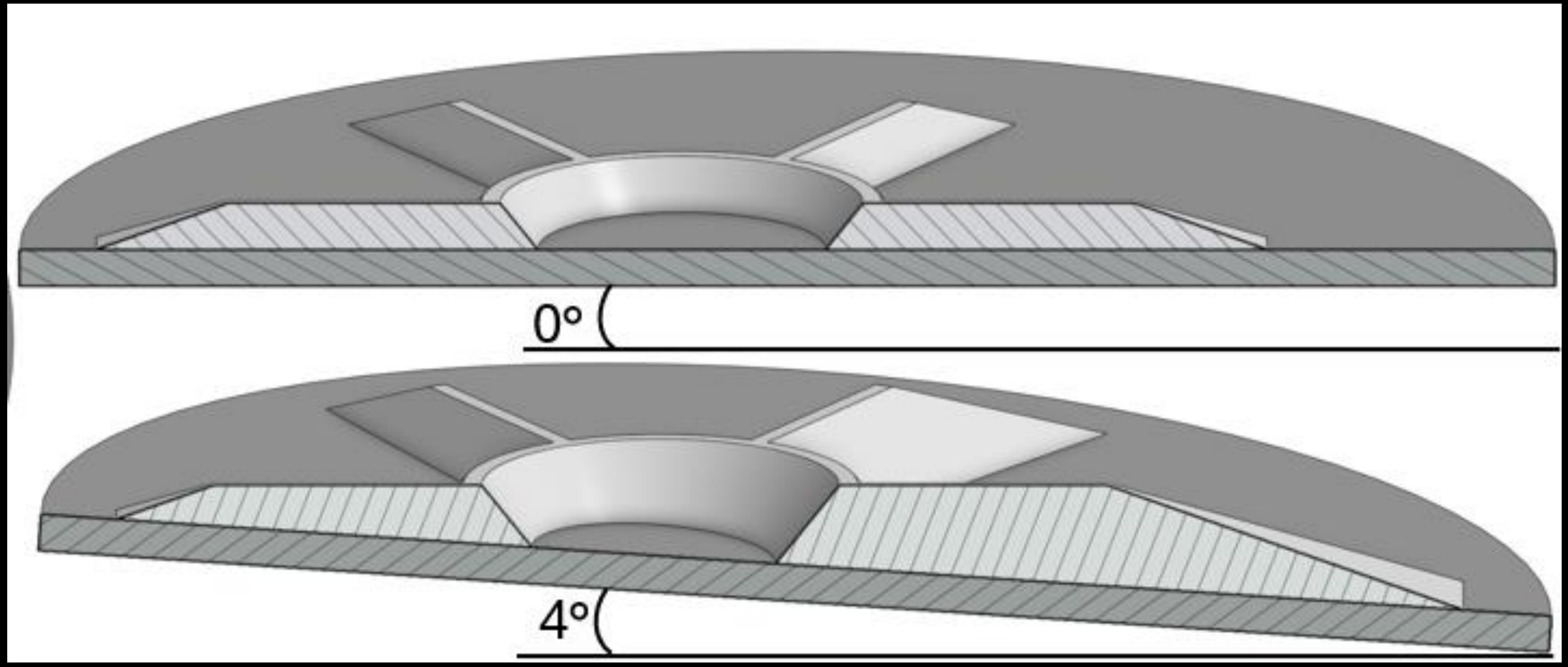
# Park Site Layout

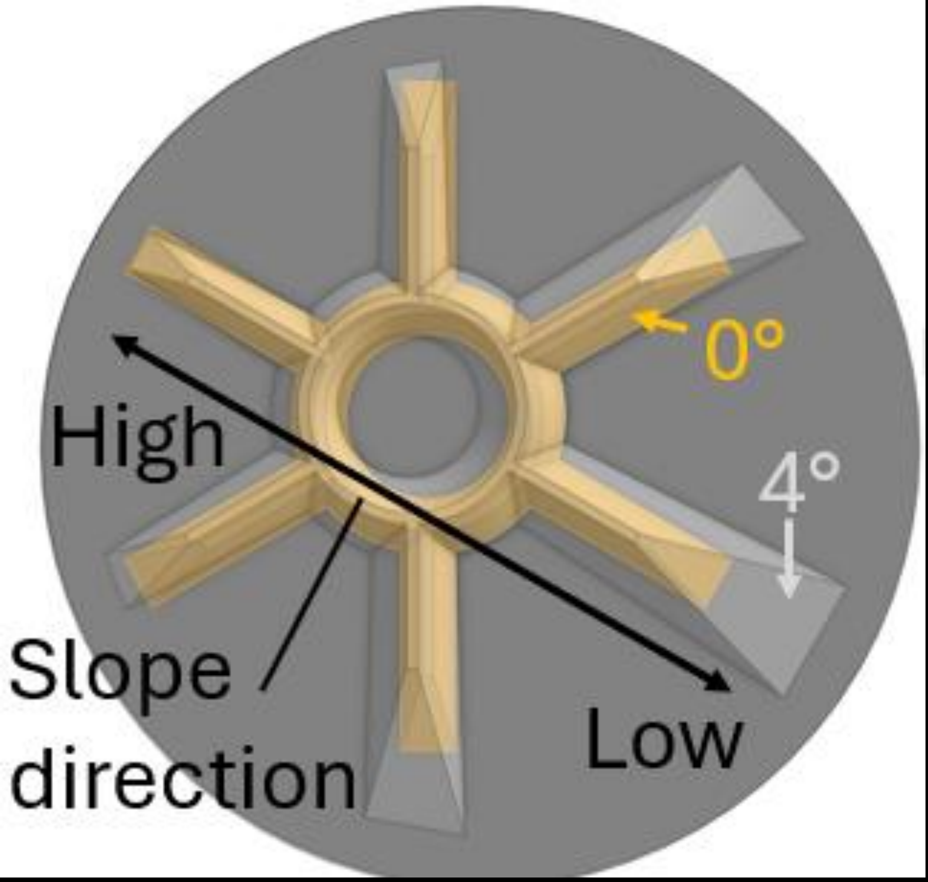
- Two regions of the Park:
  - "Hub and spokes" Industrial Area
  - Reusable Launch/Landing Pad
- Design is a function of:
  - Existing surface conditions
  - Landing accuracy
  - Lander geometry
  - VSAT geometry
  - Plume geometry
  - Ejecta erosive effect on berms
  - Secondary ejecta trajectories
- Minimizes cable run distances
- Allows for an incremental build up of collocated assets protected from PSI ejecta



