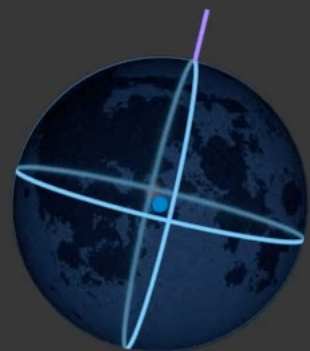




Lunar Site Selection

Sun Path

Looking EAST



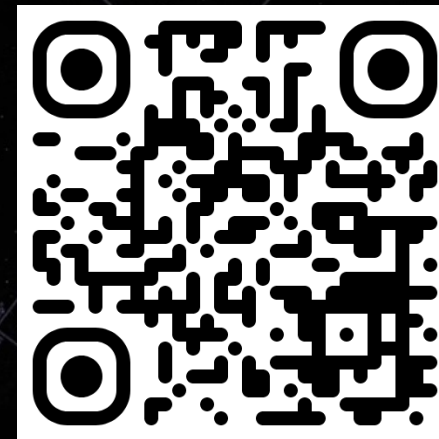
Subsolar Longitude
179°E

Earth Days

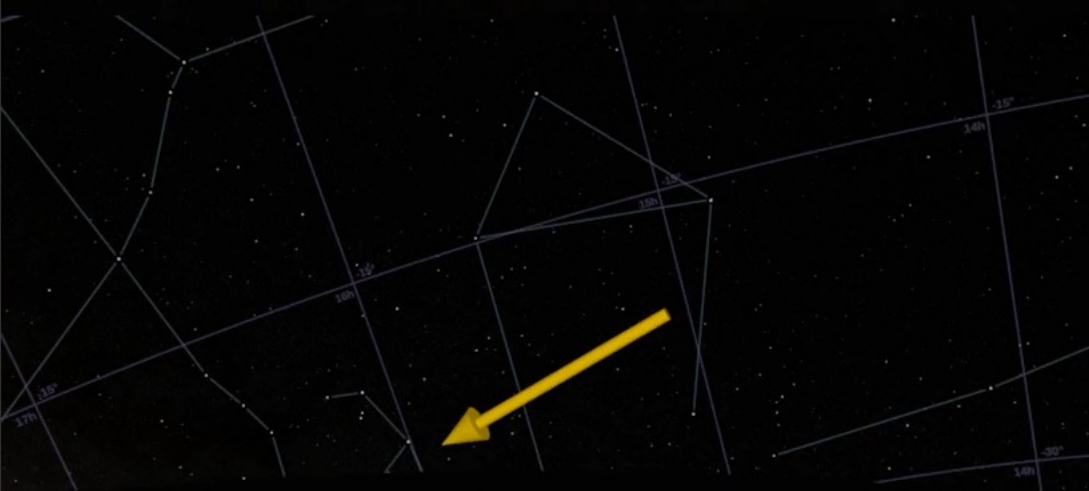
0



9°S
APOLLO 16



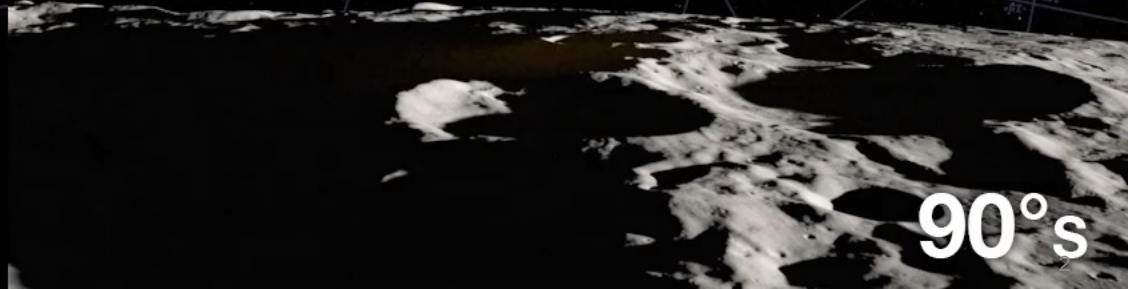
<https://svs.gsfc.nasa.gov/5038/>



60°N



90°S

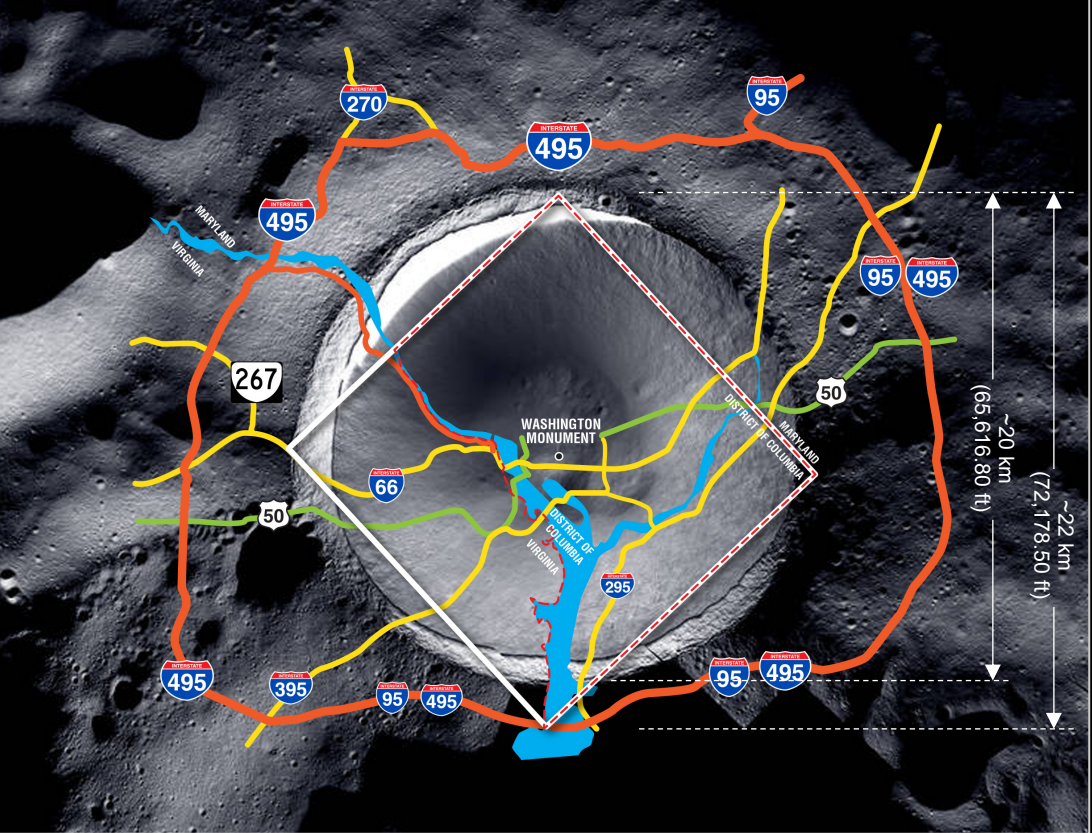


26°N
APOLLO 15

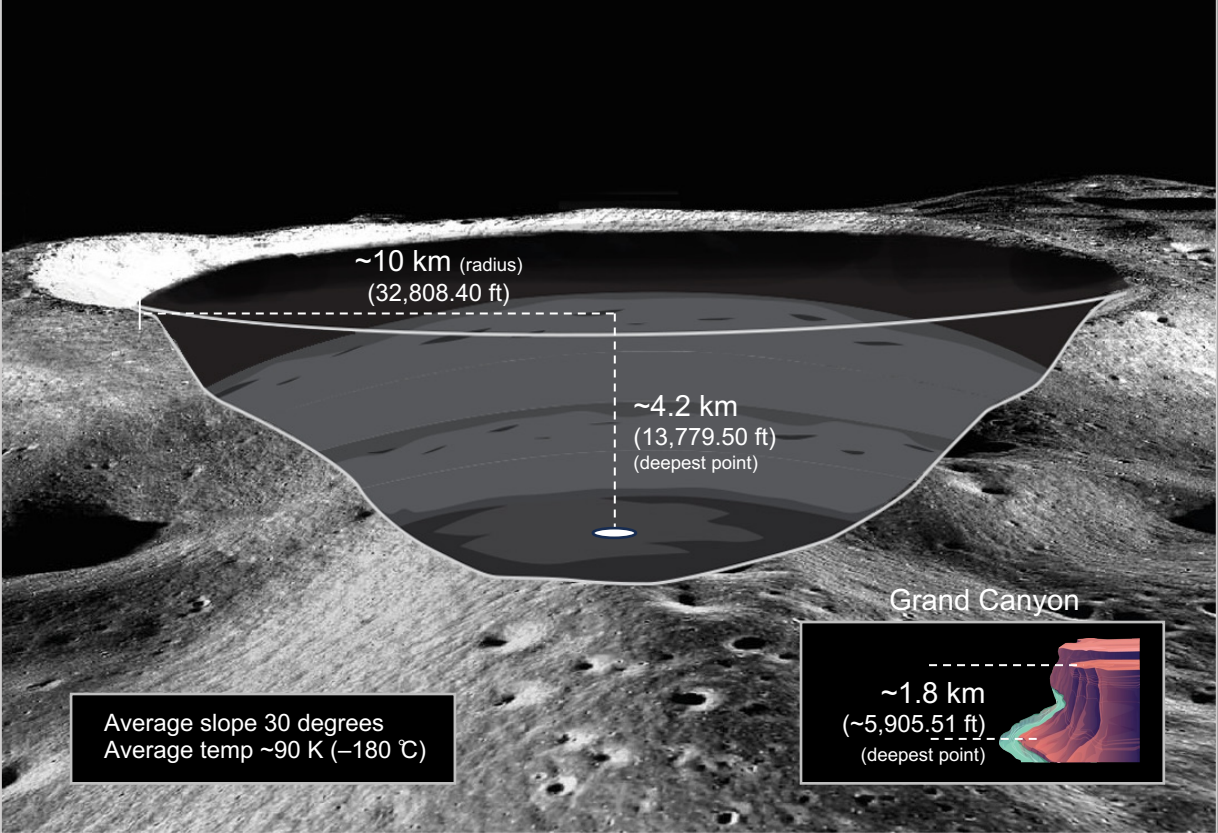
Shackleton Crater by Comparison



Shackleton Crater's area in relation to Washington DC



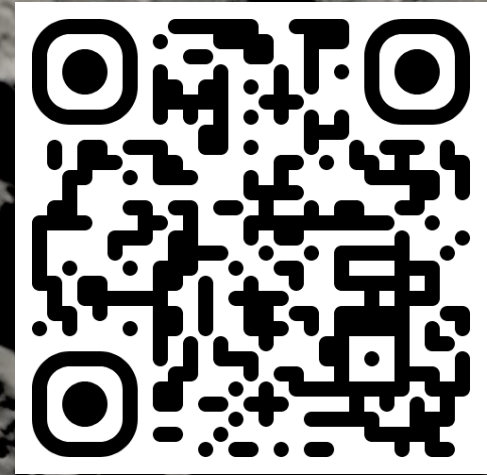
Shackleton Crater in relation to the Grand Canyon



Statue of Liberty 0.093 km (305 ft)  Space Launch System 0.098 km (322 ft) 

Lunar Seasons

SEASONAL CYCLE
(Lunar Draconic Year)
346.6 Days



<https://svs.gsfc.nasa.gov/5229>

South Pole
Summer

Credit: E.Wright (GSFC/SVS)

Landing Accuracy

Early mission success requires illumination along the approach trajectory with future missions having more flexibility in capability.