# Existing Surface Conditions

- Sites were evaluated based on criteria such as:
  - Ave surface illumination
  - Earth visibility
  - Ave slope
- 5 m/pixel LOLA data is insufficient to assess affects of natural terrain on site design and construction ops
- Preliminary analysis compared berms on a level vs 4° sloped site and yielded 2.6x increase in berm volume in the Industrial Area using conservative assumptions
- Further work must be completed using higher resolution data and/or simulated terrain roughness, slope and rock distributions



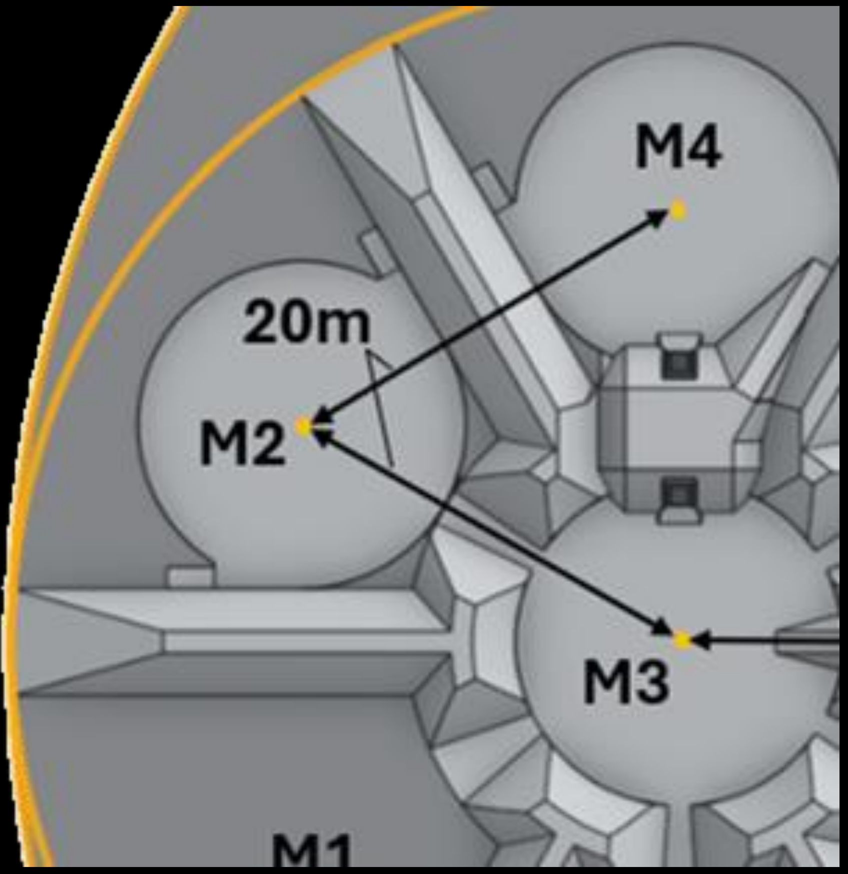
# Fundamental Regolith Features

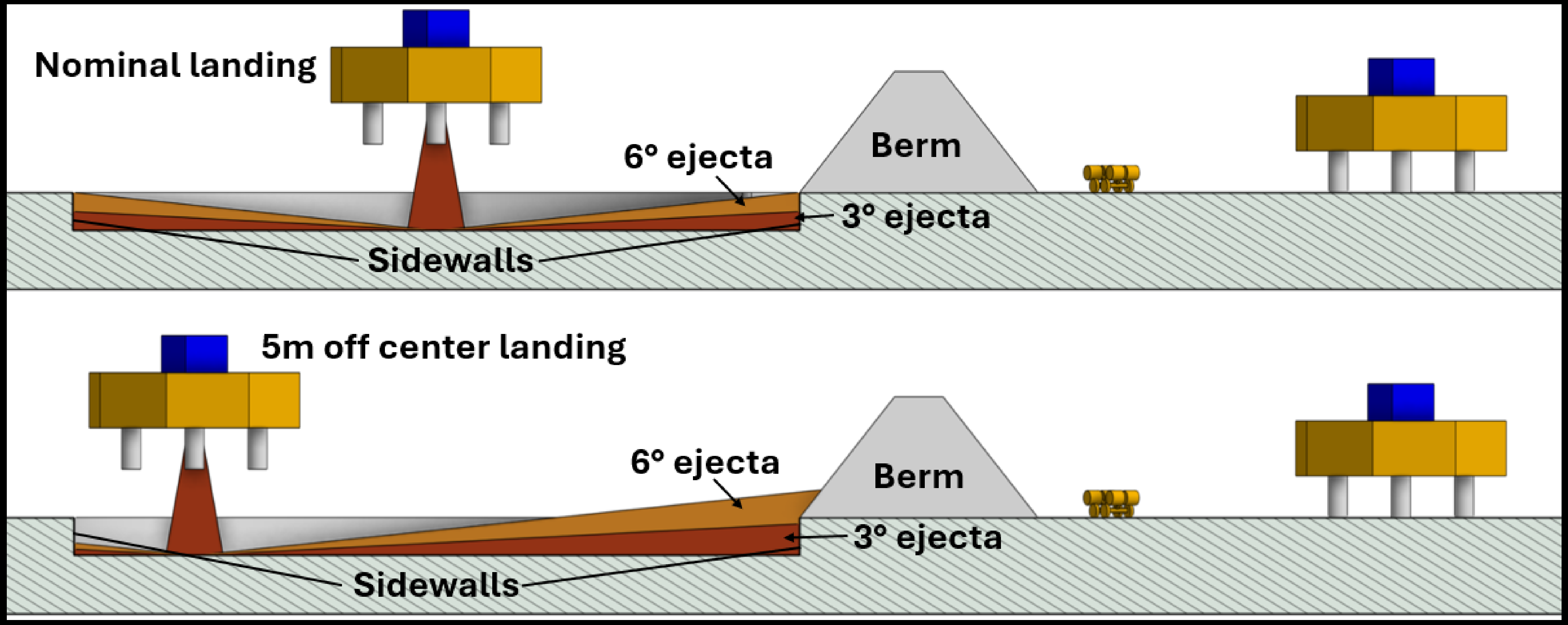
- **Berms:** Constructed walls used to shield landed assets from ejecta
- **Subgrade landing surfaces:** Flat, level, excavated, rock free landing zones designed to reduce landing hazards
- **Ramps:** Sloped surfaces to provide trafficable transitions between elevations
- **Berm cut-throughs:** Passages designed to allow mobility platforms and cabling through berms
- **Foundations:** Flat, level, rock free, compacted locations for class II or III infrastructure
- **Overburden:** Protective burial layer on an unpressurized shelter to provide meteoroid, radiation, and thermal shielding

# Single Use Landing Zone Design

- 15 m LZ diameter based on 5 m landing accuracy and 5 m lander diameter
- Center distances of 19.9 m based on LZ diam, 8 m standoff distance from ejecta impacted face of berm to landed lander*, and berm base width of 4.9 m
- Depth of LZ is 0.8 m to balance regolith cut and fill mass, provide surrounding region some protection from ejecta, and access densified regolith for the landing surface
- 1 m wide 20° sloped accessways between the landing surface and natural grade
- Open debate on landing on natural vs excavated sub-grade surfaces

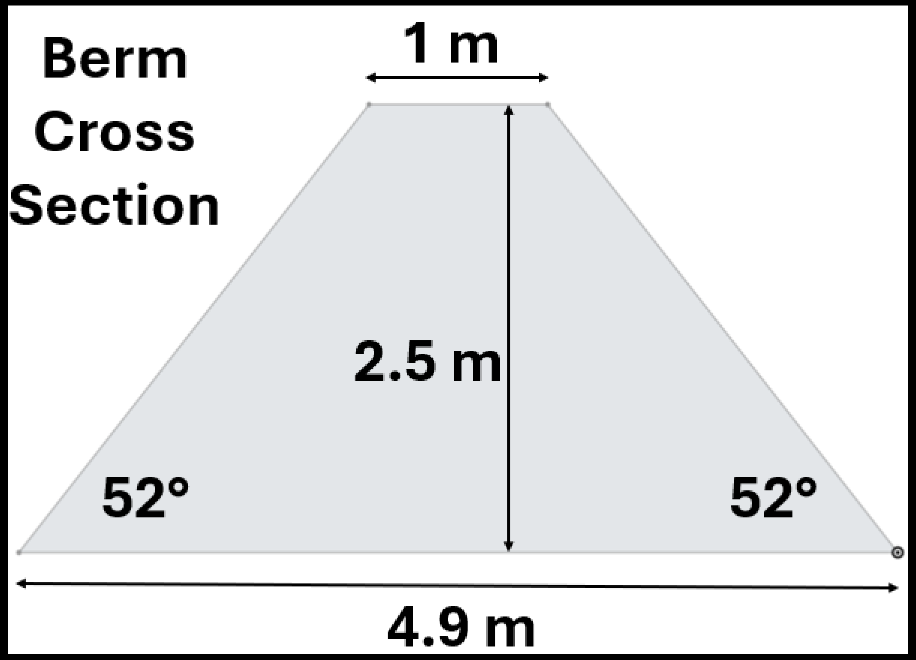
*Goudarzi, N. (2026). (manuscript in preparation). "Optimization of Lunar Materials for Launch and Landing Pads: NASA STTR Phase I Final Report (Contract 80NSSC24PB220)". Blueshift, LLC d/b/a Outward Technologies.