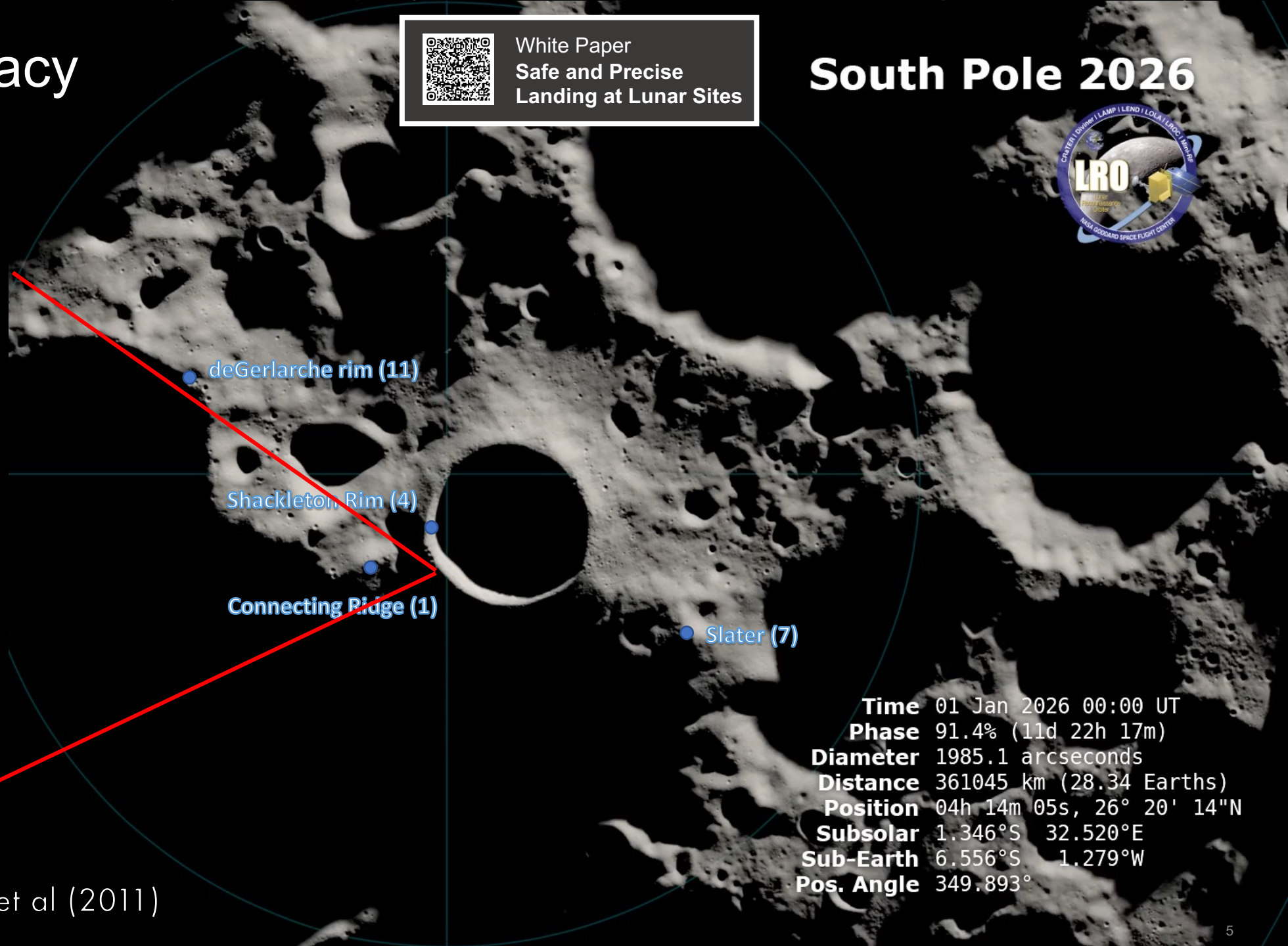
The approach trajectory is different for each landing opportunity.
[Notional range designated in red]

Sites from Mazarico et al (2011)

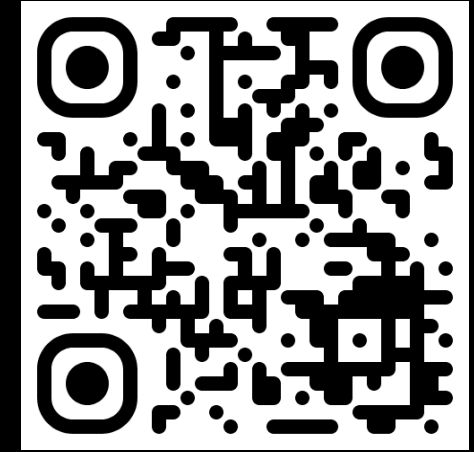


White Paper
Safe and Precise
Landing at Lunar Sites

South Pole 2026



Time	01 Jan 2026 00:00 UT
Phase	91.4% (11d 22h 17m)
Diameter	1985.1 arcseconds
Distance	361045 km (28.34 Earths)
Position	04h 14m 05s, 26° 20' 14"N
Subsolar	1.346°S 32.520°E
Sub-Earth	6.556°S 1.279°W
Pos. Angle	349.893°



<https://svs.gsfc.nasa.gov/5228>

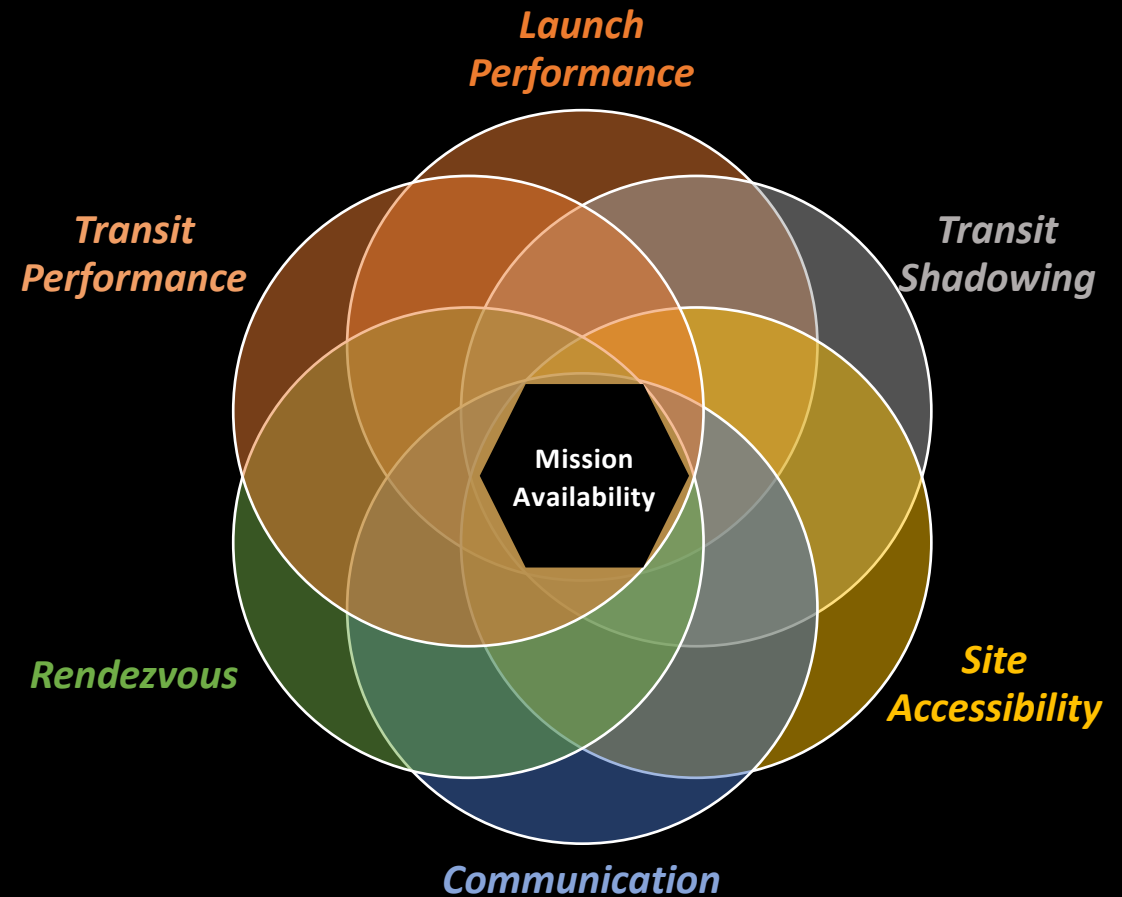
Azimuth, Elevation		
Sun	335.15°	6.85°
Earth	300.80°	9.42°
01 Jan 2026 00:00 UT		

Credit: E. Wright (GSFC/SVS)

Mission Availability is a Multidimensional Challenge



- Mission Availability is opportunity frequency at which the end-to-end mission can be viably conducted
 - Actual launch days, windows, periods
 - Some may acceptably be more constrained than others to achieve different objectives
- A distinct set of additional constraints must be incorporated when planning a human exploration mission (compared to robotic missions)
- Mission Availability analysis is an iterative process through design and development





White Paper



National Aeronautics and Space Administration

Lunar Site Selection

Introduction

Lunar site selection is an iterative process that evolves as we learn about vehicle capabilities, objectives, and architecture use cases and functions. Selecting sites for lunar operations requires identifying locations that would enable stakeholders to address one or more of NASA's Moon to Mars Objectives; in essence, "where we want to go," balanced with locations where safe lunar landings can be conducted, or "where we can go."