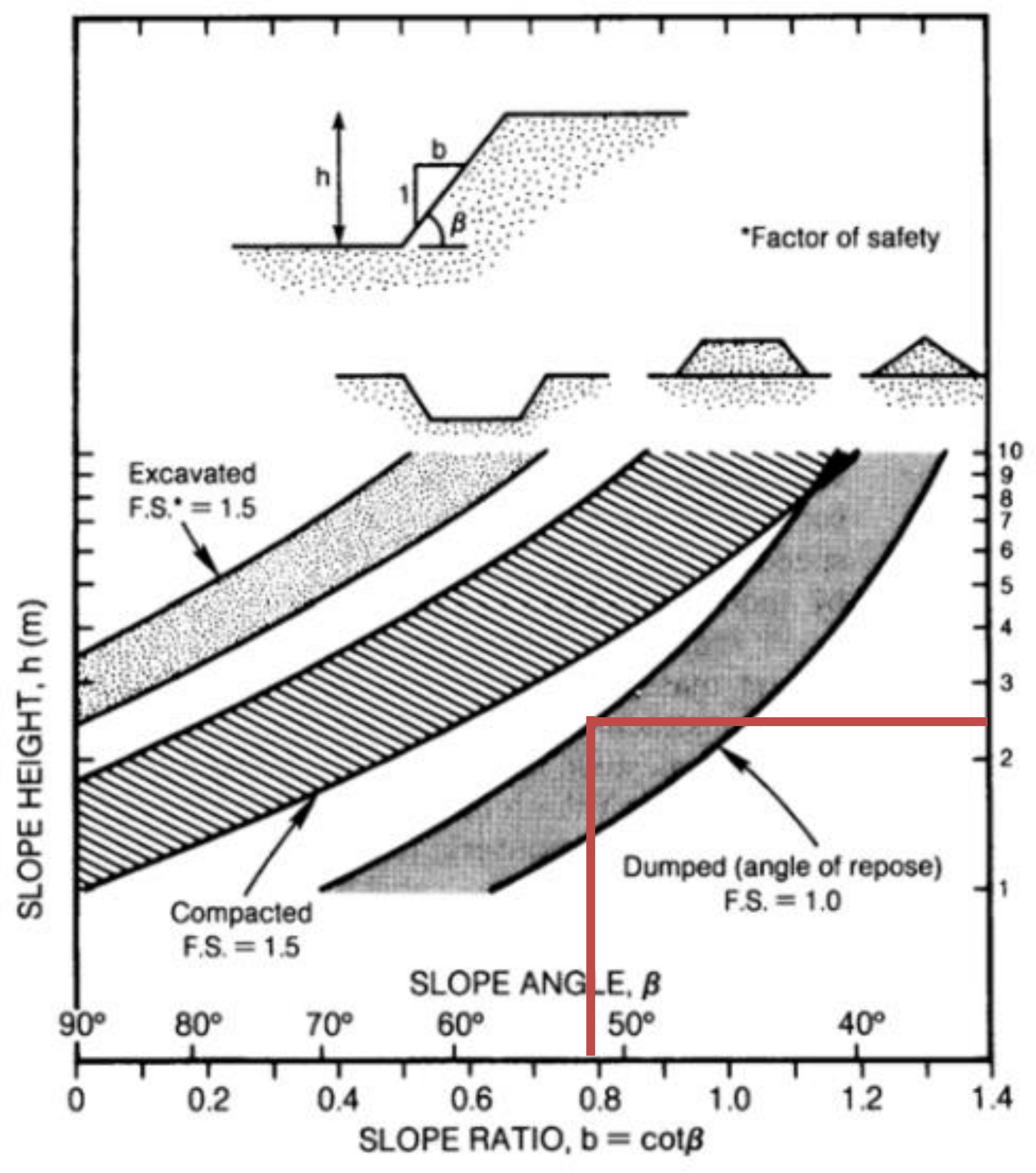


# Berm Design

- Height is 2.5 m which is the assumed lander height with VSAT stowed
  - Rational is to protect landed asset from any lateral debris
  - May be overly conservative for 3° ejecta angle
- Crest is 1 m for IPEx tracks to laterally overlap for compaction uniformity and eliminate ruts
- Side wall angle is 52° based on max "dumped" regolith angle (FS=1)* assuming limited compaction from repeated traversals
- 50% relative bulk density (1.4 g/cm$^3$) based on 30-40% RD* with 10-20% densification from repeated traversals



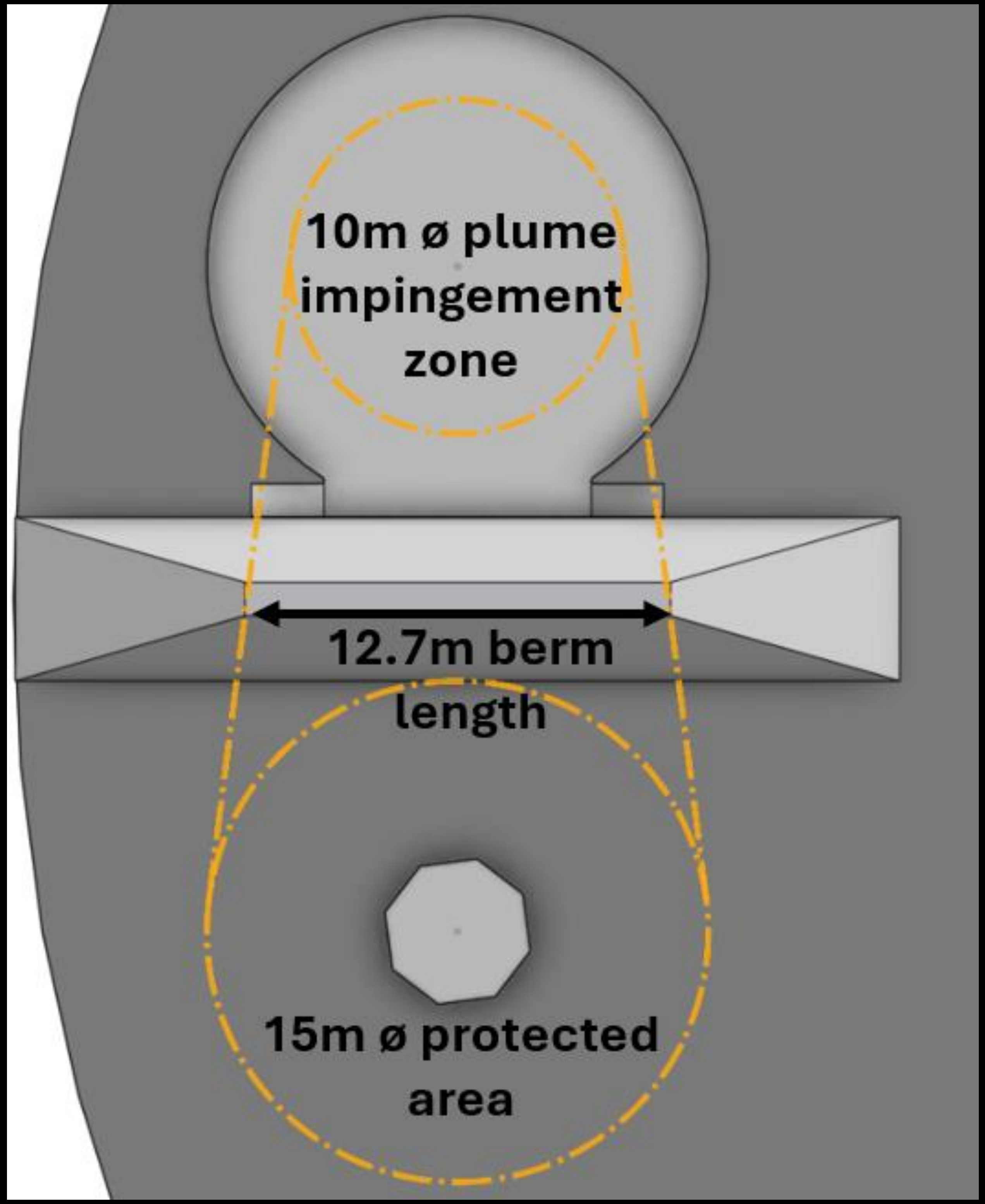

*Heiken, G. H., Vaniman, D. T., and French, B. M. (1991). Lunar sourcebook: a user's guide to the Moon. Cambridge University Press, Cambridge, UK and New York, NY.