Available capabilities will evolve throughout the Moon to Mars Architecture segments, as defined in the Architecture Definition Document¹¹, which will affect the relationship between "where we want to go" and "where we can go." As Artemis missions progress from the Human Lunar Return segment through Foundational Exploration and Sustained Lunar Evolution segments, mission planning will benefit from increased access to reusable infrastructure on the lunar surface and in orbit, as well as a better understanding of the lunar environment (for a detailed description of Moon to Mars exploration segments, refer to NASA's Architecture Definition Document).

Human Lunar Return missions will need to find safe landing locations close to the intended destination of surface operations as new systems are tested for the first time. Subsequent missions will benefit from the lessons learned during the Human Lunar Return segment, improving awareness of the lunar surface and environment and enabling more accurate landings, the ability to traverse longer distances across the Moon, and longer duration missions.

These improvements will relax the need for proximity between safe landing locations and intended targets of interest for surface operations. As the architecture evolves, "where we want to go" will influence requirements for new systems, leading to an architecture that can reliably send astronauts to locations of interest.

Objectives Traceability

The Moon to Mars Objectives define the locations that NASA and its partners will need to access on the lunar surface or in lunar orbits in order to address our goals.¹² Therefore, traceability to these objectives determines "where we want to go."

Some objectives can be addressed simply through access to lunar orbits or the surface in general, without location-specific needs (e.g., observations of the human response to the lunar environment or gravity transitions). However, some objectives require access to specific environmental conditions or physical locations on the lunar surface, such as access to lunar volatiles in persistently or permanently shadowed regions or locations near multiple diverse terrain types, which would enable us to study the history of the Moon.

Progression through the architecture segments

2023 Moon to Mars Architecture Concept Review

white paper

2023 Moon to Mars Architecture Concept Review

New systems are tested, the initial to identify relatively flat terrain, with impact craters that are within the range. This type of terrain is also of vehicular activities, or spacewalks, of new suits and surface tools are of the physical characteristics of a site requires adequate data for site lander will have a unique tolerance or obstacle size knowing if those sites requires proper data. NASA's is made publicly available via the stem¹³ (the Lunar Reconnaissance des a useful tool for accessing the resolution image data for the Moon of roughly a single meter, but this is universally available across the polar data availability (data collected prior ng) and surface characteristics affect

Also be taken into consideration; be conducted at times for which the sunlight throughout the entire mission. of Human Lunar Return landing site approximately 6-6.5 days. As the us to develop, access to sunlight missions to use long-lived, reusable generate solar power, optimize systems thermal extremes, and maintain within certain temperature ranges.

The Moon's low axial tilt results in polar lighting conditions that can range from areas of continuous darkness to areas that are often sunlit (however, there is no known location in the South Pole region that is continuously sunlit). Generally, higher topography terrain will experience a longer duration of access to sunlight. Furthermore, any hardware that provides additional height off the surface will increase sunlight access. The architecture can take advantage of this characteristic as it evolves.

Every location experiences a unique ratio or pattern of sunlight/darkness. These patterns can be predicted on the surface, but the ratio can vary significantly over short distances. Thus, the concept of a lunar day/night cycle at the poles is not consistent across the region and does not match our experience on the Earth, or even elsewhere on the Moon.