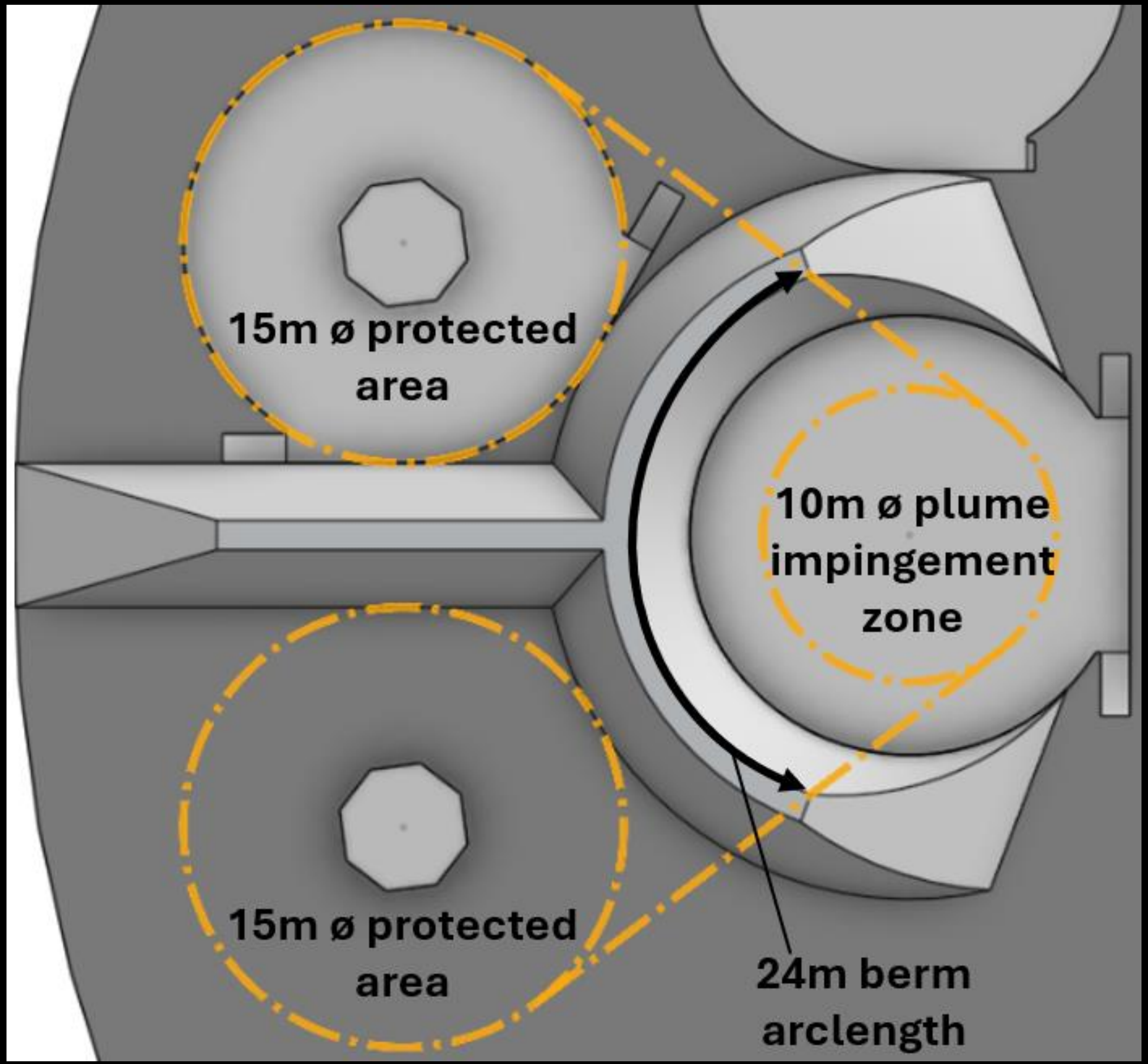
# Berm Construction Test

- A feasibility test of teleoperated robotic berm construction was completed with RASSOR 2.0 in Earth ambient with Black Point-1 simulant and had an average RD of 61% achieved by repeated trafficking


# Industrial Area Berm Layout

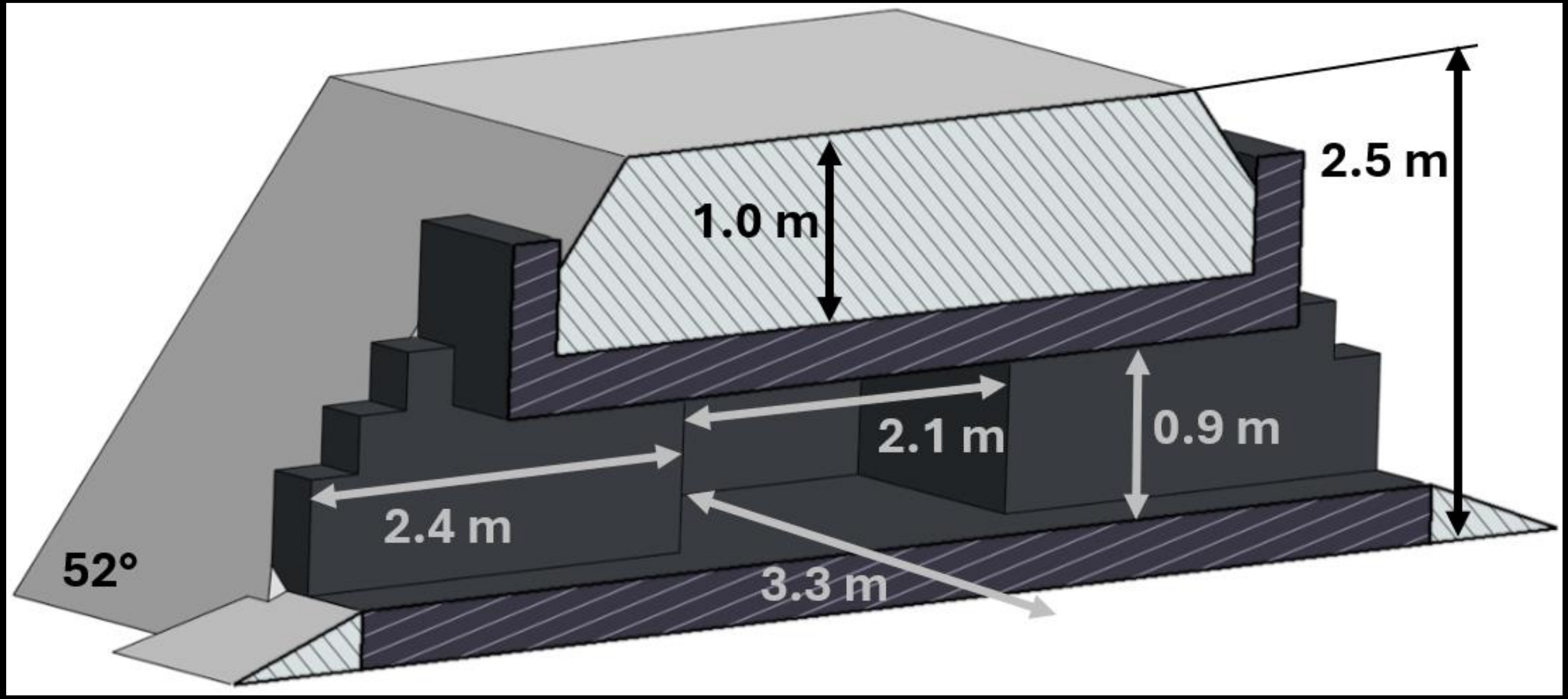
Berm length, or arc length, is sized so that every lander receives full berm height protection regardless of where it lands within its 5 m landing accuracy circle

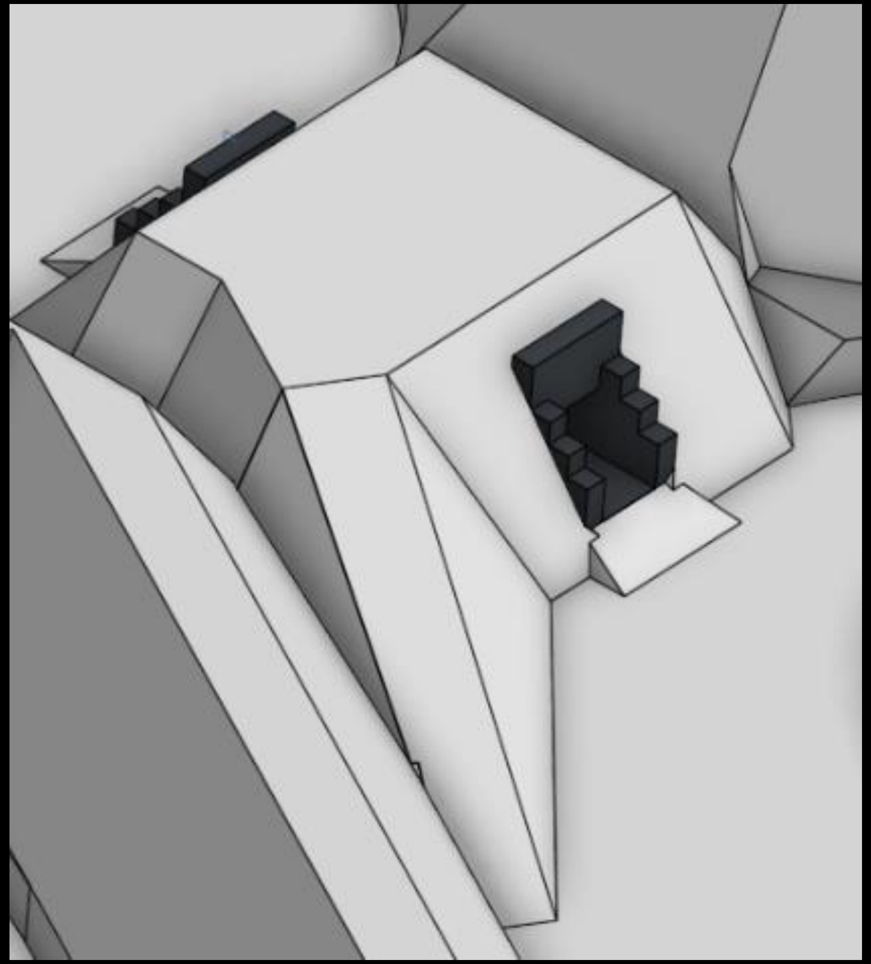


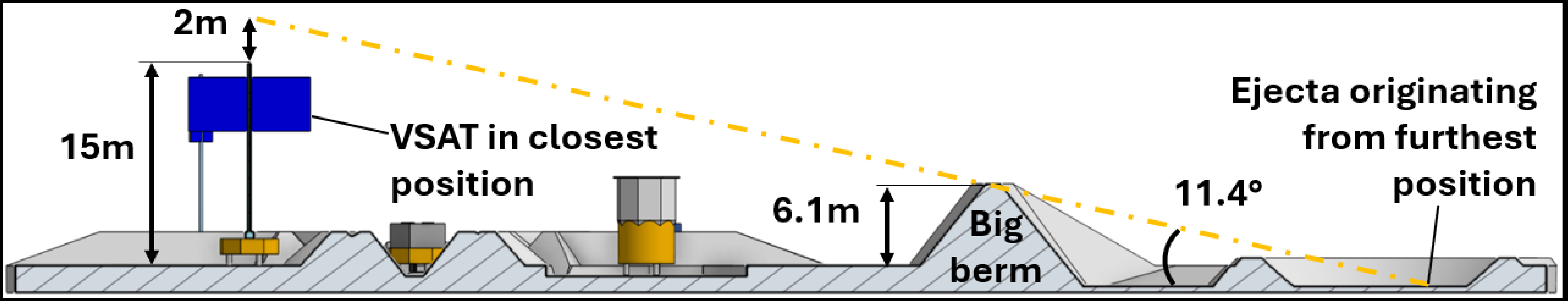
# Shelter Foundation & Overburden Design