Identifying initial locations with favorable lighting can restrict landing access to limited time periods throughout the year, and there will be times when a landing cannot be performed because the region will be in shadow (Figure 1). Therefore, depending on when the mission launches, a desired landing site with gentle sloped terrain might not be in sunlight, and the period of darkness could be brief or extensive, lasting weeks or months. For a more detailed description of the lunar south polar lighting, refer to the 2022 Architecture Concept Review white paper "Why Artemis Will Focus on the Lunar South Polar Region."¹⁴

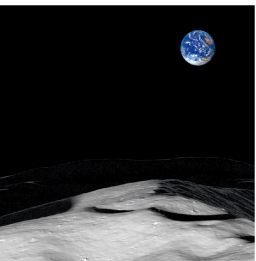
ycle does not overlap with Earth's Moon will experience roughly 11 10 Earth years. This means that over ent between lunar season and Earth e lunar summer will slip against the a series of years and the best months ar South Pole will not be the same set th. Therefore, lighting at a given site e Earth year over time. Increasing n all lighting conditions will enable runtimes.

will require communications with earth. Prior to the establishment of rastructure on or around the Moon, um landing site would likely need to e-Earth communications. This means e visible in the lunar sky from the

is landed on the Earth-facing side of arth was always visible in the lunar arth is never visible from the far side les are located along the edge of the of the Moon as viewed from Earth, facing side and far side of the Moon . Thus, much like lighting conditions, can vary (Figure 2).

ion is past the pole toward the far the Earth is to be visible (and may high-elevation terrain). Similarly, low- e Earth-facing side of the Moon

Architecture Concept Review



Showing the same view of the Earth from a location near the South Pole. The degree to which the Earth changes over time, with the Earth being completely obscured at times throughout the year. To see the please visit NASA SVS | Earth and Sun from the Moon's South Pole

near the poles might also experience periods of time without direct Earth visibility. Additional architecture capabilities, such as communication relays, will enable more site selection options. As the exploration campaign progresses, surface mobility is likely to increase as well. As a result, planning for lighting and communications will not only need to account for landing, but also for traversing the lunar surface.

Mission planning will benefit from over five decades of lunar data collection. Although lunar conditions in the South Pole region are different from past Apollo experience, these conditions are repeatable and predictable. While no single location constantly — or even routinely — has ideal lighting and Earth visibility conditions, we can identify landing sites that are available over specific periods. As the architecture evolves through each exploration segment, lighting and communications considerations can be addressed to enable better access to locations of interest.

End-to-End Mission Availability

While the considerations above focus on the lunar surface environment, constraints, and operations, NASA assesses mission planning holistically. Building on lunar site conditions, developing end-to-end mission availability metrics requires incorporating when NASA's Exploration Ground Systems/Space Launch System (GLS), and Orion spacecraft can launch the crew to rendezvous with Gateway and/or the Human Landing System, which would be located in near-rectilinear halo orbit, to perform the lunar surface sortie.¹⁵

For SLS Block 1B, the Exploration Upper Stage inserts into a circular low-Earth orbit. While this removes the performance constraint in the SLS Block 1 configuration, the new co-manifested payload capability can place additional performance demands on Orion. After the SLS Exploration Upper Stage performs the trans-lunar injection, Orion will be responsible for extracting the co-manifested payload and ferrying it to near-rectilinear halo orbit. The mass of that payload can significantly affect mission availability.

The mission designs for Artemis IV and beyond will also need to account for any timeline and consumable

2023 Moon to Mars Architecture Concept Review

ries' unique multi-vehicle, multi- also creates additional gages. For Artemis III, Orion will y with SpaceX's Starship. Human endevouring with a prepositioned additional constraints — mission the phasing of the target vehicle in a window for Orion to intercept the

Ground Systems/SLS/Orion launch ve, the vehicle configuration (SLS B) faces unique mission availability ll will be the last flight of the Block 1 his IV and beyond will use either the configuration.

vehicle launches to an intermediate orbit to best position the upper stage s-lunar injection, placing Orion on a pt the Moon. Given the necessary Exploration Ground Systems/SLS/ ve lunar orbit for roughly half of the d Earth, nearly centered around the ar declination.

near-rectilinear halo orbit must also e for the crew operations to prepare for sion. Thus, for Artemis III, mapping vailable lunar landing sites with when h and rendezvous with the Human a critical component of mission

In near-rectilinear halo orbit, the sion is expected to be viable to nding for about 90 days, meaning arrive within that window of time to ing System for a landing. Carrying to options maximizes the likelihood across a calendar year within the n constraints, one being the Human hicle lifetime. In later segments of e infrastructure could evolve to relax site availability and enable the site.

constraints. Mission availability for later Artemis missions will depend on the intersection of leveraging the range of the co-manifested payload capability and performing a lunar surface mission.