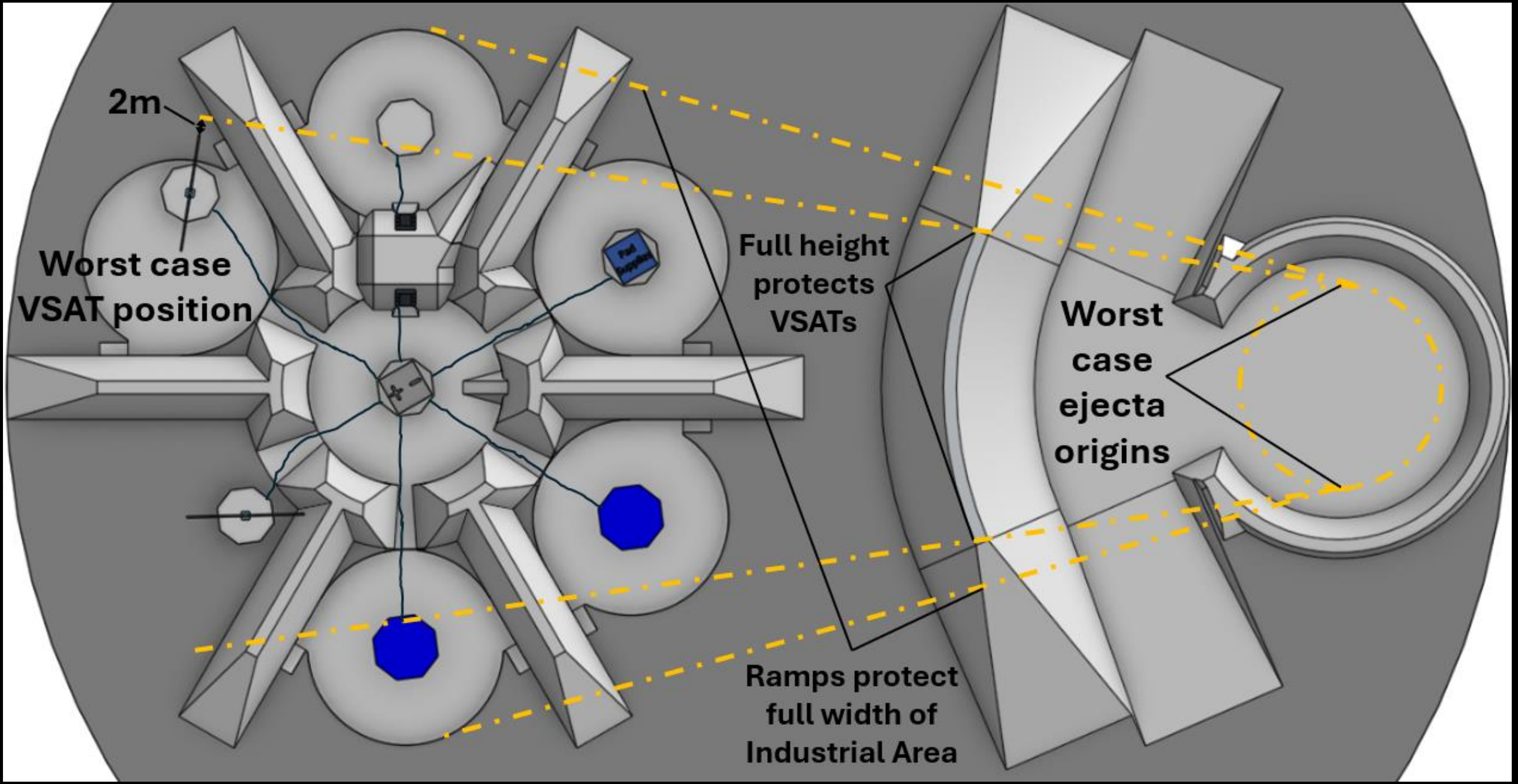
- A shelter structure was notionally designed based on NASA's ARMADAS Project voxels to accommodate 2x IPEx, CPEx, and other customers. The structure footprint is 17.4 $m^2$ and fits within a 7 x 4 m rectangular area.
- A level and compacted regolith foundation extends 1 m beyond the rectangular area assumed to be compacted to 80% RD.
- 1 m of regolith overburden covers the shelter to mitigate radiation and meteoroid impacts as well as provide a stable thermal environment
- A ramp ≥ 1 m in width with 20° slope is used to emplace overburden



# Reusable LLP Foundation and Berm Design




- 20 m diameter flat, level, rock free regolith foundation, 1.6 m below grade and compacted to 80% RD
- 15 m diameter durable pad surface built using TBD technology
- Large berm protects full height and width of Industrial Area
- Shorter semi-circle berm protects surrounding region from 6° ejecta angle
- Two 9 m wide accessways with 5° slope for cargo and/or spent lander transport
  - Spent lander transport method TBD

# Conclusions

- The Lunar Innovation Park is a near term, feasible, Moon Base concept with regolith features to enable extreme proximity landings and collocate minimum viable surface infrastructure
- Several site plan and bulk regolith feature factors need continued investigation including:
  - Site fidelity and geotechnical stability: Higher resolution lunar features such as slope, roughness, and rock distribution must be evaluated along with the long-term stability of bulk regolith features against seismic activity and thermal pumping
  - Ejecta dynamics: Knowledge of primary ejecta effects on bulk regolith features and secondary ejecta trajectories must continue to be refined
  - Lander trajectory and contamination: Development and analysis of lander flyover and ascent/descent trajectories to ensure compatibility with the Park layout
  - Landing zone design: Trade landing on natural vs improved surface

# Lunar Innovation Park