While this is a core component of near-rectilinear halo orbit accessibility, the later Artemis missions do benefit from the presence of Gateway and a lunar relay. The presence of these elements will help alleviate the challenges of direct-to-Earth communications for the Human Landing System and other future surface assets, ultimately opening additional lunar site availability.

In addition to all the nominal mission considerations above, protections for various contingency scenarios further restrict overall mission availability. The coverage for these situations is a risk-item that must maintain a delicate balance between capabilities and protecting the crew.

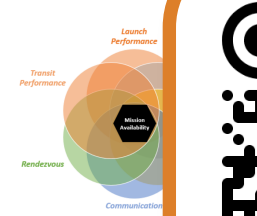


Figure 3. Mission availability coordination considerations, including vehicle capabilities, environmental and physical characteristics, must be considered when planning lunar surface operations.

Site Selection Evolution

Lunar site selection considerations include Foundational Exploration and Sustained Lunar Evolution segments. Both segments will involve capabilities to support lunar exploration and on the surface. Reusable infrastructure that can support longer duration access to preferred locations and locations will become key aspects of operations. Surface assets are likely to be consolidated at fewer more locations, which will have an impact on where we land, either to deliver new hardware or to use previously emplaced hardware.

2023 Moon to Mars Architecture Concept Review

As in the Human Lunar Return segment, the timing of a launch and landing can lead to different lighting and Earth visibility conditions from different locations across the south polar region. However, our approach to landings will evolve as our knowledge of the lunar environment and terrain characteristics increases.

For instance, the addition of communications capabilities will decrease the need for Earth visibility during landing or throughout a surface mission, and knowledge of the terrain and possible hazards for landers might lead to landing options in regions that are partially or entirely dark.

is emplaced on the lunar surface, s might need to be conducted at e locations multiple times, meaning rives the mission. Returning to the equire relaxation of site accessibility to lighting, communications, and hich could be addressed through equisition for that location and e evolving architecture.

characteristics might need to be e that remains on the surface could e to future landings and surface hardware remains in use, future to account for the plume surface anders create during descent and e deployed hardware could become

We must also consider the performance of multiple vehicles to enable spacecraft to reach Earth orbit, initiate the trans-lunar cruise, rendezvous with other previously deployed spacecraft in lunar orbit, and begin the descent to the lunar surface. Before we establish surface and orbital infrastructure to support these activities, early landing locations will be heavily influenced by when the crew launches from the Earth (Figure 3). As supporting infrastructure is emplaced and we learn about operations in the lunar south polar environment, mission planners will use the additional information to consider a broader

All partners operating on and around the Moon will need to consider these factors. As the architecture develops, it should use reusable infrastructure to relax some landing site constraints, thereby enabling mission planners to access locations of interest more dependably as missions progress. However, permanent infrastructure will also introduce important new considerations.

Summary Identifying lunar sites for landing and surface operations is an iterative process that considers vehicle capabilities, objectives, and architecture use cases and functions. Any mission must balance "where we want to go" with "where we can go" safely with our crew and other assets based on the capabilities available at that time. Site selection must account for characteristics such as surface roughness and slope, lighting, and, in early missions, visibility of the Earth. Mission planners require lunar data about these characteristics to match with vehicle capabilities.

We must also consider the performance of multiple vehicles to enable spacecraft to reach Earth orbit, initiate the trans-lunar cruise, rendezvous with other previously deployed spacecraft in lunar orbit, and begin the descent to the lunar surface. Before we establish surface and orbital infrastructure to support these activities, early landing locations will be heavily influenced by when the crew launches from the Earth (Figure 3). As supporting infrastructure is emplaced and we learn about operations in the lunar south polar environment, mission planners will use the additional information to consider a broader

2023 Moon to Mars Objectives



Figure 1. Topographic maps of the lunar South Pole showing modeling lighting conditions during the summer season (left) and the winter season (right). Earth is to the top of the images. To see the full animated video of lighting conditions around the lunar south polar region please visit: NASA SVS | Illumination at the Moon's South Pole, 2023 to 2030

2023 Moon to Mars Architecture Concept Review